MAPPING THE POTENTIAL OF VELD FIRE OCCURRENCE IN THE MOUNTAIN REGIONS OF THE SOUTH WESTERN CAPE, USING GIS

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DECLARATION

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

OA Akinnusi Date

ABSTRACT

Veld fires in the mountain regions of the South Western Cape are an annual occurrence. These veld fires occur as a result of human, natural and unknown causes. The Mediteranean weather conditions of the South Western Cape and its typical vegetation are conducive to these fires. Within the mountain regions of the South Western Cape, the use of fire can be advantageous for conservation and forest managers as a tool for fire management e.g. preparation of fire belts, reduction of veld fire occurrence by burning fuel load, rejuvenation of indigenous vegetation and enhancing the water yield of surrounding areas within their management area. Abnormally high incidences and run away veld fires within the management area of conservation and forest managers leads to the loss of biodiversity, destruction of properties and loss of human lives, and extensive soil erosion. This study aimed at identifying factors contributing towards the occurrence of veld fires in the mountain regions of the South Western Cape, and using GIS to analyse spatially the contributing variables, and to generate seasonal veld fire hazard maps.

Potential veld fire occurrence on a seasonal basis was mapped using spatial analyses of variables that are significant to the distribution of veld fires within the study area. Variables used to assess potential veld fire occurrences were: vegetation, slope, population density (human influence), proximity to roads, mean monthly maximum temperatures and mean monthly rainfall. The veld fire hazard maps generated indicated that potential for veld fire occurrence is high in the summer and autumn months, decreasing to a low in the winter and spring seasons. The exception is the Southern Cape sub-region where the possibility of veld fires can be quite high in winter as a result of Föhn-like berg winds. These winds are characterized by sudden increases in temperature and decreases in humidity that may pose severe fire hazards.

Reducing and containing veld fires in the mountain regions of the South Western Cape depends on the effective use of the seasonal veld fire hazard maps. The maps can be used to delineate critical zones of veld fire occurrence which can be used for evaluating cost-effective control measures and can be implemented to reduce the level of veld fire danger within the management areas of conservation and forest managers. There is a need for a Catchment Management System (CMS) (Richardson, Van Wilgen, Le Maitre, Higgins & Forsyth, 1994) that can be used to generate daily probabilities of veld fire occurrence and to link these to fire-spread models for predicting or simulating expected fire directions and severities or intensities, and educating people about fires and the damage it can do.

OPSOMMING

Elke jaar kom daar veldbrande in die berggebiede van die Suidwes-Kaap voor. Die oorsake van hierdie veldbrande is van menslike, natuurlike of onbekende oorsprong. Die Mediterreense weersomstandighede en die tipiese plantegroei van die Suidwes-Kaap is ook bevorderlik vir die ontstaan van veldbrande. In die berggebiede van hierdie streek kan die gebruik van vuur egter ook tot voordeel van natuurbewaring en bosbou aangewend word deurdat dit gebruik kan word as 'n metode om die brande te bestuur, soos in die voorbereiding van brandpaaie, in die vermindering van die voorkoms van veldbrande deur vooraf van die brandbare materiale af te brand, in die vernuwing van die inheemse plantegroei en in die verhoging van wateropbrengs in die omliggende gebiede binne die area wat bestuur moet word. 'n Abnormale hoë voorkoms van veldbrande binne die bestuursgebied van bewarings- en bosboubestuurders lei egter tot 'n verlies aan biodiversiteit, die vernietiging van eiendom, 'n verlies aan menselewens en uitgebreide gronderosie. Die doel van hierdie studie was om die faktore wat bydra tot die voorkoms van veldbrande in die berggebiede van die Suidwes-Kaap te identifiseer, om GIS te gebruik om 'n ruimtelike analise van die bydraende veranderlikes te doen en om dan 'n seisoenale veldbrandgevaarkaart saam te stel.

Die potensiële voorkoms van veldbrande op 'n seisoenale basis is gekarteer deur gebruik te maak van ruimtelike analises van die veranderlikes van belang in die verspreiding van veldbrande in die studiegebied. Die volgende veranderlikes is gebruik om die potensiële voorkoms van veldbrande te bepaal: plantegroei, helling, bevolkingsdigtheid (invloed van mense), afstand vanaf paaie, gemiddelde maandelikse maksimum temperature en gemiddelde maandelikse reënval. Die veldbrandgevaarkaarte wat ontwikkel is, het aangetoon dat die potensiële voorkoms van veldbrande hoog is in die somer- en herfsmaande en dan afneem tot 'n laagtepunt in die winter en lente. 'n Uitsondering is die

Suid-Kaap-substreek waar die moontlikheid van veldbrande selfs in die winter taamlik hoog is as gevolg van Föhn-tipe bergwinde.

Hierdie winde word gekenmerk deur 'n skielike toename in temperatuur en 'n afname in humiditeit wat die brandgevaar skerp kan verhoog. Die vermoë om veldbrande in die berggebiede van die Suidwes-Kaap te verminder en te beperk, sal grootliks afhang van die effektiewe gebruik van die seisoenale veldbrandgevaar-kaarte. Die kaarte kan gebruik word vir die afbakening van kritieke sones vir die voorkoms van veldbrande wat dan gebruik kan word vir die evaluering van koste-effektiewe beheermaatreëls.

Hierdie kaarte kan dan geïmplementeer word om die vlakke van veldbrandgevaar binne die gebiede waarvoor bewarings- en bosboubestuurders verantwoordelik is, te verminder. Daar is 'n behoefte aan 'n opvanggebiedbestuurstelsel (OGB) (Richardson, Van Wilgen, Le Maitre, Higgins & Forsyth 1994) wat gebruik kan word om daaglikse waarskynlikhede vir die voorkoms van veldbrande te genereer. Dit kan gekoppel word aan brandverspreidingsmodelle wat die verwagte rigting van brandverspreiding, asook die erns of intensiteit daarvan, kan voorspel of simuleer. Die publiek moet ook ingelig word oor veldbrande en die skade wat daardeur aangerig kan word.

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CHAPTER 1: VELD FIRE OCCURRENCE IN THE MOUNTAIN REGIONS OF THE SOUTH WESTERN CAPE

1.1 Introduction: Veld fires from a geographic perspective

Veld fires in South Africa occur at regular intervals, and have become an integral part of the South African environment. If not contained it can be disastrous to properties, forest plantations, and lead to loss of human lives and soil erosion (Davis & Midgley 1990; Smith 1995; Whelan 1995; Turner & Van Hoven 1997). According to Kruger (1977), it is difficult to determine where and when a fire may occur, because it varies as a function of vegetation age, ignition probability and long-term weather patterns. In the mountain regions of the South Western Cape, veld fires occur annually with high incidences in summer months and low incidences in winter months (Van Wilgen 1980; Kruger & Bigalke 1984).

Fire is the rapid oxidation of matter with the emission of heat, flame, smoke and gases (Botkin & Keller 1989). Since time immemorial fire has been one of man's greatest allies in changing the environment for their own benefit but, if not controlled, can cause devastating damage to nearby settlements, widespread soil erosion and loss of human lives (Christensen 1995; Whelan 1995). Fire varies geographically with changes in weather and type of fuel present (Minnich 1977). The occurrence of fire depends on the build up of fuels and appropriate climatic condition at the ignition point (Clark 1989; Cowling 1992; Le Maitre, Van Wilgen, Chapman & McKelly 1996).

Fuel flammability is enhanced by fuel characteristics such as moisture, compactness, quantity and climatic conditions (Van Wilgen 1980; Horne 1981; Edwards 1984 a). Lightning and falling rocks were the main causes of veld fires in the past in the South Western Cape, the more recent occurrence of frequent veld fires is caused intentionally and unintentionally by man due to burning of firebreaks and by careless picnickers, however the cause of most fires cannot be ascertained (Van Wilgen 1981). The types of fires occurring in the natural vegetation and forest plantations in the South Western Cape are surface fires that burn above ground and are more common than crown fires that sometimes accompany surface fires (De Ronde 1988; Theron 1994; Van Wilgen 1999).

GIS has been used in forestry for simulating fire behaviour and severity conditions (Kessel 1990; Szecsei 1995; Harms, Lavdas & Saveland 1996; Lee 1996), while in mountain catchment areas it has been used as a tool for fire management (Richardson, Van Wilgen, Le Maitre, Higgins & Forsyth 1994). Mapping the probability of veld fire occurrence for areas under different conditions would be possible if there is sufficient information and thorough understanding of the environmental, human, and spatial parameters as well as their interactions (Chou 1990). This would aid fire department officers, nature conservation and forest managers in containing the spread.

The purpose of this research is to generate fire hazard maps to aid fire departments, nature conservation and forest managers to plan and prepare in anticipation for likely occurrence of veld fires within their management areas. This will also contribute to contain the spread of veld fires, reduce the loss of private and public property, nature conservation areas, forest plantations, and reduce the tremendous costs of fighting veld fires.

The specific objectives of the study are the following:

1. To identify the *factors* contributing towards the occurrence of veld fires in the mountain regions of the South Western Cape.
2. To use GIS to analyse variables contributing towards veld fires.
3. To generate seasonal fire hazard maps depicting the potential of veld fire occurrences in the mountain regions of the South Western Cape.
4. To make recommendations about how to use the seasonal fire hazard maps in delineating critical zones of veld fire occurrence.

1.2 The mountain regions of the South Western Cape as a study area

The study area is situated in the South Western Cape and is bordered by the Olifants River in the northeast, Breede River in the east, Atlantic Ocean in the west and the Indian Ocean in the south (Figure 1.1). The mountain regions of the South Western Cape have been chosen because veld fires occur regularly and are becoming more frequent, and because of its unique fynbos plant cover which is a sclerophyllous vegetation type well adapted to periodic fires (Acocks 1988).

This area also includes forest plantations found on the lower slopes of the Hottentots-Holland (Jonkershoek, Grabouw, Steenbras, Lebanon and Nieuweberg) and Drakenstein (La Motte) mountain ranges, with smaller plantations in the Cedarberg (Algeria), Elandskloof (Kluitjjjeskraal), Klein Drakenstein (Hawequas), Table Mountain (Tokai, Cecelia, Devil's Peak), Langeberg (Garcia, Swellendam and Grootvadersbosch) mountains and various dry non-fynbos shrublands (Donald 1982; Acocks 1988; Low & Rebelo 1996). These mountains are known as the Cape Folded Belt with an average maximum elevation of 1000m - 1500m with individual peaks reaching over 2000m (King 1963; Campbell 1985).

The climate of the study area is referred to as typically Mediterranean, although this is not strictly true for the whole area (Di Castri & Mooney 1975). Throughout the study area there are marked rainfall gradients in response to the altitude gradients e.g. ranging from 300mm to 2500mm or more per year (Campbell 1985). The western part of the study area receives more that half of its rain in winter and, to the east, rainfall is more evenly distributed throughout the year (Van Wilgen 1981). Föhn-like bergwinds often occur during the winter season, along the southern and western coastal regions. These winds are characterised by sudden increases in temperature and decreases in humidity, resulting in severe fire hazards (Van Wilgen 1984).

Mean annual temperatures vary from 15°C to 16°C at the coast to 17°C to 18°C at inland weather stations and to less than 13°C at high altitudes (Campbell 1985). For the purpose of discussion and interpretation of the spatial and seasonal fire distributions, the study area is divided into four zones, namely, the West Coast, Boland, Peninsula and Southern Cape, using magisterial district boundaries. In demarcating areas within the study area that are mountainous (Figure 1.1), a land-cover coverage of the study area was converted into a grid data-set with a spatial resolution of 1km by 1km in ArcView. This was combined with the gridded slope data. Several criteria from both gridded data-sets were used (for example landcover that equals to forest plantations, barren rocks and shrubland, according to their coded value; and slope greater than or equal to 15°) to give a resultant map depicting only mountainous areas within the study area (Figure 1.1).

All resultant seasonal veld fire hazard maps will be combined with the mountainous grid data-set to depict potential veld fire occurrence in the mountaineous regions of the South Western Cape. The major features of each zone is discussed below:

i. ***West Coast zone***: This zone is bordered by the Olifants River in the north and east, Atlantic Ocean in the west, and the Boland and Peninsula zone in the south (Figure 1.1). Much of this zone is occupied by cultivated land or strandveld of the West Coast, that is likely to carry fire less often than fynbos because of lower fuel loads, sparse canopy and relatively more succulent plants than in the other regions (Van Wilgen 1984). This zone has a population density of 37 people per square kilometre, and accommodates 9 per cent of the total population of the South Western Cape (Meintjies, Rousseau & Viljoen 1995).

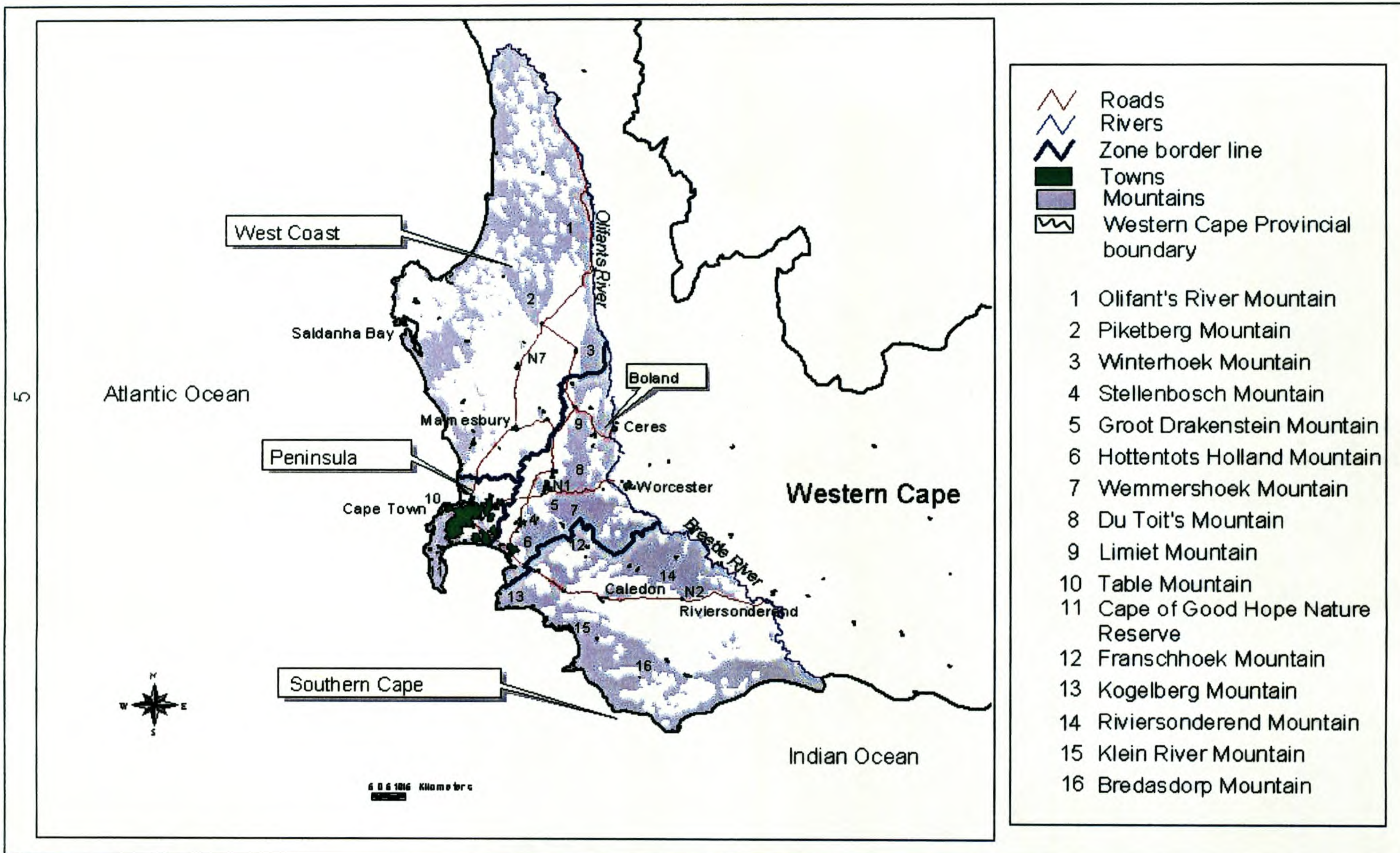


Figure 1.1: Study area, mountain regions of the South Western Cape.

ii. ***Boland zone***: This zone is bordered by the West Coast zone in the north, Southern Cape in the south, Breede River in the east, and the Peninsula zone in the west (Figure 1.1). The mountains in this zone are covered largely by fynbos which is highly flammable due to the presence of combustible oils, finely divided canopies and continuous structure (Rutherford & Westfall 1986). The rest of the vegetation consists of Central Mountain Renosterveld. The Boland zone is populated with a population density of 148 people per square kilometre, hosting 19 per cent of the South Western Cape population (Meintjies, Rousseau & Viljoen 1995).

iii. ***Peninsula zone***: Bordered by the West Coast in the north, Indian Ocean in the south, Boland zone in the east, and the Atlantic Ocean in the west (Figure 1.1). Much of the natural vegetation cover in this zone is made up of Mountain Fynbos and Pine that carries fire more often than West Coast Renosterveld (Low & Rebelo 1996). This zone is densely populated with a population density of 1352 people per square kilometre, hosting 67 per cent of the South Western Cape's population (Meintjies, Rousseau & Viljoen 1995).

iv. ***Southern Cape zone***: This zone is bordered by the Boland zone in the north, the Indian Ocean in the south and west, and Breede River in the east (Figure 1.1). The natural vegetation cover in this zone is made up of Lateritic and Limestone Fynbos which forms part of the Coastal Fynbos, and Mountain Fynbos which is highly flammable due to their finely divided canopies, continous structure and combustible oil (Rutherford & Westfall 1986). Smaller proportions of Afromontane Forest, Central Mountain Renosterveld and South & South-West Coast Renosterveld that are less susceptible to fire also occur in the region (Rutherford & Westfall, 1986). This zone has a population density of 30 people per square kilometre, which is quite low compared to the other zones within the study area, and represents 5 per cent of the total population of the South Western Cape (Meintjies, Rousseau & Viljoen 1995).

1.3 Data collection

In mapping the potential of veld fire occurrence in the mountain regions of the South Western Cape, primary data was collected through the use of questionnaires and fire record data from 1985 to 1999. Data-sets in ArcView shapefile format of factors that contribute towards veld fires were used as secondary data to generate seasonal veld fire hazard maps. The collection of data used for the study is discussed in the section that follow.

1.3.1 Primary data

Questionnaires (Appendix A) were sent to managers of Municipal Parks and Forests in the Cape Metropolitan Area, the divisional office of the Cape Nature Conservation Board (CNC) and South African Forestry Company (SAFCOL) in the South Western Cape, and Cape Peninsula National Park in Cape Town. Information was acquired from ten nature conservation managers, three municipal parks and forest managers, two silviculture foresters and three fire-service officials.

The data collected were analysed using Microsoft Excel for producing tables and charts illustrating the occurrence of fires, uses, advantages and disadvantages of fires. The causes and types of veld fires within the management area of the respondents were also investigated. ArcView was used primarily to map the spatial extent and variation in these data-sets.

Fire records from 1985 to 1999 containing information about daily incidence of mountain fires were obtained from six of the sixteen respondents (Appendix A (Table A.1.)). The low response rate for the provision of the fire records is attributed to a lack of adequate and correct fire records within the different organisations and the practice of some institutions to destroy their fire records after every five years. Data was available for 213 mountain fire incidences that occurred in the Peninsula and Boland zone only, over the period 1985 to 1999, while fire record data for the West Coast and Southern Cape zone were unavailable.

Thus the information available in the fire record data were time of occurrence, type of incident, duration, extent, cause and location in these two zones only. Microsoft Excel was used to process the data obtained from the fire records, so as to determine which months of the year have the lowest and highest occurrence of veld fires, and to determine the annual incidences of veld fires as a result of human, natural and unknown causes over the past fourteen years.

1.3.2 Secondary data

- *Climate*: Climate data consisting of monthly average rainfall and monthly average maximum temperature figures for the past twenty years from thirty-five weather stations within the study area, was obtained from Elsenburg Agricultural Research Institute, Stellenbosch. These data were used in calculating the dryness index for veld fire occurrence within the study area.

- *Landcover:* The landcover data-set in ArcView shapefile format was obtained from CSIR (Council for Scientific and Industrial Research, Pretoria). It consists of landcover types within the study area, for example forest plantations, shrubland, thicket & bushes, mountain & lowland fynbos.

- The remaining data-sets listed below were obtained from the Department of Geography and Environmental Studies, University of Stellenbosch in ArcView shapefile format.

  - *Vegetation*: These spatial data consist of both vegetation and forest type within the study area, and are categorised according to Low & Rebelo (1996). The vegetation coverage consists of eight classes namely, Succulent Karoo, Central Mountain Renosterveld, Afromontane Forest, South & South-West Coast Renosterveld, West Coast Renosterveld, Laterite Fynbos, Limestone Fynbos, and Mountain Fynbos. The plantation coverage contained two classes, i.e. Pine and Eucalyptus.

  - *Roads*: This data-set consists of all national, municipal, local and gravel roads for computing accessibility within the study area.

  - *Slope*: This data-set consists of gridded slope values (1km by 1km spatial resolution) of the entire study area.

  - *Population density*: Population density of the study area was derived from the 1996 population census data-set per enumeration area.

  - *Magisterial district boundaries*: This data-set consists of magisterial district boundaries within the study area. The magisterial district boundaries were used for dividing the study area into four zones for the purpose of discussion and interpretation of the spatial and seasonal fire distributions, as proposed in Section 1.3.

1.4 Outline of chapters

The next section will provide an overview of the seasonal occurrence of veld fires, its use, advantages and disadvantages, factors contributing towards the occurrence and type of veld fires in the mountain regions of the South Western Cape. The third section deals with the use of GIS in mapping the potential of veld fire occurrence on a seasonal basis. A summary of findings, conclusions, recommendations for containing veld fire occurrences and further research possibilities are presented in the final section.

CHAPTER 2 OCCURRENCE OF VELD FIRES IN THE SOUTH WESTERN CAPE

This chapter focuses on the seasonal frequency of veld fires, factors that contribute towards veld fires, the uses, advantages and disadvantages of veld fires within the study area, distribution of the total vegetation biomass available for fire and their relative susceptibility to fire. Thereafter, the types of fires that occur during veld fire incidences in the mountain regions of the South Western Cape are described.

2.1 Temporal occurrence of veld fires

Occurrence of fire is influenced by climatic factors and by seasonal variations in fuel properties (Van Wilgen 1984). In the South Western Cape, veld fires normally occur during warm, sunny conditions whatever the season (Van Wilgen, Everson & Trollope 1990), however most large veld fires in the South Western Cape occur in the summer season (Bands 1977). Months with the highest and lowest risk of veld fire occurrence within the study area are provided in Table 2.1.

According to the questionnaire survey, fourteen of the sixteen respondents indicated that February is the month with the highest probability of veld fire occurrences, and all the respondents indicated July as the month with the lowest probability of veld fire occurrences within their management areas. Seasonally, the probability of veld fire occurrences increases during the summer months of December to February, decreasing towards the autumn months of March to May, through the winter months of June to August and starts to pick up during the spring month of September. Although these perceptions are generally valid, there maybe regional variations based on local weather conditions and other factors contributing to veld fire occurrence.

Seasons with low probability of veld fire occurrence, for example, autumn and early spring season, are the most favourable time for the deliberate burning of the mountain fynbos catchment areas. Deliberate burning is also referred to as prescribed burning. It is defined as the deliberate application of fire to wildland fuels under specific conditions of weather, fuels and topography so as to achieve specific objectives safely (Green 1981; Van Wilgen, Everson & Trollope 1990). In the South Western Cape this is done for the purpose of managing the fynbos mountain catchment areas, to ensure a sustained yield of high quality water, reduce fire hazard, control woody weeds and to rejuvenate the fire adapted vegetation.

The policy on the season of burning in the Western Cape as outlined by the Department of Environmental Affairs during 1970 (Unpublished records, Forestry Branch of the Department of Environmental Affairs 1970), stated that burning operations are prescribed in terms of the fire regime, based on knowledge of the effects of fire at different frequencies, different seasons and at different intensities on the vegetation (Bands, 1977; Van Wilgen & Richardson 1985 a). All respondents noted that veld fires had occurred within their management area for the past twenty years or more, having both positive and negative implications.

Table 2.1: Monthly fire risk assessment in the surveyed Nature Reserves[(1)], according to the opinion of respondents.

Monthly fire risk assessment					
Months with highest occurrence of veld fire	**Number of responses**	**Percentage of responses (%)**	**Months with lowest occurrence of veld fire**	**Number of responses**	**Percentage of responses (%)**
April	6	37	May	2	13
December	9	52	September	5	31
January	11	68	June	12	75
March	11	68	August	13	81
February	14	87	July	16	100

Total number of respondents = 16

N.B.: the values in the third and sixth column of Table 2.1 are derived from the total number of respondents. [(1)] The surveyed reserves were in the following areas: Hottentots Holland Mountains (Jonkershoek, Stellenbosch, Streenbas and Grabouw), Drakenstein (La Motte) and Table Mountain (Tokai, Devil's Peak and Noordhoek).

2.2 Uses, advantages and disadvantages of veld fire occurrences

Table 2.2 lists the advantages of fire within the study area. Six percent of the respondents used fire as a management tool to mosaic the vegetation of their management area. A mosaic of natural vegetation is created to ensure that patches of different veld ages and discontinuous fuels of low average flammability are generated, so as to control the rapid spread of wildfires (Kruger & Bigalke 1984).

Nineteen percent of the respondents used fire for the preparation of fire belts. Fire-breaks have the capacity to halt or divert the spread of veld fire (Theron 1994). The use of fire to counter an approaching veld fire was mentioned by 31% of the respondents. This is made possible by starting another fire that spreads against the wind direction or in the opposite direction of the veld fire path, acting as a back-burn against the initial fire (Theron 1994). Half of the respondents (50%) used fire to enhance the water yield of their surrounding area, which has been a main management objective of mountain catchment areas in the South Western Cape. Firstly, fire causes an initial increase in stream-flow by reducing evapotranspiration and eliminating water loss due to interception of rainfall by the vegetative canopy and, secondly, the rate of vegetation recovery to its pre-fire condition will determine the rate at which stream-flow returns to pre-fire levels (Bosch, Van Wilgen & Bands 1986).

Table 2.2: Advantages of veld fires.

Advantages of veld fire	**Number of respondents**	**Percentage of respondents (%**
Create patches of different veld ages that acts as a fire-breaks	1	6
Prepare fire belts	3	19
Counter veld fire occurrence	5	31
Enhance water yield of surrounding area	8	50
Control invasive and alien vegetation	11	69
Reduce veld fire occurrence by burning fuel Load	13	81
Rejuvenate indigenous vegetation	13	81

Total number of respondents = 16

N.B.: the values in the third column of Table 2.2 are derived from the total number of respondents.

Table 2.3 Disadvantages of veld fires.

Disadvantages of veld fire	Number of respondents	Percentage of respondents (%)
High cost of combating fires	1	6
Extensive soil erosion	4	25
Destruction of properties and loss of human Lives	5	31
Decrease in profit maximisation of forest Plantations	5	35
Loss of biodiversity, i.e. animal and plant Species	8	50

Total number of respondents = 16

N.B.: the values in the third column of Table 2.2 are derived from the total number of respondents.

The control of invasive alien vegetation, for example Pinus and Hakea, by means of burning was used by 69% of the respondents, because invasion of alien vegetation increases the above-ground biomass that can lead to severe and intense fires (Le Maitre, Van Wilgen, Chapman & McKelly 1996; Working for Water Programme 1998). A majority of the respondents (81%) used fire as a management tool to reduce fire occurrence and rejuvenate the indigenous vegetation within their management areas. The use of fire in the rejuvenation of indigenous vegetation is applicable especially where fire-dependent species and communities are involved (Bands 1977). Increases in fuel loads are responsible for increases in veld fire occurrence, that is, more fuel load leads to more veld fire occurrences and vice-versa. Therefore, the reduction of fuel load reduces the intensity and frequency of accidental fires (Edwards 1984 b; Van Wilgen 1999).

The use of fire as a management tool (if not controlled and applied under specific conditions of weather, fuels and topography) and frequency of veld fires that occur annually in the South Western Cape can have negative effects on surrounding areas and the conservation aim of nature conservation institutions (Van Wilgen 1985). Six percent of the respondents indicated that the cost of controlling and fighting large veld fires within their management area can be very high (Table 2.3), especially if there is need to hire extra labour and fire-fighting helicopters to reach parts of their management areas that are inaccessible to fire-fighters. Frequent veld fire occurrences leading to an increase in soil erosion within management areas was indicated by 25% of the respondents. Increased soil erosion depends on the intensity of fire, reducing the water infiltration rate, loss of vegetation and exposure of the soil to the impact of raindrops. This has a direct effect on the extent of overland flow that results in increased rill and sheet erosion (Cass, Savage & Wallis 1984; Christensen, 1995, Whelan 1995). Thirty-one percent of the respondents indicated the difficulty in containing veld fires within their management area due to its intensity and rate of spread. These factors result in casualties among their fire-fighting teams. Spreading of fire to adjacent and nearby private and public properties can cause extensive and devastating damages.

Occurrence of veld fires decreases the profit of forest plantations (35% of the respondents), due to recovery cost per hectare which increases depending on the extent of the area burnt (Donald 1982). Half of the respondents noted that frequent veld fire reduces the biodiversity within their management area, especially young plants whose growth are suppressed and negatively affected (Bond 1997). The mortality rates of some animals (e.g. tortoises) are high due to their low mobility as compared to other animals that are more mobile (e.g. baboons) and therefore can avoid the effects of fire.

2.3 Factors contributing towards veld fires

The occurrence of a veld fire depends on an ignition source coming in contact with the fuel and favourable conditions of other contributing factors such as the relative humidity of air, wind speed, air temperature and fuel moisture (Agee & Huff 1987; Chandler, Cheney, Thomas, Trabaud & Williams 1983; Van Wilgen 1999). However, Cesti (1988) notes that fire occurrences are more frequent where there are human settlements and forest activities. The factors that will be discussed are interdependent, in that for a veld fire to occur, there must be an ignition source, favourable weather conditions, suitable type of vegetation at the source of ignition and conducive terrain characteristics.

Table 2.4 summarises the factors contributing towards veld fire occurrence in the mountain regions of the South Western Cape. These will be discussed in Sections 2.3.1 and 2.3.2. Thirteen percent of the respondents indicated that the amount of biomass within their management area increases when it is invaded by alien plants. These vegetation types burn more easily and intensely due to their high oily leaf content (Le Maitre, Van Wilgen, Chapman & McKelly 1996; Working for Water Programme 1998). Fuel compactness was indicated by 87% of the respondents as having an effect on fire behaviour within their management area. Combustion is optimised when the fuel is sufficiently low to enable adequate quantities of oxygen to reach the flame zone but dense enough for efficient heat transfer to occur (Luke & McArthur 1978; Trollope 1984).

Table 2.4: Factors contributing towards veld fire occurrence.

Factors contributing towards veld fire occurrence	Number of respondents	Percentage of respondents (%)
Presence of alien vegetation	2	13
High relative humidity of air	13	81
High compactness of fuel	14	87
Low fuel moisture	15	93
High air temperature	15	93
Wind direction	15	93
High fuel loading	16	100
High wind speed	16	100
Gentle slope terrain	16	100

Total number of respondents = 16

The moisture level of fuel was indicated by 93% of the respondents as a major factor contributing towards veld fires within their management area. Fuels that have low moisture content (types with narrow leaves and thin branches) are more flammable as they lose water more rapidly and have a high ratio of fuel to air (Trollope 1984; Van Wilgen & Van Hensbergen 1992). Fuel loading is a major contributor to fire intensity as indicated by all respondents (100%), because it is directly proportional to the amount of fuel available for combustion (Brown & Davis 1973; Brown, Manders, Bands, Kruger & Andrag 1991).

2.3.1 Climate

Climate is the weather at a place or over an area for a long period of time and is expressed in averages, totals, extremes and frequencies to provide information on conditions that have occurred or may re-occur (Luke & McArthur 1978). Climatic conditions are important in determining how and when fires will burn, as it affects the amount of moisture in fuel, the ability of the fuel to ignite, sustain combustion and spread (Theron 1994; Bond 1997). The climatic condition of an area for a year or more is usually expressed per season (summer, autumn, winter and spring) and the average conditions for each season must be considered separately (Van Heerden & Hurry 1987). Climatic variables that contribute towards the occurrence of veld fires in the mountain regions of the South Western Cape are discussed next.

2.3.1.1 Temperature

Temperature is a basic climatological variable frequently used as an index of energy status of the environment (Schulze 1997). Ninety-three percent of the respondents agreed that air temperature affects fire behaviour through pre-heating of fuel and indirectly through its effect on relative humidity. Fuel moisture loss influences the temperature of the fuel and, therefore, the quantity of heat energy required to raise it to its ignition point (Trollope 1984). However, high temperature does not necessarily mean a high fire hazard, since the relative humidity may also be high (Theron 1994).

Within the mountain regions of the South Western Cape, increase in average monthly temperature northwards along the coast is less than the temperature increase inland per unit of distance (Nieman 1981). From the fire records, it was found that most incidences of veld fires in the Peninsula and inland regions of the Boland occurred in the summer season when monthly mean maximum temperatures were between 24°C and 30°C.

During the same time there were low incidences of veld fires in the coastal region northwards, along the West Coast as a result of lower average maximum temperature in summer due to the influence of the Atlantic Ocean. In the mountain regions monthly mean maximum temperatures decrease through autumn to spring and the frequency of veld fire incidences are then quite low.

In the Southern Cape, the irregularities in mean and extreme maximum temperature for short periods during the winter season can be ascribed to occassional hot bergwinds that sometimes lead to veld fire incidences (Geldenhuys 1994). Bergwinds are gusty, hot, desiccating, north-westerly to north-easterly winds that blow from the interior across the coastal mountains onto the coast. They are associated with low-pressure cells moving from west to east along the coast (Geldenhuys 1994). These extremely warm spells usually coincide with periods of lowest precipitation and atmospheric humidity (Nieman 1981), therefore the dry conditions have a high probability of veld fire occurrence especially in the Southern Cape.

2.3.1.2 Relative humidity

Relative humidity of the air is dependent upon air temperature and it varies directly with temperature. To a large extent it controls evaporation and thus the drying of various fuel types. Eighty-one percent of the respondents agreed that relative humidity of air contributes to veld fire occurrence through its effect on the moisture content of fuels.

When relative humidity is low, evaporation tends to be rapid which can lead to a high fire hazard, and when humidity is high, the reverse is the case (Theron 1994). In the mountain regions of the South Western Cape, most wild-fires were associated with a mean relative humidity between 33% - 48% (Van Wilgen 1981).

2.3.1.3 Wind characteristics

Wind dries fuels through increased moisture evaporation, ensures continued supply of oxygen during a fire, and carries burning material to ignite spot fires, tilt flames towards unburned fuel and thus increases the drying action (Theron 1994). Wind direction may be influenced by nearby topographic features (De Ronde, Goldammer, Wade & Soares 1990) and it is the most difficult factor to forecast accurately (Green 1981).

Ninety-three percent of the respondents agreed that wind is one of the most important factors contributing to veld fires in their management area. Wind direction can change indiscriminately at any time, making efforts to control fires difficult. All respondents agreed that wind speed is probably the single most important factor in the spread of veld fires. It is difficult to forecast accurately and this causes problems for fire-fighters, conservation and forest managers in containing veld fires. It is impossible to generalise wind speed in the fynbos biome as local conditions are highly variable (Green 1981; Van Wilgen 1985). In the mountain regions of the South Western Cape, local topography often enhances the channelling of synoptic scale winds so that zones of localised strong winds occur (King 1963; Van Wilgen & Richardson 1985).

In the study area, winds of southerly and south-easterly direction were mostly associated with wild-fires in the West Coast region, Cape Peninsula and Boland zone, while north-west, west or south-westerly winds prevailed during wild-fires in the Southern Cape region (Van Wilgen 1981). The burning rate of a fire is directly influenced by the rate of oxygen supply, thus increased wind speed is directly related to the rate at which energy is released by the fire (Brown & Davis 1973). Wind also causes the angle of the flames to become more acute and with increased wind velocities, flames are forced into the unburnt material, resulting in more efficient preheating of the fuel and greater rates of spread in surface head fires (Luke & McArthur 1978). Strong south-easterly winds in summer, north-easterlies in winter and warm bergwinds in autumn and spring not only aggravate the evaporative water loss of vegetation surfaces, but can lead to the enhancement and spread of veld fires in the mountain regions of the South Western Cape (Nieman 1981).

2.3.1.4 Duration since last precipitation

Six percent of the respondents indicated that number of days since the last rain could also influence the moisture content of fuels. During the summer months the weather in the study area is dominated by warm and dry air masses, with an occassional outburst of cold, moist maritime polar air that causes precipitation, mostly in the southern part of the coastal lowlands. A comparison of the annual marches of temperatures and precipitation on a comparative scale shows clearly that hot, dry conditions exist in summer over the whole area between the Cape Flats and the mouth of the Olifants River (Nieman 1981). This is suitable weather for veld fires.

In winter, precipitation is high along the coastal areas decreasing inland, and irregularities in mean maximum temperature occur for short periods during this season. Occassional hot bergwinds associated with low-pressure cells moving from west to east along the coast can sometimes lead to veld fire incidences (Nieman 1981; Van Wilgen 1984; Geldenhuys 1994).

2.3.2 Slope

The steepness of slope can also be related to the rate of fire spread. Slope significantly influences the forward rate of spread of fire burning up-slope by increasing the degree of preheating of unburnt fuel immediately in front of the flames (Clar & Chatten 1966; Trollope 1984; Whelan 1985), while a down-slope decreases the rate of spread of fire (Luke & McArthur 1978).

All respondents mentioned slope as an important factor regarding the spread and severity of veld fires, because most veld fire incidences within their management area start at lower slopes that are easily accessible to more people for recreational activities e.g. picnics and walking trails who frequently start fires. In general, it can be said that fewer people traverse the steeper slopes and numbers decrease as slope increases (Clar & Chatten 1966).

2.3.3 Vegetation

Occurrence of veld fires depends on the quantity and quality of fuel with some fuel types being more susceptible to fire than others (Trollope 1984). Within the study area, Mountain Fynbos constituted almost half of the vegetation cover, Afromontane Forest 15%, Central Mountain Renosterveld 10%, followed by South & South-West Coast Renosterveld and West Coast Renosterveld constituting 7%, while Laterite Fynbos, Limestone Fynbos, alien vegetation and Succulent Karoo constituted 3% of the vegetation cover (Figure 2.1). Pine trees constituted 65% of the forest cover and Eucalyptus 35%. Fifty-seven percent of the respondents indicated that continuity of fuel cover was highly fragmented, while 43% of the respondents mentioned that it was continuous within their management area.

Different fuels possess different traits such as concentration of oil in leaves that increase or decrease their flammability (Christensen 1995). Susceptibility of fuel type to fire was determined by asking respondents to the questionnaire to rank each vegetation type on a scale of 1 to 3 in terms of flammability (low, medium and high). These ranked values were averaged to obtain the weighted average susceptibilities (Table 2.4).

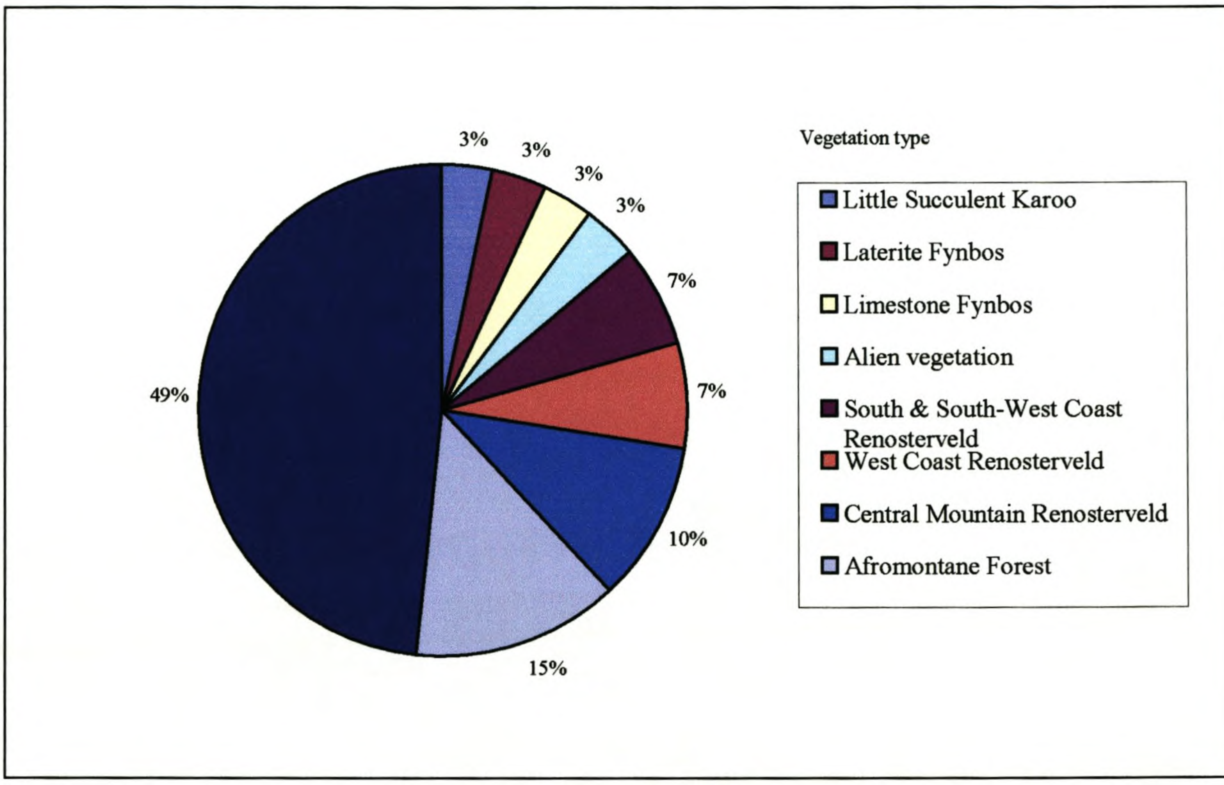


Figure 2.1: Distribution of vegetation type within the surveyed Nature Reserves[(1)], according to the opinion of respondents.

[(1)] The surveyed reserves were in the following areas: Hottentots Holland Mountains (Jonkershoek, Stellenbosch, Streenbas and Grabouw), Drakenstein (La Motte) and Table Mountain (Tokai, Devil's Peak and Noordhoek).

Table 2.5: Susceptibility of fuel types to veld fire in the mountain regions of the South Western Cape.

Fuel type	Weighted average	Susceptibility to fire
Central Mountain Renosterveld	1,0	Low
Afromontane Forest	1,0	Low
South & South-West Coast Renosterveld	1,5	High
West Coast Renosterveld	1,7	High
Laterite Fynbos	2,6	High
Alien vegetation e.g. Pinus	3,0	High
Limestone Fynbos	3,0	High
Mountain Fynbos	3,0	High

Susceptibility to fire: 0.0 - 1.0 = Low 1.1 - 1.3 = Medium 1.4 and above = High

N.B.: Susceptibility of fuel type to fire was determined by asking respondents to the questionnnaire to rank each type on a scale of 1 to 3 in terms of flammability (low, medium and high). These ranked values were averaged to obtain the weighted average susceptibilities. Susceptibility scale of fuel to fire was classified using the 33rd and 66th percentiles.

Central Mountain Renosterveld, Afromontane Forest, South & South-West Coast Renosterveld and West Coast Renosterveld have a low susceptibility to fire, followed by Pine and Laterite Fynbos with a medium susceptibility to fire. Fuel types with high susceptibility to fire within the study area are alien plants, Limestone Fynbos and Mountain Fynbos. The low fuel load and high frequency of non-flammable succulent plants of the Succulent Karoo biome result in virtual exclusion of fire in this biome (Edwards 1984; Rutherford & Westfall 1986). Distribution patterns of fires in the Afromontane Forests are determined by warm and dry winds, therefore, having a high susceptibility to fire (Geldenhuys 1994; Midgley, Cowling, Seydack & Van Wyk 1997).

The Renosterveld vegetation type (Central Mountain Renosterveld, South & South-West Coast Renosterveld and West Coast Renosterveld) constitutes only a very small proportion of the remaining natural vegetation in the fynbos biome. No data is available on the fuel properties of this vegetation. Fortunately, this vegetation type is currently not important in landscape-level fire patterns (Van Wilgen 1987). Laterite and Limestone Fynbos which are part of the Coastal Fynbos biome (Low & Rebelo 1996), and Mountain Fynbos are highly flammable due to the presence of combustible oils, finely divided canopies and continous structure (Rutherford & Westfall 1986). Coastal fynbos are similar to Dry or Mesic Mountain Fynbos where fires are possible under mild climatic conditions in older vegetation, as well as in stands with post-fire ages of less than four years that have enough fuel to support a fire (Van Wilgen 1987). Mountain Fynbos is highly susceptibile to hot fires that remove almost all above-ground fuel (Low & Rebelo 1996).

Alien vegetation accounts for more than twenty percent of the vegetation cover in the mountain region of the South Western Cape (Working for Water Programme 1998). Alien vegetation e.g. Pinus, increases fuel load of any biome that they invade, thus increasing fire hazard (Richardson, MacDonald, Hoffmann & Henderson 1997), and due to their high oily leaf content, burn at high intensities under moderate weather conditions (Van Wilgen & Richardson 1985).

2.3.4 Anthropogenic factors

Recorded veld fire occurrences by human, natural and unknown origins in the Cape Province are not always complete (Horne 1981). Keeping records of the extent, locality, cause and effects of fire is problematic, because at the time of arrival at the fire incidence, fire fighters and forest managers are unable to establish the cause of fire, time it started and after it as been extinguished the approximate extent of the area burnt. Therefore good fire records are rare (Richardson, Van Wilgen, Le Maitre, Higgins & Forsyth 1994; Van Wilgen 1999).

Data were available for 213 mountain fire incidences over the period 1985 to 1999 from five institutions visited (Winelands District Council (WDC), Stellenbosch; Noordhoek Forest Station; South Peninsula Municipality; Stellenbosch Fire Department and Cape Nature Conservation (Jonkershoek). The study was based only on data for date of occurrence, type of incident, time of occurrence, duration of fire, extent of fire, cause of fire and location.

Figure 2.2 depicts the annual frequency of veld fires caused by human, unknown and natural causes recorded over a period of 14 years within the management area of the five institutions used for the study. It is clear from Figure 2.2 that the total number of fires had increased over the fourteen year period. This may be due to natural population growth and large immigrations since the abolishment of influx control measures.

Human-induced occurrences of veld fires are either intentional or unintentional, and are common throughout the year. Very large areas are affected, and the damage they cause may be disproportionate to the number of incidences, when incendiarists choose weather and fuel conditions favourable to fires (Bond, 1997). Possible human causes include arson, work related activities e.g. clearing of land using earth moving machines, picnics, burning of firebreaks, uncontrolled prescribed burning, careless discarding of cigarette buts, children playing with matches or fire-works, and pleasure at witnessing destruction (Luke & McArthur 1978; Van Wilgen 1999).

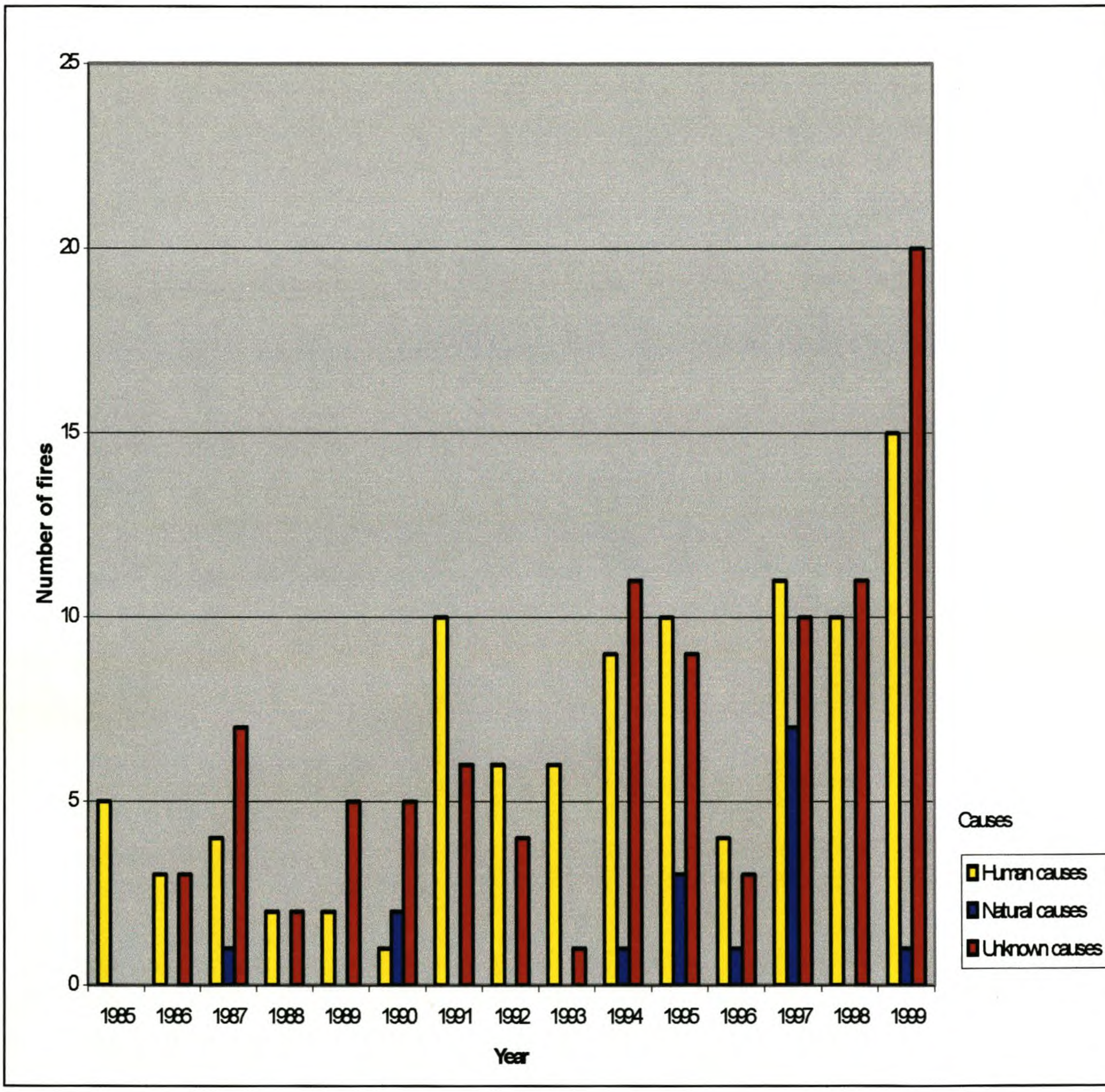


Figure 2.2: Annual incidence of veld fires by cause in the surveyed Nature Reserves[1], 1985 – 1999.

[1] The surveyed reserves were in the following areas: Hottentots Holland Mountains (Jonkershoek, Stellenbosch, Streenbas and Grabouw), Drakenstein (La Motte) and Table Mountain (Tokai, Devil's Peak and Noordhoek).

2.3.5 Natural and other factors

The natural causes of fire ignition in vegetation (excluding man) include sparks from falling rocks, spontaneous combustion and lightning, with lightning generally considered the most significant of the natural causes (Edwards 1984). Although lightning is accepted as an ignition source, opinions differ as to the frequency and importance of lightning-induced fires in the natural ecosystem. Firstly, there is difficulty of recording with certainty the occurrence of a lightning-induced fire, and secondly the ignition of the veld by lightning depends on the nature of the topography. The subsequent sustained combustion depends on the availability of suitable quality and quantity of fuel and weather conditions (Horne 1981). Veld fires by natural causes have had a low frequency of occurrence on an annual basis (Figure 2.2). Despite the low frequency of lightning storms in most parts of the South Western Cape, fires caused by lightning are common in some other parts of the country (Kruger 1977). Incidences of veld fires by unknown origin increased dramatically over the fourteen-year period. Through personal communication, all respondents noted that recorded incidences of unknown causes within their management area, is as a result of lack of information as to the cause of the fire, the late arrival of fire-fighters and nature conservation managers to the initial start of the fire, and the possibility that most fires of unknown causes were probably caused by human negligence.

Figure 2.3 depicts the number of fire occurrences at a 4 year interval of all veld fire occurrences irrespective of cause for all regions. The diagram shows an exponential increase over the fourteen year period (1985 - 1999). With the yearly increase in the frequency of veld fires, the expected number of veld fire occurrences can be estimated using the Microsoft Excel *forecast* function on a regression analysis trend-line (Figure 2.3). According to the observed average annual frequency of veld fires, the region can expect to record about seventy fires annually by 2005. This represents a hundred percent increase over a five year period in the mountain region of the South Western Cape and could have serious and devastating consequences should current trends persist.

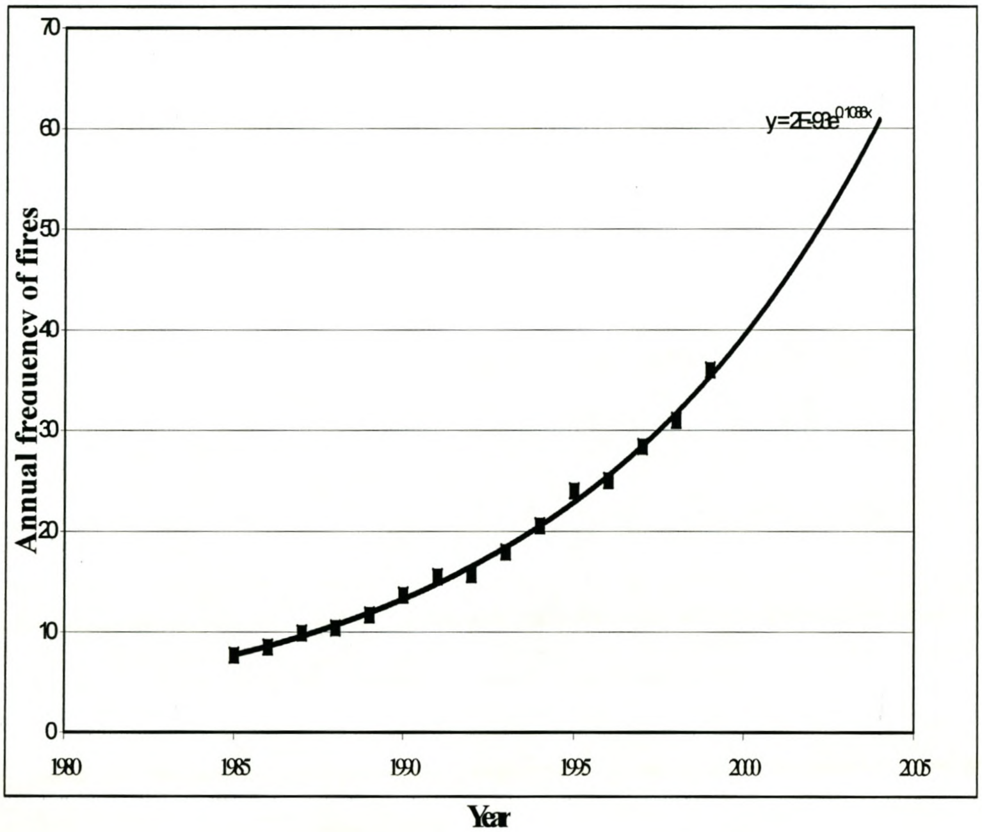


Figure 2.3: Observed and expected frequencies of veld fires in the surveyed Nature Reserves(1), 1985 – 1999.

(1) The surveyed reserves were in the following areas: Hottentots Holland Mountains (Jonkershoek, Stellenbosch, Streenbas and Grabouw), Drakenstein (La Motte) and Table Mountain (Tokai, Devil's Peak and Noordhoek).

2.4 Types of fires in the South Western Cape

Different fires can be classified according to the level at which burning takes place or the manner in which they progress. Three types are generally distinguished, namely crown, surface and ground fires (Luke 1961; Luke & McArthur 1978). In the South Western Cape, the fynbos vegetation accumulates a fair amount of fuel for fire. This vegetation is comprised of well-dispersed, bulky, flammable material in the lower shrub strata above soil level and burns as surface fires. Crown fires occur in taller shrubs (Kruger & Bigalke 1984). Crown, surface and ground fires may occur simultaneously or in all possible combinations (Brown & Davis 1973).

Table 2.6: Types of fire in the mountain regions of the South Western Cape.

Type of fire	Yearly interval	Number of respondents	Percentage of respondents (%)
Ground fire	2 - 4	8	50
Crown fire	2	10	62
Surface fire	1	12	75

Total number of respondents = 16

The types of fire that reportedly occur in the study area are shown in Table 2.5 above. The second column gives the average annual interval of the fire types occurring within the management area of respondents.

2.4.1 Ground fire

Ground fires burn within the thick layers of humus and decomposing plant material (Trollope 1984). It spreads in the organic horizon of the soil rather than on the surface, burning slowly but consistently with intense heat and is difficult to detect and control, and can cause complete shifts in vegetation (Luke 1961; Luke & McArthur 1978; Ellery, Ellery, McCarthy, Cairncross & Oelofse 1989). Fifty percent of the respondents recorded that ground fires take place within their management area at an interval of 2 - 4 years.

2.4.2 Surface fire

Surface fires burn on or just above the ground surface, and consumes shrublet communities, seedlings and loose surface litter. These are fine fuels which can support intense surface fires in direct proportion to the quantity of material per unit area (Trollope 1984). A majority of the respondents (75%) indicated that surface fire occurs mostly within their management area at a yearly interval.

2.4.3 Crown fire

This fire type includes all combustible material, live or dead, located in the understorey and upper canopy of tree and shrub communities and can be more or less independent of a surface fire (Brown & Davies 1973). The foliage is usually consumed and the vegetation may be killed through overheating of branches (Luke 1961). Sixty-two percent of the respondents indicated that within their management area, crown fires occur in their vegetation cover at average intervals of two years.

CHAPTER 3 GIS ANALYSIS OF VELD FIRES IN THE SOUTH WESTERN CAPE

Geographic information systems (GIS) can be described as computer information systems which can be used to enter, manipulate, analyse and display geographically referenced data of the world. GIS supports a wide range of spatial analyses that include processes to create new classes of spatial objects, analyse the location and the attributes of objects, and perform spatial modelling using multiple classes of objects and the relationship between them (Environmental Systems Research Institute 1987; Dharmesh, Udoyara & Robert 1995; Zietsman & Lochner 1998). GIS can be used to integrate spatial data acquired at different scales and times, and in different formats into a single database. It can also be used to measure, map, monitor and model spatial phenomena. However, the quality of data used during manipulation and analysis is a key factor in the interpretation of the results (Star & Estes 1990).

Fire occurrence probability is defined as the number of fire occurrences per unit area over a given duration. Mapping fire occurrence thus requires spatial analyses of variables that are related to the distribution of fires, such as vegetation, topography, temperature, time since last precipitation and human activities (Lowell & Astroth 1989; Chou, Minnich & Chase 1993).

3.1 Variables influencing the occurrence of veld fires in the South Western Cape

The following variables were used for modelling and mapping the potential of veld fire occurrence in the mountain regions of the South Western Cape:

- i Climatic conditions: average monthly rainfall and average maximum temperatures
- ii Vegetation and fuel occurrence: natural vegetation and forest plantations
- iii Slope
- iv Distance to roads
- v Population density

Each of the above listed variables is represented by a different layer of information in a GIS, that can be overlayed to model and map the potential of wildfire occurrence within an area (Chuvieco & Congalton 1989).

3.2 Data preparation and structuring of variables

The listed variables in Section 3.1 are in ArcView shapefile formats. The data-set for the climatological variables was obtained from the Elsenburg Agricultural Research Institute, Stellenbosch; the vegetation variable from CSIR (Council for Scientific and Industrial Research, Pretoria); and data-sets for slopes, roads and population density from the Department of Geography and Environmental Studies, University of Stellenbosch. Preparation and structuring of these variables for mapping the potential of veld fires in the mountain regions of the South Western Cape are discussed below.

3.2.1 Climatic conditions

To account for the influence of climatic conditions on fire occurrence, a point data-set of mean monthly rainfall (millimetres) and mean monthly maximum temperature (^{o}C) interpolated from thirty-five weather stations in the study area, were used for modelling fire potential. For climatic conditions the following were calculated: Mean monthly rainfall and mean monthly maximum temperatures were averaged for each of four seasons (summer, autumn, winter and spring). These values were used to compute the 33rd and 66th percentiles for each of the seasons, after which the respective climatic variables were categorised on a scale of 1 - 3 (low, average and high) for seasonal probability of influencing veld fire occurrence.

Both rainfall and temperature climate data-sets were combined to create a dryness index on a scale of 1 (low) to 9 (high), for veld fire potential using the categorised value of 1 – 3 of both the mean seasonal maximum temperature and mean seasonal rainfall, in the following way: If mean seasonal rainfall is low (3) and mean seasonal maximum temperature is high (3), the potential for a veld fire occurrence is high, therefore an index value of 9 was assigned. Conversely, if the mean seasonal maximum temperature is low (1) and the mean seasonal rainfall is high (1) a value of 1 was allocated i.e. the product of the two sets of ranks (Table 3.1). The ranking of mean seasonal rainfall was reversed because the relationship between rainfall and veld fire potential is inverse on a nominal scale.

Table 3.1: The calculation method of a dryness index for veld fire potential.

	Mean seasonal rainfall		
Mean seasonal maximum temperature	**High (1)**	**Medium (2)**	**Low (3)**
High (3)	3	6	9
Medium (2)	2	4	6
Low (1)	1	2	3

Finally, four seasonal dryness indices were interpolated to a grid data-set with cell sizes of 1km by 1km using the *interpolate* function in ArcView. These interpolated values were reclassified into nine classes using quantiles to produce Figures 3.1, 3.2, 3.3 and 3.4. The summer season dryness index is very high in the eastern part of the study area where mean monthly maximum temperatures are high and mean monthly rainfall is low, decreasing to a low and extremely low veld fire potential towards the north-western and southern coastal regions of the study area. The low fire potential in the north-western coastal area is related to lower mean monthly temperatures due to the influence of the cold ocean, in comparison with the interior mountainous areas. Similar patterns of dryness index for veld fire potential occur throughout the autumn, winter and spring season.

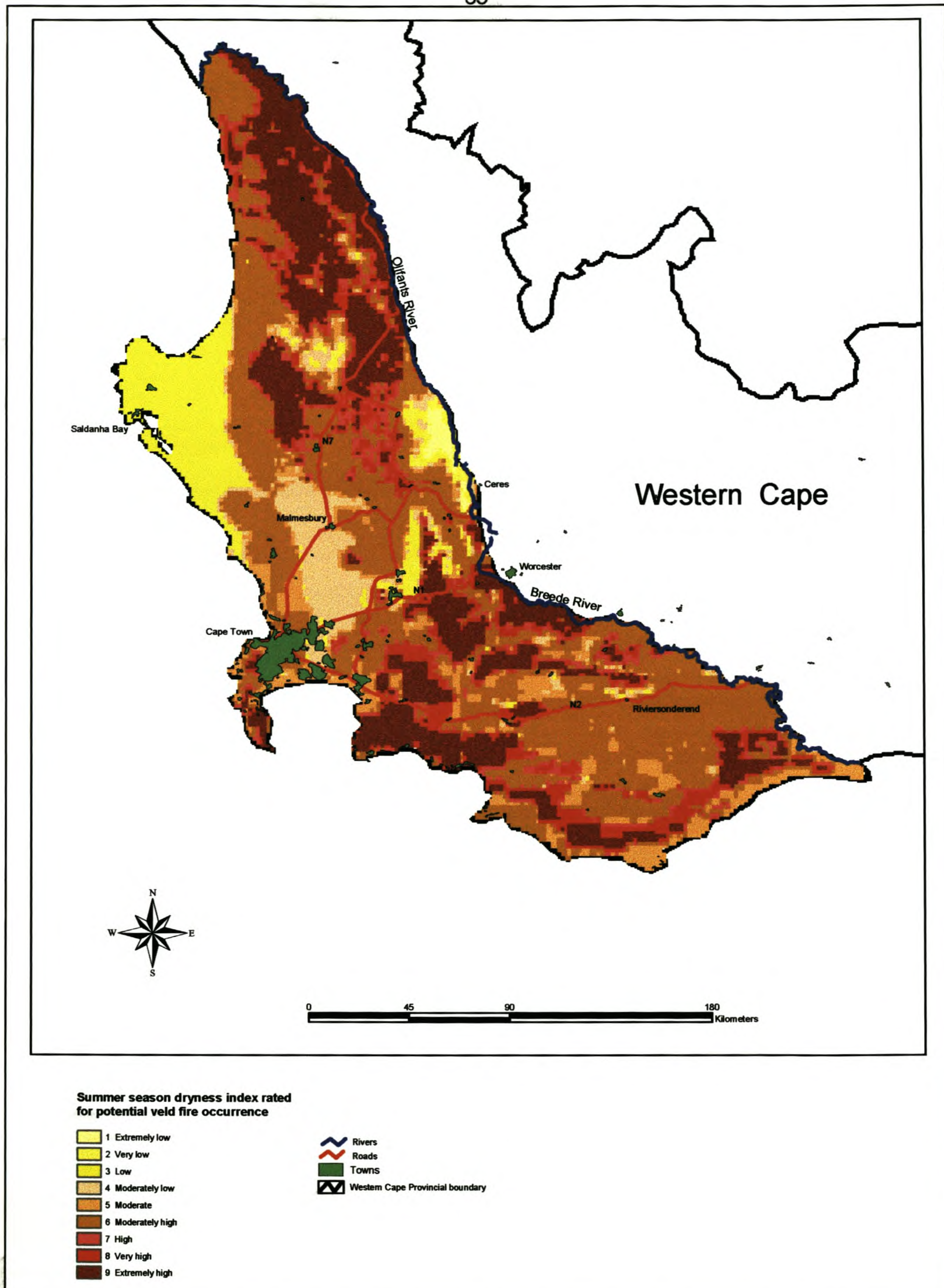


Figure 3.1: Summer season dryness index rated for potential veld fire occurrence in the South Western Cape.

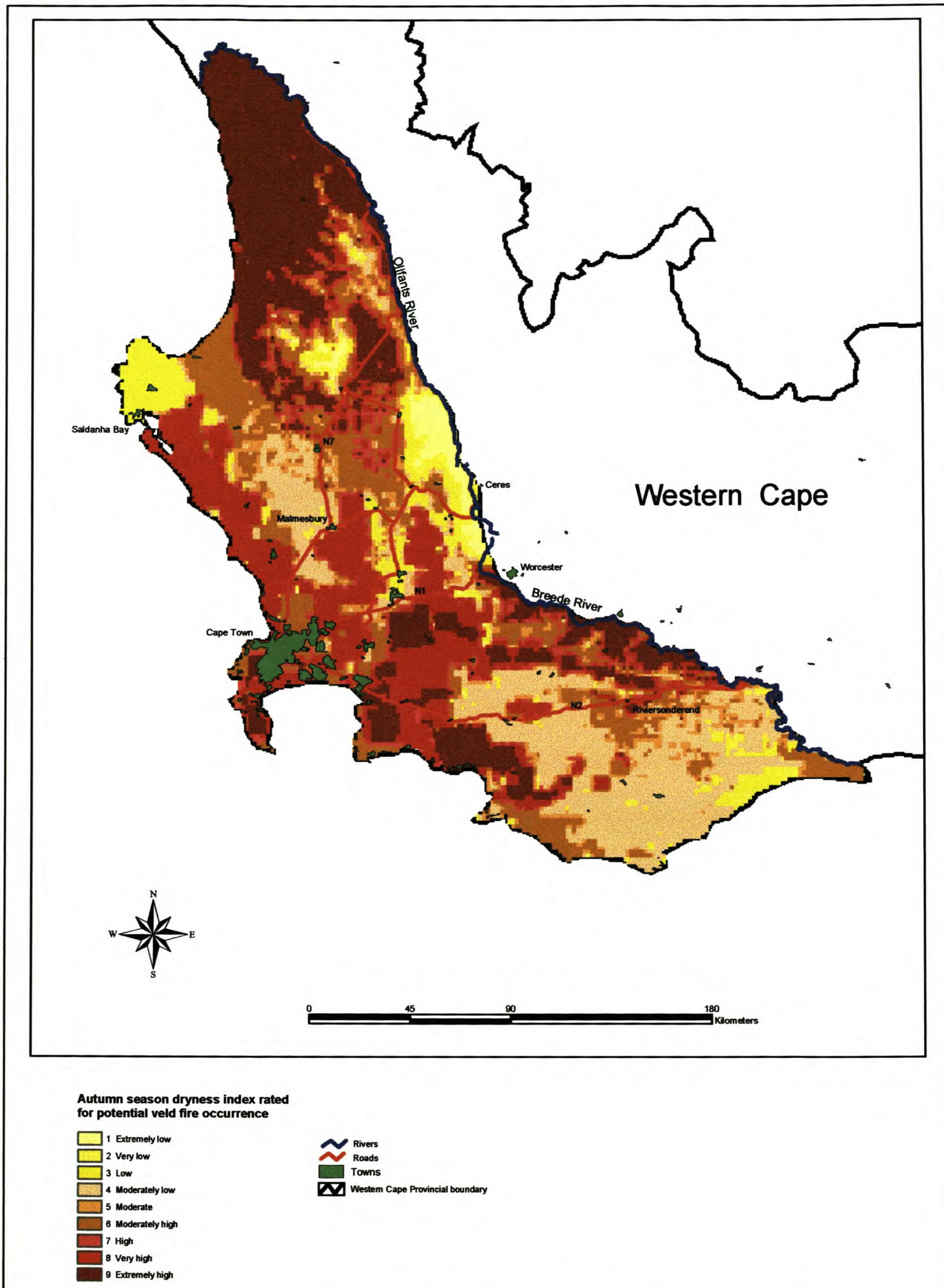


Figure 3.2: Autumn season dryness index rated for potential veld fire occurrence in the South Western Cape.

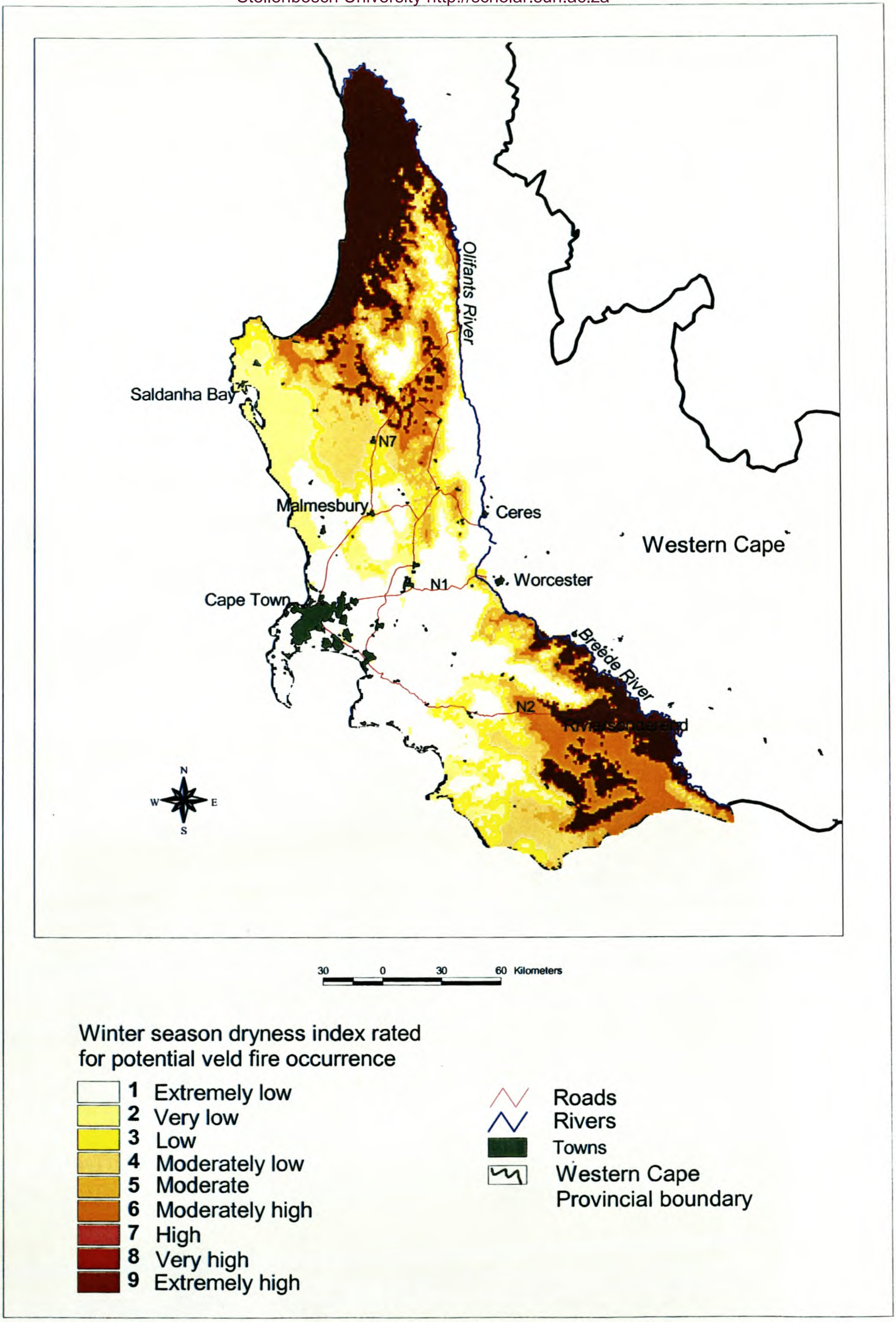


Figure 3.3: Winter season dryness index rated for potential veld fire occurrence in the South Western Cape.

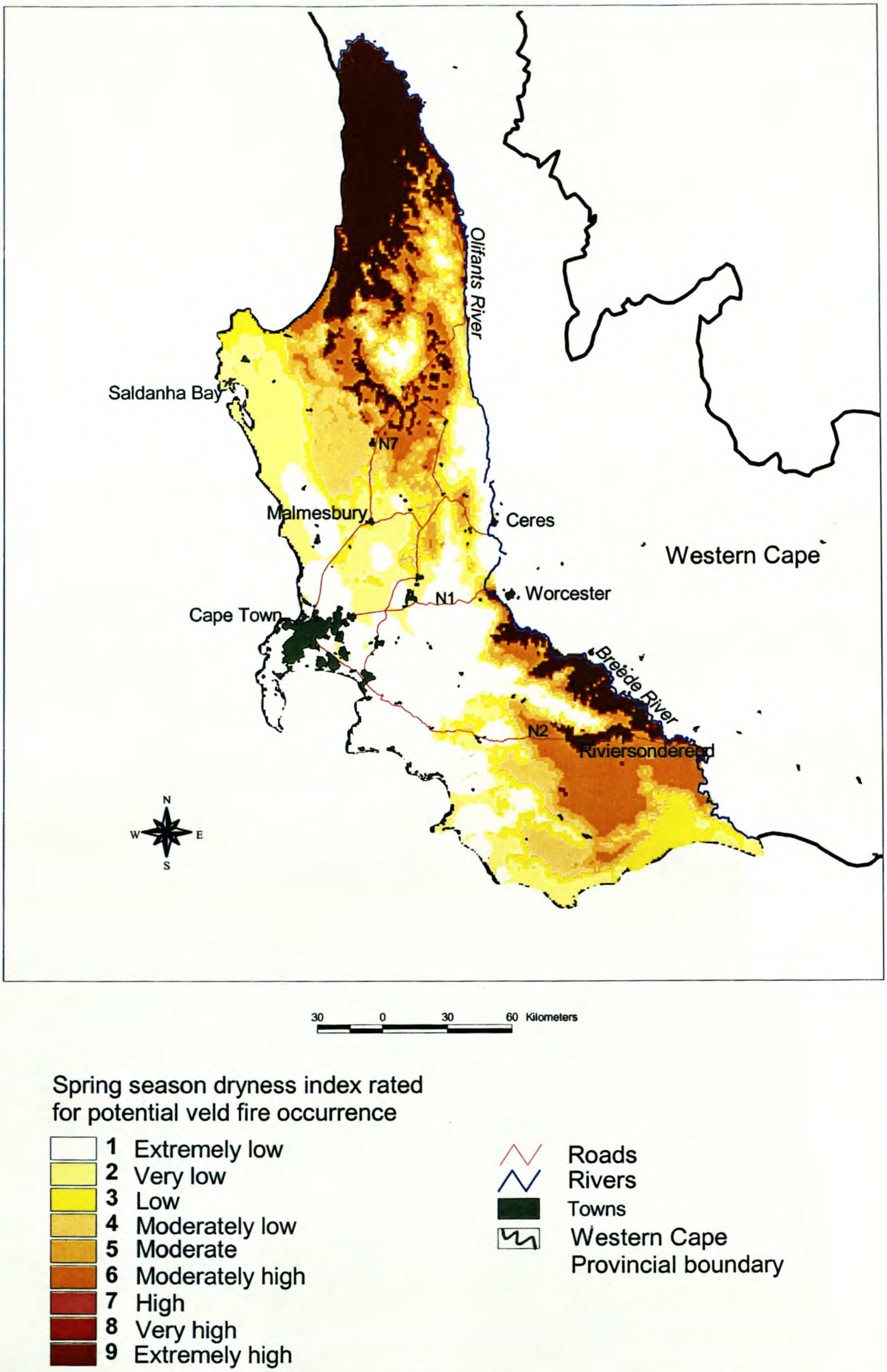


Figure 3.4: Spring season dryness index rated for potential veld fire occurrence in the South Western Cape.

3.2.2 Vegetation and fuel occurrence

This index is based on the natural vegetation and forest plantation coverage in the study area. The polygons of the existing Low & Rebelo (1996) vegetation coverage consists of seven vegetation communities, that is, Central Mountain Renosterveld, Afromontane Forest, South & South-West Coast Renosterveld, West Coast Renosterveld, Laterite Fynbos, Limestone Fynbos, and Mountain Fynbos. The forest plantation coverage consists mainly of two tree species, namely, Pine and Eucalyptus.Using the *query-builder* tool and *calculate* function in ArcView, the nominal values for natural vegetation and forest plantation type coverages were recoded to ordinal values of 1 - 3 (as calculated in Table 3.2) according to the susceptibility to veld fire of each type. The rating in Table 2.4 was used as coding reference (1 = low; 2 = moderate; 3 = high).

Table 3.2: Ranked index values assigned for fuel susceptibility for veld fire potential.

Fuel	Fuel susceptibility to fire	Fuel index
Central Mountain Renosterveld	Low	1
Dune Thicket	Low	1
Strandveld Succulent Karoo	Medium	2
Eucalyptus	High	3
Mountain Fynbos	High	3
Pinus	High	3
Sand Plain Fynbos	High	3
West Coast Renosterveld	High	3

N.B.: Table 3.2, shows only the vegetation types that occurs in the surveyed Nature Reserves[(1)].

[(1)] The surveyed reserves were in the following areas: Hottentots Holland Mountains (Jonkershoek, Stellenbosch, Streenbas and Grabouw), Drakenstein (La Motte) and Table Mountain (Tokai, Devil's Peak and Noordhoek).

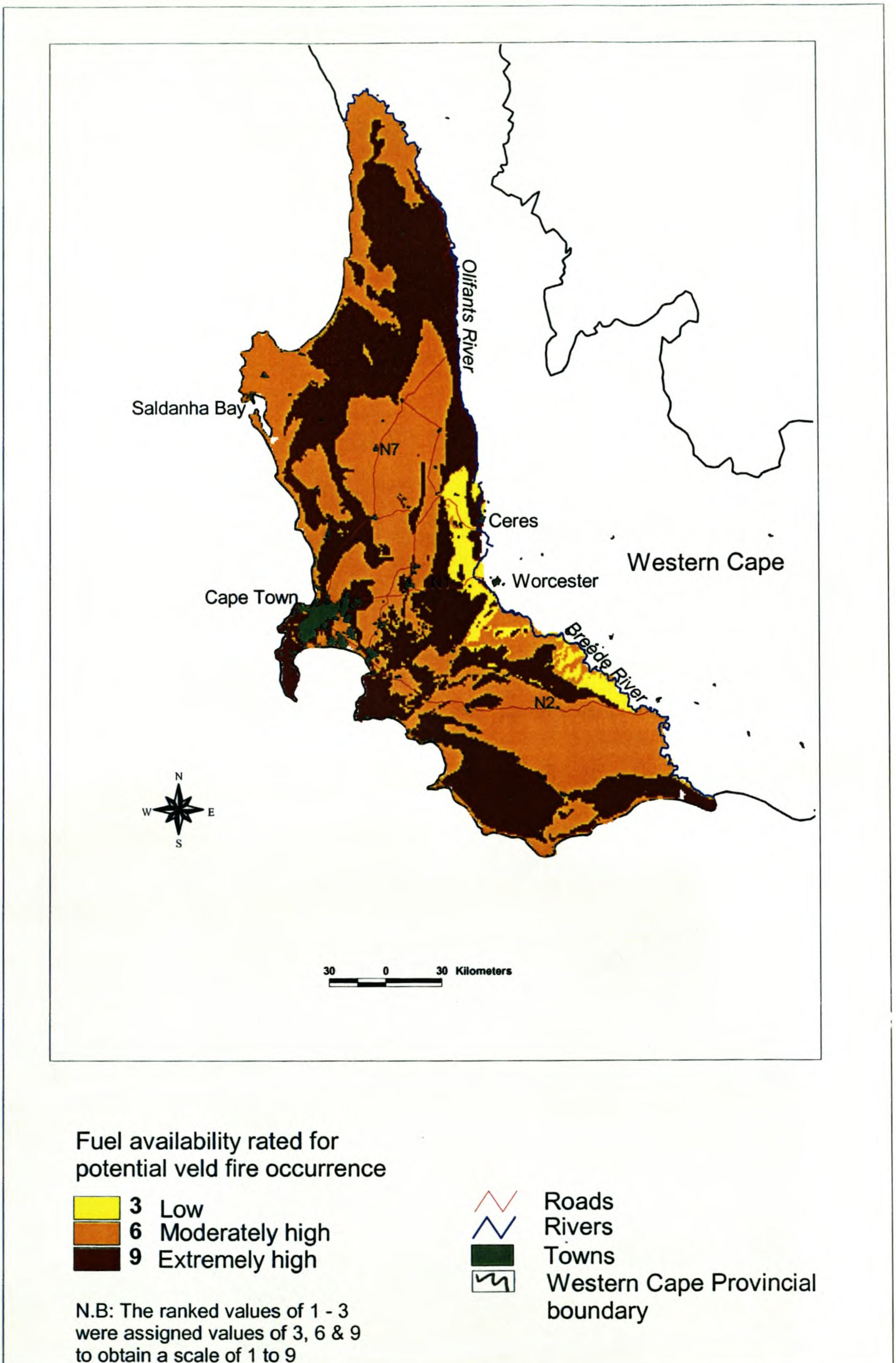


Figure 3.5: Fuel availability rated for potential veld fire occurrence in the South Western Cape.

The natural vegetation and forest plantation coverages were combined to form a composite vegetation data-set with non-overlapping polygons to create a fuel index on a scale of 1 to 3. The index values for plantation replaced the index values for natural vegetation during a logical overlay in ArcView, as natural vegetation had been removed to make way for forestry purposes. Finally, the ranked values of 1, 2 and 3 were standardized to values of 3, 6 and 9 for comparability with other indices that range between 1 and 9. Thereafter the fuel index was converted to a grid format with cell size of $1km^2$. The resulting spatial pattern is shown in Figure 3.5.

Fuel availability rated for potential veld fire occurrence is extremely high where Mountain Fynbos vegetation occurs on the northern, central and coastal regions of the study area. Areas with moderately high potential consists of Dune Thicket and West Coast Renosterveld vegetation, whereas regions where fuel availability for veld fire potential is low coincide with the distribution of Central Mountain Renosterveld and Little Succulent Karoo that have a low susceptibility to fire.

3.2.3 Slope

Slope plays a vital role in the spread of veld fires. Slope with a low inclination is more accessible to people for recreational activities, for example picnics and walking trails. An existing contour coverage with 50m intervals was converted to a gridded (1km by 1km spatial resolution) slope theme in ArcView by using the *slope* functionality (Figure 3.6).

The gradient values (0^o – 18^o) were recoded to nine classes scaled from 9 - 1 on an equal interval using the *reclassify* function in ArcView (9 = low slopes, that is highly accessible to people for recreational activities, therefore high probability for veld fire occurrence; 1 = steep slopes, fewer people traverse the steeper slopes and numbers decrease as slope increases, therefore low probability for veld fire occurrence).

This is clearly depicted in Figure 3.6, where areas starting from the coast have a very high potential for veld fire occurrence, and decreases inland as inclination increases.

3.2.4 Distance to roads

Road locations are also an important factor related to the potential of veld fires. Roads are potential routes for motorists and hikers, therefore increasing the probability of fire occurrence (Chuvieco & Congalton 1989).

All road classes (national, municipal, local and gravel roads) within the study area were converted to a 1km by 1km grid cell size data-set. By using the *find distance* function in ArcView, successive 1km distance zone from roads were created and ignition probability values of 1 – 9 assigned to them. Zones nearest to roads were given a class value of 9 (high probability for fire ignition) and those further from the roads were coded in a decreasing order to a value of 1 (low probability for fire ignition) (Figure 3.7). Within the study area, successive zones that are closer to all road classes have an extremely high potential for veld fire occurrence, decreasing inland towards the mountains to an extremely low veld fire potential, where fewer roads occur.

3.2.5 Population density

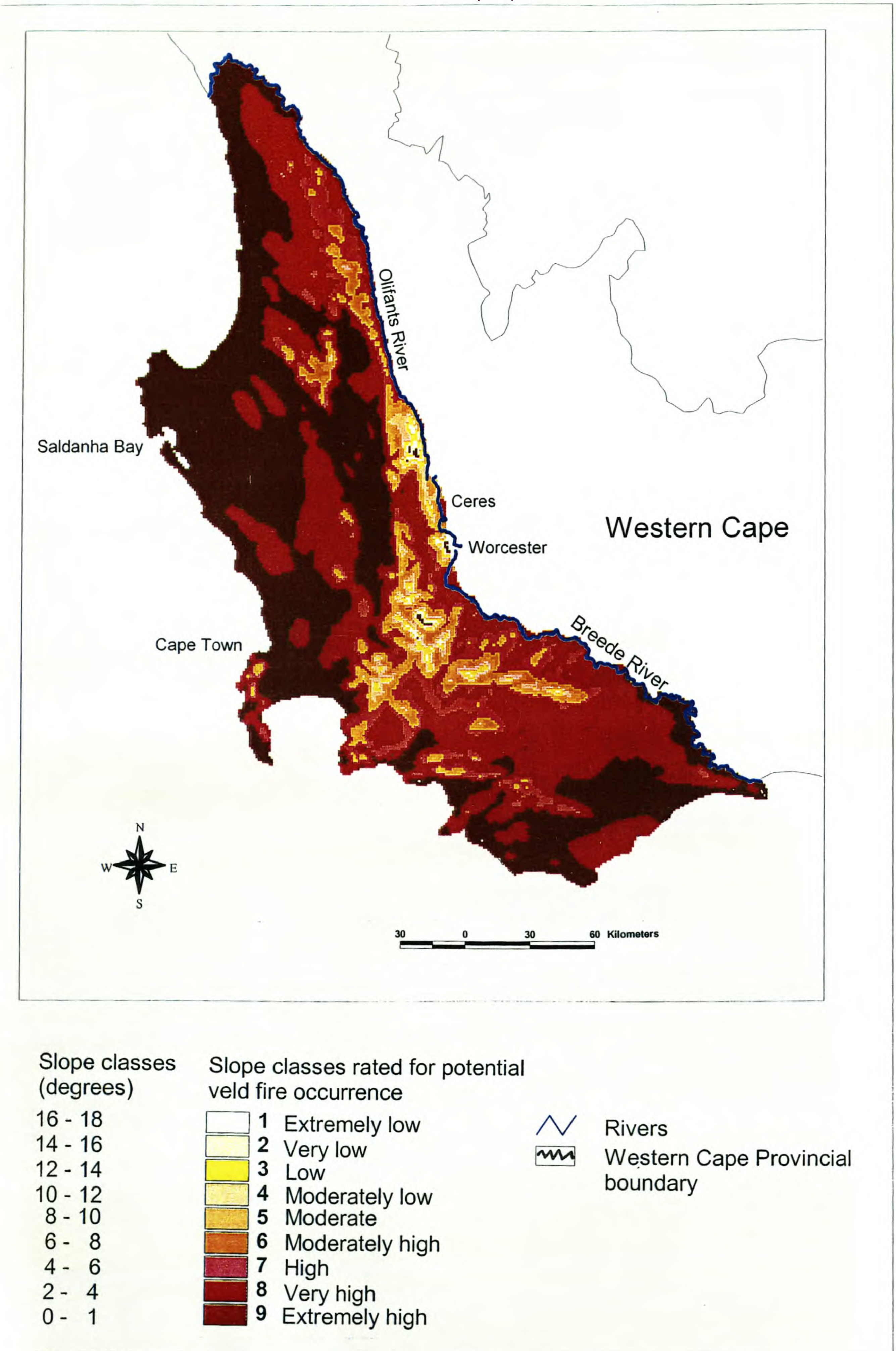
The 1996 population census data shapefile consisted of population totals per census enumeration area. Population density was expressed as the total number of people per square kilometre within the study area. Frequent occurrence of veld fires originates from human activities like camping, picnics and fire management activities. Therefore high population density is equated with high probability for fire occurrence and low population density equated with low probability for fire occurrence.

To accommodate the large range in computed population densities between rural and urban areas (ranging from 0.2 to 6710.0 persons per square kilometre) the data were logarithmically transformed, and these values were used to compute the 11^{th} percentiles of the population density variable, to create a scale of 1 - 9 (1 = low population density for low probability of veld fire occurrence; 9 = high population density for high probability of veld fire occurrence) as shown in Table 3.3.

Table 3.3: Extract from the 1996 population density database shapefile with ranked index values for veld fire potential.

Polygon_id p area number	Area (km^2)	Number of People	Population density (people/km^2)	Fire occurrence potential
1320184	198.32	428	2.2	1
1320182	131.45	493	3.8	1
1320120	1.65	809	490.0	2
1320179	6.18	1120	181.2	1
1320106	2.11	581	275.4	2
1320090	0.07	579	8271.4	5
....	....	.....	....	....

This is to counter the fact that the majority of rural enumeration areas fall into the lowest density class, whereas the high classes are mostly within the Cape Metropolitan Area. This shapefile was converted to a grid format with cell size of 1km by 1km. The resultant spatial pattern is displayed in Figure 3.8. Therefore regions with extremely high to moderate veld fire potential occur within areas that have a high population density, for example Cape Town, with low to extremely low veld fire potential occurring in regions where population density is low, for example Ceres and Riviersonderend.



gure 3.6: Slope classes rated for potential veld fire occurrence in the South Western Cape.

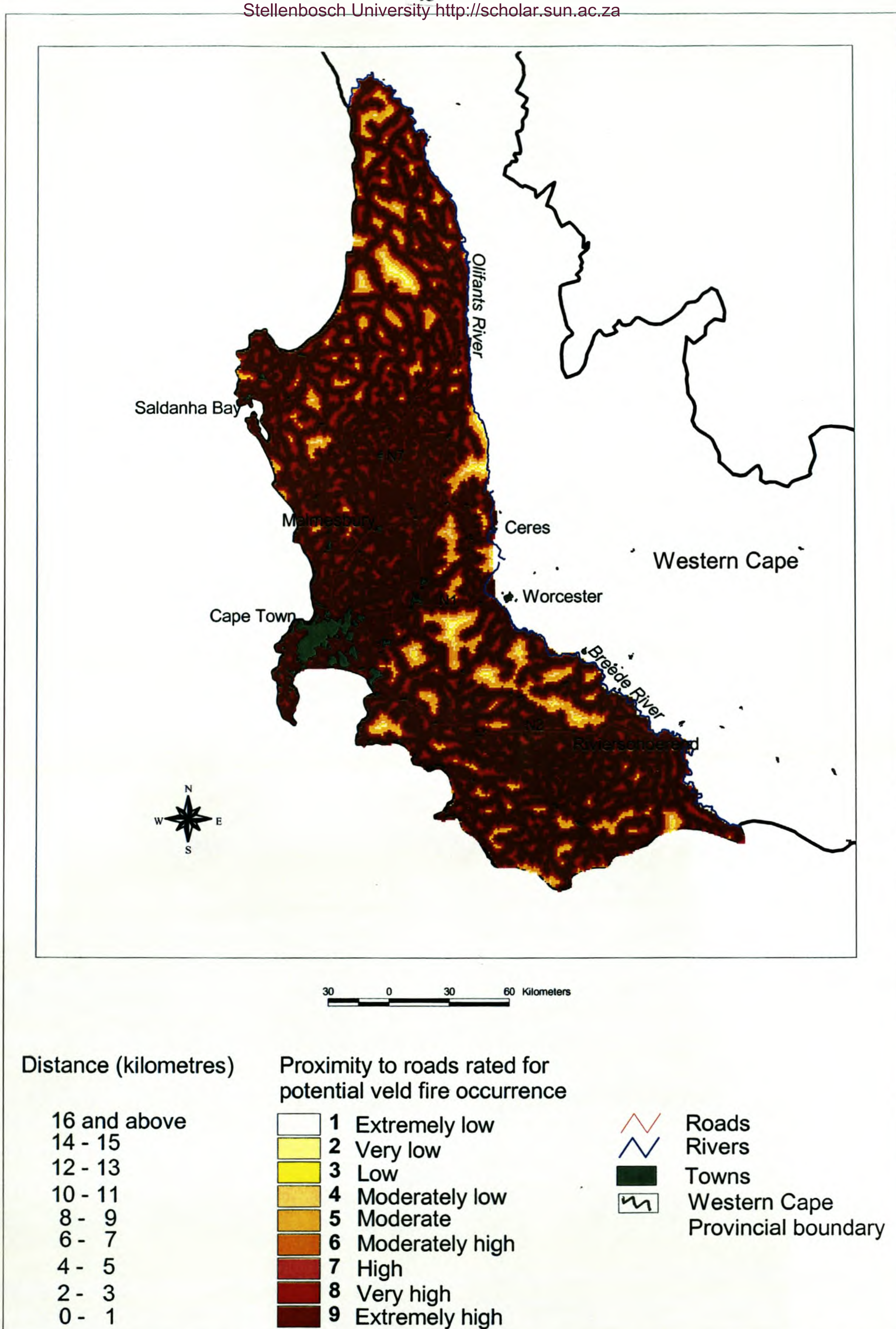


Figure 3.7: Proximity to roads rated for potential veld fire occurrence in the South Western Cape.

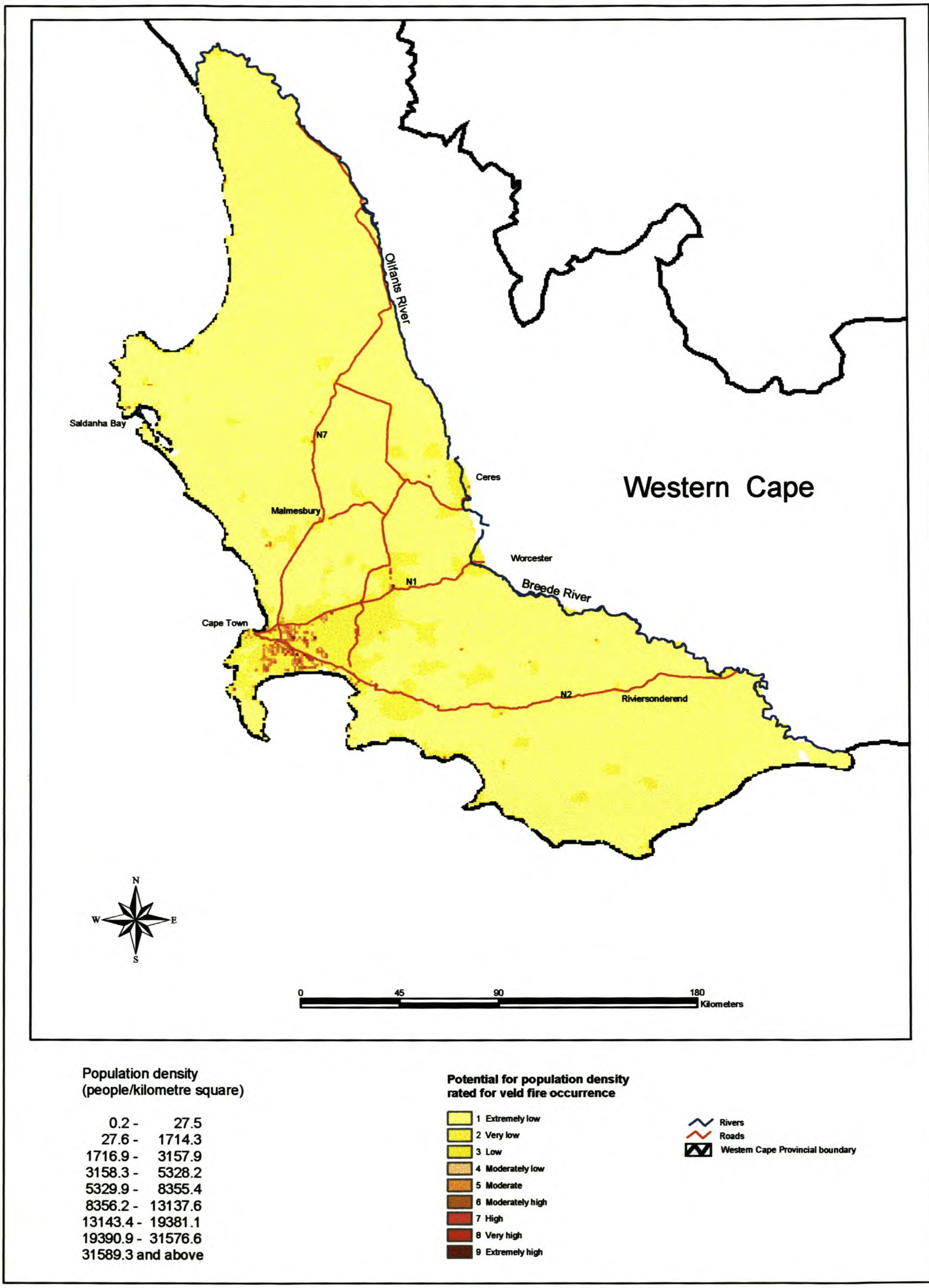


Figure 3.8: Potential for population density rated for veld fire occurrence in the South Western Cape

3.3 Weighted criteria

Assuming that some variables have a higher influence on veld fire occurrence than others, and comparing the relative importance of each season for veld fire occurrence, weights were assigned to each variable (layer) on a scale of 1 to 5 and each season on a scale of 1 to 4. These weights attempt to account for the relative importance of each variable (layer) as a factor for increasing the potential of a fire hazard (Chuvieco & Congalton 1989), and the relative importance of each season for veld fire potential.

For the influencing variables, population density was assigned a weight of five, dryness index (4), fuel (3), roads (2) and slope (1). For each season summer is weighted the highest with a weight of four, autumn (3), spring (2) and winter (1). Weights assigned to each season (Table 3.4), were based on the opinion of surveyed respondents for monthly fire risk assessment in the mountain regions of the South Western Cape. A majority of the respondents indicated that January and February were the months with the highest risk of veld fire occurrence in summer. Within the mountain regions of the Southern Western Cape, fire frequency is very high in summer, with most fires occurring in late summer (Bands 1977; Horne 1981; Van Wilgen 1984 a), therefore summer was assigned a weight of four. Most of the respondents indicated that veld fire occurrences are still relatively high in the months of March and April. According to Kruger & Bigalke (1984) and Van Wilgen (1984 a) fire danger within the mountain regions of the South Western Cape is invariably high in early autumn, therefore it was assigned a weight of three. The winter months of June, July and August were indicated by the respondents as the months with the lowest risk of veld fire occurrence within their management areas (Table 2.1). The frequency of veld fire is very low in winter, except if it is started intentionally (Horne 1981) therefore a weight of one was assigned to the winter season. Though the probability for veld fires occurring in the spring season is minimal as indicated by the respondents in (Table 2.1), Van Wilgen (1981) notes that the spring season is when the frequency of veld fires starts to pick up in the mountains of the South Western Cape, therefore a weight of two was assigned.

Most fires are ignited by people throughout the year, burning large areas no matter the season (Bond 1997). From the fire record data (Appendix A (Table A.2)), it is clear that 46% of veld fire occurrence was caused by people, with 45% as a result of unknown cause and 9% as a result of natural causes. Due to outdoor activities of people throughout the year, for example, hiking, picnics, camping, mountain management activities and uncontrolled burning of vegetation, the occurrence of fire by human activities can be very high (Horne 1981), therefore population density is given the highest weight of five.

A weight of four was assigned to the dryness index, because mean monthly maximum temperature and mean monthly rainfall (duration since last precipitation) have a strong influence on veld fire occurrence throughout the year. Hot, dry periods are associated with extreme fire danger and largely determine the occurrence of fires in summer, autumn, spring and winter (Van Wilgen 1984 a).

Fire occurrence also depends on the accumulation (quantity) and quality of fuel that varies within the study area. Depending on the physical and chemical characteristics of the fuel e.g. moisture, compactness and susceptibility to ignition, the probability for fire can be high if the fuel is ignited (Trollope 1984; Le Maitre, Van Wilgen, Chapman & McKelly 1996). For above mentioned reasons fuel was assigned a weight of three. Roads were assigned a weight of two, because roads are potential routes for transport, and can therefore increase fire occurrence due to human causes (Chuvieco & Congalton 1989). Steepness of slope on mountains has an influence on fire occurrence through the relationship with accessibility to people. Fires tend to occur where mountain slopes are less steep, therefore highly accessible, with fewer fires occurring on the steeper slopes. This is an indication that the impact of human activities decreases as slope increases (Clar & Chatten 1966; Chuvieco & Congalton 1989; Chou, Minnich & Chase 1993). Therefore slope was assigned a weight of one.

In order to obtain a combined rating for mapping veld fire potential, the weighted values for each influencing variable were multiplied with the weighted values assigned to each season to obtain an index value for veld fire potential as shown in Table 3.4.

Table 3.4: Combined rating of influencing variables and season for mapping veld fire potential.

	Seasons (weights)				
Variables (weights)	**Summer (4)**	**Autumn (3)**	**Winter (1)**	**Spring (2)**	**Total**
Population density (5)	20 (13%)	15 (10%)	5 (3%)	10 (7%)	50
Dryness index (4)	16 (11%)	12 (8%)	4 (3%)	8 (5%)	40
Fuel (3)	12 (8%)	9 (6%)	3 (2%)	6 (4%)	30
Roads (2)	8 (5%)	6 (4%)	2 (1%)	4 (3%)	20
Slope (1)	4 (3%)	3 (2%)	1 (1%)	2 (1%)	10
Total	**60**	**45**	**15**	**30**	**150**

The index values for each influencing variable per season were added to give row and column totals. The column totals were added together to obtain a grand total. To depict the spatial variation in the potential for veld fire for each influencing variable, each index value was expressed as a percentage of the grand total (150) to standardize the values between 0% and 100%. The percentage values obtained were multiplied with each influencing gridded variable data-set using the ArcView map *calculate function* under the *analysis menu* to map veld fire potential on a seasonal basis as indicated in the following paragraph. After computing the four seasonal veld fire hazard values for each grid cell in the study area, the data were ranked on a nominal scale, and class values for display purposes ranging from 1 to 9 were allocated (1 = extremely low veld fire potential to 9 = extremely high veld fire potential). This re-scaling of the data was computed using a *quantile* classification in ArcView.

The formulae for calculating veld fire potential for each season were:

Summer veld fire hazard = (Population density * 13 + Dryness index * 11 + Fuel * 8 + Roads * 5 + Slope * 3)

Autumn veld fire hazard = (Population density * 10 + Dryness index * 8 + Fuel * 6 + Roads * 4 + Slope * 2)

Winter veld fire hazard = (Population density * 3 + Dryness index * 3 + Fuel * 2 + Roads * 1 + Slope * 1)

Spring veld fire hazard = (Population density * 7 + Dryness index * 5 + Fuel * 4 + Roads * 3 + Slope * 1)

The results of these calculations are displayed and discussed in the sections that follow.

3.4 Potential veld fire occurrence

Potential for veld fire occurrences during the four seasons of the year is not static, taking into account the relative importance of each variable (layer) as a factor for increasing the probability of veld fires. To emphasize the variation in veld fire potential for the four seasons, the fire hazard maps generated have been classed into nine categories (1 = extremely low veld fire potential to 9 = extremely high veld fire potential) for the purpose of interpretation. In Table 3.5 fire potential is given for each season of the year for all the zones and sub-regions in the study area.

3.4.1 Veld fire potential in the mountain regions of the South Western Cape

Seasonal veld fire potential and possible reasons for veld fire occurrences in the sub-regions of the South Western Cape are given below in Table 3.5.

Table 3.5: Potential and possible reasons for veld fire occurrence in the different zones and sub-regions.

Season	Zone	Sub-region	Veld fire potential	Reasons for veld fire
Summer	**West Coast**	▪ Olifant's River Mountain (1)	Very high	▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consist of Mountain Fynbos which is highly susceptible Fire
		▪ Piketberg Mountain (2)	High	▪ Proximity to human settlement ▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consist of Mountain Fynbos which is highly susceptible Fire
		▪ Winterhoek Mountain (3)	Moderately high	▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consist of Mountain Fynbos which is highly susceptible to fire

Season	Zone	Sub-region	Veld fire potential	Reasons for veld fire
Summer	**Boland**	▪ Stellenbosch Mountain (4)	Moderately high	▪ Proximity to human settlement, and human activities e.g. picnics, camping and hiking ▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consists of Mountain Fynbos which is highly susceptible to fire
		▪ Groot Drakenstein Mountain (5) ▪ Hottentots Holland Mountain (6) ▪ Wemmershoek Mountain (7) ▪ Du Toit's Mountain (8) ▪ Limiet Mountain (9)	Moderately high	▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consist of Mountair Fynbos which is highly susceptible to fire
	Peninsula	▪ Table Mountain (10)	Moderately high	▪ Proximity to human settlemen and human activities e.g. camping, picnics, hiking and tourist destination ▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consist of Mountai Fynbos which is highly susceptible to fire
		▪ Cape of Good Hope Nature Reserve (11)	Moderately high	▪ Human activities e.g. camping, picnics, hiking and tourist destination ▪ Vegetation consist of Mountai Fynbos which is highly susceptible to fire

Season	Zone	Sub-region	Veld fire Potential	Reasons for veld fire
Summer	**Southern Cape**	▪ Franschhoek Mountain (12) ▪ Kogelberg Mountain (13)	Moderately high	▪ Proximity to human settlement ▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consist of Mountain Fynbos which is highly susceptible to fire
		▪ Riviersonderend Mountain (14) ▪ Klein River Mountain (15) ▪ Bredasdorp Mountain (16)	Moderately high	▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consists of Laterite, Limestone and Mountain Fynb which has a medium to high susceptibility to fire
Autumn	**West Coast**	▪ Olifant's River Mountain (1)	High	▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consist of Mountai Fynbos which is highly susceptible to fire
		▪ Piketberg Mountain (2) ▪ Winterhoek Mountain (3)	Moderately high	▪ Proximity to human settlement ▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consist of Mountai Fynbos which is highly susceptible to fire
	Boland	▪ Stellenbosch Mountain (4)	Moderately high	▪ Proximity to human settlement and human activities e.g. picnics, camping and hiking ▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consists of Mounta Fynbos which is highly susceptible to fire

Season	Zone	Sub-region	Veld fire Potential	Reasons for veld fire
Autumn	**Boland**	▪ Groot Drakenstein Mountain (5) ▪ Hottentots Holland Mountain (6) ▪ Wemmershoek Mountain (7) ▪ Du Toit's Mountain (8) ▪ Limiet Mountain (9)	Moderately high	▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consist of Mountain Fynbos which is highly susceptible to fire
	Peninsula	▪ Table Mountain (10)	Moderately high	▪ Proximity to human settlement, and human activities e.g. camping, picnics, hiking and tourist destination ▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consist of Mountain Fynbos which is highly susceptible to fire
		▪ Cape of Good Hope Nature Reserve (11)	Moderately high	▪ Human activities e.g. camping, picnics, hiking and tourist destination ▪ Vegetation consist of Mountain Fynbos which is highly susceptible to fire
	Southern Cape	▪ Franschhoek Mountain (12) ▪ Kogelberg Mountain (13) ▪ Riviersonderend Mountain (14) ▪ Klein River Mountain (15) ▪ Bredasdorp Mountain (16)	Moderately high	▪ Mean monthly maximum temperature is high and mean monthly rainfall is low ▪ Vegetation consist of Mountain Fynbos which is highly susceptible to fire

Season	Zone	Sub-region	Veld fire potential	Reasons for veld fire
Winter	**West Coast**	▪ Olifants River Mountain (1) ▪ Piketberg Mountain (2) ▪ Winterhoek Mountain (3)	Low	▪ Mean monthly maximum temperature is low and mean monthly rainfall is high
	Boland	▪ Stellenbosch Mountain (4)	Low	▪ Less human activities e.g. picnics, camping and hiking ▪ Mean monthly maximum temperature is low and mean monthly rainfall is high
		▪ Groot Drakenstein Mountain (5) ▪ Hottentots Holland Mountain (6) ▪ Wemmershoek Mountain (7) ▪ Du Toit's Mountain (8) ▪ Limiet Mountain (9)	Low	▪ Mean monthly maximum temperature is low and mean monthly rainfall is high
	Peninsula	▪ Table Mountain (10) ▪ Cape of Good Hope Nature Reserve (11)	Low	▪ Mean monthly maximum temperature is low and mean monthly rainfall is high ▪ Less human activities e.g. picnics, camping and hiking and tourist destination
	Southern Cape	▪ Franschhoek Mountain (12) ▪ Kogelberg Mountain (13) ▪ Riviersonderend Mountain (14) ▪ Klein River Mountain (15)	Low	▪ Mean monthly maximum temperature is low and mean monthly rainfall is high

Season	Zone	Sub-region	Veld fire potential	Reasons for veld fire
Winter	**Southern Cape**	▪ Bredasdorp Mountain (16)	Moderately Low	▪ Likely occurrence of Föhn-like berg-winds, accompanied by sudden increases in temperature and decreases in humidity
Spring	**West Coast**	▪ Olifants River Mountain (1)	Moderately high	▪ Mean monthly maximum temperature is moderately high and mean monthly rainfall is low ▪ Vegetation consist of Mountain Fynbos which is highly susceptible to fire
		▪ Piketberg Mountain (2) ▪ Winterhoek Mountain (3)	Low	▪ Mean monthly maximum temperature is moderately high and mean monthly rainfall is low
	Boland	▪ Stellenbosch Mountain (4) ▪ Groot Drakenstein Mountain (5) ▪ Hottentots Holland Mountain (6) ▪ Wemmershoek Mountain (7) ▪ Du Toit's Mountain (8) ▪ Limiet Mountain (9)	Low	▪ Less human activities e.g. picnics, camping and hikir ▪ Mean monthly maximum temperature is moderately high and mean monthly rainfall is low
	Peninsula	▪ Table Mountain (10) ▪ Cape of Good Hope Nature Reserve (11)	Low	▪ Mean monthly maximum temperature is moderately high and mean monthly rainfall is low ▪ Less human activities e.g. picnics, camping and touri destination

Season	Zone	Sub-region	Veld fire potential	Reasons for veld fire
Spring	**Southern Cape**	▪ Franschhoek Mountain (12) ▪ Kogelberg Mountain (13) ▪ Riviersonderend Mountain (14) ▪ Klein River Mountain (15) ▪ Bredasdorp Mountain (16)	Low	▪ Mean monthly maximum temperature is moderately high and mean monthly rainfall is low

3.4.1.1 Summer season veld fire potential

The Olifants River Mountain area north of the West Coast sub-region depicts a high potential for veld fire occurrence in *summer* (Figure 3.9), with moderately high veld fire potential occurring in the Piketberg Mountain area. Areas of very low veld fire potential are cultivated land or Strandveld Succulent Karoo, with low fuel loads, sparse canopy, and succulent plants that have a low susceptibility to fire. On the eastern part of the sub-region, the Winterhoek Mountain has a moderate veld fire potential. Within this zone as a whole, mean fire potential is high under conditions of high temperature, low relative humidity, high wind and the natural vegetation. The Olifants River, Piketberg and Winterhoek Mountains have a large proportion of Mountain Fynbos that is highly susceptible to fire in the *summer* season (Low & Rebelo 1996; Van Wilgen 1984).

Potential for veld fire occurrence in the Hottentots Holland, Stellenbosch, Groot Drakenstein, Limiet, Wemmershoek and Du Toit's Mountain areas are moderate. This zone is characterised by strong seasonal trends in fire occurrence in the *summer* months, since it is a holiday destination, monthly mean maximum temperatures are high with low monthly mean rainfall, and a large proportion of the natural vegetation cover in the mountain ranges is Mountain Fynbos that is highly susceptible to fire (Low & Rebelo 1996; Van Wilgen 1984). From the 14 year fire-data that were compiled (1985 - 1999), fifty seven percent of veld fire occurrences in this zone was as a result of unknown causes, thirty eight percent were due to human cause and five percent as result of natural causes.

The Peninsula zone depicts a moderately high veld fire potential in the Table Mountain area and Cape of Good Hope Nature Reserve that has a dense cover of fynbos vegetation, which is highly susceptible to fire (Figure 3.9). Population density in this sub-region is the highest in the study area, with more human activities such as camping, hiking and sight-seeing. This zone is mainly subjected to veld fires during the hot *summer* season, with the 14 year fire-data indicating that 48% of veld fire incidences were as a result of unknown causes, 47% are caused by humans and 5% are natural causes. Mean fire potential is high during the *summer* months under extreme conditions of high temperature, low relative humidity and high wind (Van Wilgen 1984 b).

The potential for veld fires is moderately high in the Southern Cape zone in *summer*, occurring in the Kogelberg, Klein River, Bredasdorp, Franschhoek and Riviersonderend Mountain ranges. On the northern part of the Riviersonderend Mountain, veld fire potential is moderately high. Population density is quite low here, with most of the area used for agricultural purposes e.g. wheat farming. Areas of very low potential for veld fire consist of natural vegetation cover such as Dune Thicket and Laterite Fynbos with a low fire susceptibility (Low & Rebelo 1996). Fire potential is moderate in the *summer* months in this zone (Van Wilgen & Burgan 1984). Veld fire potential in the mountain regions of the South Western Cape is high in *summer*, with a mean maximum temperature of 27.5 ^{O}C and mean maximum rainfall of 9.8mm that is conducive for veld fires.

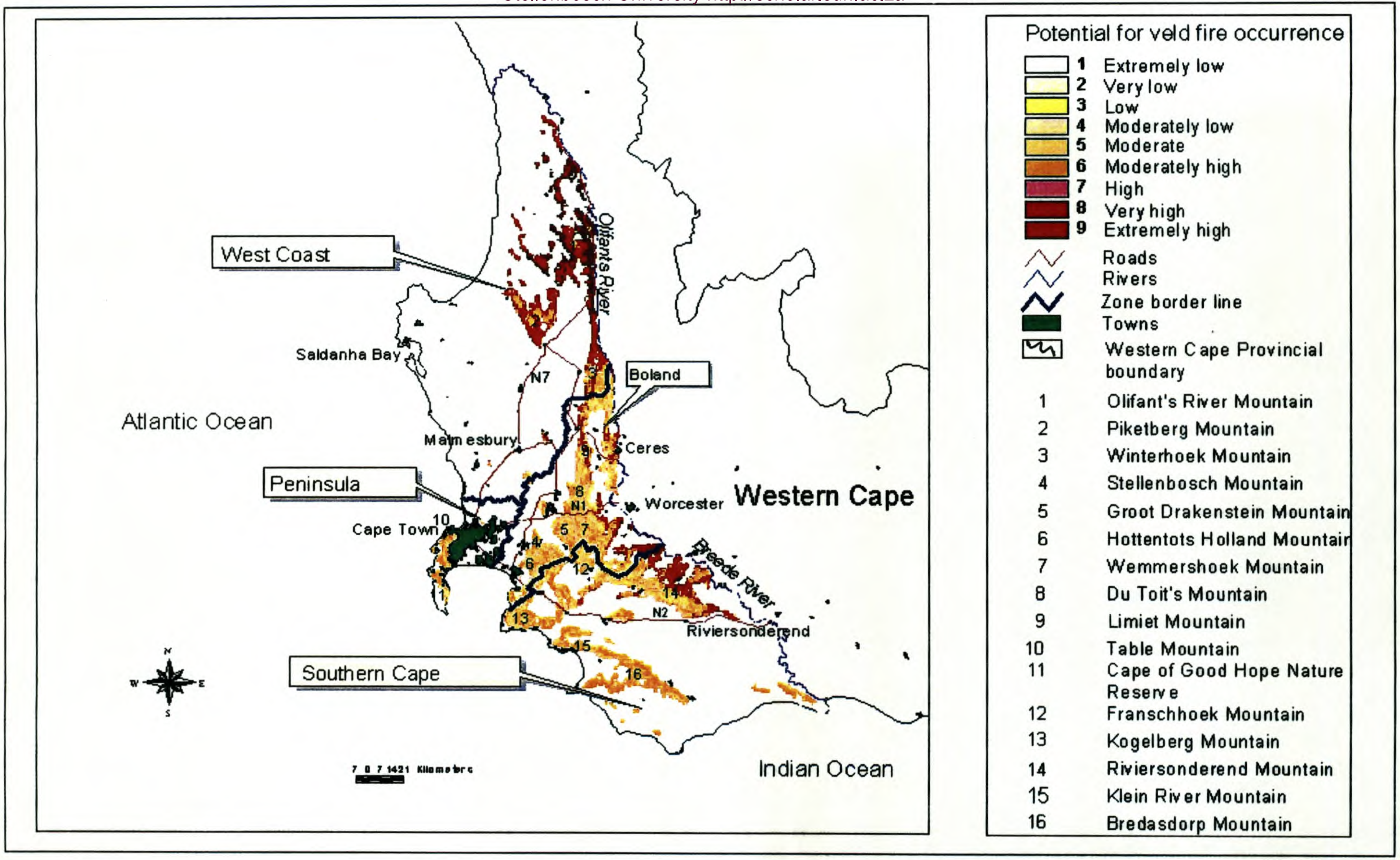


Figure 3.9: Potential for veld fire occurrence in summer in the mountain regions of the South Western Cape.

3.4.1.2 Autumn season veld fire potential

Veld fires in the Olifants River Mountain area of the West Coast have a high potential in *autumn* (Figure 3.10), with a moderate veld fire potential occurring both in the Piketberg and Winterhoek Mountain areas. The Hottentots Holland, Stellenbosch, Limiet, Groot Drakenstein, Wemmershoek and Du Toit's Mountains in the Boland sub-region depict moderate veld fire potential. The 14 year fire-data compiled indicated that fifty four percent of veld fires in *autumn* in this zone was as a result of human causes.

The Cape of Good Hope Nature Reserve and Table Mountain depict a moderately high veld fire potential in *autumn,* this is found throughout the Peninsula zone where urban and built-up areas are mostly concentrated. The 14 year fire-data compiled, indicated that within this sub-region, 38% of veld fire incidence were as a result of human causes, and sixty three percent were due to unknown causes. The Southern Cape zone has a moderately high veld fire potential in the *autumn* season within the Kogelberg, Franschhoek, Klein River, Bredasdorp and Riviersonderend Mountains, with very high veld fire potential occurring in the northern part of the Riviersondernd Mountains, have a very high veld fire potential because the natural vegetation cover is Mountain Fynbos that is highly susceptible to fire (Low & Rebelo 1996). Mean veld fire potential in *autumn* is moderate in this sub-region since it is mostly cultivated for agricultural purposes, and on the low lying areas towards the coast, the vegetation cover is Dune Thicket and Laterite Fynbos. These vegetation types have a low susceptibility to fire (Low & Rebelo 1996). There is moderate veld fire potential during the *autumn* season in the mountain regions of the South Western Cape, with mean maximum temperatures of 23.7 ^{O}C and mean maximum rainfall of 34.9mm.

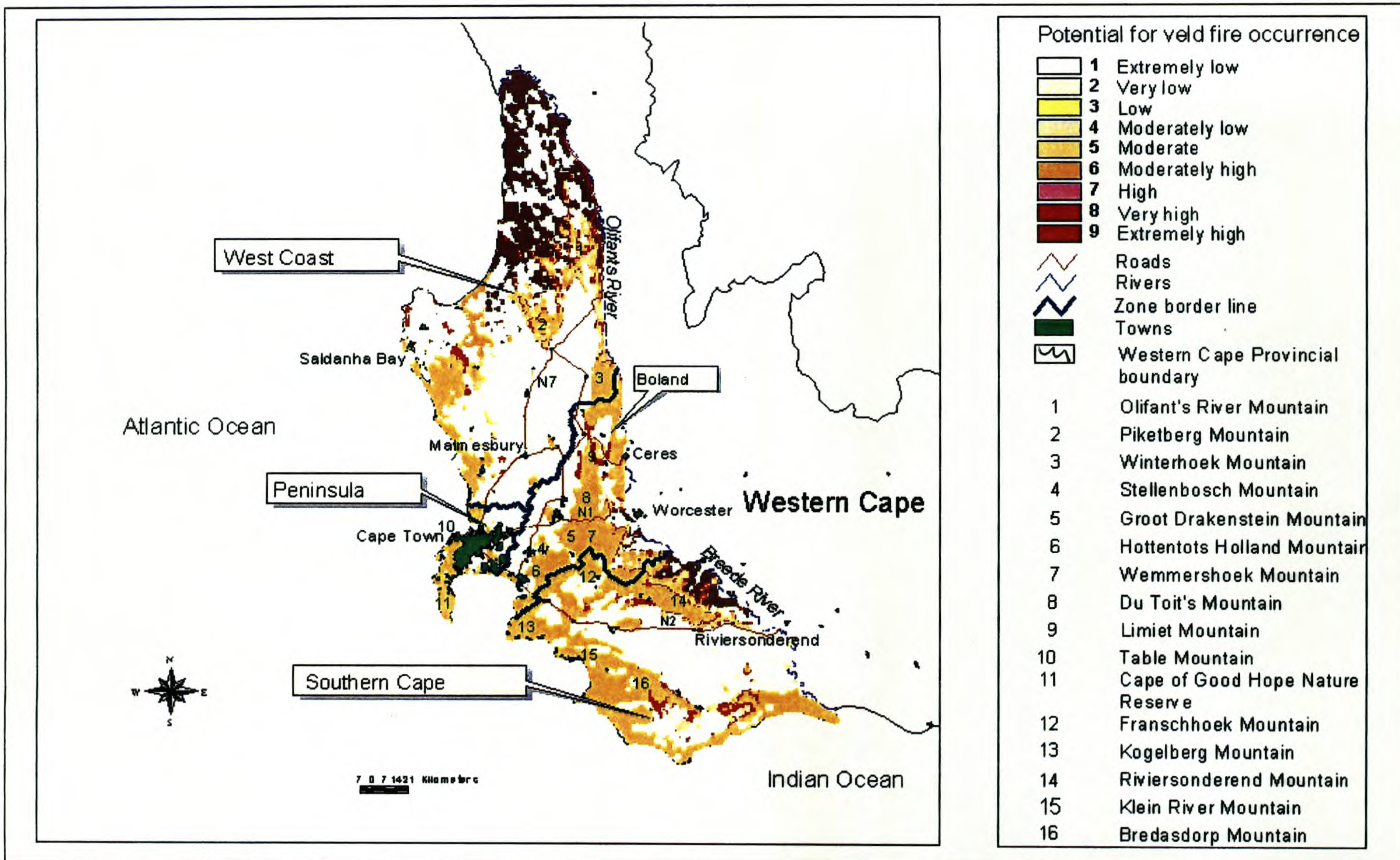


Figure 3.10: Potential for veld fire occurrence in autumn in the mountain regions of the South Western Cape.

3.4.1.3 Winter season veld fire potential

Potential for veld fire in *winter* is low in the Olifants River and Winterhoek Mountain in the West Coast zone (Figure 3.11), with very low veld fire potential in the high remote areas of the Piketberg Mountain. Occurrence of veld fires in the Boland zone in *winter* is extremely low within the Du Toit's, Limiet, Wemmershoek, Stellenbosch, Groot Drakenstein and Hottentots Holland Mountain ranges. The 14 year fire record data indicated that 60% of veld fire incidences in *winter* in this sub-region was due to human causes, while 40% was as a result of unknown causes.

The Peninsula zone also depicts a very low veld fire potential in *winter*. In this sub-region, 66% of veld fire incidences was as a result of unknown causes as indicated in the 14 year fire records, whereas veld fire incidences of human causes was 34%. Mean fire potential is low during the *winter* months in the Peninsula zone (Van Wilgen 1984).

Figure 3.11 depicts a low veld fire potential in the Franschhoek, Kogelberg and Klein River Mountain ranges of the Southern Cape sub-region in *winter*. The Bredasdorp Mountain range has a slightly higher veld fire potential, which can be as a result of Föhn-like bergwinds that occur along the southern coastal mountain ranges, and are accompanied by sudden increases in temperature and decreases in humidity that result in severe fire hazards in *winter* (Van Wilgen & Burgan 1984). The Riviersonderend Mountain ranges tend to have a high veld fire potential as a result of the more arid winter conditions and the fact the area consists largely of Mountain Fynbos that is highly susceptible to fire.

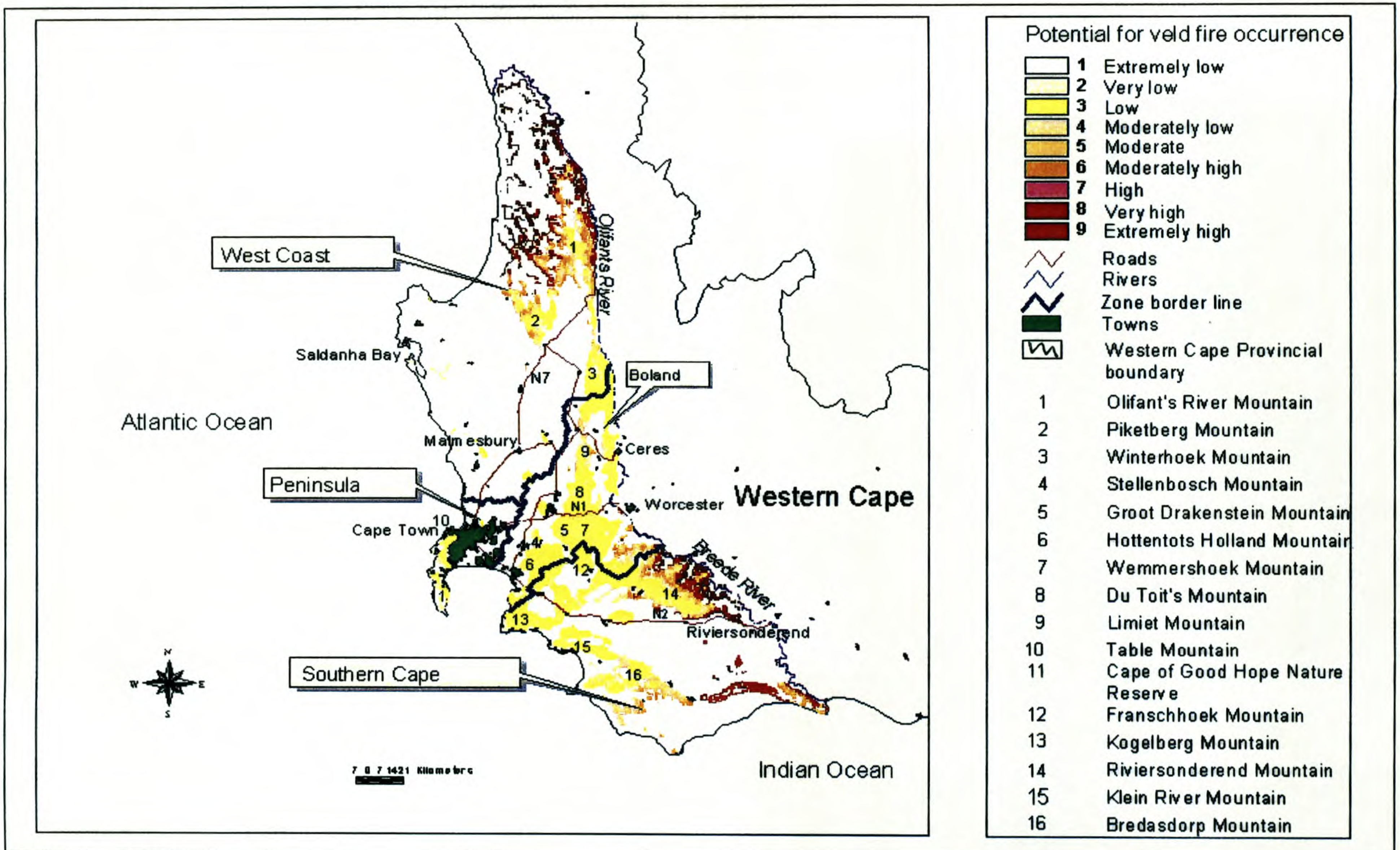


Figure 3.11: Potential for veld fire occurrence in winter in the mountain regions of the South Western Cape.

3.4.1.4 Spring season veld fire potential

The northern range of the Olifants River Mountain has a high veld fire potential in the *spring* season (Figure 3.12). A lower risk of veld fire potential exists in the Winterhoek and Piketberg Mountains. The lower slopes of the Olifants River Mountain depicts a high veld fire potential. Veld fire potential in the Boland zone is very low in *spring*.

Veld fire potential is also very low within the Cape of Good Hope Nature Reserve and Table Mountain area in the *spring* season. In the Peninsula zone, 60% of veld fire incidences in *spring* was as a result of human causes, and unknown causes accounted for forty percent of veld fire incidences. Similarly, very low veld fire potential is found in the Bredasdorp, Klein River, Koalberg, Franschhoek Mountain ranges. The exception of high veld fire occurrence is in the northern ranges of the Riviersonderend Mountains.

Although *spring* fires are possible under exceptional and rare circumstances, they hardly ever occur, unless it is a work related activity e.g. burning of firebreaks, deliberate application of fire (prescribed burning) that is uncontrollable, careless discarding of cigarette buts, children playing with matches or fire-works and intentionally started by someone (Luke & McArthur 1978; Le Roux 1988; Kromhout 1990; Van Wilgen 1999). Therefore mean veld fire potential is moderately low in *spring*.

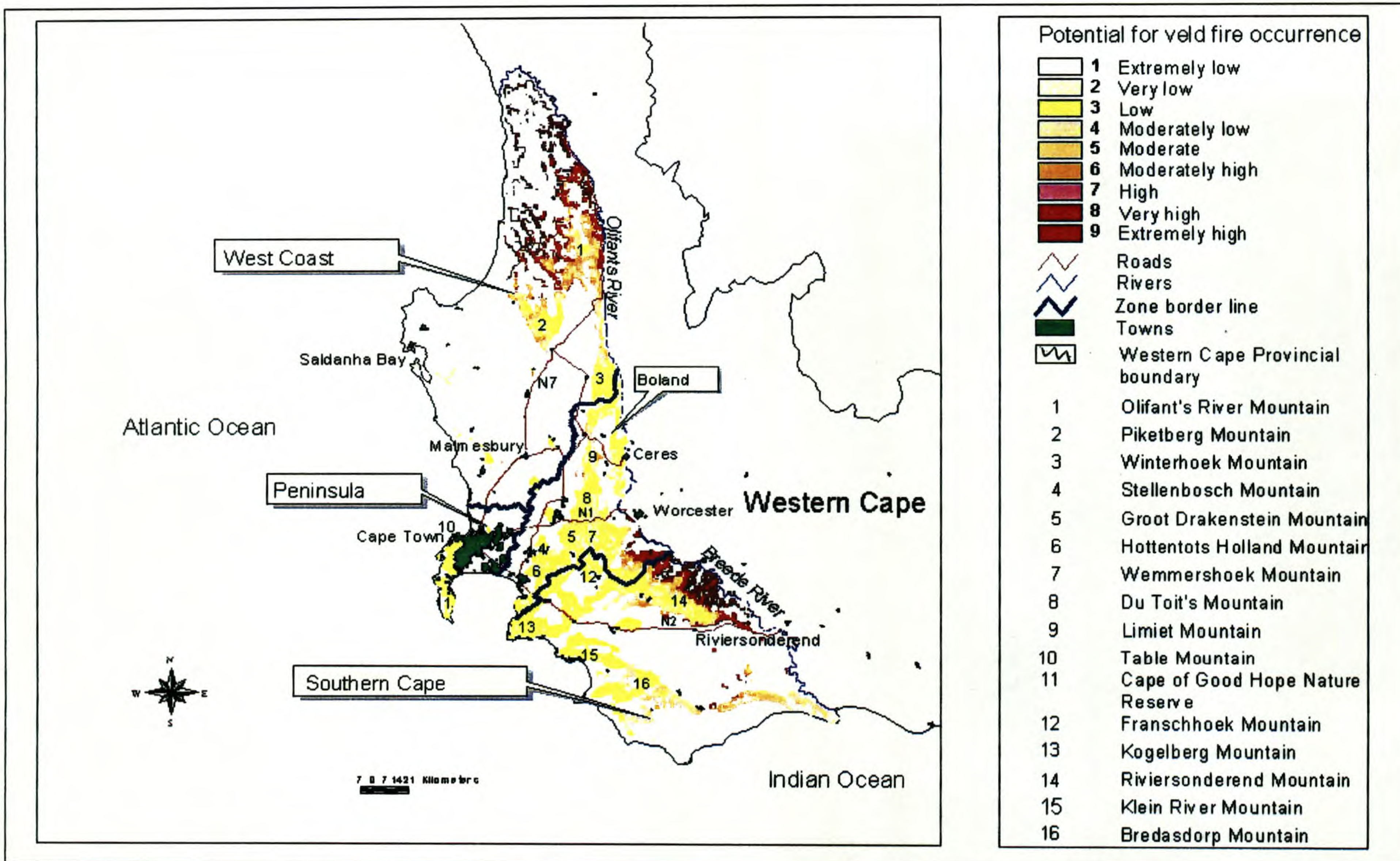


Figure 3.12: Potential for veld fire occurrence in spring in the mountain regions of the South Western Cape.

CHAPTER 4: EVALUATION OF RESULTS AND CONCLUSIONS

4.1 Summary of procedures

Veld fire occurrences are not unique. Though high incidences of veld fires occur in the summer season, other seasons, for example, winter and spring season are also prone to veld fires depending on weather conditions, vegetation type and impact of human activities within the sub-regions. Occurrence of veld fires can be advantageous and/or disadvantageous in the mountain regions. The most beneficial use of fire is in the limited control of invasive alien vegetation, reduction of fuel load and rejuvenation of indigenous vegetation in conservation management areas. Negative impacts of fires include damage to properties, loss of life, extensive soil erosion, loss of biodiversity and exhausting annual budgets in fighting veld fires.

This study aimed at identifying factors contributing towards the occurrence of veld fires in the mountain regions of the South Western Cape, and using GIS to analyse spatially the contributing variables, and to generate seasonal veld fire hazard maps. Potential veld fire occurrences on a seasonal basis were mapped using spatial analyses of variables that are significant to the distribution of veld fire within the study area. Variables used to assess potential veld fire occurrences were, vegetation, slope, population density (human influence), proximity to roads, mean monthly maximum temperatures and mean monthly rainfall. Factors that contribute to veld fire occurrence in the mountain regions of the South Western Cape are weather conditions, human, natural and unknown causes. Frequent seasonal veld fire occurrences can be largely attributed to the direct influence of human causes (47%), followed closely by unknown causes (45%) and natural causes (8%). When these veld fires do occur, its rate of spread is enhanced by weather patterns e.g. high relative humidity, high air temperature and high wind speed.

The use of GIS in mapping the potential of veld fire occurrence in the mountain regions of the South Western Cape, demonstrates its potential as a spatial analysis tool in integrating spatial variables for mapping the propensity of veld fires. The veld fire hazard maps generated clearly depicts the variation in seasonal occurrence of veld fires in the mountain regions of the South Western Cape.

Veld fire potential is high in the mountain ranges of the West Coast sub-region, with moderately high veld fire potential in the mountain ranges of the Peninsula, Boland and Southern Cape sub-regions in summer (Figure 3.9). These zones are prone to frequent veld fires due to high frequency of human activities e.g. hiking, picnics, camping and dense stands of alien plants that are highly susceptible to fire. Veld fire potential in the autumn season is moderately high in the Boland, Peninsula and Southern Cape zones, but with a high occurrence in the West Coast zone (Figure 3.10).

Potential for veld fire occurrence within the mountain regions of the South Western Cape in winter is low, with the exception of the Olifants River Mountain range (West Coast zone) where the possibility of veld fires can be quite high, and the northern part of the Riviersonderend Mountain chain (Southern Cape zone) depicting a high veld fire potential (Figure 3.11) as a result of sudden increases in temperature and decreases in humidity due to Föhn-like berg winds that often occur in winter. In the spring, veld fire potential is moderately low in the Peninsula, Boland and Southern Cape sub-regions, with a moderately high potential in the Olifants River and Riviersonderend Mountain ranges (Figure 3.12).

4.2 Conclusions

A veld fire can occur at any time of the year as clearly illustrated in the seasonal fire hazard maps that were generated, provided that there are conducive weather conditions, a source of ignition, and combustible vegetation within the area. Therefore, fire-fighting officials, conservation and forest managers should constantly be on the alert for possible veld fires within their management areas.

Factors contributing towards the occurrence of veld fires are weather patterns, nature of natural vegetation, terrain of the area, human, natural and unknown causes. In mapping seasonal veld fire potential, digital data of factors contributing to veld fires were analysed using GIS (ArcView). The seasonal veld fire hazard maps generated depicted a high veld fire potential in the summer and autumn months, with low veld fire potential occurring in the winter and spring season.

To fight veld fires successfully requires that conservation and forest managers understand the nature of the veld, local weather patterns, have information on the dates on which the veld was last burnt, its relative flammability, locations of natural fire barriers within their management area, and a well trained labour force at their disposal.

4.3 Recommendations

The system of block-burning, that is: controlled burning of patches of vegetation that acts as a fire-break, is one of the positive applications that acts effectively in the reduction of veld fire spread and occurrence, within the management area of conservation and forest managers. Controlled burning means that fires will be deliberately started only when a certain set of conditions is met such as suitable weather conditions.

The seasonal fire hazard maps only depict the seasonal potential of veld fire occurrence in a relative way, these verbal descriptions and visual cartographic displays do not show when or where a veld fire will occur. To use the results effectively, there is a further need for fire-fighting officials, conservation and forest managers to delineate critical zones of veld fire occurrence, by marking out areas of moderate to extremely high veld fire potential, in order to use it as a base map for evaluating how cost-effective alternative control measures can be implemented to reduce the level of veld fire danger within their management areas.

There is also a need for conservation, nature-park and fire-fighter service institutions to keep a proper and correct inventory of veld fire occurrences within their management areas on a database, stating the date of occurrence, type of incident, time of occurrence, duration of fire, extent of area burnt, cause of fire and location of fire.

In order to have an effective means of containing veld fires because of their dynamic nature and potentiality to occur at any season, there is the need for a Catchment Management System (CMS) (Richardson, Van Wilgen, Le Maitre, Higgins & Forsyth 1994) that can be used to generate daily probabilities of veld fire occurrence and to link these to fire-spread models for predicting or simulating expected fire directions and severities or intensities.

Due to annual increase of veld fire occurrences in the mountain regions of the South Western Cape there is a need to implement a proper awareness programme in the communities and districts of the South Western Cape, in order to educate the public about the devastation caused by veld fires and safety pre-cautions to be taken whenever a veld fire occurs within their vicinity. Better fire management by doing control burns in the right weather conditions and season could also reduce fire occurrence and damages. Enforcement of stricter fire controls for land-owners in and around high fire risk areas could also ameliorate the situation. Lastly, alien plants are highly susceptible to fire because of their oily leaf content, and constitute more than 35% of the vegetation cover (Working for Water Programme 1998) in the mountain regions of the South Western Cape.

Therefore, more funding should be made available to the Working for Water Project (Department of Water Affairs and Forestry) by the Republic of South Africa government to carry out effective control operations to reduce or eradicate alien plant cover.

4.4 Further research possibilities

Further research should be devoted to adding additional variables to this seasonal veld fire map model, by testing the impacts of selected new variables, such as the spatial distribution of alien vegetation, the inclusion of wind speed and directions in the mountain regions of the South Western Cape. As fire intensity increases due to increased fuel loads (Van Wilgen & Richardson 1985), it would be beneficial to include vegetation indices such as the *Normalise Difference Vegetation Index* (NDVI) of both the natural and alien vegetation per square kilometre in the mountain regions of the South Western Cape from satellite images e.g. LANDSAT TM imagery, so as to model the fuel potential or the total fuel load that is available for mapping the probability of veld fire occurrences.

Using multi-criteria evaluation (MCE) as available in IDRISI may be useful to determine the relative importance of the variables and their contributions towards determining veld fire potential for use in generating probabilities of seasonal veld fire hazard maps.

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APPENDICES

APPENDIX A:

Table A.1.: Respondents contacted for the study of veld fire occurrence in the mountain regions of the South Western Cape, 1999.

Institution	Purpose	Data collected	Format
South Peninsula Municipality	Questionnaire	Fire records	Hardcopy
Cape Nature Conservation Board, Jonkershoek	Questionnaire	Fire records	Hardcopy
Cape Nature Conservation Board, Jonkershoek	Questionnaire	Fire records	Hardcopy
Noordhoek Forest Station	Questionnaire	Fire records	Hardcopy
Stellenbosch Municipality	Questionnaire	Fire records	Hardcopy
Winelands District Council, Stellenbosch	Questionnaire	Fire records	Hardcopy
Elsenburg Agricultural Research Institute	Data collection	Weather data-sets e.g. Rainfall, for the past 20 years from 34 weather stations within the study area	ArcView Shapefiles
Department of Geography & Environmental Studies, University Stellenbosch	Data collection	Rivers, roads, fuel types, Contour and population Density for the year 1996, magisterial and catchment boundary of the study area	ArcView Shapefiles

Table A.2.: Fire record data collected for veld fire incidences from 1985 – 1999, in the surveyed Nature Reserves [(1)]

[(1)] The surveyed reserves were in the following areas: Hottentots Holland Mountains (Jonkershoek, Stellenbosch, Streenbas and Grabouw), Drakenstein (La Motte) and Table Mountain (Tokai, Devil's Peak and Noordhoek).

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1985/02/04	Mountain Fire	15:25	011 30	1.0	Arson	Vishoek
1985/11/23	Fynbos & Port Jackson fire	13:45	026 48	1000.0	Accidental	Simonsberg
1985/11/24	Fynbos & Port Jackson fire	13:45	026 48	1000.0	Accidental	Simonsberg
1985/11/25	Fynbos & Port Jackson fire	13:45	026 48	1000.0	Accidental	Simonsberg
1985/11/28	Fynbos & Acacia fire	15:54	026 15	150.0	Accidental	Cape Point Nature Rese
1986/01/23	Mountain Fire	02:20	030 56	120.0	Unknown	Hout Bay
1986/01/23	Fynbos fire	14:05	003 20	20.0	Construction Worker	Chapman's Peak, Rylaan

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1986/02/02	Fynbos fire	15:29	040 30	3000.0	Arson	Cape Point Nature Reserve
1986/03/10	Fynbos fire	14:25	008 15	300.0	Unknown	Klawerkamp
1986/03/10	Fynbos fire	18:14	008 37	5.0	Arson	Ocean View
1986/03/29	Fynbos fire	20:00	011 55	30.0	Unknown	Millerspoint
1987/01/02	Mountain Fire	15:56	010 07	800.0	Arson	Kommetjieberg
1987/02/16	Mountain Fire	13:10	006 10	0.0	Unknown	Ocean View
1987/02/22	Mountain Fire	15:20	005 15	0.0	Arson	Begraafplaas
1987/06/23	Fynbos fire	18:15	021 22	100.0	Unknown	Kleinplaatsdam
1987/09/28	Fynbos & Acacia fire	14:53	009 54	20.0	Children	Ocean View
1987/11/23	Fynbos & Acacia fire	15:47	001 45	0.5	Unknown	Soetwater
1987/12/02	Fynbos & Acacia fire	15:05	002 55	1.0	Unknown	Ocean View
1987/12/02	Fynbos fire	15:05	003 55	1.0	Unknown	Ocean View
1987/12/20	Fynbos & Acacia fire	16:43	003 30	0.0	Arson	Ocean View
1987/12/21	Fynbos fire	11:23	001 40	0.5	Lightning	Kommetjieberg
1987/12/24	Fynbos fire	18:10	001 12	0.0	Unknown	Soetwater
1987/12/26	Fynbos fire	11:00	003 47	0.5	Unknown	Soetwater
1988/03/06	Mountain Fire	10:29	020 06	40.0	Unknown	Scarborough

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1988/05/02	Alien infested Fynbos fire	15:30	064 30	800.0	Burning of fi belt	Simonstown
1988/10/30	Fynbos fire	13:18	096 22	75.0	Arson	Ocean View
1988/12/11	Fynbos fire	22:43	014 16	0.5	Unknown	Soetwater
1989/01/26	Fynbos & Acacia fire	20:50	113 32	120.0	Unknown	Scarborough
1989/02/03	Fynbos fire	19:20	012 58	60.0	Arson	Cape Point Nature Reserve
1989/02/06	Fynbos & Acacia fire	18:37	012 30	8.0	Unknown	Ocean View
1989/02/16	Fynbos fire	20:42	004 04	1.0	Unknown	Cape Point Nature Reserve
1989/02/18	Fynbos fire	17:00	007 45	40.0	Ground fire	Cape Point Nature Reserve
198/03/04	Acacia fire	14:20	010 50	1.0	Unknown	Ocean View
1989/04/14	Fynbos fire	19:44	004 42	4.0	Unknown	Ocean View
1990/01/22	Fynbos & Acacia fire	11:45	005 45	20.0	Unknown	Redhill
1990/01/23	Fynbos & Acacia fire	20:53	030 55	75.0	Unknown	Redhill
1990/01/27	Fynbos & Acacia fire	20:42	007 42	0.5	Arson	Redhill
1990/04/02	Fynbos & Acacia fire	20:42	074 55	50.0	Unknown	Redhill
1990/11/25	Fynbos fire	11:46	024 00	4.0	Unknown	Kommetjie

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1990/12/08	Fynbos fire	12:26	050 00	4.0	Lightning	Cape Point Nature Reserve
1991/01/25	Mountain Fire	21:56	014 15	0.0	Unknown	Ocean View
1991/01/26	Fynbos & Acacia fire	00:20	012 50	5.0	Arson	Mountain View
1991/02/10	Fynbos fire	13:14	013 50	0.0	Unknown	Ocean View
1991/03/17	Fynbos, Acacia & Pine fire	22:30	061 52	30.0	Arson	Redhill
1991/03/15	Fynbos & Acacia fire	10:15	134 28	170.0	Arson	Ocean View
1991/03/15	Acacia & Eucalyptus Fire	17:23	051 06	0.0	Arson	Ocean View
1991/03/30	Fynbos fire	15:45	402 07	1100.0	Unknown	Scarborough
1991/04/11	Fynbos & Acacia fire	14:14	037 48	20.0	Arson	Kommetjie
1991/04/11	Mountain Fire	14:14	010 31	0.0	Unknown	Kommetjie
1991/06/15	Fynbos fire	12:28	004 48	1.0	Accidental	Cape Point Nature Reserv
1991/12/04	Fynbos & Acacia fire	12:28	076 22	60.0	Arson	Soetwater
1991/12/04	Fynbos fire	12:28	014 28	0.0	Unknown	Soetwater & Kommetjie

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1991/12/14	Fynbos & Acacia fire	01:10	002 12	3.0	Unknown	Simonstown
1991/12/21	Plantation Fire	21:50	005 15	0.0	Accidental	Stellenbosch
1991/12/30	Mountain Fire	15:40	007 03	0.0	Arson	Soetwater & Kommetjie
1991/12/30	Fynbos fire	15:40	026 37	3.0	Arson	Soetwater
1992/01/04	Fynbos fire	15:15	018 46	0.0	Arson	Cape Point Nature Reserv
1992/01/15	Fynbos fire	16:04	058 45	0.0	Unknown	Hout Bay
1992/01/17	Mountain Fire	14:27	010 26	0.0	Arson	Silvermine Nature Reserv
1992/01/29	Fynbos fire	13:30	014 54	0.0	Unknown	Sun Valley
1992/02/17	Plantation Fire	12:26	011 33	0.0	Accidental	Stellenbosch
1992/04/25	Fynbos fire	18:53	010 46	0.0	Unknown	Llandudno
1992/06/05	Fynbos fire	10:56	012 26	0.0	Unknown	Cape Point Nature Reserv
1992/11/17	Mountain Fire	20:05	008 46	0.0	Unauthorized Burning	Stellenbosch
1992/12/14	Plantation Fire	00:20	022 30	0.0	Accidental	Stellenbosch
1992/12/14	Fynbos fire	20:24	001 46	0.0	Children	Hout Bay
1993/01/02	Mountain Fire	13:55	188 54	0.0	Unknown	Ocean View
1993/11/11	Fynbos fire	00:00	051 10	1.5	Unknown	Baviaanskloof

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1993/12/11	Mountain Fire	09:42	020 36	0.0	Unknown	Stellenbosch
1993/12/11	Fynbos fire	15:20	076 01	0.0	Unknown	Noordhoek
1993/12/22	Fynbos fire	12:15	049 48	0.0	Unknown	Ocean View
1993/12/29	Fynbos fire	11:40	078 28	550.0	Uknown	Redhill
1994/01/03	Mountain Fire	14:34	090 45	0.0	Accidental	N/A
1994/01/06	Mountain Fire	16:13	010 44	0.0	Farm laboure	Paarl
1994/01/23	Mountain Fire	10:18	063 38	0.0	Unknown	N/A
1994/01/29	Mountain Fire	15:30	060 48	0.0	Unknown	N/A
1994/02/06	Fynbos fire	06:18	158 41	250.0	Unknown	Constantiaberg
1994/02/08	Mountain Fire	15:07	048 33	0.0	Accidental	Stellenbosch
1994/02/15	Plantation Fire	19:50	020 29	0.0	Unknown	Stellenbosch
1994/02/20	Mountain Fire	01:00	045 38	1600.0	Unknown	Simonstown
1994/02/20	Fynbos fire	14:00	120 26	150.0	Unknown	Llandudno
1994/02/23	Mountain & Plantation Fire	15:02	000 00	0.0	Control burni	Stellenbosch
1994/02/24	Mountain Fire	13:47	070 48	0.0	Reoccurrence Fire	Stellenbosch

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1994/03/14	Mountain Fire	14:22	009 20	0.0	Unauthorized Burning	Paarl
1994/03/29	Plantation Fire	09:29	000 50	0.0	Control burni	Paarl
1994/03/29	Mountain Fire	11:48	016 25	0.0	Unauthorized Burning	Paarl
1994/11/02	Mountain Fire	00:00	000 00	0.0	Unknown	Helderberg
1994/12/09	Mountain Fire	19:12	020 19	0.0	Unknown	Stellenbosch
1994/12/10	Mountain Fire	11:16	094 33	0.0	Unknown	Wellington
1994/12/10	Mountain Fire	22:35	021 41	0.0	Unauthorized Burning	Stellenbosch
1994/12/14	Mountain & Plantation Fire	13:51	230 35	0.0	Unknown	Wellington
1994/12/18	Mountain Fire	16:10	019 49	0.0	Accidental	Stellenbosch
1994/12/30	Plantation Fire	15:34	006 58	0.0	Unknown	Wellington
1995/01/09	Plantation Fire	18:10	019 37	0.0	Unknown	Stellenbosch
1995/02/10	Fynbos fire	21:50	134 19	0.0	Arson	Cape Point
1995/02/16	Fynbos fire	22:25	086 59	5.0	Arson	Cape Point Nature Reserve

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1995/02/16	Mountain Fire	23;45	001 50	0.0	Lightning	Stellenbosch
1995/02/18	Mountain Fire	05:00	013 24	0.0	Lightning	Stellenbosch
1995/02/19	Mountain Fire	20:47	029 35	0.0	Unknown	Stellenbosch
1995/02/28	Fynbos fire	17:40	112 26	20.0	Arson	Redhill pass
1995/03/06	Fynbos fire	20:08	075 40	1.5	Arson	Klaasjagerberg
1995/03/16	Mountain Fire	07:25	052 37	0.0	Uncontrolled Burning	Stellenbosch
1995/03/18	Forest & Mountain Fire	19:45	003 00	0.0	Lightning	Chapman's Peak
1995/05/08	Forest & Mountain Fire	01:03	022 15	65.0	Unknown	Chapman's Peak
1995/05/08	Forest fire	02:30	018 14	50.0	Unknown	Noordhoek
1995/05/28	Mountain Fire	12:33	031 59	0.0	Unknown	Wellington
1995/06/03	Mountain Fire	11:08	027 58	0.0	Unknown	Stellenbosch
1995/10/29	Fynbos fire	10:19	246 50	500.0	Unknown	Hout Bay
1995/11/18	Bush & grass fire	11:43	021 12	0.0	Arson	Melton Rose
1995/12/03	Mountain Fire	14:58	006 39	0.0	Unauthorized Burning	Stellenbosch

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1995/12/09	Mountain Fire	12:40	014 23	0.0	Children	Stellenbosch
1995/12/15	Mountain Fire	22:30	011 24	0.0	Unauthorised Burning	Wellington
1995/12/16	Fynbos fire	15:28	079 34	40.0	Unknown	Hout Bay
1996/01/16	Fynbos fire	12:20	108 10	50.0	Arson	Ocean View
1996/01/20	Mountain Fire	14:28	044 28	0.0	Unknown	Stellenbosch
1996/02/10	Mountain Fire	14:38	008 10	0.0	Reoccurrence Fire	Stellenbosch
1996/02/12	Mountain Fire	16:54	033 21	0.0	Accidental	Stellenbosch
1996/02/17	Mountain Fire	16:52	007 04	0.0	Cigarette	Stellenbosch
1996/12/08	Forest fire	11:00	023 25	0.0	Unknown	Kommetjie
1996/12/30	Fynbos fire	14:00	039 25	25.0	Arson	Soetwater
1997/02/02	Mountain fire	06:59	078 31	0.0	Unknown	Lowry's Pass
1997/02/02	Mountain fire	11:00	264 00	900.0	Accidental	Assegaaibosch
1997/02/08	Mountain fire	16:05	027 18	0.0	Unknown	Somerset West
1997/02/24	Mountain fire	23:00	240 00	5900.0	Unknown	Helderberg
1997/02/25	Mountain fire	23:30	061 02	0.0	Unknown	Somerset West

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1997/10/15	Mountain fires	14:00	048 00	800.0	Accidental	Brandvlei
1997/10/16	Mountain fire	11:00	024 00	16.0	Unknown	Rawsonville
1997/10/17	Mountain fires	17:34	153 46	0.0	Unknown	Jonkershoek
1997/10/17	Mountain fire	18:20	096 00	700.0	Accidental	Mount Happy
1997/10/18	Mountain fire	19:00	096 00	1100.0	Lightning	Mont Fleur
1997/10/22	Mountain fire	11:45	024 00	3.0	Power lines	Leeuklip Kop
1997/11/02	Mountain fire	24:00	168 00	1400.0	Unknown	Elandskloof
1997/11/02	Mountain fire	19:30	048 00	7.0	Accidental	Rawsonville
1997/11/04	Mountain fire	10:55	072 00	600.0	Accidental	Pringle Bay
1997/11/28	Mountain fires	15:00	024 00	3.5	Accidental	Rawsonville
1997/11/29	Mountain fire	14:00	048 00	270.0	Arson	Steytens Mountains
1997/12/03	Mountain fire	22:47	018 10	40.0	Arson	Klaasjagersberg
1997/12/11	Mountain fire	14:58	014 01	0.0	Unknown	Pringle Bay
1997/12/15	Mountain fire	02:19	054 32	40.0	Arson	Cape Point Nature Reserve
1997/12/22	Mountain fire	12:00	012 00	2.0	Unknown	Simonsberg

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1998/01/15	Fynbos fire	15:00	036 00	12.0	Unknown	Elandskloof
1998/01/15	Fynbos fire	15:00	036 00	12.0	Unknown	Elandskloof
1998/01/28	Mountain fire	18:00	048 00	10.0	Accidental	Stellenbosch
1998/01/05\	Mountain fire	07:30	006 55	0.0	Unknown	Stellenbosch
1998/01/28	Mountain fire	00:45	005 31	0.0	Unknown	Helderberg
1998/02/09	Mountain fire	16:05	003 28	0.0	Unknown	Helderberg
1998/02/24	Mountain fire	13:15	066 42	40.0	Unknown	Red Hill
1998/02/28	Mountain fire	10:00	018 00	4.0	Accidental	Mont fleur
1998/03/03	Mountain fire	13:50	024 00	80.0	Accidental	Du Toits Kloof
1998/03/19	Fynbos fire	15:19	020 20	0.0	Unknown	Witsand
1998/ 04/02	Fynbos fire	13:05	026 07	0.0	Accidental	Ocean View
1998/08/18	Mountain fire	06:14	051 01	0.0	Control burning	Wellington
1998/09/18	Mountain fire	13:00	048 00	11.0	Accidental	Nuweberg
1998/09/19	Mountain fire	18:16	239 03	0.0	Uncontrolled burning	Stelllenbosch
1998/09/23	Mountain fire	12:00	024 00	150.0	Accidental	Elgin
1998/09/30	Mountain fire	08:37	072 00	26.0	Burning of fire belt	Daspos
1998/10/10	Mountain fire	09:28	082 10	0.0	Unknown	Stellenbosch
1998/10/10	Mountain fire	10:02	011 30	0.0	Unknown	Stellenbosch
1998/10/28	Mountain fire	09:00	072 00	10.0	Unknown	Du Toit's Kloof
1998/11/20	Mountain fire	19:00	048 00	3.0	Accidental	Simonsberg
1998/12/04	Mountain fire	11:57	034 00	0.0	Unknown	Stellenbosch

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1998/12/22	Mountain fire	11:45	012 00	5.0	Unknown	Stellenbosch
1999/01/08	Mountain fire	22:04	042 32	0.0	Accidental	
1999/01/09	Mountain fire	23:35	011 15	0.0	Accidental	Stellenbosch
1999/01/16	Mountain & plantation fire	02:51	005 34	0.0	Unknown	Wellington
1999/01/22	Mountain fire	13:35	096 00	160.0	Accidental	Rawsonville
1999/01/23	Plantation fire	14:33	016 25	0.0	Arson	Stellenbosch
1999/01/26	Mountain fire	12:38	041 40	0.0	Accidental	Stellenbosch
1999/02/03	Plantation fire	17:03	014 47	0.0	Unknown	Stellenbosch
1999/02/03	Mountain fire	20:40	057 19	0.0	Accidental	Stellenbosch
1999/02/03	Mountain fire	21:13	014 40	0.0	Unknown	Stellenbosch
1999/02/04	Mountain fire	17:20	020 08	0.0	Unknown	Stellenbosch
1999/02/07	Plantation fire	13:49	184 05	0.0	Unknown	Stellenbosch
1999/02/08	Mountain fire	16:59	001 43	0.0	Unknown	Stellenbosch
1999/02/11	Plantation fire	13:34	022 59	0.0	Unknown	Stellenbosch
1999/02/11	Plantation fire	16:05	040 41	0.0	Unknown	Stellenbosch
1999/02/12	Plantation fire	17:57	038 18	0.0	Unknown	Stellenbosch
1999/02/13	Mountain fire	11:00	168 00	15000.0	Arson	Wemmershoek

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1999/02/13	Mountain & plantation fire	12:40	467 14	0.0	Arson	Wennershoek Dam
1999/02/13	Mountain & plantation fire	12:40	467 14	0.0	Arson	Wennershoek Dam
1999/02/19	Plantation fire	01:34	007 14	0.0	Unknown	Simondium
1999/02/20	Mountain fire	18:04	011 59	0.0	Unknown	Stellenbosch
1999/02/26	Mountain fire	16:00	408 00	85000.0	Accidental	Rawsonville
1999/03/08	Mountain fire	08:00	367 57	0.0	Unknown	Franschhoek
1999/03/16	Mountain fire	20:55	247 40	0.0	Firespread	Hermon
1999/03/22	Mountain fire	20:32	001 47	0.0	Unknown	Kylemore
1999/03/25	Mountain fire	14:00	384 00	45000.0	Accidental	Kylemore
1999/03/27	Mountain fire	00:47	005 30	0.0	Unknown	Franschoek
1999/03/31	Mountain fire	00:28	013 37	0.0	Unknown	Stellenbosch
1999/03/31	Mountain fire	06:30	004 03	0.0	Unknown	Du Toit Kloof Pass
1999/04/02	Mountain fire	20:39	007 46	0.0	Accidental	Jonkershoek
1999/04/02	Mountain fire	21:34	004 40	0.0	Unknown	Stellenbosch
1999/04/03	Mountain fire	01:55	001 54	0.0	Unknown	Paarl
1999/04/05	Mountain fire	14:00	051 18	0.0	Unknown	Franschoek
1999/04/09	Mountain fire	23:46	000 00	0.0	Re-occurrence of fire	Franschoek
1999/04/11	Mountainfire	13:35	006 27	0.0	Unknown	Franschoek

Date occurrence	Type of incident	Time occurrence	Duration of fire (Hour, minutes)	Extent of (Hectares)	Cause of fire	Location of fire
1999/08/12	Mountain fire	11:00	024 00	15.0	Power lines	Du Toits kloof
1999/08/17	Mountain fire	13:07	053 56	0.0	Controlled burning	Stellenbosch

Table A.3.: Weather stations used for the study in mapping the potential of veld fire occurrence in the mountain regions of the South Western Cape.

Station Name	**Latitude (degrees, minutes)**	**Longitude (degrees, minutes)**
Beinne Donne	33 50 S	18 59 E
Citrusdal	32 34 S	18 59 E
De Keur	32 58 S	19 18 E
Elgin	34 08 S	19 02 E
Elsenburg	35 51 S	18 50 E
Franschoek	33 53 S	19 04 E
Graafwater	32 09 S	08 25 E
Groot Constantia	34 02 S	18 25 E
Gydo	33 13 S	19 20 E
Jakkelsrivier	34 09 S	19 08 E
Jonaskraal	34 24 S	19 54 E
Jondershoek	33 57 S	18 55 E
Karringmelk Rivier	34 08 S	20 46 E
Klawer	31 47 S	18 38 E
Kogelberg	34 08 S	19 01 E
Koo	31 47 S	19 51 E
Koringberg	33 01 S	18 41 E
Landau	33 36 S	18 58 E
Langgewens	33 17 S	18 42 E
Malmesbury	33 27 S	18 44 E
Moorreesburg	33 09 S	18 40 E
Nietvoorbij	33 54 S	18 52 E
Philadelphia	33 40 S	18 35 E
Porterville	33 01 S	19 00 E
Prinskraal	34 38 S	20 07 E
Protem	34 16 S	20 05 E
Riebeeck West	33 21 S	18 25 E
Riverside	33 12 S	19 18 E
Robertson	33 50 S	19 54 E
Tygerhoek	34 09 S	19 54 E
Vredenburg	32 54 S	18 00 E
Welgevallen	33 56 S	18 51 E
Westevreden	33 56 S	20 37 E
Wolseley	33 27 S	19 12 E
Zachariashoek	33 49 S	19 00 E

Key: S = South, E = East

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QUESTIONNAIRE: MAPPING THE POTENTIAL OF VELD FIRE OCCURRENCE IN THE MOUNTAIN REGIONS OF THE SOUTH WESTERN CAPE, USING GIS

The undersigned is a registered masters student in the Department of Geography and Environmental Studies, University of Stellenbosch. The aim of this study is to:

- To identify the *factors* contributing towards the occurrence of veld fires in the mountain regions of the South Western Cape.
- To use GIS to analyse factors influencing veld fires.
- To generate seasonal fire hazard maps depicting the *potential* of veld fire occurrences in the mountain regions of the South Western Cape.

The success of this study requires your co-operation. Therefore, it would be greatly appreciated if you would complete this questionnaire. All information gained from the questionnaire will be treated in the strictest confidence and used for academic purposes only. Thanks for your co-operation.

Yours sincerely,

Supervisor: Mr BHA Schloms
Co-supervisor: Prof. HL Zietsman

E-mail: 13037994@narga.sun.ac.za

SECTION A

1. Within the South Western Cape, which area of natural vegetation reserve and/or plantation falls under your management?

……………………………………………………………………………………………
………………...

2 a.) What type of vegetation can be found within your management area? Give approximate area in hectares.

Vegetation type	Yes	No	Area (hectares)
1. Afromontane forest			
2. Dune Thicket			
3. Strandveld Succulent Karoo			
4. Little Succulent Karoo			
5. Central Mountain Renosterveld			
6. West Coast Renosterveld			
7. South & South-West Coast Renosterveld			
8. Mountain Fynbos			
9. Laterite Fynbos			
10. Limestone Fynbos			
11. Sand Plain Fynbos			
12. Others			

2 b.) What tree species are found in the plantations in your area? Give approximate area in hectares.

Tree species	Yes	No	Area (hectares)
1. Pine			
2. Eucalyptus			
3. Others			

2 c.) For the vegetation type and tree species listed above are they

Vegetation type	Yes	No
Continuos		
Fragmented		

Tree species	Yes	No
Continuos		
Fragmented		

3. What is the susceptibility of the vegetation type and tree species listed below to veld fires in the area?

N.B.: please tick the appropriate boxes below the given three classes

	High	Medium	Low
1. Afromontane forest	☐	☐	☐
2. Dune Thicket	☐	☐	☐
3. Strandveld Succulent Karoo	☐	☐	☐
4. Little Succulent Karoo	☐	☐	☐
5. Central Mountain Renosterveld	☐	☐	☐
6. West Coast Renosterveld	☐	☐	☐
7. South & South-West Coast Renosterveld	☐	☐	☐
8. Mountain Fynbos	☐	☐	☐
9. Laterite Fynbos	☐	☐	☐
10. Limestone Fynbos	☐	☐	☐
11. Sand Plain Fynbos	☐	☐	☐
12. Others			
....	☐	☐	☐
....	☐	☐	☐
....	☐	☐	☐

	High	Medium	Low
1. Afromontane forest	☐	☐	☐
2. Dune Thicket	☐	☐	☐
3. Others			
....	☐	☐	☐
....	☐	☐	☐

4 a.) Has there been any occurrence of veld fires within the area, during the past 20 years?

Yes ☐ No ☐

4 b.) If yes, how serious have past fires been?

i. Very serious	
ii. Serious	
iii. Not serious	

4 c.) Can you provide fire data indicating?

	Yes	No
i.) Date of occurrence	…..	…..
ii.) Time of occurrence	…..	…..
iii.) Location of fire	…..	….
iv.) Duration of fire	…..	…..
v.) Extent of the fire	…..	…..

4 d.) If yes, for how long have you had the fire incidence records?………………………………

4 e.) Which three months of the year have the highest probability for veld fire occurrence in the area?

i.) ……………………..

ii.) ……………………..

iii.) ……………………..

4 f.) Which three months of the year have the lowest probability for veld fire occurrence in the area?

i.) …………………….

ii.) …………………….

iii.) …………………….

5. What were the possible causes of veld fires in the area? Rate risk on a three-point scale.

Possible causes	Yes	No	High	Medium	Lo
1. Adjacent human settlement					
2. Arson or incendiarism					
3. Burning of firebreaks/prescribed burns (jump fires)					
4. Campers and picnickers					
5. Children					
6. Honey hunters					
7. Lightning					
8. Powerlines					
9. Railway engines					
10. Smokers e.g. cigarette stubs					
11. Miscellaneous e.g. falling stones, baboons and glass					
12. Other possible causes					

6. Which of the factors listed below influence the spread and extent of veld fires in your area?

Rate the effect on a three-point scale.

Factors	Yes	No	High	Medium	Low
1. Fuel loading (amount of dry debris)					
2. Size distribution of fuel (fineness of dry material)					
3. Compactness of fuel					
4. Continuity of fuel (patchiness)					
5. Fuel moisture (dryness of material)					
6. Air temperature					
7. Relative humidity of air					
8. Wind direction					
9. Wind speed					
10. Slope of the terrain					
11. Other factors					

7. What types of fires for both listed vegetation type and tree species ***(Question 3),*** have occurred in your area?

Vegetation type				
Type of fire	**Yes**	**No**	**Number of occurrences**	**Year of first occurrence**
1. Crown fire				
2. Surface fire				
3. Sub-surface or Ground fire				

Tree species				
Type of fire	**Yes**	**No**	**Number of ocurrences**	**Year of first occurrence**
1. Crown fire				
2. Surface fire				
3. Sub-surface or Ground fire				

8. Do you use fire as a tool to

	Yes	No
i.) Rejuvenate the natural vegetation?	…..	…..
ii.) Reduce the occurrence of veld fires?	…..	…..
iii.) Control invasive plants?	…..	….
iv.) Enhance water yield around the surrounding area?	…..	…..
v.) Other use of fire		

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9. Do you regard the occurrence of fire or the use of fire within your area as

* Good	
** Bad	

i.) If (*), please state the benefits

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ii.) If (**), please state the damages, loss and negative effects

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10. Do you have any suggestions for reducing the risk of unwanted veld fires within your area?

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SECTION B

11. Can you please provide the following information?

i.) Surname……………………………………………………………………

ii.) Name of organization…………………………………………………..

iii.) Position held at organisation……………………………………………

iv.) Contact address at work…………………………………………………..

………………………………………………………………………………

v.) Telephone number at work………………………………………………..

'Thank you very much for your help.'