ASSESSMENT OF ENVIRONMENTAL IMPACTS OF GROUNDWATER ABSTRACTION FROM TABLE MOUNTAIN GROUP (TMG) AQUIFERS ON ECOSYSTEMS IN THE KAMMANASSIE NATURE RESERVE AND ENVIRONS

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EXECUTIVE SUMMARY

Background and Motivation

The effect of large-scale groundwater abstraction on the environment is largely unknown as very few studies in this field have been conducted in South Africa. The Klein Karoo Rural Water Supply Scheme (KKRWSS) that abstracts water from the Table Mountain Group aquifers, is situated in the Little Karoo, South Africa. This abstraction has been effected for seven years. A previous study funded by the Water Research Commission (WRC) on the geohydrology of the western section of the Kammanassie Mountain recommended that the impact of water abstraction on the environment should be investigated. As a result WRC initiated this study to investigate the effects of large-scale groundwater abstraction of this scheme on the environment.

Objectives of the project

To determine the impact of groundwater abstraction on:

- Riparian vegetation
- Terrestrial vegetation
- Springs
- Cape Mountain Zebra

Climate change in the Little Karoo

The Little Karoo is regarded as a dry region averaging monthly totals of less than 31 mm per month. Rainfall over the region does not exhibit a distinctive bimodal seasonal cycle.

A long rainfall record (1925 to 2000) reveals that the Little Karoo experienced unusually high rainfall during 1981, 1985 and 1996. These high rainfall values contribute to a general positive rainfall trend since 1925. If the shorter period of the recent 30/31 years (1971 to 2000/1) is considered, a general negative trend appears, implying that in both the Oudtshoorn and Kammanassie areas a decrease in the amplitude of the rainfall variability occurred over the past thirteen years. The trend is most obvious in the DJF, MAM and JJA seasons while rainfall totals increased over the SON season. The negative trends are not unusual and can be regarded as a return of rainfall totals to the longer-term norm (see Hoekplaas analysis – figures 3.4 and 3.5). A strong deviation from the norm was rather the extreme wet years that occurred in the 1970s and 1980s.

The more recent period of smaller rainfall deviations (1989 to1999) might have contributed to less soil moisture than for the preceding extremely wet period. In particular, a sequence of below-normal rainfall years appears in the JJA record (1985 to 2000). The period of smaller deviations does not necessarily point towards a drought, but compare well with rainfall variability experienced before the 1970s.

Impacts of groundwater abstraction on springs on the Kammanassie Mountain

Groundwater abstraction by the KKRWSS has impacted on the low-flow discharging of the Vermaaks River. Base flow in the Huis River has most probably been influenced by abstraction from the well field though the volume cannot be quantified. Superimposed on this abstraction is a declining precipitation trend since the commissioning of the well field. Under natural conditions permanent water occurs at two localities in the Vermaaks River Valley where springs emanated in the river course. These springs support localised ecosystems. Abstraction dried up one of these "permanent water" localities (spring 009) causing localised impact. The other spring (051) was temporarily affected and stopped flowing for 6 months. In the majority of cases the combined effect of the negative rainfall trend over the past 13 years is the probable cause of springs drying up. There appears to be a lag period (7 years) between the start of abstraction and a resultant significant impact on surface flow in the Vermaaks River.

Of the 53 springs on the Kammanassie Mountain Range, nine fall into the most vulnerable category, 10 into the intermediate vulnerability and the remaining 34 are the least vulnerable to the influence of abstraction. Twenty-seven springs (50%) on the Kammanassie Mountain clearly emanate from perched groundwater systems (type1), which cannot be influenced by groundwater abstraction and are excluded from potential influence. Sixteen (30%) “water table” (type 2) springs occur and are potentially vulnerable to the effects of abstraction if all the other hydrogeological parameters permit. In a further 10 cases (19%) there is a possibility that the springs emanate from perched systems but there is an element of doubt. Thirteen (48%) of the perched groundwater table springs have dried up since the well field was established indicating their susceptibility to low/irregular recharge from rainfall and snow. Of the 9 most vulnerable springs, 3 are excluded from influence, as they are perched. Only one has definitely dried up as a result of abstraction. A further two of these springs are still flowing. In the remaining 4 cases there is a strong case to suggest other factors (agricultural, other scheme well fields and climate) have played a significant role in springs drying up.

Of the 10 intermediate vulnerability springs, 3 have been disqualified on the basis of timing of dry up and one on the basis of being perched. In the remaining 6 cases there are strong indications that influences other than Vermaaks well field abstraction have played a major role in springs drying up. It has long been recognised that the Cedarberg shale plays a major role in the occurrence of springs. It has become clear that a large portion of these springs emanates from perched groundwater tables and is therefore not vulnerable to influences of abstraction.

This research has only focused on the impact of abstraction of 0.6 million m3/a from the Vermaaks river well field. It has to be recognised though that other groundwater users tapping this resource will also impact the aquifer and potentially influence surface/near surface flow.

Impacts of groundwater abstraction on the vegetation of the Vermaaks and Marnewicks Valleys

In order to determine suitable control sites for plant water stress tests, TWINSPAN classification, refined by Braun-Blanquet procedures were carried out in the

Vermaaks, Marnewicks and Buffelsklip Valleys. Twenty-seven plant communities, which could be grouped into 13 major communities were identified. A classification and description of these communities as well as a vegetation map are presented. The diagnostic species as well as the prominent and less conspicuous species of the tree, shrub, herb, restio and grass strata are outlined.

A checklist was produced for the Vermaaks, Marnewicks and Buffelsklip Valleys to determine the plant species richness for these areas in order to compare these sites for plant water stress tests. A total of 481 plant species were found for the Vermaaks, Marnewicks and Buffelsklip Valleys while a new *Erica* species was found at Buffelsklip.

The total of 441 plant species was identified in the Vermaaks Valley, which represent 229 genera and 76 families. Flowering plants are represented by Monocotyledoneae with 98 species in 16 families, Eudicotyledoneae with 329 species in 53 families and the Palaeodicotyledons with 1 species and 1 family. The Pteridophytes with 13 species in 9 families represent the non-flowering plants. A total of 189 plant species were recorded in the Marnewicks Valley, which represent 120 genera and 57 families. Flowering plants are represented by Monocotyledoneae with 42 species in 10 families and Eudicotyledoneae with 145 species in 44 families The Pteridophytes with 3 species in 3 families represent the non-flowering plants. A total of 171 plant species were recorded in the Buffelsklip Valley representing 118 genera and 55 families. Flowering plants are represented by Monocotyledoneae with 38 species belonging to 12 families and Eudicotyledoneae with 128 species and 40 families. The Pteridophytes with 5 species and 3 families represent the non-flowering plants.

Thirteen families dominate the Vermaaks, Marnewicks and Buffelsklip flora. The two largest families are the Asteraceae with 77 species and Poaceae with 40 species. A total number of six red data species were recorded.

Three experimental sites were selected in the Vermaaks Valley with control sites at the Marnewicks and Buffelsklip Valleys. Vermaaks 1 was at the site of abstraction;

Vermaaks 2 was downstream of Vermaaks 1, where a spring had dried up in 1999 and Vermaaks 3 was downstream of Vermaaks 2, where a spring was still flowing. The Marnewicks Valley is similar to the experimental sites in geology, climate, topography and vegetation. The Buffelsklip site was found to be an unsuitable control site as rainfall and water table readings were found to vary considerably from the Vermaaks and Marnewicks Valleys.

At each of the 5 sites, five individuals of *Rhus pallens*, *Dodonaea angustifolia*, *Acacia karroo*, *Nymania capensis* and *Osyris compressa* were randomly selected and permanently marked for the duration of the study. Three types of plant water stress tests were carried out on these individuals namely: plant moisture stress (Shölander pressure gauge); leaf water content (leaf disc method) and stomata resistance (porometer). Tests were carried out in spring, summer and winter over a 2-year period.

ANOVA, t-test (parametric), Mann-Whitney and Kruskal Wallis tests (non-parametric) were used to ascertain whether there were significant differences (p-value<0.05), per season, per species, per test between the following sites: Vermaaks 1 and Marnewicks; Vermaaks 2 and Marnewicks; Vermaaks 3 and Marnewicks (t-tests and Mann-Whitney) and all 4 sites (ANOVA and Kruskal Wallis). Boxplots (Box-and-whisker diagram) were used to graphically depict the results of the test results obtained. Pearson's Product Moment correlation coefficients were calculated to determine whether there were any correlations between the plant water stress tests (plant moisture stress, stomata resistance and leaf water content) per season, per species.

A 24-hour study was carried out to determine the most suitable time to collect plant material for plant water stress tests. Results indicated that variables such as (light, temperature, wind and relative humidity) were most stable between 22:00 and 03:00. Therefore plant material for plant moisture stress and leaf water content tests were collected simultaneously at each site at 22:00. The time most suitable for Porometer readings was found to be between 10:00 and 14:00.

All species except *Nymania capensis*, showed similar trends in plant moisture stress and leaf water content stress tests for spring, summer and winter, with more pronounced results in summer. The karroid plant *Nymania capensis* was found to be an unsuitable species for plant water stress tests. This could be ascribed to this plant probably having anatomical or physiological adaptations to drought, particularly in summer. Furthermore porcupine damage to the base of the stem of this species could also have induced plant moisture stress. The plant species *Rhus pallens, Dodonaea angustifolia*, *Acacia karroo* and *Osyris compressa* were found to be suitable species for plant moisture stress tests. Higher plant water stress in summer could be attributed to drier conditions (less rainfall) and increased groundwater abstraction.

The control site at Marnewicks was less stressed than Vermaaks 1, 2 and 3. Vermaaks 3 was less stressed than Vermaaks 2, while Vermaaks 1 was the most stressed. Higher stress at Vermaaks 1 is probably caused by drier conditions of the ecosystem at this site. The drier ecosystem, as a result of higher altitude, comprises more open woody vegetation. Groundwater abstraction also caused a drop in the water table (34.64 - 60 metres below surface).

According to the statistical analysis there is significant plant water stress in Vermaaks 2 compared to the control site at Marnewicks. Vermaaks 3 also shows higher plant water stress than Marnewicks (the control), especially in the summer months, though less than Vermaaks 2. Vermaaks 3 is further away from abstraction than Vermaaks 2 and also falls within the alluvium basin. Plant water stress at Vermaaks 2 and 3 is partially due to groundwater abstraction as these sites receive similar rainfall to Marnewicks, which was the least stressed site. The significant plant water stress results for summer, that revealed Vermaaks 2 & 3 as significantly more stressed than Marnewicks, seem to indicate that groundwater abstraction (elevated during the summer months) places additional water stress on vegetation during their growing season. The data from Vermaaks 2 & 3 seem to indicate that groundwater abstraction, superimposed by decreased rainfall and recharge, has a significant negative impact on plant water stress at the experimental sites in the Vermaaks River

Valley. Changes in the water abstraction management could perhaps improve the situation.

There was a negative correlation between plant moisture stress and leaf water content tests for *Rhus pallens*, *Dodonaea angustifolia*, and *Nymania capensis*. *Acacia karroo* and *Osyris compressa* showed a negative correlation between stomata resistance and leaf water content.

Data obtained from the porometer readings varied. This can be ascribed to the dependency of stomata closure on light intensity, wind and temperature. Statistical analysis (Pearson Correlations) between stomata resistance and light intensity confirmed this correlation. Because of the limitations of available equipment, porometer readings could not be measured simultaneously at all sites. This resulted in a great variation in the porometer readings. It was therefore decided to discard these results.

Impacts of groundwater abstraction on the vegetation of springs on the Kammanassie Mountain

A checklist was produced to determine the plant species richness for springs on the Kammanassie Mountain. A total of 244 plant species were recorded for the springs, which represent 145 genera and 71 families. Flowering plants are represented by Monocotyledoneae with 63 species belonging to 7 families and Eudicotyledoneae with 156 species and 43 families. The Pteridophytes with 12 species in 8 families represent the non-flowering plants. A total of 12 species in 12 families of Bryophytes were found. One species of Gymnosperm was found. The two largest families found were Asteraceae with 41 species and Poaceae with 25 species. Two red data species were found.

Flowing springs have very different plant communities to those that are dry. A difference between how long a spring has been dry also determines the plant community present. Very strong differences occur in plant species in flowing springs with ferns, mosses and water plants dominating these springs. Springs, that have been dry for a number of years, have a shrub, grass and restio dominance. Springs that have dried up recently (within the past 3 years) show a distinct difference once again, with the herbaceous layer being dominant.

Impacts of groundwater abstraction on Cape Mountain Zebra on the Kammanassie Mountain

Most of the Cape mountain zebra today, live in seeded populations, most of which were derived from the largest and most successful of the relict populations – the Cradock population of Mountain Zebra National Park. The two smallest relict populations in the Kammanassie and Gamka Mountains, both reduced to critically small numbers, may not have recovered from the extreme genetic bottlenecking. In the last 30 years, both these populations have not increased in number from 10 - 40 animals each. The Cape mountain zebra thus remains at the status of "endangered" in the IUCN's red data book of threatened species. Each stock population therefore represents 1/3rd of the entire Cape mountain zebra gene pool. This is alarming given that 2/3rds of the gene pool exists in only 5% of the metapopulation, i.e. 38 animals at Kammanassie Nature Reserve and 24 at Gamka Mountain Nature Reserve. In terms of conservation management, these two reserves are critically important in the maintenance of genetic diversity of Cape mountain zebras. A loss of one of these populations will reduce the genetic variation by a third.

There are currently 38 Cape Mountain Zebra on the Kammanassie Mountain that depend on springs for drinking water. A total of four Cape Mountain zebra died between November 2000 and August 2001. All four of these deaths were either directly or indirectly linked to springs drying up or to inaccessibility to flowing springs. Two artificial watering points have been installed to give foals and pregnant mares easy access to drinking water. Without artificial watering points at strategic places on the Kammanassie Mountain the 38 endangered Cape Mountain Zebra risk extinction as a result of natural water sources (springs) drying up.

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Parts of this project will be submitted by Ms G Cleaver for the degree: Magister Technologiae Nature Conservation, Technikon SA. The title of this report is “Environmental impacts of large-scale groundwater abstraction on ecosystems of the Kammanassie Mountain”. The promoter for the MTech: Nature Conservation is Prof. LR Brown (Technikon SA: Applied Natural Sciences).

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GLOSSARY

Alleles/locus: One of the two or more alternative states of a gene.

Alluvial aquifers: An aquifer formed of unconsolidated sediments deposited by a river or stream; typically occurring beneath or alongside a current channel, or in a buried old or paleo-channel of the river.

Angiosperm: Flowering plants.

Anisotropy: Physical properties that are different in different directions.

Anticline: A fold of rock layers that is convex upwards. Antonym of **syncline**.

Aquifer: Defined as a saturated geological unit that is permeable enough to yield economic quantities of water to wells.

Aquitard: A geological unit that is permeable enough to transmit water in significant quantities when viewed over large areas and long periods, but its permeability is not sufficient to justify production wells being placed in it.

Baseflow: The water in the stream when at its minimum or base level of flow; this is the level to which the stream flow returns between storms; in climates with season rainfall it is often treated as the dry season flow and it is derived from soil water drainage and groundwater.

Biome: A group of similar types of plant communities characterised by their distinctive plant types, e.g. tropical rain forest, savanna.

Competent: A strong rock or denotes a contrast in strength.

Confined Aquifer: An aquifer whose upper and lower layers are low permeability layers which confine the groundwater under greater than atmospheric pressure.

Dicotyledoneae: One of the two classes of angiosperms, characterised by having two cotyledons, net-veined leaves, and flower parts usually in fours or fives.

DNA: Deoxyribonucleic acid. Carrier of genetic information in cells.

Environmental isotopes: Naturally occurring stable isotopes, Hydrogen (^{2}H), Deuterium (D), Oxygen-16 (^{18}O), Carbon-12 (^{12}C), and Carbon-13 (^{13}C) and the radioactive forms, Tritium (^{3}T) and Carbon –14 (^{14}C).

Gene: The biologic units of genetic information; self-reproducing and located in definite positions (loci) on particular chromosomes.

Gene Pool: The totality of all the genes and their alleles of all of the individuals of a population.

Genetic bottleneck: When a population is greatly reduced in size, rare alleles in the population will be lost if no individuals possessing those alleles survive.

Genetic drift: The tendency within small interbreeding populations for heterozygous gene pairs to become homozygous for one allele or the other by chance rather than by selection.

Genetic variability: Populations may represent only a limited portion of the gene pool of a species. It occurs as a result of individuals having different forms of genes, known as alleles within a population, these alleles may vary in frequency from common to very rare (Primack, 1993).

Gymnosperm: Cone-bearing plants.

Fitness: An animal's success in bequeathing its genes to subsequent Generations (Apps, 1995).

Fynbos: The sclerophyllous vegetation that is native to the western and southern Cape regions of South Africa.

Groundwater: The use of this term should be restricted to water in the zone of saturation. It flows into boreholes/wells, emerges as springs, seeps out in streambeds or elsewhere in surface catchments and is not bound to rock (particle) surfaces by forces of adhesion and cohesion. Water contained in aquifers.

Heterozygosity: When an organism contains two dissimilar alleles.

Isotope: A variety of a chemical element having same atomic number but different atomic mass.

IUCN: International Union for the Conservation of Nature

Lineaments: Linear topographic features that may depict crustal structure

Monocotyledoneae: A plant whose embryo with one cotyledon; flower parts usually in threes; many scattered vascular bundles in the stem. One of the two classes of angiosperms.

Parshalls: Small flow measuring gauges that were built at the origin of the Vermaaks spring to monitor spring flow.

Piezometric pressure: The water pressure in a confined aquifer.

Pteridophytes: Ferns & fern-allies

Recharge: The portion of rainfall which reaches an aquifer irrespective of whether it follows a preferential flow path via fractures, or drains through a soil column, infiltration of standing water in river channels or local surface depressions.

Riparian: Growing by rivers or streams.

Stratigraphy: The description of strata – in terms of lithologic composition, fossil content, age, origin and history.

Succulent: A plant which accumulates water in fleshy, water-storing stems, leaves or roots.

Talus/scree: A pile of rock fragments lying at the bottom of the cliff or steep slope from which they have broken off.

Water table: The upper surface of the zone of saturation of an unconfined aquifer.

Wetland: A plant community or site with a soil that is flooded for sufficiently long periods for waterlogging to become the dominant factor determining its diagnostic characteristics.

Xerophytic: A plant adapted to dry or arid habitats.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

1.1.1 Klein Karoo Rural Water Supply Scheme

The Klein Karoo Rural Water Supply Scheme (KKRWSS) is a government water scheme operated by Overberg Water. The Scheme supplies purified domestic water, at subsidised rates, to the town of Dysselsdorp, to farms in the Olifants River Valley, to tributary valleys downstream of the Stompdrift and Kammanassie Dams and to the Gamka River Valley downstream of Calitzdorp. The initial investigation into the Scheme was started in 1984 and it was commissioned in 1987. Construction of the Scheme commenced in 1990 and was completed in 1993. Abstraction commenced in 1993. The Department of Water Affairs and Forestry (DWAF), that is responsible for its management, funded the Scheme. The Scheme was designed to supply up to 4.674 x 10^6 m^3/a of purified water and comprises an Eastern (Dysselsdorp) and Western (Calitzdorp) sector with groundwater being abstracted from 18 production boreholes in seven well fields (DWAF, 1999). The scheme abstracts approximately 1.1 x $10^6 m^3$/a.

The focus of this study, the Vermaaks river wellfield in the Eastern Sector, abstracts approximately 0.65 x $10^6 m^3$/a from 5 boreholes. A total of 4 production boreholes were drilled into the Peninsula formation on the Kammanassie Nature Reserve, namely boreholes VR6, VR7, VR8, and VR11. Production borehole VG3 is on declared private catchment and has been drilled into the Nardouw formation, within the Vermaaks River catchment. All borehole numbers used in this report are according to the numbering system used by Mulder (1995).

A re-evaluation of existing pumping test results, aquifer water levels, volumes abstracted and rainfall for the three years prior to June 1995 indicated that the estimated sustainable yield for the Scheme of 4.674 x $10^6 m^3$/a was closer to 1.11 x $10^6 m^3$/a (Kotze, 1995). According to DWAF (1999), the considerable difference in sustainable yield calculations can be attributed to the following reasons:

- Differences in management scenarios between the Nardouw and Peninsula aquifers;

- Interconnectivity between boreholes and well fields;

- Clogging of borehole screens by iron-reducing bacteria;

- Impact of abstraction from the Peninsula aquifer on springflow;

- Inefficient borehole construction and drilling;

- Environmental impacts of deep abstraction on vegetation;

- Inadequate quantification of the water balance;

- A poor understanding of the regional groundwater flow regime and conceptual hydrogeological model for TMG aquifers.

1.1.2 The effect of large-scale groundwater abstraction on the environment

The South African National Water Act No. 36 of 1998 makes provision for the environmental "Reserve", which includes the quantity and quality of water required to protect aquatic ecosystems in order secure ecologically sustainable development and use of the relevant water resource. This Act however explicitly identifies only aquatic systems and does not require that water allocations meet the needs of all ecosystems (Hatton, 2000). According to Hatton (2000) methods to determine the environmental water Reserve must include additional allocations required by non-aquatic ecosystems and aquifer protection. The identification of groundwater dependent ecosystems including cultural, biological and economic significance of dependant ecosystems must be identified and included into Reserve determination in South Africa (Hatton, 2000).

Large-scale groundwater abstraction was highlighted as one of the activities that could have a detrimental impact on the environment, and was listed by the Minister of

Environmental Affairs under section 21 of the Environmental Conservation Act No. 73 of 1989. Unfortunately no Ecological Impact Assessment (EIA) had been carried out prior to the KKRWSS, as such was not required by legislation at the time.

According to Dr Tom Hatton of the CSIRO in Australia, who visited South Africa in February 2000, no single environmental parameter could be utilised as an indicator of the possible impacts of groundwater utilisation. Measuring change in the environment can be attributed to so many different aspects, that assessment of impacts of groundwater utilisation cannot be assessed properly within a decade or even longer. The full implication of the effects of large-scale groundwater abstraction on the environment is not clearly understood and this has resulted in the Western Cape Nature Conservation Board (WCNCB) adopting a conservative approach. The WCNCB is the custodian of biodiversity in the Cape Floristic Kingdom and cannot risk losing species, especially rare and endangered ones, because of large-scale groundwater abstraction. A very strict policy has been drafted by WCNCB for bulk water supply utilising groundwater water resources. This policy cannot prevent abstraction from large-scale groundwater schemes. However as one of the main custodians of the environment in the Western Cape, the WCNCB can influence decision making by Government and ensure that the necessary precautions are taken to minimise and monitor potential environmental impacts of such schemes. This policy is attached in Appendix 1. The policy statement is as follows (Roets, 2001):

The Western Cape Nature Conservation Board will not support any underground water supply schemes for bulk supply purposes (including underground water abstraction for agricultural activities), unless each individual application was properly assessed by a stringent Environmental Impact Assessment (EIA). If no clear-cut recommendations on the potential impacts and mitigation thereof are forth coming the Western Cape Nature Conservation Board will not, and cannot approve of it.

The WCNCB’s conservative approach and policy statement on bulk water supply of groundwater has led to difference of opinions between conservationists and water resources managers.

To date research has concentrated on understanding the geology and geohydrology of the Kammanassie Mountain and this research has been applied to enable better management of the KKRWSS. Very few of the studies however have taken the environment, especially the non-aquatic ecosystems, into consideration. The Western Cape Nature Conservation Board was further concerned that, according to DWAF (1998) the KKRWSS demand for water in the year 2030 has been estimated at an additional 1 million m^3/a. The proposal was then made to increase abstraction from the Vermaaks River well field to yield 1.1 x 10^6 m^3/a (35 l/s) via VR7 and VR11 in order to augment the Eastern Sector of the Scheme (DWAF, 1999). The recommended amounts of groundwater abstraction for the KKRWSS, calculated for the Scheme and specifically Vermaaks River, is considered by geohydrologists to be an acceptable amount to allow for a sustainable yield from this groundwater resource. These figures however are not acceptable to conservationists, as they have not been calculated to include the sustainability of the environment and ecosystems. Furthermore the total amount of groundwater abstracted from this aquifer is unknown. Farmers abstract a large amount of groundwater from this aquifer for agricultural purposes and this amount must be taken into account when calculating an acceptable amount of abstraction. In order to plan for the future it is imperative that a better understanding is achieved of the effects of large-scale groundwater abstraction on the environment.

The Western Cape Nature Conservation Board manages the Kammanassie Nature Reserve where the KKRWSS abstracts water from the Vermaaks River. As early as 1995, Cape Nature Conservation officials expressed concern that large-scale groundwater abstraction by the KKRWSS was having a negative impact on the environment. It was observed that numerous springs on the Kammanassie Mountain had started drying up and vegetation in the Vermaaks River Valley started showing signs of water stress. The vegetation of this area is a remarkable mosaic of dry mountain fynbos and succulent karoo (Southwood, Van der Walt & Marshall, 1991).

1.1.3 Cape Mountain Zebra

The Cape Mountain Zebra (*Equus zebra zebra*) once inhabited the entire fold mountain region south of the Karoo, South Africa. By 1950, hunting, habitat destruction and agricultural competition had reduced the number of Cape Mountain

Zebra to 91 individuals in five, isolated populations. A further two of these populations have become extinct without contributing to the gene pool of the metapopulation. Thus the entire Cape Mountain Zebra population in its present existence consists of descendants of no more than 58 animals in the remaining three locations. Intensive protection and reintroduction programmes initiated by conservation authorities have resulted in an increase in the number of animals to approximately 1200 in 6 national parks, 10 provincial reserves and 14 private game farms. Most of the Cape Mountain Zebra today live in these seeded populations. Furthermore most were derived from the largest and most successful of the relict populations – the Cradock population of Mountain Zebra National Park. According to Moodley (2002) not all seeded populations have been successful and, more alarmingly, the two smallest relict populations in the Kammanassie and Gamka Mountains, both reduced to critically small numbers, may not have recovered from the extreme genetic bottlenecking. In the last 30 years, both these populations have increased in number from 10 to 30 animals each. The Cape Mountain Zebra thus remains at the status of "endangered" in the IUCN's red data book of threatened species (Moodley, 2002).

Severe population bottlenecks, such as the one experienced by the Cape Mountain Zebra, have serious genetic consequences since they drastically reduce genetic variation and leave populations open to the effects of inbreeding with continuing loss of genetic diversity due to genetic drift. If left unchecked, inbreeding may reach levels where fitness is compromised thereby leading to the extinction of the sub-species (Moodley, 2002).

The Wildlife Genetics Unit, University of Cape Town, obtained genetic samples (in the form of blood, tissue, skin or faeces) from over 100 Cape Mountain Zebras, including 9 animals from Kammanassie and 9 from Gamka. They investigated the variation in DNA of these animals and compared these populations to:

- one another
- closely-related Hartmann's mountain zebra (*Equus zebra hartmannae*) which are still free ranging in Namibia (Moodley, 2002).

According to Moodley (2002) the results show that all three Cape Mountain Zebra stocks are grossly inbred, with low numbers of alleles/locus and low heterozygosity. In comparison, the 9 Hartmann's mountain zebra populations looked at showed no loss of genetic variation and therefore did not appear to have undergone any genetic bottlenecking. However as a consequence of inbreeding, genetic drift and marked reduction of genetic variation, all three relict Cape Mountain Zebra stocks are significantly differentiated from one another. So the entire Cape Mountain Zebra metapopulation has still maintained much of its historical genetic variation, albeit in three separate and very inbred stocks. Each stock population therefore represents one third of the entire Cape Mountain Zebra gene pool. This is alarming given that two thirds of the gene pool exists in only 5% of the metapopulation, i.e. 38 animals at Kammanassie Nature Reserve and 24 at Gamka Mountain Nature Reserve (Moodley, 2002).

In terms of conservation management, these two reserves are critically important in the maintenance of genetic diversity of Cape Mountain Zebras. A loss of one of these populations would reduce the genetic variation by a third. It has been suggested that instead of extending the Mountain Zebra National Park, which conserves only one third of the Cape Mountain Zebra gene pool, money would be better spent on obtaining new reserves and on restocking these with mixed herds from each of the three relict stocks. In the meantime, every possible precaution should be taken to protect the two most vulnerable stock populations at Kammanassie and Gamka (Moodley, 2002).

The Kammanassie Nature Reserve was established in 1978 and the conservation and preservation of this pure Cape Mountain Zebra population was considered a priority. When the Reserve was established in 1978 the number of Cape Mountain Zebra on the reserve was estimated at only 6 animals (Odendal, 1978). The earliest record of Cape Mountain Zebra on the Kammanassie Mountain is for 1949, with a total of 15 animals recorded. Today 24 years later the population consists of 38 confirmed Cape Mountain Zebra. Although the Kammanassie Nature Reserve and declared mountain catchment comprise 44 000 hectares the Cape Mountain Zebra only utilise a very small percentage of the protected area as a whole. They are only found in areas where the required type of grazing, a plentiful water supply and shelter in the form of kloofs and ridges are readily available (Skinner and Smithers, 1990). They prefer the low-lying areas in the winter and move up into the higher lying areas in the summer (Skinner and Smithers, 1990). In the past these animals were free to roam where they chose, but today their movements are limited by fences which contain them within the protected area for their own safety

According to Skinner and Smithers (1990), Cape Mountain Zebra must drink water daily, normally in the late morning and then again in the afternoon. They have a distinct preference for clear water and avoid muddy water. Penzhorn (1975) states that Cape Mountain Zebras have been observed drinking daily. Penzhorn (1984) reports that Cape Mountain Zebras dislike the muddy water around the edge of a dam. Therefore should the water be muddy on the edge they usually wade a few paces into the water before drinking. This observation has been confirmed by the Reserve staff who closely monitor the Kammanassie population of Cape Mountain Zebra. The major water source utilised by Cape Mountain Zebra on the Kammanassie Nature Reserve is the natural springs situated around the mountain. These springs supply a constant supply of clean drinking water for the numerous animal species on the Kammanassie Nature Reserve. When springs on the reserve started drying up, within the last five years, the Western Cape Nature Conservation Board became concerned about the continued survival of Kammanassie population of Cape Mountain Zebra. Without easy access to clean drinking water, the Kammanassie population of Cape Mountain Zebra is under threat of extinction. Intervention in the form of artificial watering points has become necessary to ensure the survival of this population and ultimately of the sub-species as a whole.

1.2 OBJECTIVES AND AIMS OF THE PROJECT

The aims of this project, as stated in the research proposal to the Water Research Commission, were as follows:

To determine the impact of groundwater abstraction on:

- Riparian vegetation
- Terrestrial vegetation
- Springs
- Cape Mountain Zebra

To achieve these aims the following objectives were set:

- To find a suitable control site for comparative plant water stress tests
- To determine if plant water stress in the Vermaaks River Valley is significant
- To determine if plant water stress in the Vermaaks River Valley, if significant, could be related to groundwater abstraction.
- To determine if plant water stress in the Vermaaks River Valley, if significant, could be related to climatic change.
- To understand why springs on the Kammanassie Mountain are drying up and if this could be related to groundwater abstraction.
- To determine the extent to which Cape Mountain Zebra on the Kammanassie Mountain rely on springs for drinking water and to determine where artificial water points are required to ensure the survival of this species.

In order to achieve these aims and objectives in the Kammanassie Nature Reserve and adjacent mountain catchment areas, the following studies were carried out:

- Spatial and temporal rainfall variability and trends to determine the Little Karoo for long-term (75 years) and short-term (30/31 years).

- Vegetation surveys were carried out in the Vermaaks, Marnewicks and Buffelsklip River Valleys

- Vegetation surveys were carried out at each spring on the Kammanassie Mountain

- Plant water stress tests were conducted at three experimental sites in the Vermaaks River and a control site at Marnewicks River.

- Routine monitoring of groundwater levels in existing monitoring and production boreholes, establishment of additional monitoring boreholes specifically at vegetation monitoring sites and flow at v-notches in the Vermaaks and Marnewicks Rivers.

- Accurate location of springs with a Global Positioning System to monitor flow status and sampling sites and site inspections.

- Springs were ranked according to probability of being influenced by Vermaaks well field abstraction.

- Utilisation of springs by Cape Mountain Zebra and zebra movement related to springs/dry spring.

1.3 LITERATURE SURVEY

1.3.1 Cape Floristic Kingdom

Southern Africa has 10% of all plant speicies in the world. South Africa is also one of the only country to totslly contain one of the worlds six Floral Kingdoms – the Cape Floral Kingdom. Ons third of South Africa's plants occurs in this Kingdom (Low and Rebelo (1996).

According to Low and Rebelo (1996), the Kammanassie Nature Reserve falls into the Fynbos, Forest and Thicket Biomes. Very small pockets of the Forest Biome is found in kloofs on the southern slopes. Characteristics of these three biomes are as follows:

Fynbos Biome

Mountain Fynbos (S.A. Veld type 64 (Low and Rebelo, 1996) Acocks Veld Type 69 (Acocks 1988) covering 66 % of the Fynbos Biome.

Low and Rebelo (1996) recognise 5 major vegetation types within Fynbos: Mountain

Fynbos (64); Grassy Fynbos (65); Laterite Fynbos (66); Limestone Fynbos (67); and Sand Plain Fynbos (68).

The Fynbos Biome is characterised by its high richness in plant species (over 8000 species) and the high number of endemic plants - over 80% (Low and Rebelo 1996). The main physiognomic features of the vegetation are: the prevalent sclerophyllous shrub form, the scarcity of trees and the relatively minor importance of grasses and of evergreen succulent shrubs (Kruger 1979). Fynbos is characterised by the presence of the following three elements: a restioid component; an ericoid or heath component; and a proteoid component.

Rainfall varies from 200 to 2000 mm per year. Below 200 mm Fynbos is replaced by Succulent Karoo (Low and Rebelo 1996).

Thicket Biome

Valley Thicket (S.A. Veld Type 5, (Low and Rebelo, (1996), Acocks Veld Type 23 (Acocks 1988)), covering about 55 % of the Thicket Biome (Low and Rebelo, 1996).

Low and Rebelo (1996) recognise 5 major vegetation types within this biome: Dune Thicket (4), Mesic Succulent Thicket (7), Spekboom Succulent Thicket (8), Valley Thicket (5) and Xeric Succulent Thicket (6).

Subtropical thicket is described as closed shrubland to low forest dominated by evergreen, sclerophyllous or succulent trees, shrubs and vines, many of which have spines. It is often almost impenetrable and with very little herbaceous cover (Low and Rebelo 1996).

Rainfall varies between 300 and 1500 mm per year (Low and Rebelo 1996).

Forest Biome

Afromontane Forest (SA Veld Type 2, (Low and Rebelo, (1996), Acocks Veld Type 4 (Acocks 1988)), covering about 82% of the Forest Biome (Low and Rebelo 1996).

Low and Rebelo (1996) recognise 3 major vegetation types within this biome: Afromontane Forest (2), Coastal Forest (1) and Sand Forest (3).

The canopy cover of forests is continuous, comprising mostly evergreen trees, with multi-layered vegetation beneath. Herbaceous plants, particularly ferns are only common in the montane forests, whereas lianas and epiphytes are common throughout. The ground layer is almost absent due to the dense shade. On the edges of the patches, distinct communities, the so-called fringe and ecotonal communities, which are able to tolerate fire (Low and Rebelo 1996).

Rainfall greater than 525mm in the winter rainfall regions and greater than 725mm in the summer rainfall regions (Low and Rebelo, 1996).

1.3.2 Relationships between vegetation and groundwater

According to Scott and Le Maitre, (1998) the following generalised interactions between vegetation types and groundwater are given for the biomes present in the area:

- In the thicket biome groundwater interactions are probably limited to riparian situations, although many shrubs and trees have the ability to develop deep root systems where rocks are deeply weathered or fractured.

- In the fynbos biome, which is dominated by shrub species, shrubs are likely to be able to develop deep roots where possible but because groundwater resources are very limited in the shales and sandstones, interactions with groundwater are probably minimal.

According to Scott and Le Maitre, (1998) the abstraction of groundwater may affect vegetation that is reliant on that groundwater body, where it discharges in springs, streams, rivers or wetlands or where it occurs near the ground surface and is directly tapped by plants.

Riparian zones, especially in semi-arid to arid areas, are important for biodiversity as they offer habitat and refuge for a variety of organisms (Milton, 1990). In nonperennial riparian zones, many are supported by alluvial aquifers and the perennial systems receive a substantial proportion of local groundwater fed baseflow (Colvin, Le Maitre and Hughes, 2002).

Exploitation of groundwater resources can have a negative impact on both riparian and wetland communities, especially where wetlands depend on access to groundwater (Scott and Le Maitre, 1998). The impacts can be subtle. By lowering water tables seedling recruitment can be prevented and ultimately vegetation dynamics can be altered, but with little impact in the short term (Scott and Le Maitre, 1998). Community responses can be delayed until droughts or high abstraction rates, or both, lower the water table to a point where it passes the threshold of community resilience and there is mass mortality (Scott and Le Maitre, 1998).

Where groundwater is accessible, ecosystems will develop some degree of dependence on it and that dependence is likely to increase with increasing aridity of the associated environment (Hatton and Evans, 1998). Hatton and Evans, (1998) identified four kinds of ecosystem dependence on groundwater, namely: terrestrial vegetation, river base flow systems, wetlands and spring systems and aquifer and cave ecosystems (subterranean living organisms). These types focus on direct users of groundwater but there are examples where the ability of these species to access groundwater maintains other species in that ecosystem (Colvin *et al.,* 2001). An example is “hydraulic lift” where deep-rooted plants absorb water during the day and then release it from their shallow root systems at night (Richards and Caldwell 1987; Caldwell, Dawson and Richards 1998). The additional water released into the surface soil layers may be critical for maintaining shallow-rooted plants and any other dependent organisms in this kind of system (Colvin *et al.*, 2001). According to Colvin *et al.* (2001) the loss of deep-rooted species through, for example, lowering of the water table therefore may result in a collapse or major transformation of such ecosystems.
As early as 1989 farmers in the Klein Karoo suggested that groundwater exploitation was having a detrimental effect on karoo veld productivity (Landelike Water Skema Klein Karoo, 1989).

1.3.3 Plant water stress

The stomata, in addition to permitting the entry of carbon dioxide, allow for the evaporation of water from the interior of the leaves, a phenomenon called transpiration (Roberts, 1986). Although transpiration can take place through the stems, the leaves with their large surface area and abundant stomata are the main source of water loss (Roberts, 1986). External conditions affecting transpiration include: temperature, relative humidity, air movements, atmospheric pressure, light and water supply (Raven, Evert and Eichhorn, 1986). Transpiration depends on the walls of the mesophyll cells being thoroughly wet. For this to be so the plant must have an adequate water supply from the soil. If for some reason the plant cannot take up water from the soil (for example if it is too dry), soon or later the stomata close, thus reducing the rate of transpiration (Roberts, 1986).

According to Roberts (1986), when a plant loses more water through transpiration than it can take up into its roots, it wilts and is said to suffer from water stress. The loss of water from the leaves raises the tension of the water columns in the xylem, and the water potential gradient from the soil to the xylem increases. As a result the roots attempt to remove more and more water from the soil. If this situation continues the stomata close rapidly, thereby cutting down water loss to a minimum. The closing of the stomata reduced photosynthesis, which is one of the most notable side-effects of water stress. According to Raven *et al.* (1986), the main function of transpiration is to cool the leaves, an important effect particularly in hot conditions. Transpiration also provides pathways through which mineral elements are transported.

An increase in water stress as groundwater availability decreases (e.g. lowering the water table) would indicate groundwater dependence and could be a good indicator of when the stress is approaching the stage of plant die-back or mortality (Colvin *et al.*, 2001).

1.4 REPORT LAYOUT

This report begins with a brief background to the Klein Karoo Rural Water Supply Scheme and the concerns of Western Cape Nature Conservation Board on the effects of large-scale groundwater abstraction on the environment. A brief literature summary follows (Chapter 1). A general overview of the study area of the Kammanassie Nature Reserve, Vermaaks, Marnewicks and Buffelsklip River Valleys are described in Chapter 2.

The report comprises three sections:

- **Climate** – spatial and temporal rainfall variability and trends in the Klein Karoo (Chapter 3)
- **Geohydrology -** springs on the Kammanassie mountain (Chapter 4)
- **Ecosystems** – the effect of groundwater abstraction on ecosystems (Chapters 5, 6 and 7)

The **final conclusions and recommendations** for all three sections are presented in Chapters 8 and 9.

CHAPTER 2

STUDY AREA

2.1 KAMMANASSIE NATURE RESERVE

2.1.1 Locality

The Kammanassie Mountain complex is situated between the towns of Uniondale in the east and De Rust/Dysselsdorp in the north-west and west. The mountain is an inselberg within the Little Karoo between the Swartberg and Outeniqua Mountains (Figure 2.1).

The total area of the mountain range, managed by the Western Cape Nature Conservation Board (WCNCB), is 49 430 hectares of which 21 532 hectares are a privately-owned declared mountain catchment area. The remaining 27 898 hectares are state land, of which 17 661 hectares have been declared forest in terms of section 10(1) of the Forest Act No. 122 of 1984. The Kammanassie Nature Reserve is situated between 33°33’50”S and 33°37’10”S and 22°27’29”E and 23°01’55”E.

2.1.2 Climate

A summary of the position and details of the weather stations used in this study are given in Table 2.1 and shown in Figure 2.2.

The Reserve receives rain throughout the year with an average annual rainfall of approximately 450-mm (Figure 2.3). Drier periods are from November to February.

Six manual weather stations with rain gauges and minimum and maximum thermometers have been established and used since 1976 on the Kammanassie Nature Reserve. These thermometers are read once a month. Thus the absolute maximum and minimum temperatures for the month are recorded and not the true average temperatures.

Furthermore, there are two automatic weather stations (AWS) on the Reserve, one at Paardevlakte and the other in the study site in the Vermaaks River Valley. Minimum and maximum temperature, rainfall, Relative humidity, wind speed and wind direction is recorded at these weather stations. Recordings at these stations are taken hourly.

Temperatures and rainfall vary considerably from the high mountain peaks to the low-lying areas.

The average maximum temperature is 29°(Figure 2.4) and minimum is 2°C (Figure 2.5). The coolest months are from May to August.

2.1.3 Drainage

The main drainage direction in this region is westward, the perennial Olifants River draining the area to the north of the Kammanassie Mountain Range (KMR) and the Kammanassie River, which is also perennial to the south of the Range. Tributaries of Olifants River arising on the northern slopes of the KMR include the Vermaaks, Marnewicks and Buffelsklip Rivers. The southern flanks are drained by rivers, that include the Huis, Diep, Klein, Klues and Mill Rivers. All drain into the Kammanassie River. These relatively short tributaries are ephemeral in the steep upper reaches, with more sustained flow in the lower reaches.

2.1.4 Geology, geomorphology and hydrogeology

The geology of the area is explained in some detail in Kotze (2001). Aspects of particular relevance to this project have been extracted from that document, and form the bulk of the section presented below.

2.1.4.1 Stratigraphy

The stratigraphy of the region is summarised in Table 2.2 and shown in Figure 2.6. The Kammanassie Mountain Range (KMR) comprises almost exclusively the resistant quartz arenites of the Table Mountain Group (TMG), overlain on the lower slopes by the shale of the Bokkeveld group. A very important shale marker horizon, the Cedarberg formation (varying between 50 and 120 metres thick) occurs within the TMG, separating formations of the Peninsula formation from the lithologies comprising the Nardouw.

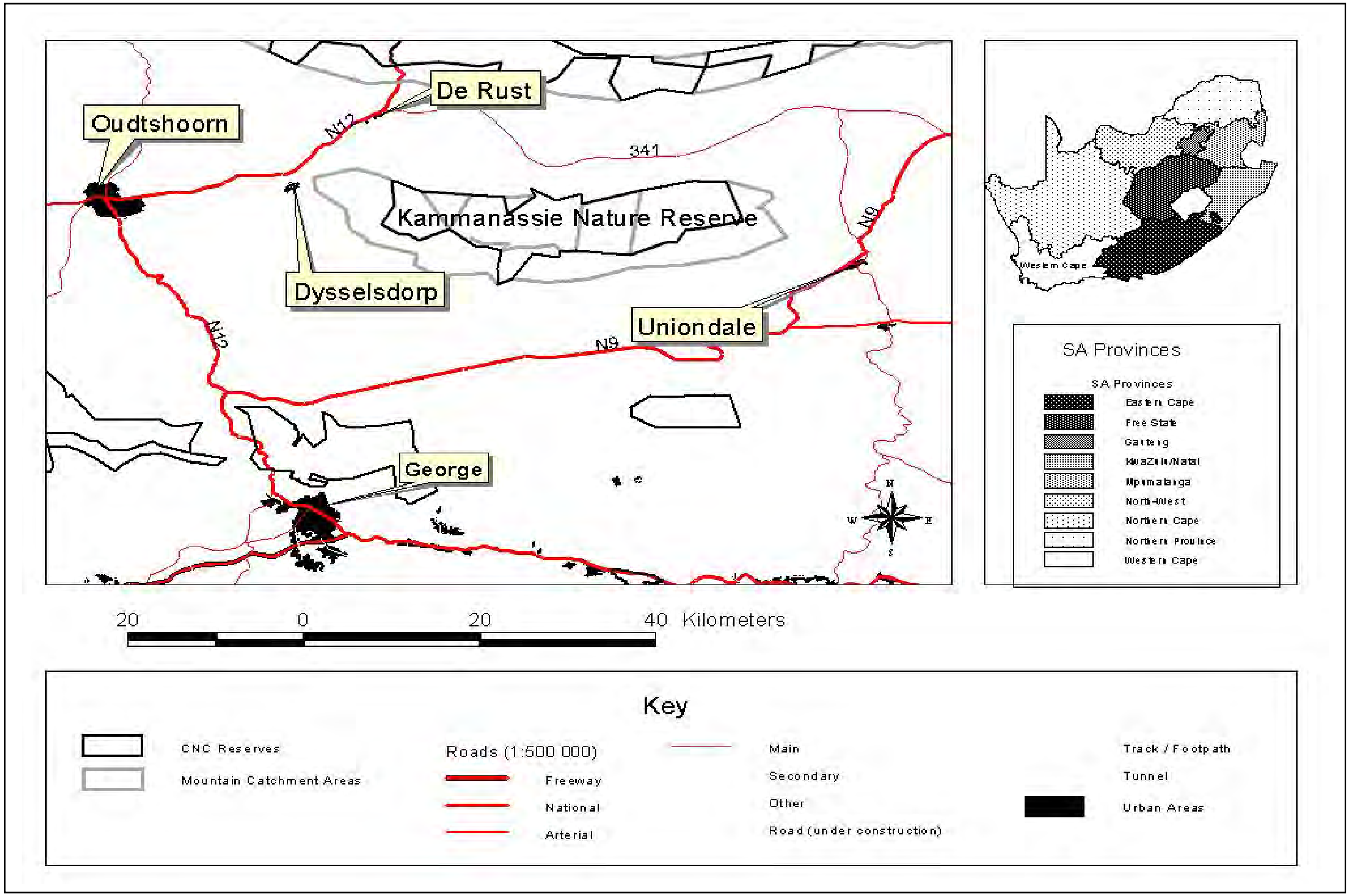


Figure 2.1: Locality of the Kammanassie Nature Reserve

Table 2.1: A summary of data for weather stations used in this study

Station	Co-ords (S)	Co-ords (E)	Altitude (m)	Aspect	Avg Rainfall (mm)	Avg Max (°C)	Avg Min (°C)	Year Established
Paardevlakte 1 WCNCB	33°36’31.9”	22°51’09.2”	1500	N	509.6	27	1.5	1976
Paardevlakte 2 WCNCB	33°37’43.4”	22°51’09.2”	1494	N	640.7	26.7	2.6	1976
Paardevlakte * (AWS) WCNCB	33°37’14.8	22°52’0.01”	1490	N	*	*	*	May 1989
Buffelsklip WCNCB	33°34’04.7”	22°53’22.1”	686	N	256.8	29.4	3.9	1987
Buffelsklip Official:00296924	33°32’38”	22°53’47”E	610	N	196.57	-	-	1913
Hoekplaas Private	33°33’03”	22°58’30”	648	N	236.24	-	-	1925
Elandsvlakte WCNCB	33°39’26.6”	22°45’27.2”	1210	S	575.6	27	3.5	1976
Wildealsvlei WCNCB	33°39’11.6”	22°40’03.9”	1100	S	611.0	29.6	3.3	1976
Wildebeesvlakte WCNCB	33°37’36.4”	22°35’09”	926	W	442.2	31.8	1.22	1976
Wildebeesvlakte KKRWSS	33°37’40.3”	22°35’09.2”	985	W	476.4	-	-	Sept 1993
Vermaaks (AWS) WCNCB	33°36’11.5”	22°31’56.2”	679	W	290.3 (2001)	39.37	2.62	30/12/2000

* Data from this AWS was not used in this study as problems with the station resulted in incomplete data.

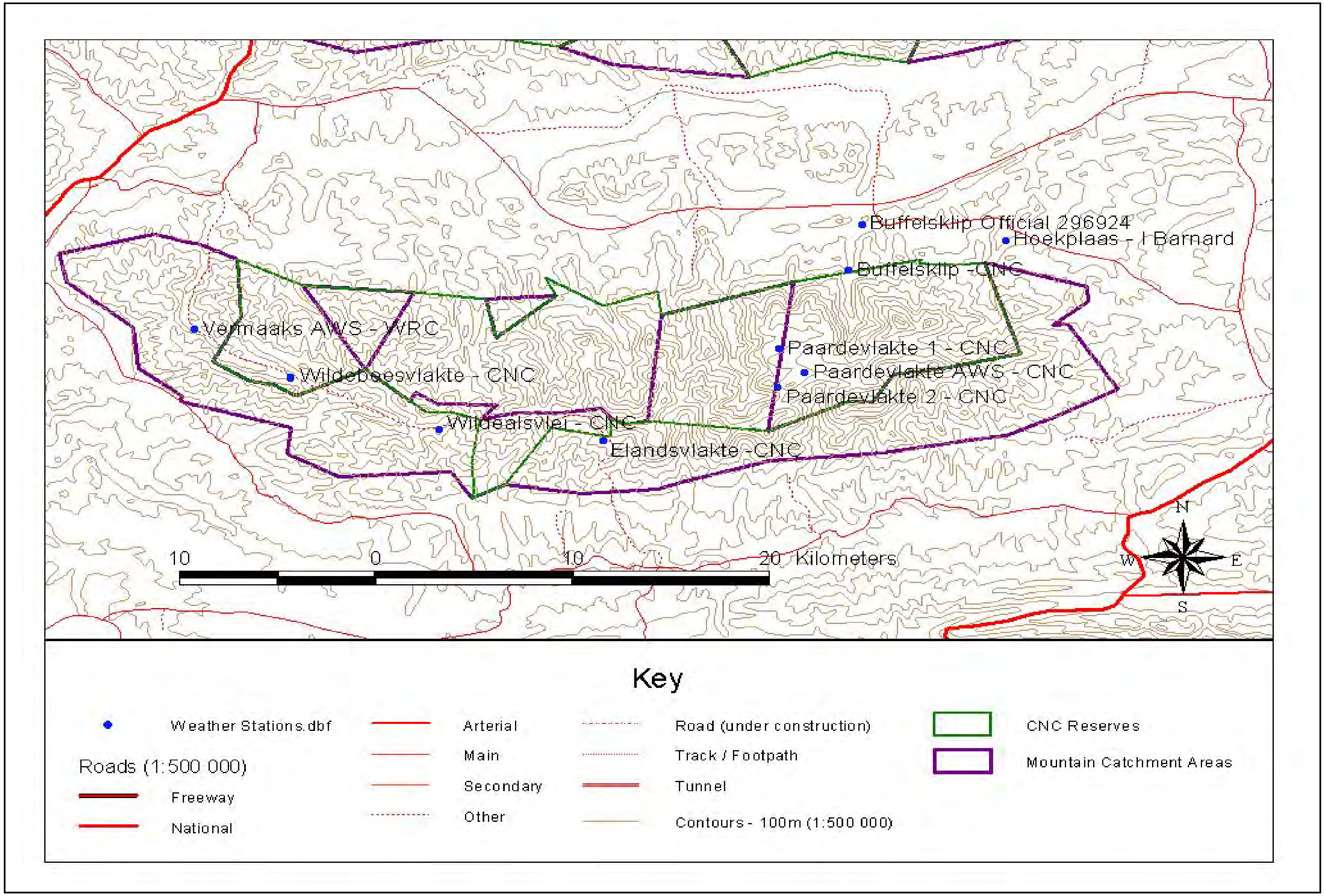


Figure 2.2: The locality of the various weather stations on the Kammanassie Mountain

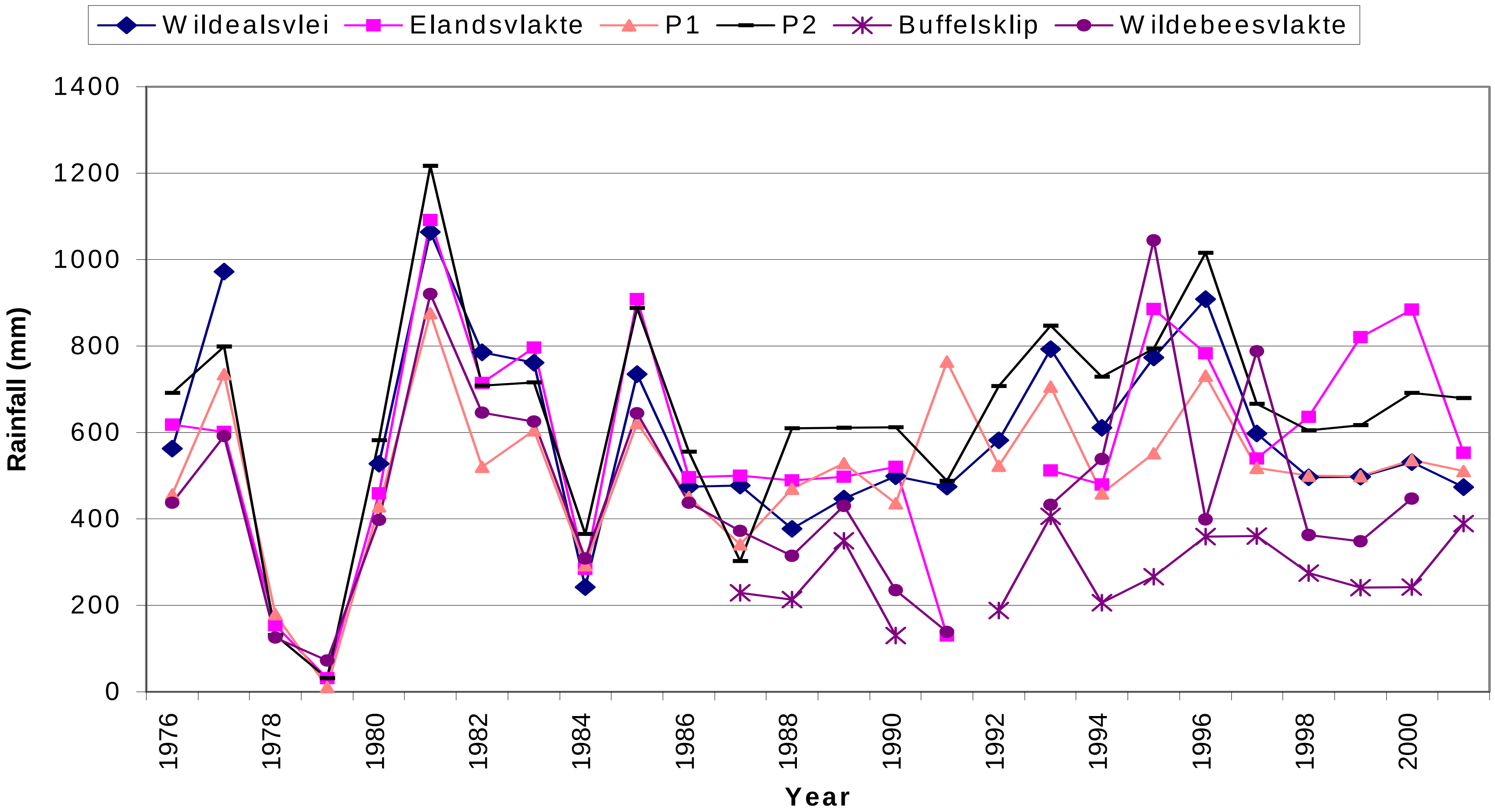


Figure 2.3: Rainfall for the Kammanassie Nature Reserve (1976-2001)

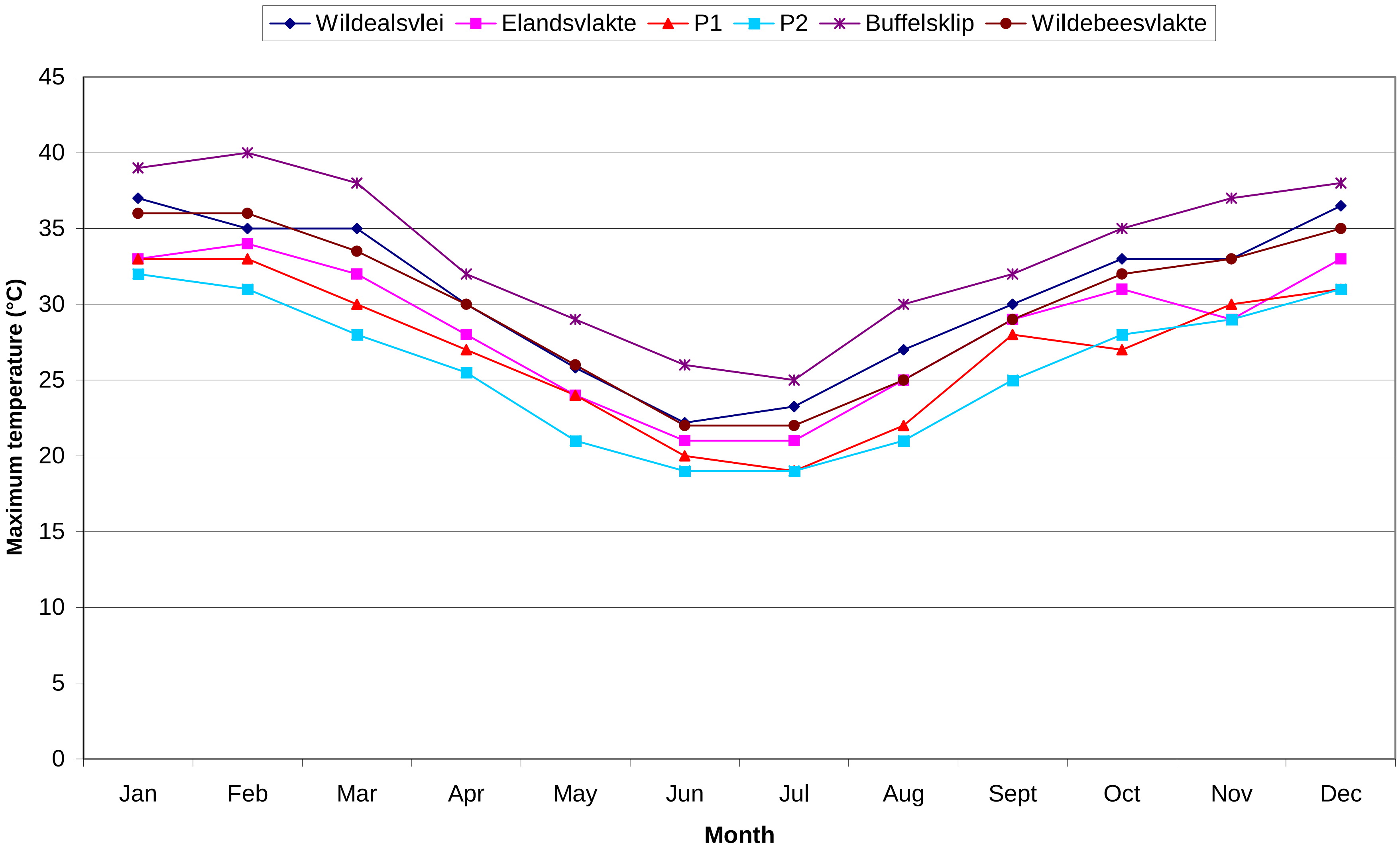


Figure 2.4: Maximum temperatures for the Kammanassie Nature Reserve (1976-2001)

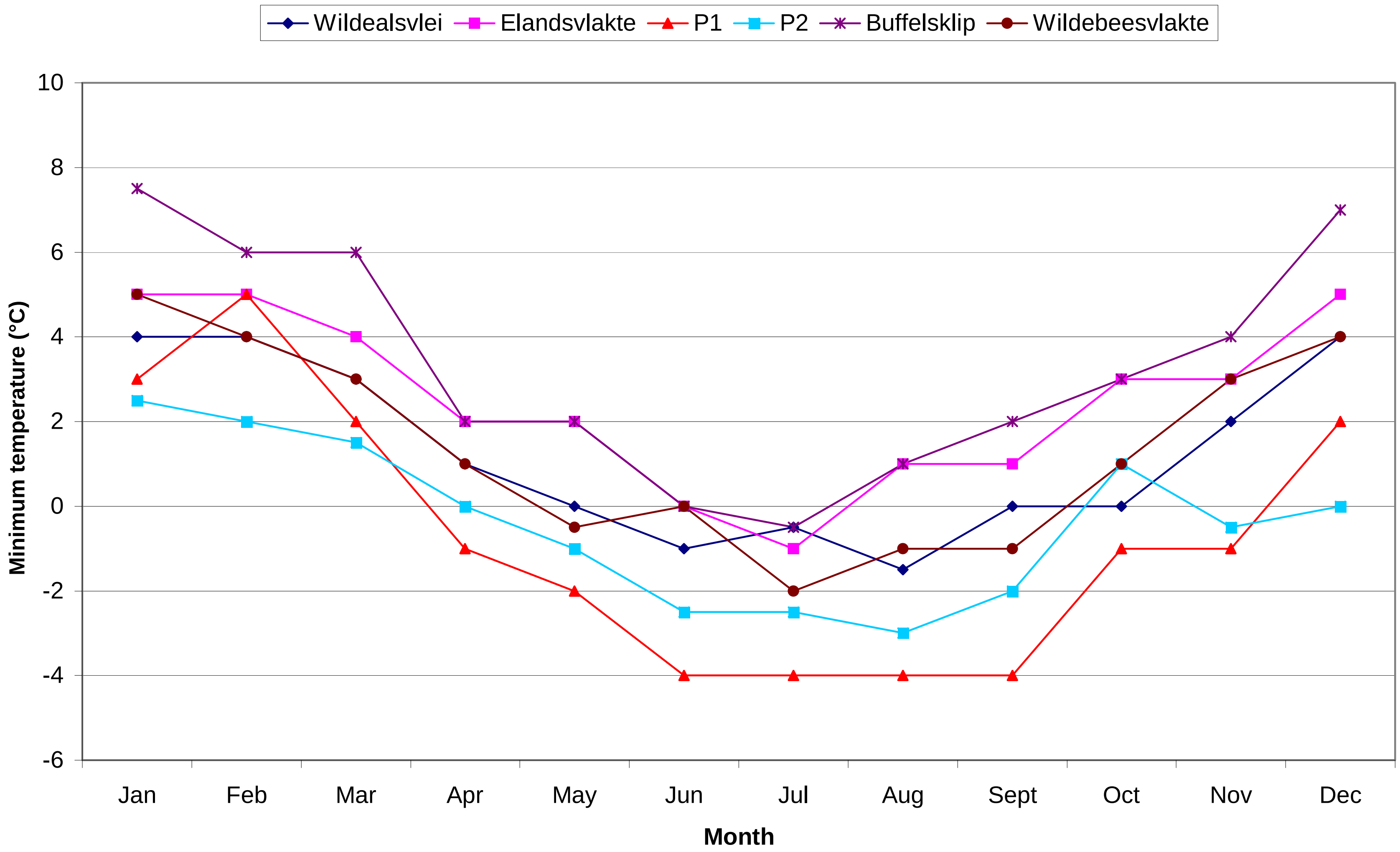


Figure 2.5: Minimum temperatures for the Kammanassie Nature Reserve (1976-2001)

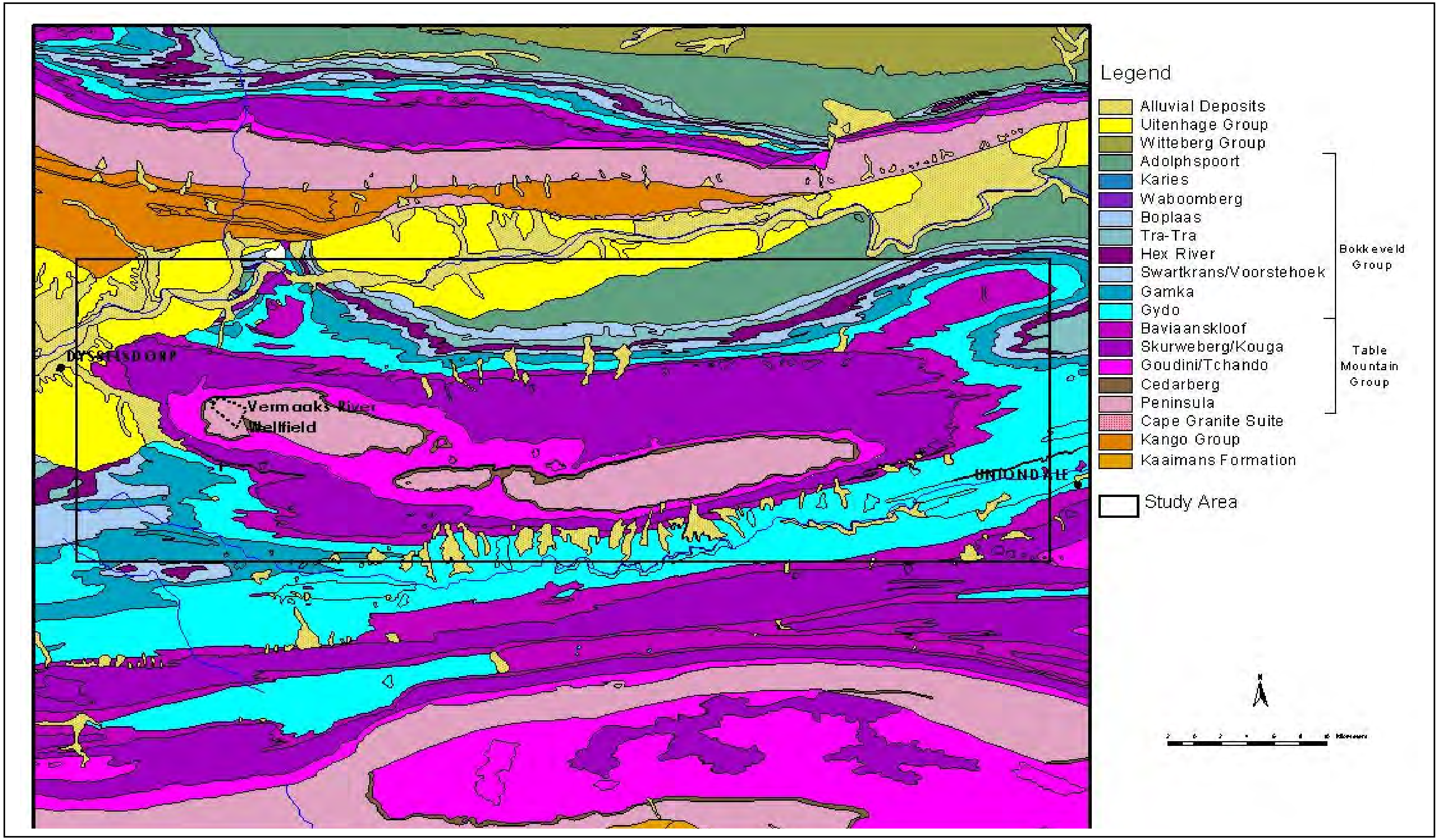


Figure 2.6: The stratigraphy of the Kammanassie study area

The Peninsula formation is a highly competent succession of medium to coarse-grained, thickly bedded, grey sandstone. The Nardouw weathers more brownish, and thin shale intercalations are more common, than in the Peninsula formation. The Nardouw formation is more ductile as a result.

Recent deposits occur in the floor of the steep-sided Vermaaks River Valley where talus/scree accumulations up to 20 metres thick are encountered. These deposits comprise large angular quartzite fragments, in some cases metres in diameter, set in an unconsolidated silty matrix. Similar accumulations may occur in the other valleys, which have not been investigated in detail.

Soils generally form a thin (<1 metre) veneer of silty sands/sandy silts as a result of the steep slopes of the Kammanassie Mountain and predominantly quartzitic rocks. Locally clayey soils occur in association with weathered shale horizons, and in particular the Cedarberg formation.

2.1.4.2 Structural geology

Folding

The Kammanassie is one of the prominent E-W trending ranges comprising the southern branch of the Cape Fold Belt. It was formed as a result of N-S oriented compressive stress during the Cape Orogeny 123-200 million years ago. The KMR is an eroded remnant of the Kammanassie mega-anticline (Halbich and Greef, 1995). It comprises almost exclusively resistant quartz arenites of the TMG. The core of this mega-anticline constitutes a gently overturned northern limb. Compressional deformation during the Cape Orogeny was followed by extensional tectonics resulting in regional E-W faulting. Several examples of recent tectonic activity (neotectonics) have been documented in the S-E Cape, which suggests an extensional regime is still prevailing with extension in a NNE – SSW direction, and compression in a WNW-ESE direction (Kotze, 2001).

TABLE 2.2: Geological succession of the Klein Karoo

SUPER GROUP	SUB-GROUP	GROUP	FORMATION	THICKNESS (m)	LITHOLOGY
					Alluvium, sand gravel and other unconsolidated deposits as well as calcrete
	Uitenhage		Buffelskloof		Conglomerate, thin sandstone, siltstone and mudstone
			Kirkwood		Conglomerate, siltstone, mudstone
			Enon		Conglomerate, thin sandstone, siltstone and mudstone
Karoo	Beaufort		Teekloof	1000	Mudstone and shale
			Abrahamskraal	2400	Mudstone, siltstone and sandstone
	Ecca		Waterford	800	Sandstone, minor siltstone and shale
			Fort Brown	1000	Shale, thin siltstone and sandstone
			Laingsburg/Rippon	1000	Sandstone, greywacke, siltstone/mottled grey sandstone, shale
			Vischkuil	100	Arenaceous shale, siltstone and thin sandstone
			Collingham	30	Siltstone, chert, sandstone, volcanic ash
	Dwyka			600	Diamictite and shale
Cape	Witteberg	Lake Mentz	Waaipoort	340	Shale, siltstone, thin sandstone
			Floriskraal	80	Sandstone, siltstone, shale and grit
			Kweekvlei	200	Shale
			Witpoort	850	Quartzitic sandstone, minor siltstone
		Weltevrede		800	Micaceous, purple to red brown siltstone, mudstone and shale
	Bokkeveld	Traka	Adolphspoort	1000?	Siltstone, shale, sandstone
			Karies	1200	Shale
		Bidouw	Waboomberg	200	Siltstone, shale
			Boplaas	100	Sandstone
			Tra-Tra	350	Shale, siltstone
			Hex Rivier	70	Sandstone, siltstone
			Voorstehoek/Swartkrans	300	Shale, siltstone
			Gamka	200	Sandstone, siltstone
			Gydo	600	Shale, siltstone
	Table Mountain		**Nardouw**: Baviaanskloof	300	Feldspathic quartz arenite
			Nardouw: Kouga	500	Quartz arenite
			Nardouw: Tchando	400	Brown-weathering arenite, minor siltstone, shale
			Cedarberg	50	Prominent shale marker
			Peninsula	1500	Quartz arenite

Disconformity (break in the geologic record)

Cango Group			Schoemanspoort	600	Grit, greywacke, subarkose, conglomerate
	Kansa		Schoongezicht	?	Conglomerate, greywacke, shale
			Gezwindskraal	?	Fine-grained greywacke, shale
			Uitvlugt	?	Cross-bedded greywacke, shale
	Goegamma		Vaartwel	?	Quartz-pebble and conglomerate
			Groendfontein	2400?	Grit, arenite, fine-grained greywacke, shale, limestone lenses
			Matjiesrivier	?	**Kombuys Member:** Limestone, siltstone and shale
				?	**Nooitgedagt:** Limestone, shale, greywacke and subarkose
Cape Granite					Gneissic granite
Kaaimans				85?	Feldspathic quartzite

Fracturing/Faulting

Larger fractures (joints and faults) are usually readily identifiable as linear features on aerial photographs and satellite images due to the abundant rock exposure. Analysis of lineaments identified by remote sensing led Chevallier (1999) to divide the Kammanassie Anticline into four different structural domains, each related to different styles of fracturing prevailing in the anticline. Each domain shows a different fracture pattern, which could imply different hydrodynamic properties (Figure 2.7).

Faults, fold and contact relationships around the periphery of the westward plunging nose of the Kammanassie mega-anticline were mapped in detail by Halbich, and Greef (1995) providing insight into the nature of the structures responsible for these lineaments (Figure 2.8).

Four types of faulting were distinguished:

- The 200 m wide and 9 km long Vermaaks River fracture zone, occurring along the Vermaaks River Valley.
- Smaller faults, e.g. the ESE trending Brillkloof, SSE-trending Leeublad and Rooikrans and three E-W trending Klapperskloof Faults with sharply defined planes with up to 20 m wide breccia zones.
- Breccia, consisting of rounded rotated fragments in a fine-grained ground mass.
- Homogeneous mass of very fine-grained cataclasite, which is partly recemented and extremely hard.

Halbich, and Greef (1995) found NW and NE trending open joints to be most prominent in the Nardouw subgroup. In the Peninsula Formation E-W trending joints are closed and filled with quartz, whereas N to NE and NW trending joints are open. The spacing of orthogonal joints varies from several decimetres to approximately one metre, and depends on the thickness of quartzite layers. Single straight master joints continue from several metres to tens of metres along the same bedding plane. Apart from regional faults, intense fracturing along fold axial planes occurs.

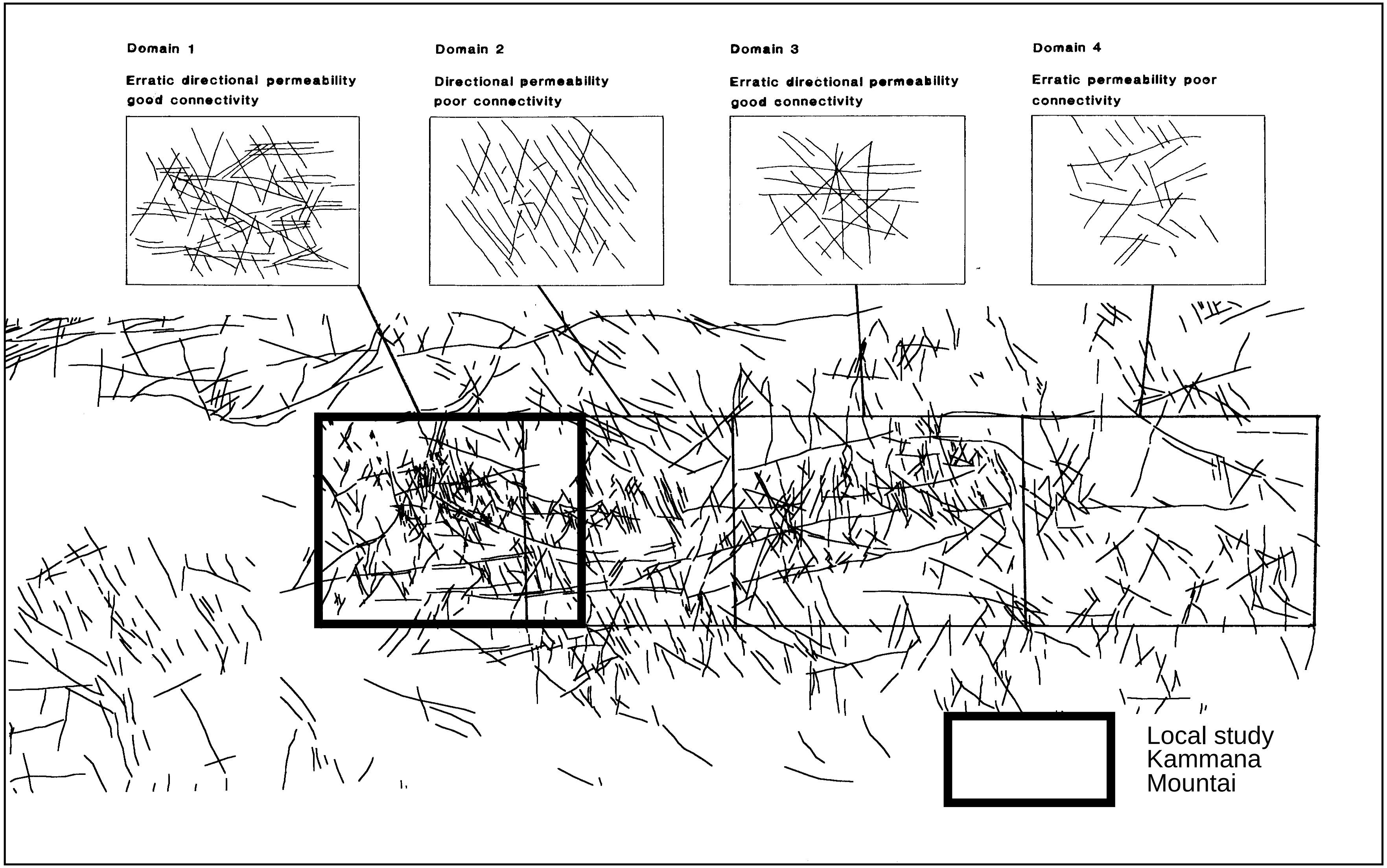


Figure 2.7: Hydrodynamic parameters – Kammanassie Mountains (Chevallier, 1999)

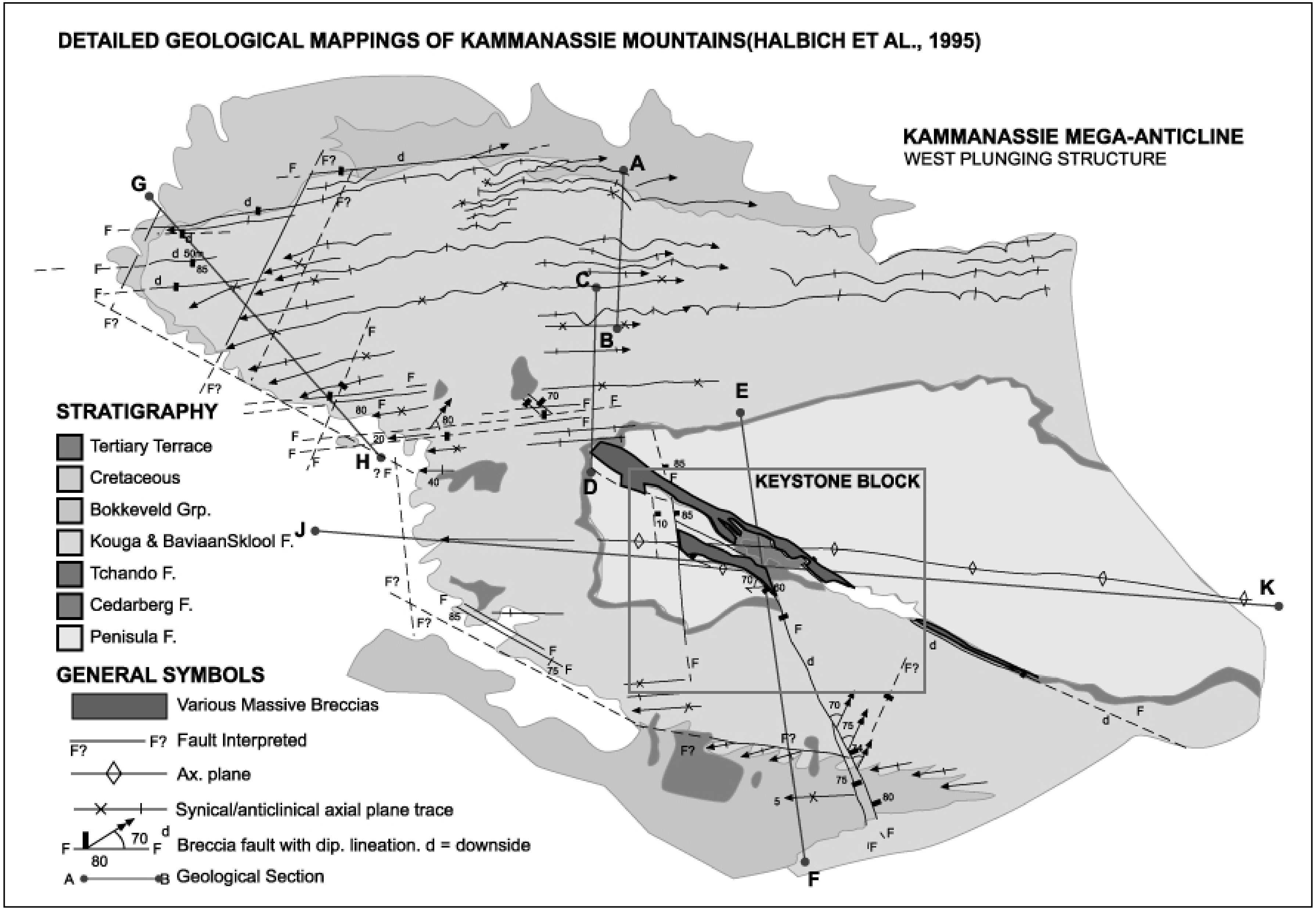


Figure 2.8: Detailed geological mapping of the Kammanassie Mountains (Halbich and Greef, 1995)

Kotze (2001) recognised 3 scales of fracturing:

The smallest scale of the order of tens of metres deep (those striking NW-SE, N-S and NE-SW) and corresponding with mechanical failure of the rocks near surface.

An intermediate scale fracture resulting from folding or faulting (e.g. Vermaaks River Valley) penetrating to several hundreds of metres. The largest scale associated with deep-seated movements in the earth's crust allowing circulation to surface of hot groundwater under artesian pressure.

2.1.4.3 Hydrogeology

The rocks of the TMG possess essentially no primary porosity, and groundwater flow is restricted to fractures in joint and fault zones. Groundwater flow in these fractures is controlled by fracture characteristics such as connectivity openness and geometry.

Groundwater recharged (14% of mean annual precipitation) (Kotze, 2001) predominantly in the topographic highest parts of the Kammanassie mountain. The precipitation percolates into fractures of varying orientation and scale. Water accumulations in shallow fractures above localised aquitards result in the occurrence of perched springs and seeps. Migration of the groundwater under the influence of gravity into larger deeper fractures leading ultimately to the water table / piezometric surface where it becomes part of the regional groundwater flow system, discharging toward the foot of the mountain where the groundwater table / piezometric surface daylights as springs, as well as baseflow in river courses. Discharge in rivers occurs preferentially where there is good interconnection between fractures and the riverbed.

An understanding of the factors controlling groundwater flow, the locality of groundwater discharges as well as factors influencing the degree of interconnectivity with abstracted groundwater is required to make a judgement of the potential influence groundwater abstraction could have on groundwater near the surface. It would be beneficial in this respect to examine the lithostratigraphic control on fracture formation and spring occurrence. Hydrochemistry can also, to some degree, provide supporting evidence for groundwater origin or flow paths.

Hydrostratigraphy

Lithological factors play a significant role in influencing the nature of fracturing and therefore influence hydraulics. Shale has a great impact on fracturing and folding style and therefore hydraulic conductivity. Increased shale component results in more ductile deformation. In addition clay resulting from chemical weathering of feldspar can clog fractures and reduce permeability further.

For example a more dynamic free circulating groundwater regime can be expected in the Peninsula Formation comprising almost exclusively quartz arenite. This is because the virtual absence of shale results in a higher potential for brittle failure during deformation. A higher fracture frequency and secondary porosity results and the absence of clay weathering products typical of shale reduce the chances of blockage.

Flow is more restricted in the Nardouw aquifer, which consists of arkosic sandstones with silty/shaley interbeds. More ductile deformation results in lower fracture frequency, lower porosity and clay weathering products will further reduce permeability. The Baviaanskloof, Kouga and Tchando formations comprise this Nardouw aquifer.

The Cedarberg Formation (CF), separating the Peninsula formation from the Nardouw, is an aquitard, containing water but does not transmit significant amounts of groundwater unless disrupted by a fault. The CF aquitard is intact along much of the Kammanassie Mountain range inhibiting flow between the Nardouw subgroup and Peninsula formations. It is disrupted on the southern flanks of the Western end of the Kammanassie Range in the Keystone Block (Halbich and Greef, 1995) by a number of faults, such as the Leeublad, Rooikrantz, Brillkloof and Vermaaks River faults and results in juxtaposition and interconnection of the Nardouw and Peninsula aquifers along a preferential groundwater flow path. Kotze (2000a), basing arguments on hydrochemical and structural considerations, suggests that that interaction in this zone is so extensive that this “Aquizone” should be managed as a single hydrogeological unit.

The Bokkeveld shales are also poor aquifers inhibiting regional flow.

Spring occurrence

Typical spring occurrence is illustrated in Figure 2.9. More detail on the type and locality of springs is given in 4.3.5.

Kotze (2001) identified essentially three different types of spring in the Klein Karoo.

Type 1 – Shallow springs emanating at perched water tables.

The springs seep from a network of joints, small irregular fractures and from bedding planes within the TMG aquifers directly above localised aquitards. These seasonal, low-yielding features are associated with locally perched water levels and are responsible for the many springs/seeps emanating form TMG aquifers after precipitation. Meyer (2001) confirms that these springs are highly seasonal, and that flow diminishes at the onset of dry conditions. These are not connected to the greater groundwater flow system on any scale i.e. local, intermediate or regional. According to Kotze (2001) groundwater abstraction from any part of the TMG aquifer will not impact Type 1 springs.

Wet zones occur on hill slopes within the first metre or so of fractured rock from surface. This rock, together with the bottom portion of the thin soil cover, can be saturated depending on locality and seasonal precipitation. Flow is likely to occur in these periodically saturated zones, down slope at the bedrock interface zone as well as vertically to the water table / piezometric surface. The down-slope flow probably contributes to sustaining "perched" springs and stream flow. Transpiration by vegetation intercepting this water results in desiccation of this zone in dry periods and substantial recharge may be required before saturation/flow returns. Regular recharge of this zone will on the other hand result in sustained flow of springs and streams.

Type 2 – Lithologically controlled springs, due to the presence of inter-bedded aquitards.

Lithologically controlled springs emanate at the contact with the aquitard. The springs are connected to the intermediate and regional scale flow system. (Kotze, 2001).

Typical Type 2 localities in the study area are where groundwater emanating from the Peninsula formation discharges at the contact with the Cedarberg Formation shale. Another is discharge from the Nardouw aquifer at the contact between the Kouga formation and the more feldspar rich Baviaanskloof in close proximity to the contact with Bokkeveld Group contact, as well as at the contact itself. It is possible for groundwater abstraction from the regional aquifer system to influence these types of springs provided there is interconnection and the spring occurs within the radius of influence of abstraction. According to Kotze (2001) emanations of Type 2 surfacing in springs and narrow valleys provide up to 90% of the stream flow in the form of base flow.

<u>Type 3 – Fault controlled springs</u>.
These mostly represent hot springs and intercept the regional flow system.

Hydrochemical classification and isotopes
TMG groundwater in the Klein Karoo is classified as Na/Cl type with all other ions at very low concentration. It is characterised by low mineralisation with an electrical conductivity of 10 mS/m for the well field. The spring water has a similar character and therefore not readily distinguishable from the groundwater.

Due to the similarities in geochemical signature, trilinear hydrochemical plots are not useful for distinguishing groundwater from particular formations within the TMG or devising flow paths. Environmental isotopes can provide tools when used in conjunction with other data such as lineaments from remote sensing to conceptualise the system (Kotze, 2001).

Using these techniques, Peninsula groundwater could be distinguished from purely Nardouw groundwater and from Nardouw groundwater associated with Bokkeveld shale. However Peninsula and Nardouw could not be distinguished in the Keystone block where mixing occurs due to structural interconnection.

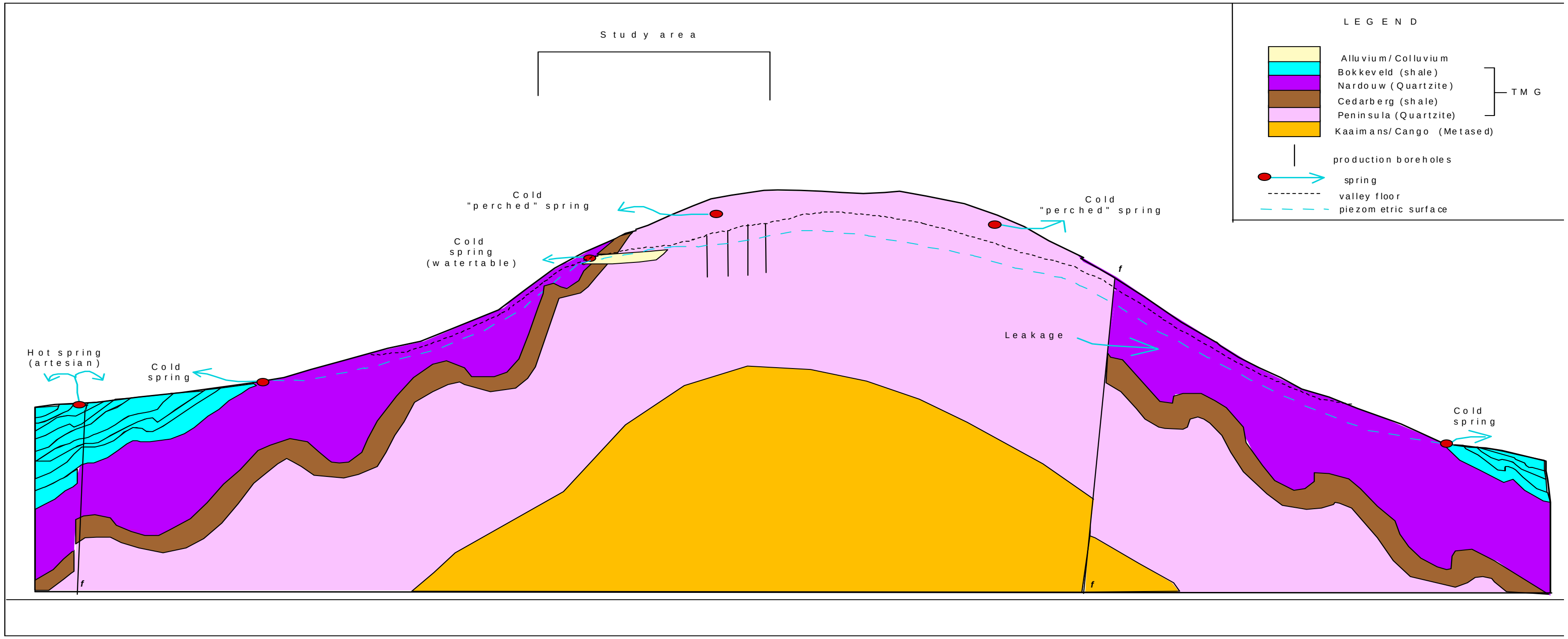


Figure 2.9: Typical spring localities in the Kammanassie area

2.1.5 Flora

According to Rebelo (1996) and Lubke (1996) the Kammanassie Mountain falls into the fynbos and thicket biome. Very small pockets of the forest biome are found in kloofs on the southern slopes (Lubke and McKenzie, 1996).

The vegetation types have been mapped and described on the basis of structure, floristic component and habitat characteristics, using the framework developed by Bond (1981). The following paragraphs are a brief summary of results taken from the Management Plan for the Kammanassie Mountain Catchment Area (Southwood, Van der Walt and Marshall, 1991) Figure 2.10. Plant taxon names used here are those used by the authors. Recent name changes have not been into account.

2.1.5.1 Fynbos biome

Mountain fynbos (64)

A: H1 Crest community

This community occurs on steep rocky slopes, peaks and ridges. It occurs above an altitudinal line of approximately 1700 m on southern aspects and 1800 m on northern aspects. Soils are generally shallow. There is a high percentage of surface rock, with the plants growing in cracks and between large stones. These sites are exposed to regular strong winds and snow in winter.

Members of the Ericaceae and other small-leafed shrubs are common. Ground proteas, e.g. *Protea venusta*, endemic to high mountain peaks are restricted to this community. There is a concentration of rare, localised plant species within this community. These species have small, disjointed distributions, possibly the remains of a cooler climate. Diagnostic species for this community include:

- **Proteaceae**: *Protea venusta*, *P. scolopendriifolia*, *P. pruinosa*.
- **Other shrubs**: *Metalasia strictifolia*, *Stoebe plumosa*
- **Restionaceae**: *Hypodiscus synchroolepis*, *Elegia filacea*.

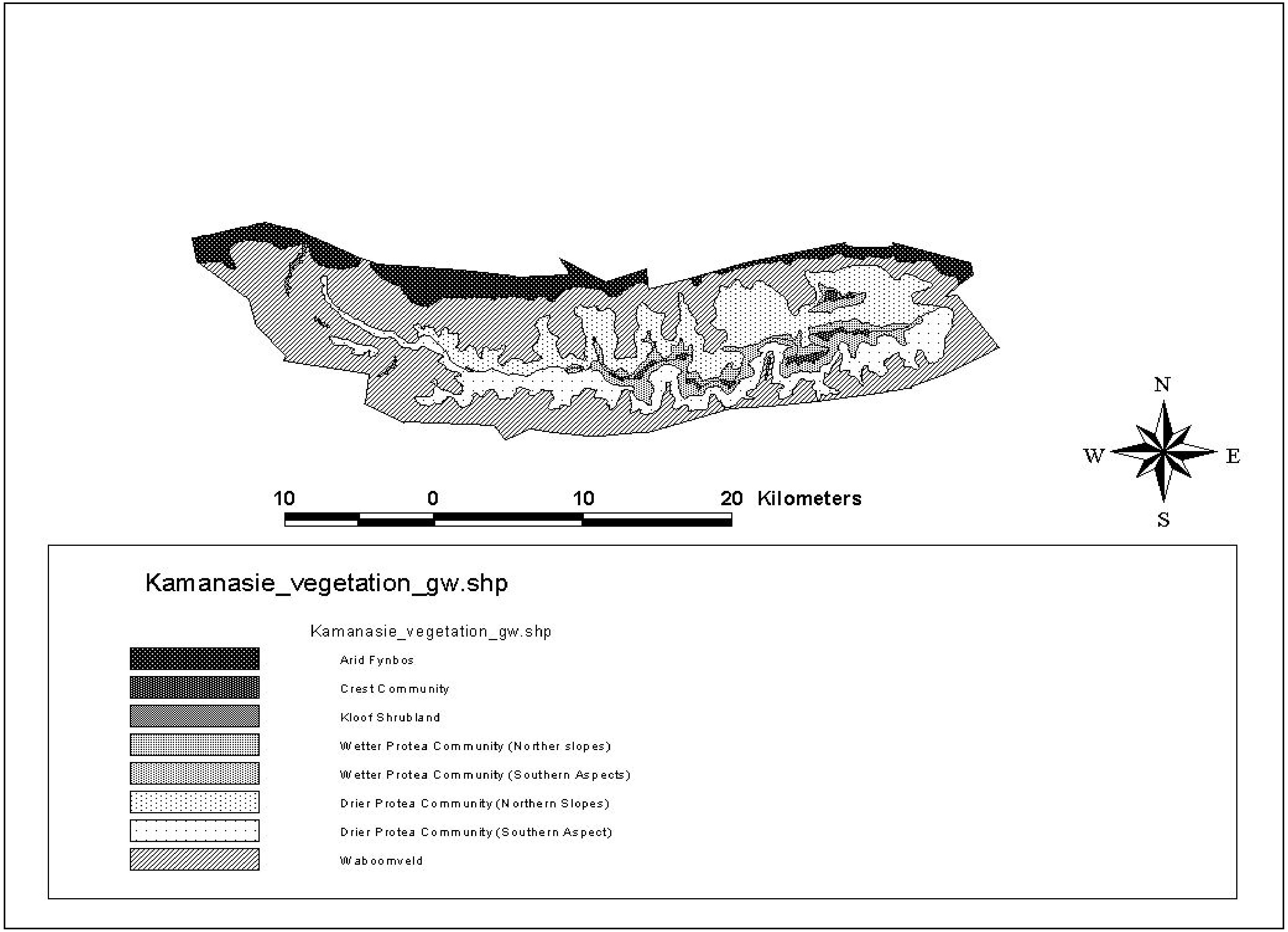


Figure 2.10: Vegetation units of the Kammanassie Nature Reserve according to Southwood *et al*. (1991)

B: P1(S) Wetter Protea Community (Southern Aspects)

This community occurs on the steep southern slopes at an altitude of between 1400 - 1800 m. The soils are relatively deep with a dark A horizon.

The crown layer is characterised by *Protea punctata*, 1,0 – 1,5 m tall. The density of this layer varies from place to place depending on the soil depth and possibly fire history. The lower layers are rich with Ericaceae and other ericoid components. Structurally the community can be described as relatively tall, mid-dense to dense Proteoid veld, with a low-to-medium tall, mid-dense ericoid under-story. Common species found are:

- **Proteaceae**: *Protea punctata*, *P. eximia*, *P. scolopendriifolia*, *Leucadendron album, L*. *spissifolium*.
- **Shrubs**: *Erica setacea*, *E. glomiflora*, *E. cerinthoides*, *Stoebe plumosa*, *Metalasia muricata, Agathosma capensis*.

C: P2(S) Drier Protea Community (Southern Aspects)

This community occurs on medium steep to steep southern slopes at altitudes ranging between 1100-1400 m. At lower altitudes this community is replaced by Waboomveld, particularly on talus slopes and on east and west facing slopes. The soils are generally shallow to relatively deep and stony.

This is a medium to tall (1.5–2.5 m) mid-dense to dense Protea shrubland, with an open erica-restio under-story. The restios are more visually dominant in this community type than in P (S). This plant community is characterised by the following species:

- **Proteaceae**: *Protea repens*, *P. eximia*, *P.neriifolia*, *P. punctata*, *Leucadendron album*, *L. rubrum.*
- **Other shrubs**: *Cliffortia ilicifolia*, *Agathosma recurvifolia*, *Muraltia alopecuroides*, *Agathosma ovata*, *Erica melanthera*, *E. speciosa*, *Agathosma pungens*, *Passerina obtusifolia.*
- **Restionaceae**: *Hypodiscus alboaristatus*, *Elegia vaginulata*, *Staberoha distachya*, *Cannomios scirpoides.*

D: P1(N) Wetter Protea Community (Northern Slopes)

This community occurs on steep, rocky, northern aspects above 1700 m. *Protea scolopendriifolium* and *Leucadendron album* occur as the upper story proteoid element. The height varies between 1.0 and 1.5 m. The Proteas are more scattered than in P (S). The community can be distinguished from P (S) in that it has a lower under story and fewer shrub species. It can be differentiated from P2 (N) in that it has a relatively prominent under story of grasses and restios. The structure can be described as medium tall, mid-dense Proteoid veld, with an ericoid under story. Where Proteas are absent there is a short to mid-tall, open grassy ericoid veld.

E: P2(N) Drier Protea Community (Northern Slopes)

Habitat is steep rocky northern slopes (1400 – 1800 m above sea level). Sparse widely spread proteas, with tall restios (1m). These tall restios distinguish the P2 (N) community from the arid fynbos, in the absence of the Proteoid element.

- **Proteaceae**: *Protea lorifolia, P. repens, P. eximia, Leucospermum wittebergense, Leucadendron salignum.*
  The Protea species vary according to the altitude and moisture gradient.
- **Shrubs**: *Disparago ericoides, Syncarpha paniculata, Agathosma mundii, Agathsma capensis, Passerina obtusifolia.*
- **Restionaceae**: *Cannomois scirpoides, Willdenowia teres, Hypodiscus striatus, Thamnochortus cirerens.*

F: Waboomveld

This veld type occurs mainly on the lower foothills of the southern slopes, particularly on the eastern and western aspects of the kloofs. The soils usually have a higher clay fraction than higher lying areas and are usually higher in nutrients. This is the predominant veld type on the northern slopes, changing into arid fynbos near the foot of the mountain.

The unifying element of this veld type is the presence of waboom (*Protea nitida*) scattered throughout. At the upper, wetter boundary the structure is medium-high, open ericoid veld with a proteoid and restioid element. At the lower, drier boundary species from the arid fynbos community, particularly the Asteraceae and Poaceae become more dominant.

Species vary greatly over the range of this veld type, depending upon the various local conditions such as climate, slope, soils and aspect. Characteristic species include:

- **Proteaceae**: *Protea nitida* (dominant), *P. eximia, P. lorifolia, P. repens, Leucadendron salignum*. The latter species occur in localised patches.
- **Other shrubs**: *Phylica paniculata, Passerina obtusifolia, Felicia filifolia, Dodonaea angustifolia, Aloe ferox, Maytenus oleoides, Cliffortia stricta, Rhus lucida, Elytropappus rhinocerotis.*
- **Restionaceae**: *Ischyrolepis gaudichaudiana*
- **Sedges and grasses**: *Cymbopogon marginatus, Ehrharta ramosa, E. bulbosa, Themeda triandra, Merxmuellera stricta, Ficinia nigrescens*.

G: Kloof shrubland

This community occurs in some of the kloofs, often forming a thin, narrow belt along rivers where the topography provides some protection from fires.

Small trees, 3-5 m high, form the upper mid-dense canopy. *Acacia karroo* is often visually dominant. Common species are:

- **Trees and shrubs**: *Acacia karroo, Tarchonanthus camphoratus, Rhus lucida, R. glauca, Osyris compressa, Psoralea pinnata, Chrysanthemoides monilifera, Nymania capensis, Dodonaea angustifolia, Cliffortia ruscifolia*.
- **Rare species**: *Lachnostylis bilocularis* and *Pelargonium pseudoglutinosum*.

South and south-west coast Renosterveld (63)

A: Arid fynbos

Arid fynbos occurs on the lower foothills of the northern slopes.

This is a low, sparse to medium dense ericoid/restioid veld. The grass cover is generally low, but with local patches where *Merxmuellera arundinaceae* is common.

Renosterbos veld dominated by *Elytropappus rhinocerotis*, occurs at the transition between arid fynbos and Karoo veld. Diagnostic species include:

- **Proteaceae**: *Leucadendron salignum, Protea lorifolia, Leucospermum wittebergense*.
- **Other shrubs**: *Phylica axillaris, Maytenus oleoides, Clutia polifolia, Euclea undulata, Elytropappus rhinocerotis, Passerina obtusifolia, Felicia filifolia, Aspalathus hystrix.*
- **Restionaceae**: *Ischyrolepis gaudichaudina, Thamnochortus cirerens, Hypodiscus striatus*.
- **Sedges and grasses**: *Merxmuellera stricta, M. arundinacea*.
- **Succulents**: *Crassula* and *Ruschia* species are common.

2.1.5.2 Thicket biome

Spekboom succulent thicket (8)

Spekboom is typical of lower, dry north-facing slopes. The soils are shallow and may be derived from sandstone or shale.

This community consists predominantly of *Portulacaria afra* (1,2–1,5 m) and *Rhigosum obovatum*. Smaller trees in this community area include: *Maytenus heterophylla*, *Carrissa bispinosa*, *Rhus glauca*, *Euclea undulata* and *Pappea capensis*. The following shrubs occur in this community: *Pteronia fascicularis, P. incana, Euphorbia mauitanica, Galenia africana, Montinia caryphyllacea, Zygophyllum* sp. and *Nymania capensis.* Succulents are common in the community with *Crassula rupestris* and *Cotyledon orbiculata* particularly abundant. Other members of the Crassulaceae and Mesembryanthemaceae are also frequent.

2.1.5.3 Forest biome

Afromontane forest (2)

Small patches of indigenous Afromontane forest (Acocks' Veld Type 4) occur in deep ravines on the south and upper north-facing slopes of the Kammanassie mountains. These forests remain in the deep ravines where they are protected against regular fires and there is a relatively constant water flow.

This community consists of a broken canopy layer (12–20 m high) and a shrub layer. The most common species are the trees: *Kiggelaria africana*, *Ilex mitis Pterocelastrus rostratus* and *Olea africana.* The following shrubs form a sub-canopy: *Halleria lucida*, *Brachylaena nerifolia*, *Rhus lucida*, *Buddleia salviifolia*, *Psoralea pinnata*, *Freylina lanceolata* and *Euclea polyandra*. Shrubs such as *Rapanea melanophloeos* and *Maytenus acuminata* occasionally occur in this community.

2.1.6 Fauna

There is a population of 38 endangered Cape Mountain Zebra (*Equus zebra zebra*) on the Reserve (Cleaver, 2002). Small populations of klipspringer, grey rhebuck, common duiker, grysbuck, kudu, mountain reedbuck and chacma baboon also occur on the Reserve. Leopards frequent the mountain but are seldom seen.

A total of 66 bird species have been recorded (Cleaver, 2002). Raptors such as the black eagle and jackal buzzard are common.

Butterflies are abundant and 46 species have been recorded (Cleaver, 2002). The recently discovered Kammanassie Blue (*Orachrysops brinkmani*) belongs to the same genus as the endagered Brenton Blue and Karkloof Blue.

The endangered slender redfin (*Pseudobarbus tenus*) is found in most rivers around the Kammanassie Mountain, including the Vermaaks, Marnewicks and Buffelsklip Rivers. Other indigenous fish species found in rivers around the Kammanassie mountain include: Cape Galaxis (*Galaxias zebratus)* and Cape Kurper (*Sandelia capensis*). Frogs found on the Kammanassie Mountain include: Common river frog (*Rana angolensis*), Cape river frog (*Rana fuscigula),* Clicking stream frog (*Strongylopus grayii grayii* and *Strongylopus grayii*), Ghost frog (*Heleophryne* species), Karoo toad (*Bufo gariepensis*), Raucous toad (*Bufo rangeri*), Sand toad (*Bufo angusticeps*), Tradouw's Mountain toad (*Capensibufo tradouwi*) and Bronze caco (*Cocosternum nanum nanum*). The River crab (*Potamonautes sidneyi and Potamonautes perlatus*) occurs frequently in river around the Kammanassie Mountain.

2.2 VERMAAKS RIVER

A total of three experimental sites (Figure 2.11) were selected to fall within the Vermaaks River Valley, where large-scale groundwater abstraction is currently taking place. Figure 4.3 provides a conceptual diagram of the geohydrology along the Valley.

2.2.1 Locality

The Vermaaks River Valley is situated on the most western section of the Kammanassie Nature Reserve (Figure 2.11). The phytosociology study of the Vermaaks River Valley falls within the area marked in black in Figure 2.11.

Site 1: Vermaaks 1 (33°36'42.9"S and 22°32'43.4"E)

Vermaaks 1 experimental site is situated at the WCNCB gate in the Vermaaks River. The Klein Karoo Rural Water Supply Scheme (KKRWSS) pumphouse VR6 is situated within this study site (Figure 4.3). According to figures obtained from KKRWSS monthly reports, 257 457 kilolitre of groundwater are abstracted from borehole VR6 annually.

Site 2: Vermaaks 2 (33°36'11.2"S and 22°31'56.2"E)

Vermaaks 2 experimental site is at the spring (number Kamm/w/009), that dried up during August/September 1999 (Figure 4.3). 1999. Three monitoring boreholes are situated within this site. The automatic weather station is also located at this site.

Site 3: Vermaaks 3 (33°35'21.6"S and 22°31'42.2"E)

This site is situated between the Vermaaks River weir and Site 2. Spring number Kamm/w/051 is located within this site (Figure 4.3). This spring dried up in December 2001 after the Department of Water Affairs and Forestry drilled a monitoring hole 200 m below this spring in November 2001. Flow returned 6 months later once the borehole had been effectively sealed.

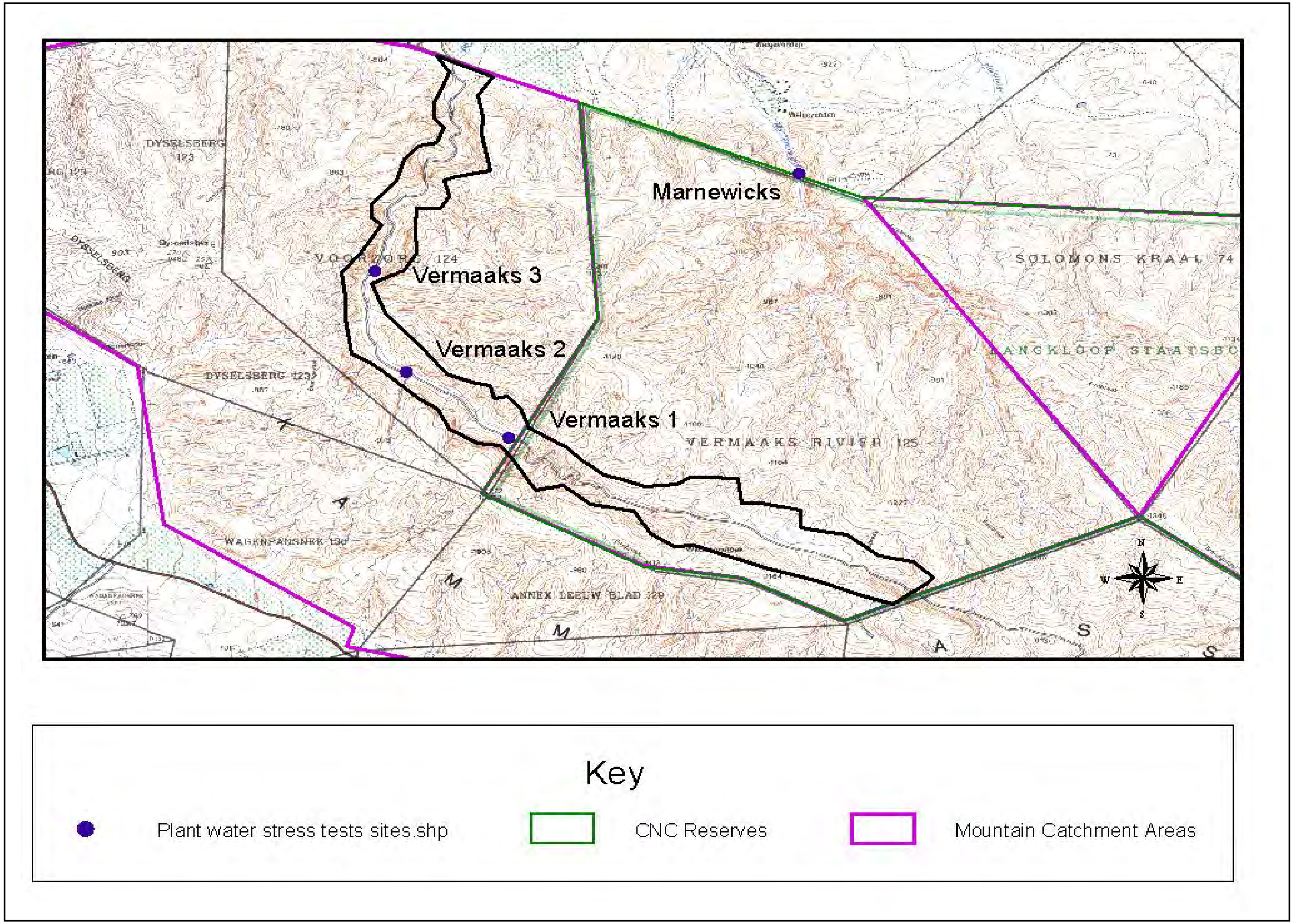


Figure 2.11: The study area for the vegetation surveys and plant water stress tests

2.2.2 Climate

The warmest months are November-February with temperatures reaching 37°C and the coolest months are from May to August with minimum temperatures ranging between –5 to +4ºC. Average rainfall is 461 mm per annum (Figure 2.12).

2.2.3 Geohydrology, geomorphology and soils

See section 2.1.4.

At site 1 there is a 16 m thick unconsolidated valley fill consisting of quartzite boulders set in a clayey sand matrix. This is underlain by fractured Peninsula formation bedrock. No permanent surface water occurs naturally at this site. The 1989 groundwater level (unimpacted) was 34 metres below surface (Mulder,1995). By 2001 the groundwater level, as a result of abstraction, had dropped to 60 m below surface at this site.

At site 2 the geology the alluvium/colluvim is 20m thick and is also underlain by Peninsula formation. The Cedarberg formation shale sub outcrops in the palaeovalley within 100m down gradient of this site. Prior to abstraction the groundwater level at this site was at surface where spring 009 emanated in the river course. The depth to groundwater level across the remainder of the site varies as a result of topography, and was probably 5 metres below surface at some localities before abstraction took place. A detailed description of the drying up of the spring at this site is given in section 4.3.3. The groundwater level is unlikely to have been impacted significantly until mid 1998. Subsequently the groundwater level across the site gradually dropped by approximately 3 metres.

At site 3 the alluvium/colluvium is also 20 m thick but is underlain in this instance by fractured Nardouw bedrock. The groundwater level is shallow, discharging in the river course at spring 051. The groundwater level may be 4 m below surface at some localities on this site, depending on topography. Impacts of abstraction on groundwater levels at this site are negligible, except for the period between December 2001 and June 2002 when a decline of 0.3 metres was recorded.

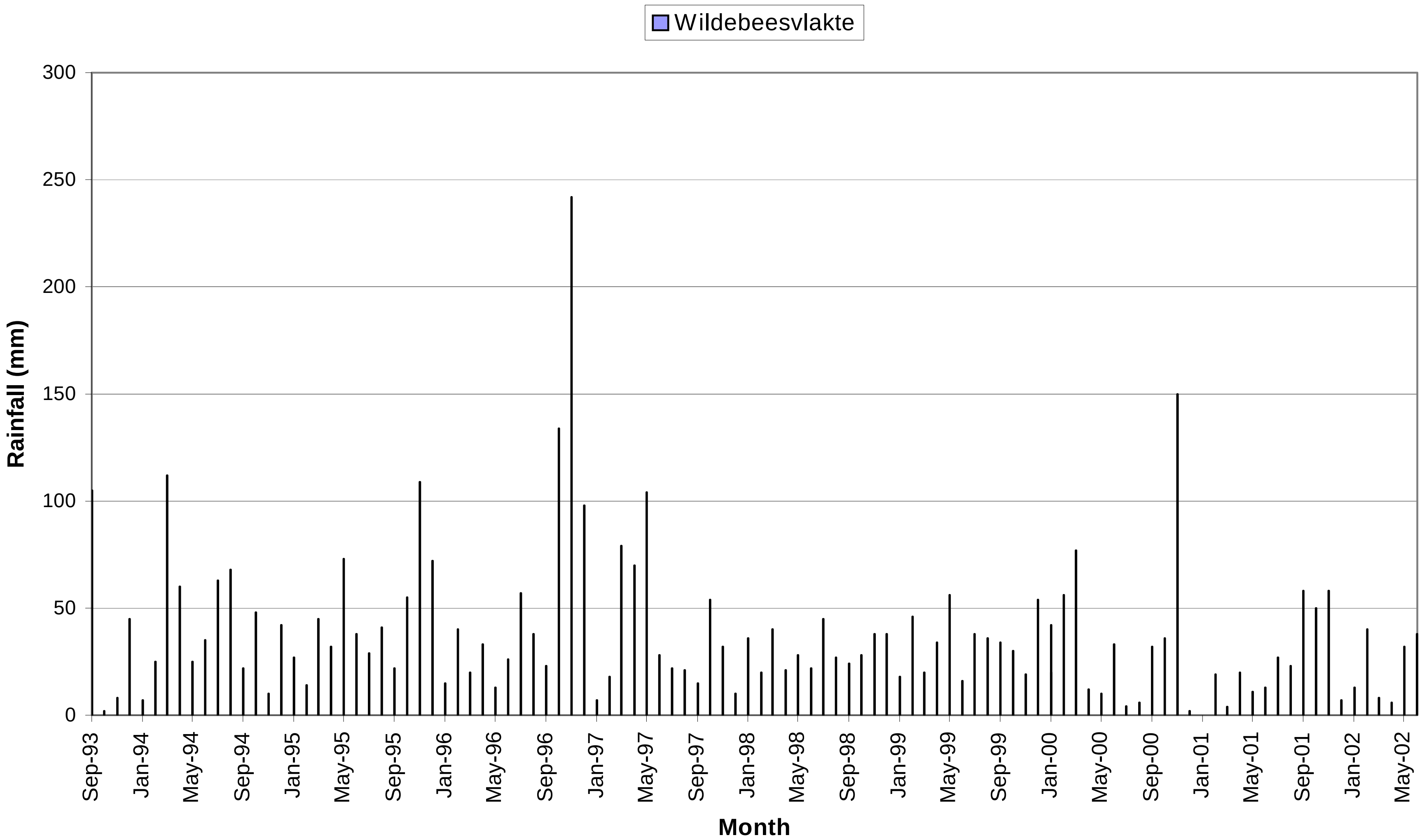


Figure 2.12: Rainfall for Vermaaks River Valley (Wildebeesvlakte : KKRWSS station)

2.2.4 Flora

According to Southwood *et al*. (1991), arid fynbos is found at the entrance to the Vermaaks River Kloof. The valley bottom is kloof shrubland. The slopes of the valley are waboomveld dominant. A small section of the Drier Protea community (southern aspects) is found in the upper most reaches of the Valley basin.

2.2.5 Fauna

A total of 12 Mountain Reedbuck were introduced in this area in 1979 (Cleaver, 2002). The population has remained very small, with less than 9 animals present today. Cape Mountain Zebra have recently started to utilise this area and drink water at the DWAF weir in the Vermaaks River Valley. Klipspringer, duiker, baboons and dassies are abundant while leopard spoor is frequently seen in this area. Porcupines have also been sighted in this area at night.

The endangered slender redfin (*Pseudobarbus tenus*) is found at the weir in the Vermaaks River Valley.

2.3 MARNEWICKS RIVER

2.3.1 Locality

Marnewicks River Valley was selected as a control site as no abstraction is taking place in this area. Marnewicks River (33°34'33.8"S and 22°34'57.0"E) is not far from the Vermaaks River Valley (Figure 2.11).

2.3.2 Climate

The rainfall and temperature for this site is similar to Vermaaks River, Wildebeesvlakte weather station (Figure 2.12).

2.3.3 Geology, geomorphology and soils

See section 2.1.4.

The geology and hydrogeology is similar to the sites in the Vermaaks river valley. It is alluvium/colluvium filled valley - these unconsolidated sediments being 12 metres thick. Nardouw fractured rock aquifer (Baviaanskloof formation) occurs beneath the alluvium. The groundwater level across this site varies from being at surface along the Marnewicks river to approximately 5 metres below surface depending on the topographic height above river level. The groundwater level measured in a borehole on this site during the course of this study varied between 0.132 meters and 2.205 metres below surface.

2.3.4 Flora

Arid fynbos is found at the entrance to the Marnewicks River Valley, with waboom veld on the valley slopes. In the plant community kloof shrubland is dominant in the river valley (Southwood *et al*.,1991).

2.3.5 Fauna

Klipspringer, duiker and baboons are common. No Cape Mountain Zebra utilise this area. Evidence of porcupine and bush pig, in the form of spoor and droppings, has been found.

The endangered slender redfin fish (*Pseudobarbus tenus*) is found at the weir in the Marnewicks River Valley. Common River frog (*Rana angolensis*) is abundant.

2.4 BUFFELSKLIP

2.4.1 Locality

The Buffelsklip River Valley is situated 38 km from Uniondale on the Hoeplaas-Snyberg road and falls within the Buffelsberg Forest Reserve 61 section of the Kammanassie Nature Reserve (Figure 2.11). The co-ordinates for this site are 33°34’07”S and 22°53’28”E.

Although no groundwater abstraction is taking place, a large amount of surface water is abstracted for agricultural purposes. All stream flow of the Buffelsklip River is channelled into a furrow, 2 km from the Kammanassie Nature Reserve boundary fence. It is transferred into a pipeline when it leaves the reserve and is utilised by 6 individual landowners on a rotational basis.

2.4.2 Climate

Buffelsklip is an arid area with an average annual rainfall of 281 mm (Figure 2.13).
Summer temperatures can reach up to 50°C in February. The warmest months are October to April with an average maximum temperature of 40°C and minimum of 8°C in the summer months. The coldest months are June and July with an average maximum temperature of 20°C and minimum of 0°C.

2.4.3 Geology, geomorphology and soils

The Buffelsklip control site is situated on the contact between the Bokkeveld formation and the Baviaanskloof formation (feldspathic sandstone) of the Table Mountain Group. South of the Baviaanskloof formation is the Kouga formation (quartz sandstone), also the Table Mountain Group. The topography of this site is fairly steep and hence the groundwater level varies substantially across the site. During the study period groundwater is at surface at the stream course and varied between 9.866 and 13.57 meters below surface in a monitoring borehole situated 87metres from the stream.

2.4.4 Flora

According to Southwood *et al*. (1991), the three dominant vegetation types are found at Buffelsklip are:

- Succulent spekboom thicket which is dominated by spekboom (*Portulacaria afra).*
- Common mountain fynbos species such as the shrubs *Dodonaea angustifolia and Nymania capensis*, the grass *Themedra trianda* and *Crassula* species.
- Afro-montane forest species that include *Acacia karroo*, *Ficus burtt-davyi, Rhus glauca* and *Osyris compressa*.

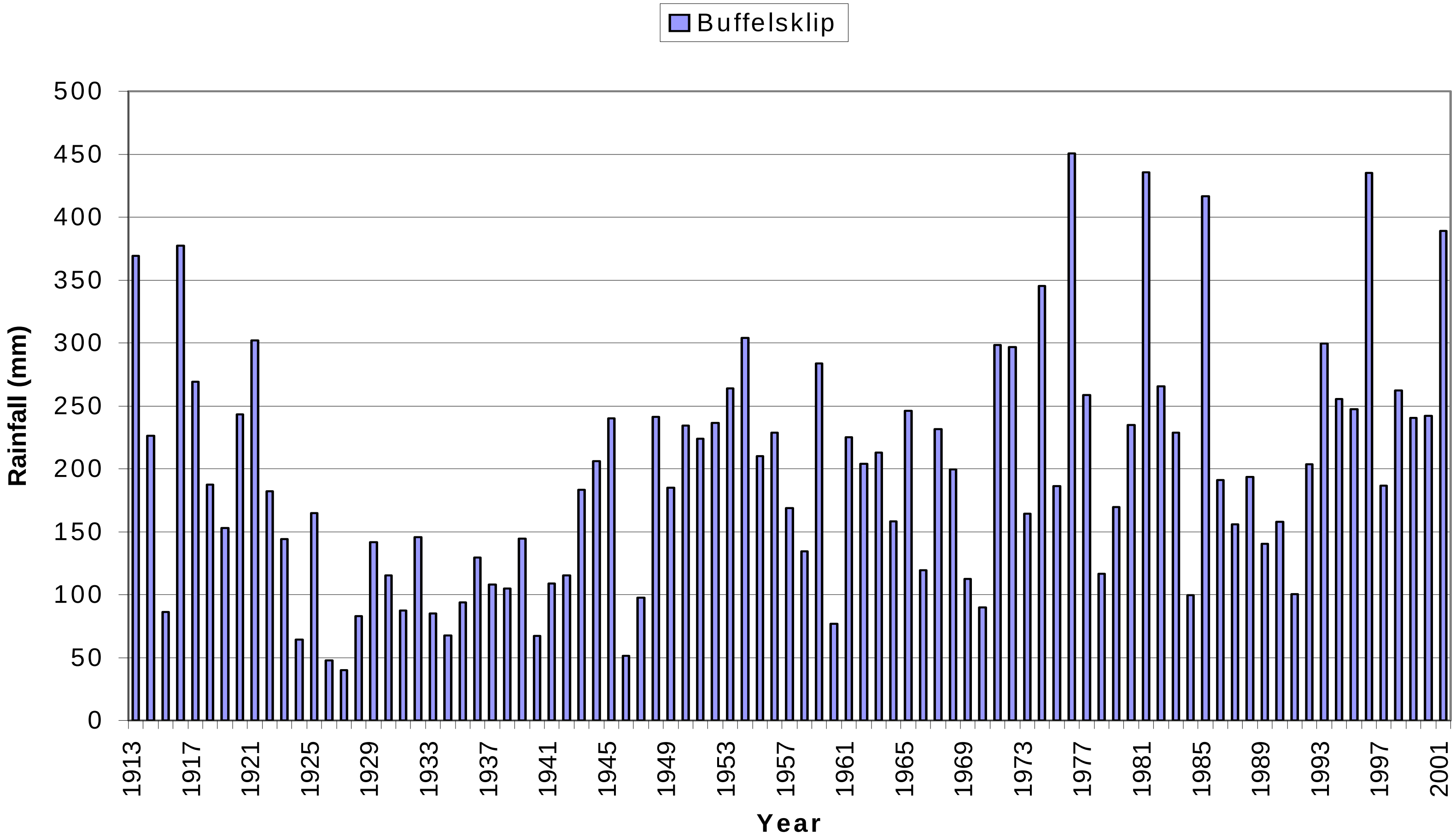


Figure 2.13: Rainfall for Buffelsklip (1913-2001)

2.4.5 Fauna

Species in this area include Chacma baboons, klipspringer, common duiker, grysbuck, steenbok, Cape clawless otter, porcupines, rock dassies, scrub hare and bushpig.

A large population of the endangered slender redfin (*Pseudobarbus tenus*) is present above the furrow. Common River frog (*Rana angolensis*), Clicking Stream frog (*Strongylopus grayii grayii*), Karoo toad (*Bufo gariepensis*) and Brown River crabs (*Potamonautes sidneyi*) are abundant.

CHAPTER 3

SPATIAL AND TEMPORAL RAINFALL VARIABILITY AND TRENDS IN THE LITTLE KAROO REGION

3.1 INTRODUCTION

Known as a semi-arid region, the Little Karoo is surrounded by some of the highest mountains found in South Africa. To the south, the Outeniqua Mountains forms a barrier between the Little Karoo and a relatively narrow coastal plain. The northern boundary of the Little Karoo is formed by the gigantic Swartberg, which separates the region from the rest of the country. Oudtshoorn is generally regarded as the "capital" of the Little Karoo, and can be found in an area of lower altitude (33.58^o South; 22.20^o East and indicated by a circle in figure 3.1). The domain selected for the study in this chapter extends from 33^o to 34^o South and 22^o to 24^o East (figure 3.1). In the report more emphasis is placed on the Kammanassie Mountain area that is located in the Little Karoo between the Swartberg and Outeniqua Mountain at a longitude of approximately 22.8^o East (box in figure 3.1).

Concern has been expressed amongst farmers in the Kammanassie Mountain area about a noticeable drop in the level of the water table and declining surface flow during the past few years. This chapter aims to determine whether the latter may be attributed to either long-term trends in the historical rainfall record or unusually long dry episodes that might have occurred more recently in the rainfall variability record of the Little Karoo.

Rugged terrain in the region under investigation (figure 3.1) might lead to complex mesoscale atmospheric flow patterns that will enhance the spatial variability of rainfall. Local convection caused by topographic lifting with adequate atmospheric moisture will certainly contribute to the development of rain producing clouds, implying that the spatial extend of rain strongly depends upon the direction of moisture flux governed by various types of synoptic scale systems. Under these conditions the application of rainfall-topography relationships might yield unreliable results. One must therefore be cautious to use conventional algorithm to interpolate rainfall values for regions that contain no rainfall observations. Station data, rather than interpolated grid field data, are therefore considered in the rainfall variability analyses.

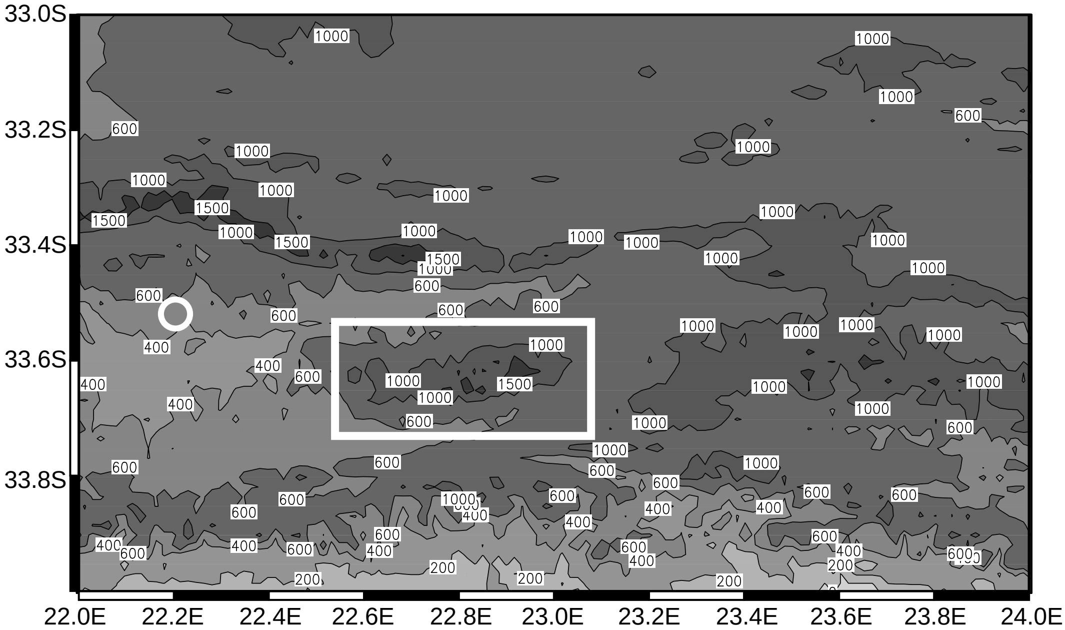


Figure 3.1: The region (33^{o} to 34^{o}South and 22^{o} to 24^{o}East) selected to perform the Little Karoo rainfall analysis. Contours are in meters above mean sea level. The circle and box represents the location of Oudtshoorn and the Kammanassie Mountain area. respectively.

Spatial rainfall variability might also change with season, since diverse synoptic scale circulation patterns contribute to rainfall over the Little Karoo during summer and winter months. Winter rainfall is usually formed by means of postfrontal convection when cold air masses (fronts) sweep over the southern parts of South Africa. During the eastward propagation of a frontal cyclone winds over the Little Karoo might vary from southwesterly to northeasterly winds. Even summer rainfall might be influenced by mid-latitude frontal systems that propagate eastwards and is normally followed from behind by denser air masses with higher pressures. The latter phenomenon is more commonly revere to as the Atlantic High that ridges in to the south of the country. Such a system of anti-cyclonic circulation will result in an onshore flow of moisture along the southern coastline, which might intrude the Little Karoo from the southern ocean to form rainfall. Summer rain might also emanate from continental convection caused by surface and upper air troughs over the interior. Moist tropical air masses link up with higher latitude systems causing a northwesterly flow over the Little Karoo.

The monthly rainfall climate of the Little Karoo exhibits no distinctive bimodal seasonal cycle (figure 3.3), although rainfall totals decrease somewhat during the mid-winter and mid-summer months. A 75-year rainfall record of Hoekplaas (location indicated by a triangle in figure 3.6) is examined to determine how rainfall varied over the past few decades.

Four seasons have been considered in a shorter-term (30/31-years) regional rainfall variability analysis over the Little Karoo and adjacent region, namely December-January-February (DJF), March-April-May (MAM), June-July-August (JJA) and September-October-November (SON). Observed rainfall and anomaly time series for the Kammanassie and Oudtshoorn areas have been investigated separately. Trends in the amplitude time series of the rainfall patterns are calculated to determine whether rainfall totals have declined or increased over a period of time.

3.2 RAINFALL CLIMATE

Three different long-term rainfall records were used to determine and confirm the climate of the monthly total rainfall for the Little Karoo region.

3.2.1 District rainfall (76 years)

Figure 3.2 depicts the standard 93 homogeneous South African rainfall districts as defined by the South African Weather Service (SAWS). District rainfall values from 1921 to 1996 (76 years) have been considered. The Little Karoo is located in district 10 (shaded domain in figure 3.2). The rainfall value allocated to each district represents the spatial average of rainfall station observations over that district.

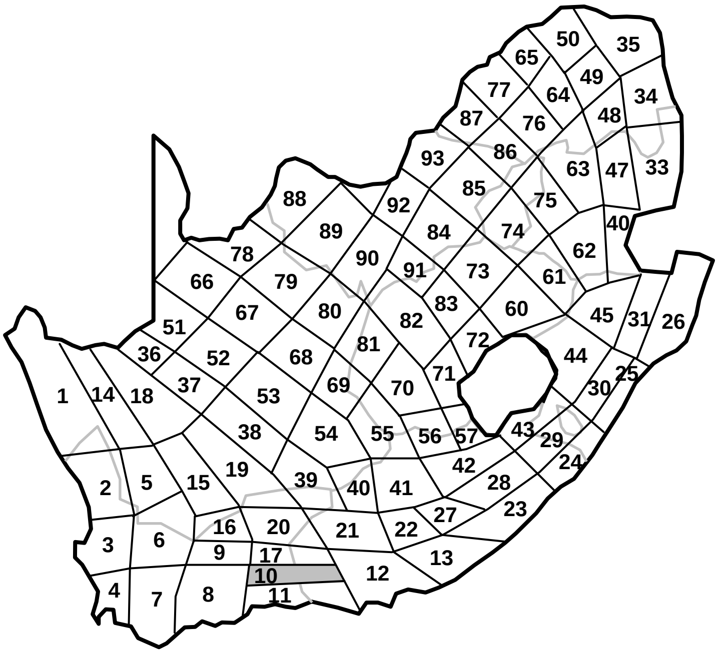


Figure 3.2: Homogeneous rainfall districts over South Africa as defined by the South African Weather Service (SAWS). The Little Karoo is located in district 10 (shaded)

3.2.2 Ensemble of station data (31 years)

The average of monthly total rainfall data over the Little Karoo region (figure 3.1) for the period 1971 to 2001 (31 years) has been acquired from the Agriculture Research Council - Institute of Soil Climate and Water (ARC-ISCW) Agromet databank (data includes SAWS and ISCW records). A total of 31 stations (listed in table 1 and depicted in figure 3.6) with monthly records over a period of 31 years have been identified. In the final selection of rainfall time periods for the different seasons, approximately 90% of the stations had complete records and the remainder had approximately 5% of the records missing. The long-term rainfall average from district 10 (figure 3.2) was used to replace missing values. The same data was used in the observed rainfall variability and TPA analysis discussed in sections 3.4 and 3.5, respectively. In section 3.4 the monthly climate over a period of 30/31 years (1971-2000/1) for the ensemble of stations 1, 3, 4, 10, 24 and 31 (Little Karoo in figure 3.6) were calculated.

3.2.3 Oudtshoorn record from the SAWS WB40 publication (41 years)

Point station observations over a period of 41 years (1926-1966) for Oudtshoorn alone as recorded in the SAWS WB40 publication have been used to compile the third and final monthly climate record. The SAWS WB40 is widely used in South Africa as a reference for station climate of different variables such as atmospheric temperature and moisture as well as rainfall.

3.2.4 Discussion

Figure 3.3 gives the monthly average rainfall over a period of 76 years (1921-1996) calculated for district 10 in figure 3.2 (black), over a period of 30 years (1971-2000) calculated for stations 1, 3, 4, 10, 24 and 31 in figure 3.6 (white) and over a period of 41 years (1926-1966) for Oudtshoorn alone (grey) as published in the SAWS WB40.

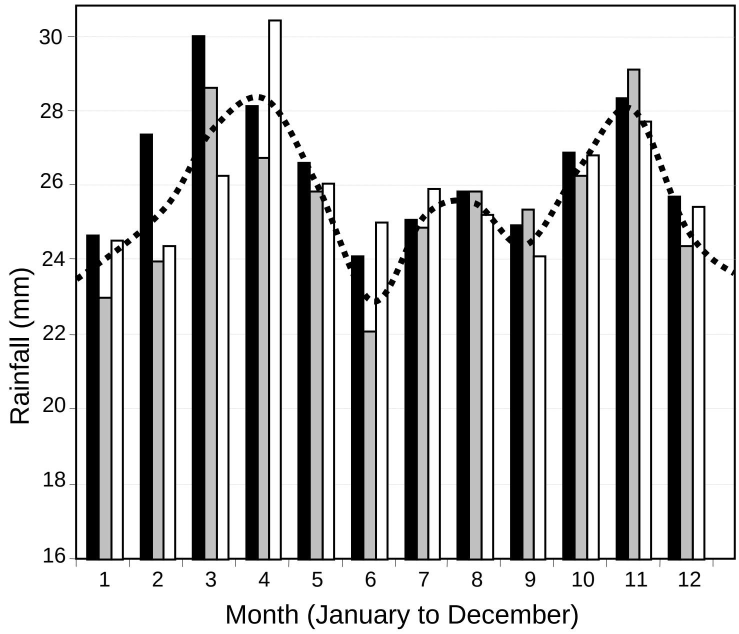


Figure 3.3: Monthly average rainfall over a period of 76 years (1921-1996) calculated for district 10 in figure 3.2 (black), over a period of 30 years (1971-2000) calculated for stations 1, 3, 4, 10, 24 and 31 in figure 3.6 (white) and over a period of 41 years (1926-1966) for Oudtshoorn (grey).

Figure 3.3 indicates that the Little Karoo region receives less than 31mm per month on average, which confirms why the region is regarded as a dry or semi-arid region. These conditions may result in limited water recourses. Although there is a slight increase in average rainfall for the months March, April and November (less than 10mm increase), and although it appears as if somewhat drier conditions prevail over the mid-summer and mid-winter months, the monthly rainfall climate of the Little Karoo exhibits no bimodal distinctive seasonal cycle. The annual average rainfall over the Little Karoo is in the order of 25mm.

3.3 HOEKPLAAS ANNUAL RAINFALL RECORD (1925-2000)

The rainfall record of Hoekplaas (33° 33' 03"S and 22° 58' 30" E and owned by I Barnard – unofficial site) is certainly one of the longest complete records available for the Little Karoo, and especially the Kammanassie Mountain area. The data record extends over a period of 75 years (1925-2000). The position of Hoekplaas is indicated by a triangle in figure 3.6.

Figure 3.4 illustrates annual rainfall totals measured in mm over the 75-year period. Linear regression indicates that the record contains a gradual positive trend in rainfall since 1925 with a slope of +0.6227. The high rainfall values measured in 1981, 1985 and 1996 is indicative of an increase in the amplitude of rainfall totals implying a increase in the magnitude of extreme rainfall events. These extreme events might have contributed to the positive trend present in the rainfall time series. In the more recent period drier conditions have been experienced during 1986 to 1992 (7 years) and 1997 to 2000 (4 years). According to the historical record these drier conditions with annual rainfall totals of less than 300mm are not unusual.

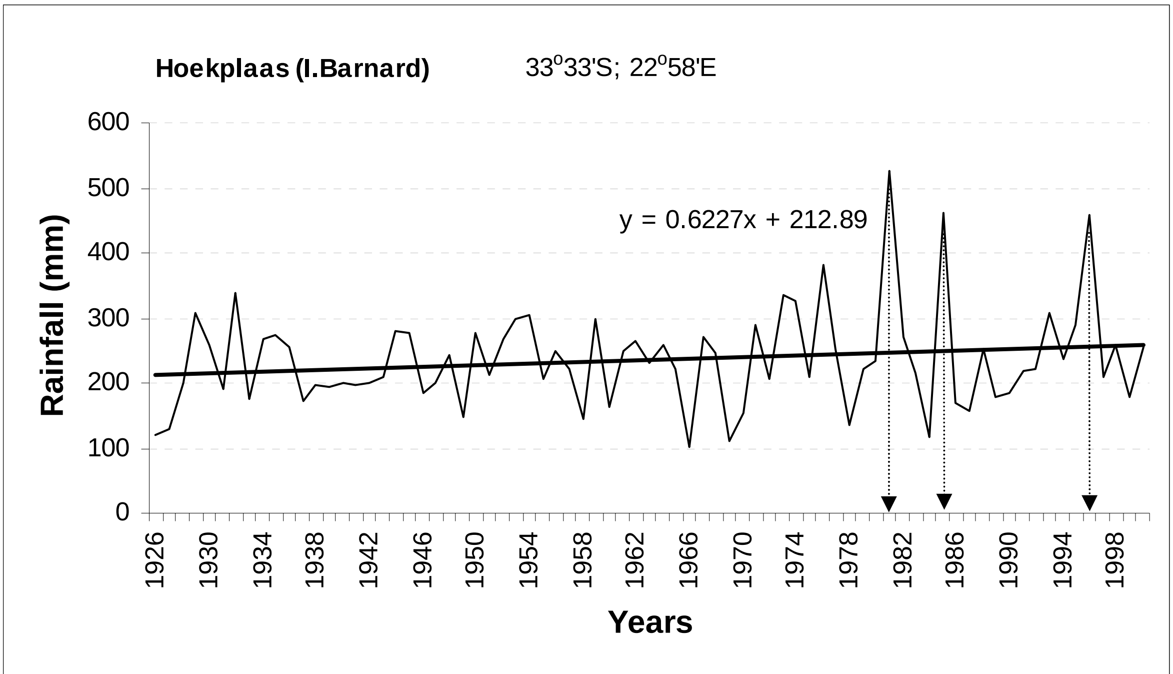


Figure 3.4: Annual rainfall totals for the period 1925-2000 (75 years) as recorded on the farm Hoekplaas in the Kammanassie Mountain area (thin line) and the long-term rainfall trend with a slope of +0.6227 (thick line). Note how the amplitude of rainfall increases over recent years.

Anomaly patterns could be an alternative measure to investigate rainfall trend. Of particular interest are accumulated anomalies, which give an excellent indication of rainfall trends. A sequence of positive anomalies added together will clearly exhibit a positive trend while a sequence of negative anomalies will give a negative trend. Rainfall anomalies calculated for the 75-year period at Hoekplaas, as well as accumulated anomalies are shown in figure 3.5. A 3rd order polynomial curve has been fitted through the accumulated anomaly time series. According to the curve a consistent positive trend appeared since 1970 in annual rainfall totals of Hoekplaas.

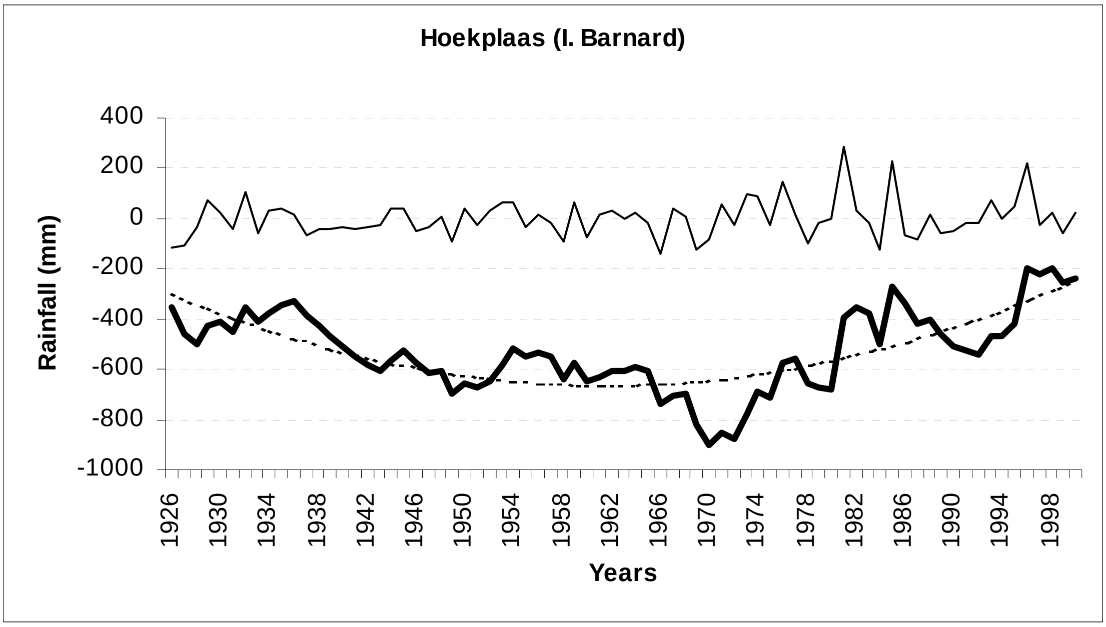


Figure 3.5: Anomalies of the annual rainfall totals for the period 1925-2000 (75 years) as recorded on the farm Hoekplaas in the Kammanassie Mountain area (thin solid line) as well as accumulated anomalies for the same period (thick solid line). The dotted line that depicts trends in the accumulated anomalies indicates a positive trend since 1970.

3.4 OBSERVED RAINFALL VARIABILITY ANALYSIS (30/31 years)

As mentioned in section 3.2.2, monthly rainfall totals over the Little Karoo region for the period 1971 to 2001 (31 years) has been acquired from the Agriculture Research Council - Institute of Soil Climate and Water (ARC-ISCW) Agromet databank. A total of 31 stations (listed in table 1 and depicted by circles in figure 3.6) with monthly records over a period of 30/31 years have been identified.

Rainfall time series are expressed in terms of 3-month averages to form four seasons over a period of one year. These seasons are defined as December-January-February (DJF), March-April-May (MAM), June-July-August (JJA) and September-October-November (SON). As indicated below, the final selection of rainfall time periods for the different seasons differs slightly in length:

DJF:	*Dec1970Jan1971Feb1971 to Dec2000Jan2001Feb2001*	(31 years)
MAM:	*Mar1971Apr1971May1971 to Mar2001Apr2001May2001*	(31 years)
JJA:	*Jun1971Jul1971Aug1971 to Jun2000Jul2000Aug2000*	(30 years)
SON:	*Sep1971Oct1971Nov1971 to Sep2000Oct2000Nov2000*	(30 years)

The analysis will focus on six selected rainfall stations over two areas (Oudtshoorn area and Kammanassie area) located in the Little Karoo region. These stations, according to numbers in Table 1, are:

OUDTSHOORN AREA		KAMMANASSIE AREA	
Station 1:	*Welbedag*	Station 10:	*Buffelsklip*
Station 3:	*Oudtshoorn*	Station 24:	*De Rust*
Station 4:	*Groot Doornrivier*	Station 31:	*Rooirivier*

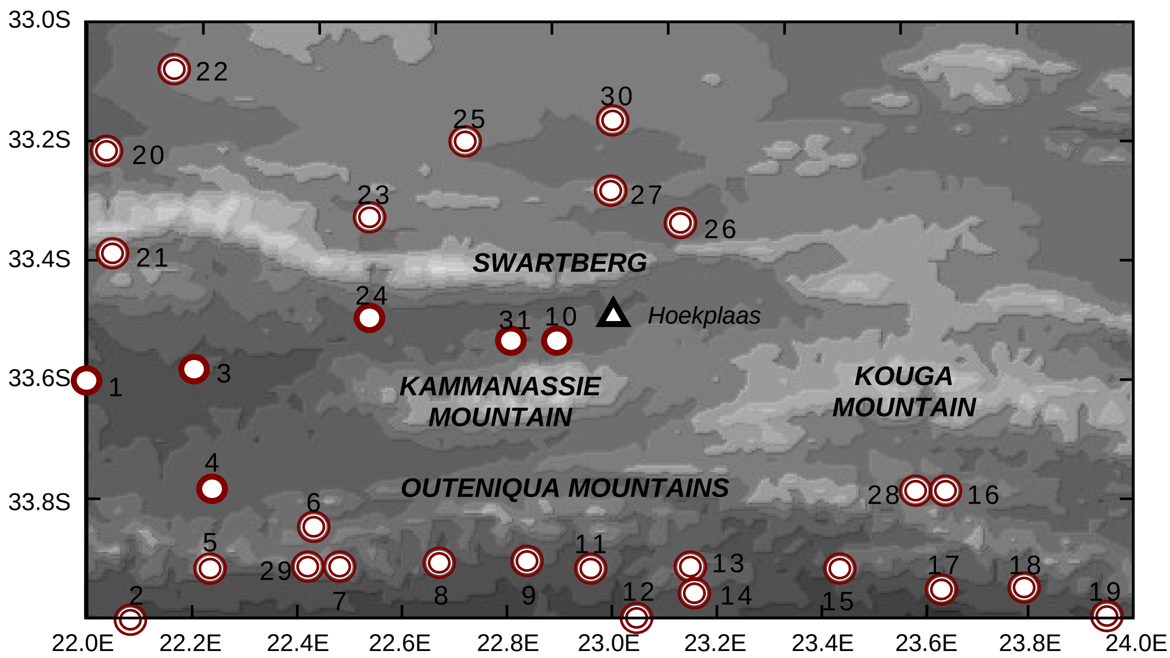


Figure 3.6: Geographical location of the 31 rainfall stations over the Little Karoo region. Stations with a rainfall record of 30/31-years have been considered to investigate rainfall variability (and trends) for the DJF, MAM, JJA and SON seasons. Stations in the Little Karoo have been defined as 1, 3, 4 (Oudtshoorn area) and 10, 24, 31 (Kammanassie area). The location of Hoekplaas is indicated by a triangle.

The spatial average of rainfall totals, anomalies as well as accumulated anomalies with the associated polynomial trend curves for the four seasons in the Oudtshoorn and Kammanassie areas are displayed in figures 3.7.1 to 3.7.16. Time series for the individual stations are also included in the rainfall total graphs (thin lines) to give an indication of the spread in rainfall measurements at the tree points from which the area averages were derived.

Table 3.1: **List of the 31 rainfall stations illustrated in figure 3.6 and used in the 30/31-year rainfall variability analysis**

	STATION NAME	LAT	LON	ALT	ST.NO.
1: 10381	WELBEDAG	-33.6	22	292	0027/876 0
2: 10385	KWEPERTUIN	-34	22.08	213	0028/150 4
3: 10388	OUDTSHOORN - TNK	-33.5833	22.2	332	0028/335 5
4: 10394	GROOT DOORNRIVIER	-33.7833	22.23	533	0028/407 5
5: 10395	JONKERSBERG - BOS	-33.9167	22.23	678	0028/415 9
6: 10406	HEROLD - POL	-33.85	22.43	711	0028/771 X
7: 10407	WITFONTEIN - BOS	-33.9167	22.43	610	0028/775 7
8: 10423	BERGPLAATS - BOS	-33.9	22.67	457	0029/294 5
9: 10433	KARATARA - BOS	-33.9	22.85	297	0029/624 7
10: 10436	BUFFELSKLIP	-33.5333	22.9	610	0029/692 4
11: 10437	GOUDVELD - BOS	-33.9167	22.95	396	0029/805 0
12: 10443	CONCORDIA - BOS	-34	23.05	259	0030/090 3
13: 10447	BUFFELSNEK - BOS	-33.9167	23.15	724	0030/265 7
14: 10449	DIEPWALLE – BOS	-33.95	23.17	519	0030/297 2
15: 10460	KEURBOOMSRIV - BOS	-33.9167	23.43	501	0030/775 5
16: 10465	BRUINKLIP	-33.7833	23.62	610	0031/197 0
17: 10466	BLOUKRANS - BOS	-33.95	23.63	243	0031/237 5
18: 10470	LOTTERING - BOS	-33.95	23.78	229	0031/507 8
19: 10478	BLUELILIESBUSH - BOS	-34	23.95	300	0031/810 7
20: 10706	PRINCE ALBERT - TNK	-33.2167	22.03	686	0048/043 2
21: 10710	MATJIESRIVIER - SKL	-33.3833	22.05	732	0048/083 1
22: 10712	ZACHARIASFONTEIN	-33.0833	22.17	815	0048/275 4
23: 10720	KLAARSTROOM - POL	-33.3333	22.53	732	0049/050 0
24: 10721	DE RUST - POL	-33.5	22.53	533	0049/060 8
25: 10729	RONDAWEL	-33.2	22.72	853	0049/372 3
26: 10747	TUINTJIESKRAAL	-33.3333	23.13	672	0050/230 4
27: 10758	WILLOWMORE – MUN	-33.2833	23.5	840	0050/887 2
28: 20021	LANGKLOOF (NIVV)	-33.7833	23.58	722	0031/137L0
29: 20023	OUTENIQUA (WRS)	-33.9167	22.42	361	0028/745L0
30: 20908	MOOREDALE	-33.1667	23.75	686	0051/430 7
31: 21022	ROOIRIVIER	-33.5333	22.82	564	0029/542 X

3.4.1 Variability of rainfall totals for the DJF season over the Oudtshoorn area

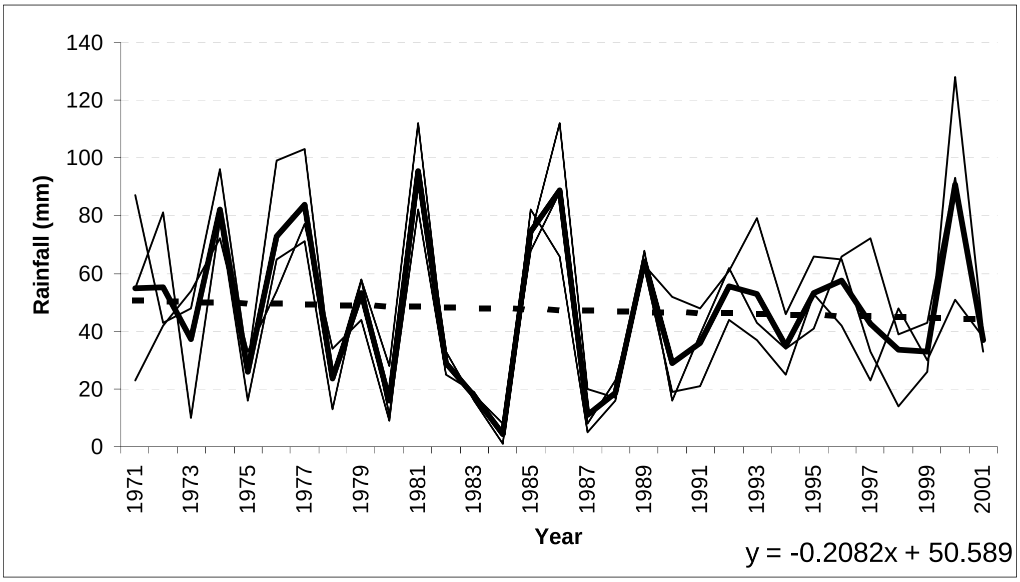


Figure 3.7.1: Rainfall time series for the Oudtshoorn area (DJF season) for stations 1, 3 and 4 (thin black lines). The thick black solid line represents the average for the stations with the associated linear regression line (dashed).

3.4.2 Rainfall anomalies for the DJF season over the Oudtshoorn area

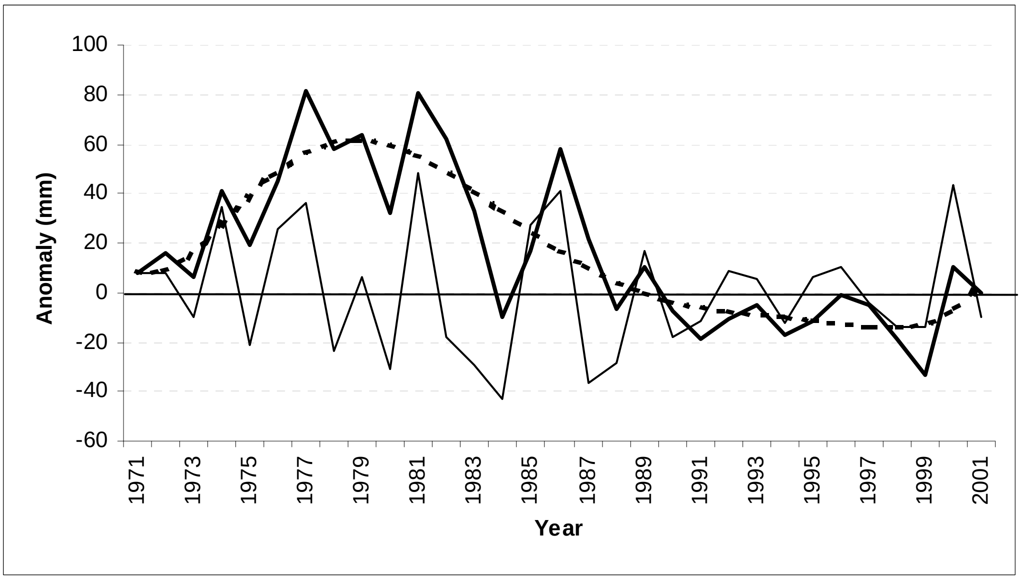


Figure 3.7.2: Rainfall anomalies for the Oudtshoorn area during the DJF season (thin black line). The accumulated anomalies are depicted by a thick black line with the associated polynomial fit (dashed line)

3.4.3 Variability of rainfall totals for the DJF season over the Kammanassie area

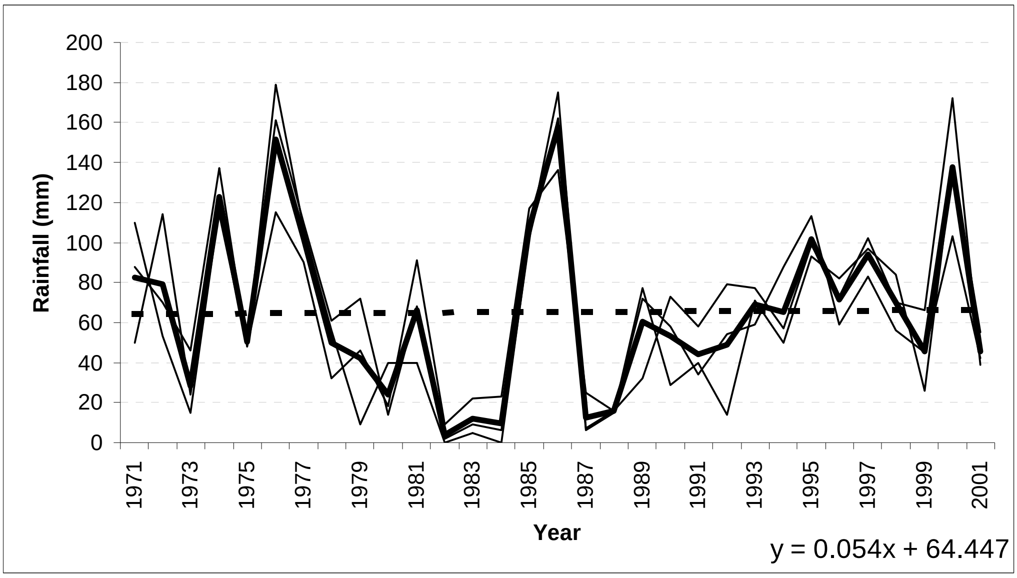


Figure 3.7.3: Rainfall time series for the Kammanassie area (DJF season) for stations 1, 3 and 4 (thin black lines). The thick black solid line represents the average for the stations with the associated linear regression line (dashed).

3.4.4 Rainfall anomalies for the DJF season over the Kammanassie area

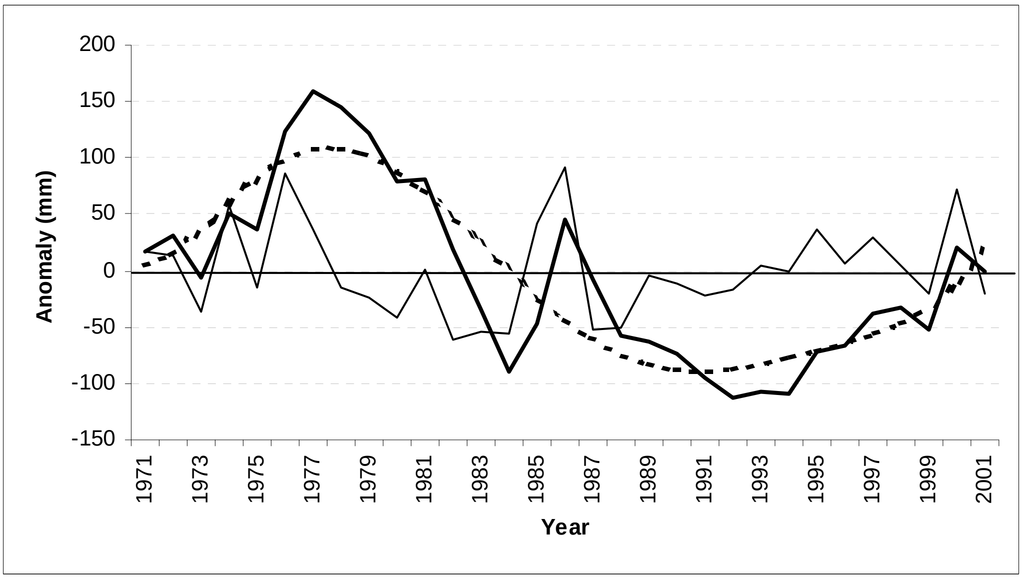


Figure 3.7.4: Rainfall anomalies for the Kammanassie area during the DJF season (thin black line). The accumulated anomalies are depicted by a thick black line with the associated polynomial fit (dashed line)

3.4.5 Variability of rainfall totals for the MAM season over the Oudtshoorn area

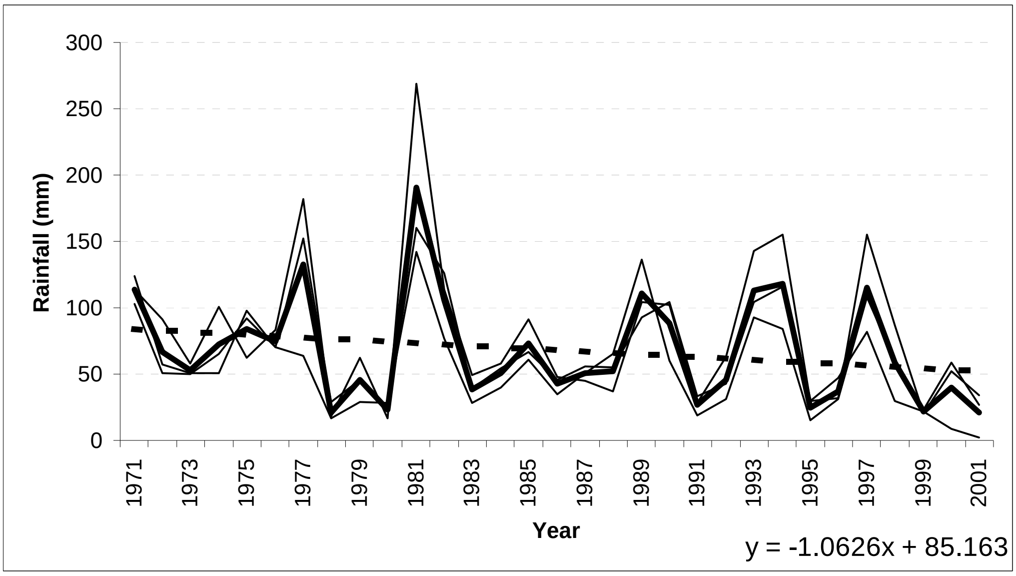


Figure 3.7.5: Rainfall time series for the Oudtshoorn area (MAM season) for stations 1, 3 and 4 (thin black lines). The thick black solid line represents the average for the stations with the associated linear regression line (dashed).

3.4.6 Rainfall anomalies for the MAM season over the Oudtshoorn area

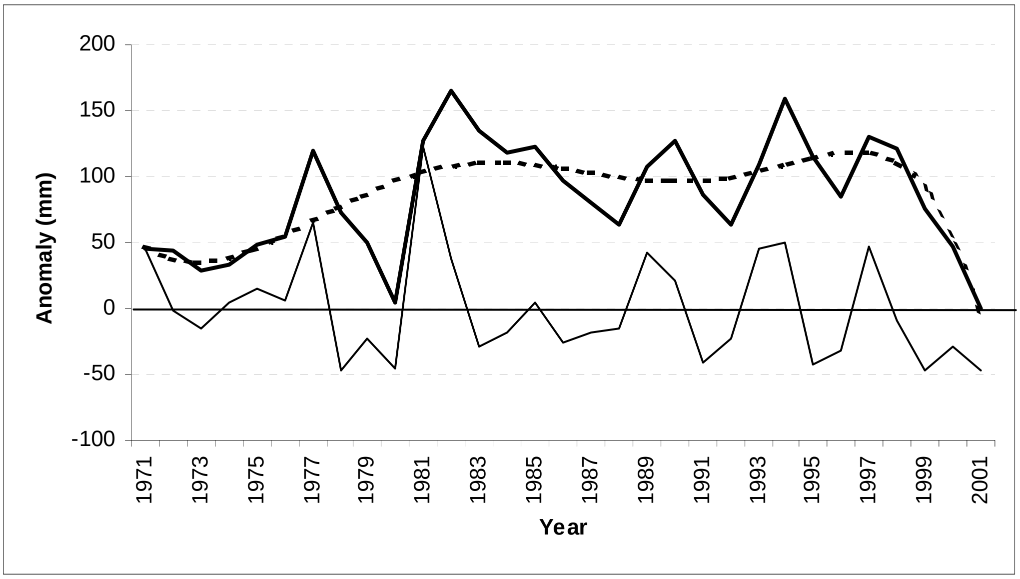


Figure 3.7.6: Rainfall anomalies for the Oudtshoorn area during the MAM season (thin black line). The accumulated anomalies are depicted by a thick black line with the associated polynomial fit (dashed line).

3.4.7 Variability of rainfall totals for the MAM season over the Kammanassie area

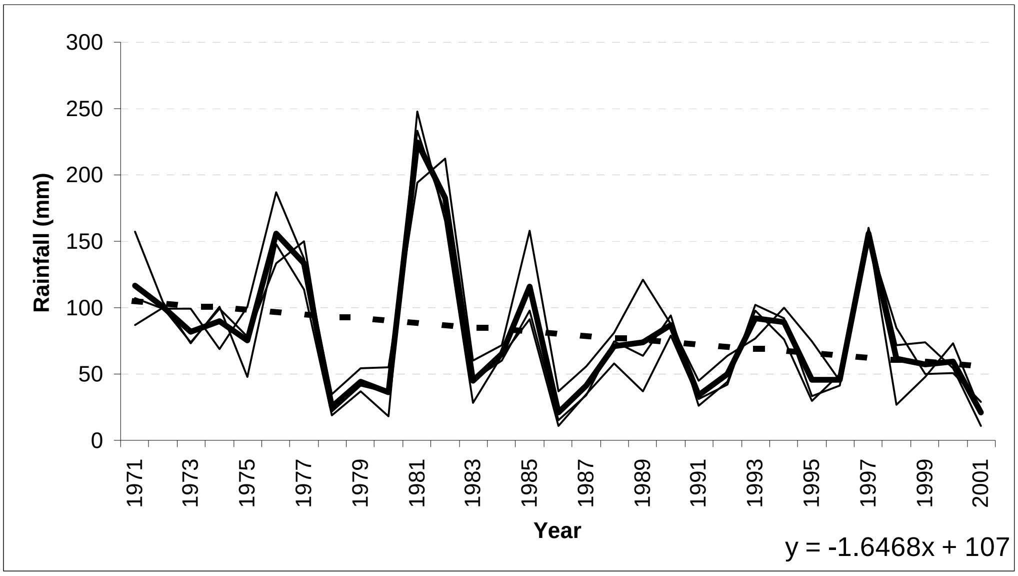


Figure 3.7.7: Rainfall time series for the Kammanassie area (MAM season) for stations 1, 3 and 4 (thin black lines). The thick black solid line represents the average for the stations with the associated linear regression line (dashed).

3.4.8 Rainfall anomalies for the MAM season over the Kammanassie area

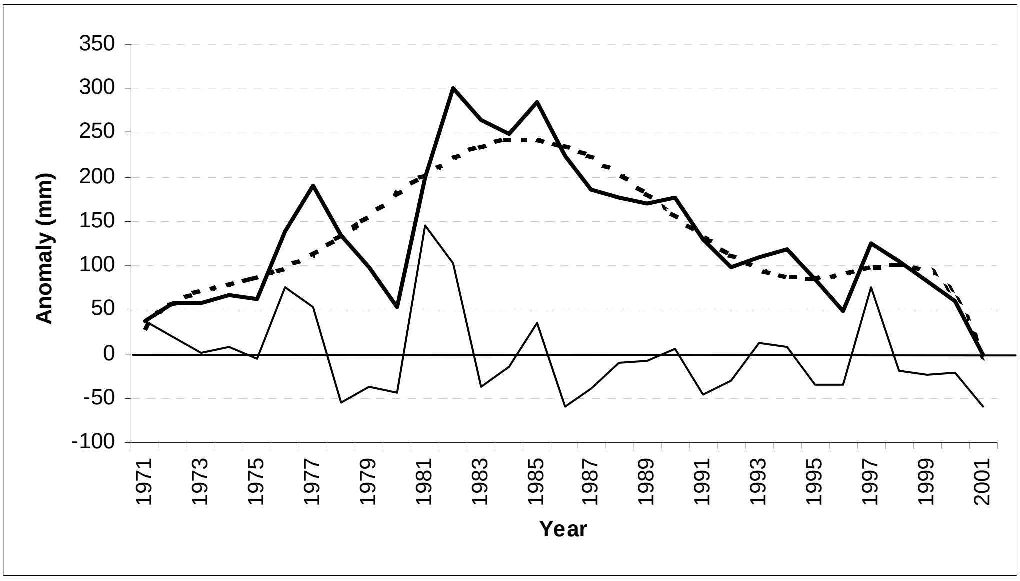


Figure 3.7.8: Rainfall anomalies for the Kammanassie area during the MAM season (thin black line). The accumulated anomalies are depicted by a thick black line with the associated polynomial fit (dashed line)

3.4.9 Variability of rainfall totals for the JJA season over the Oudtshoorn area

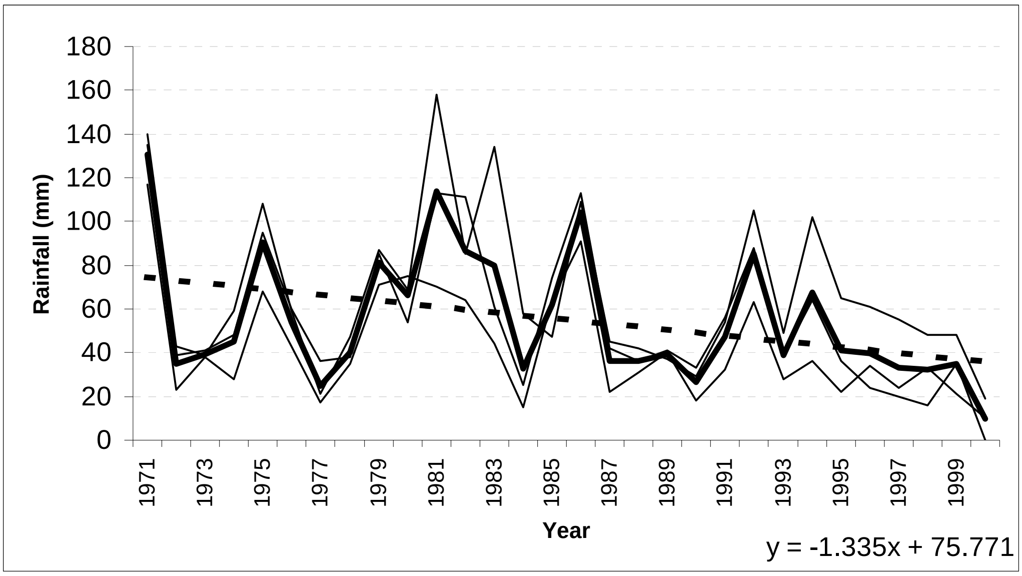


Figure 3.7.9: Rainfall time series for the Oudtshoorn area (JJA season) for stations 1, 3 and 4 (thin black lines). The thick black solid line represents the average for the stations with the associated linear regression line (dashed).

3.4.10 Rainfall anomalies for the JJA season over the Oudtshoorn area

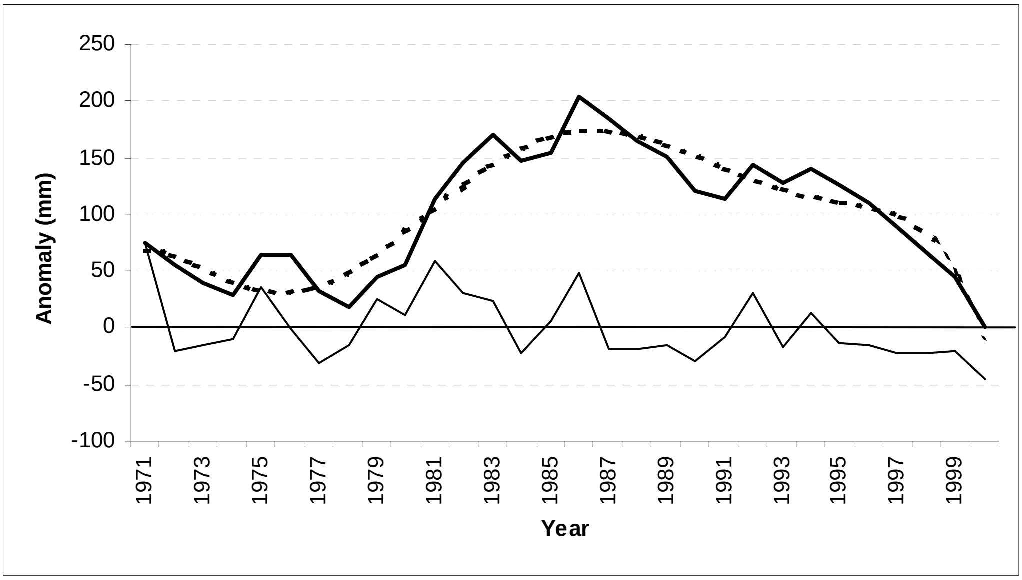


Figure 3.7.10: Rainfall anomalies for the Oudtshoorn area during the JJA season (thin black line). The accumulated anomalies are depicted by a thick black line with the associated polynomial fit (dashed line).

3.4.11 Variability of rainfall totals for the JJA season over the Kammanassie area

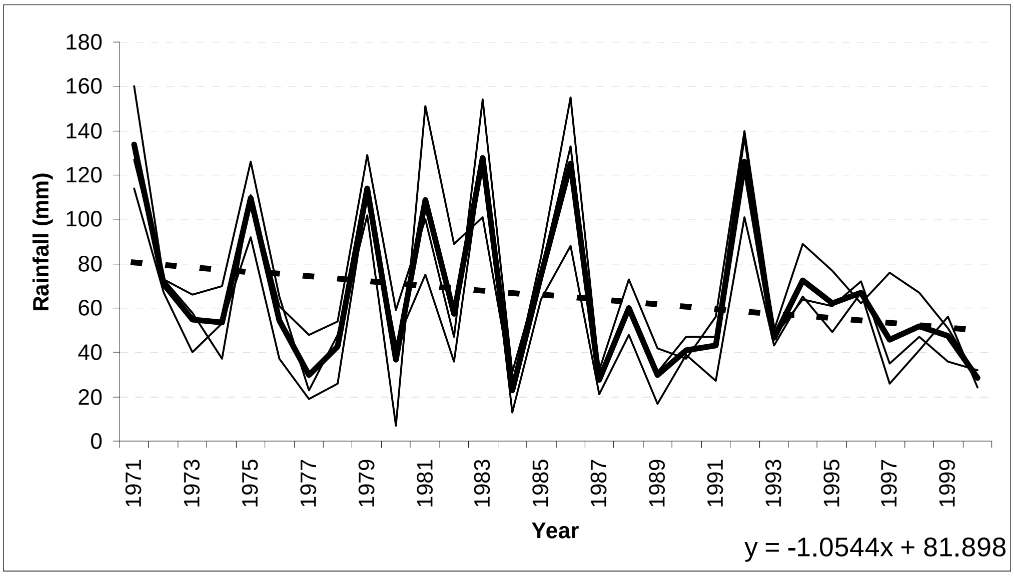


Figure 3.7.11: Rainfall time series for the Kammanassie area (JJA season) for stations 1, 3 and 4 (thin black lines). The thick black solid line represents the average for the stations with the associated linear regression line (dashed).

3.4.12 Rainfall anomalies for the JJA season over the Kammanassie area

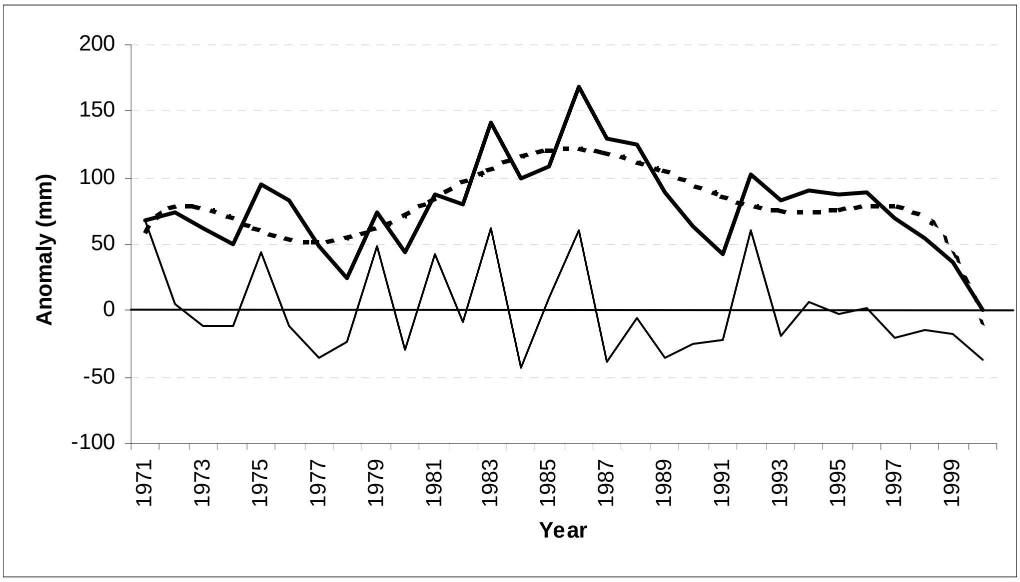


Figure 3.7.12: Rainfall anomalies for the Kammanassie area during the JJA season (thin black line). The accumulated anomalies are depicted by a thick black line with the associated polynomial fit (dashed line)

3.4.13 Variability of rainfall totals for the SON season over the Oudtshoorn area

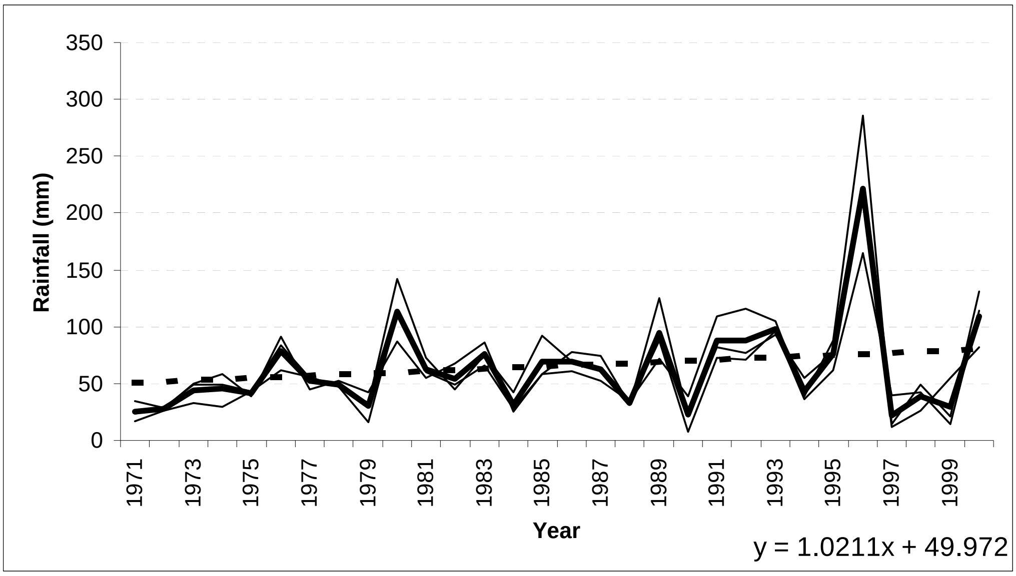


Figure 3.7.13: Rainfall time series for the Oudtshoorn area (SON season) for stations 1, 3 and 4 (thin black lines). The thick black solid line represents the average for the stations with the associated linear regression line (dashed).

3.4.14 Rainfall anomalies for the SON season over the Oudtshoorn area

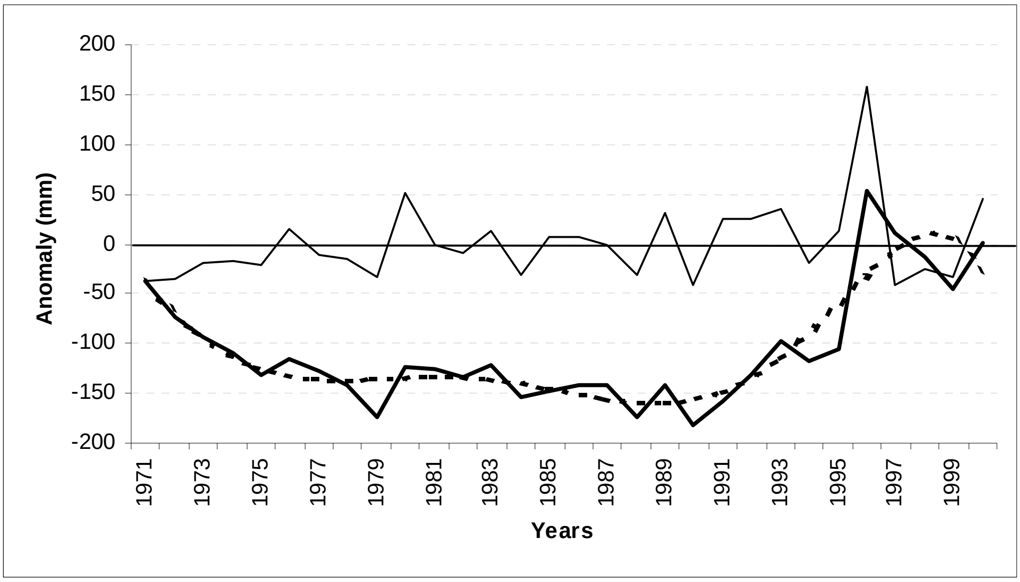


Figure 3.7.14: Rainfall anomalies for the Oudtshoorn area during the SON season (thin black line). The accumulated anomalies are depicted by a thick black line with the associated polynomial fit (dashed line).

3.4.15 Variability of rainfall totals for the SON season over the Kammanassie area

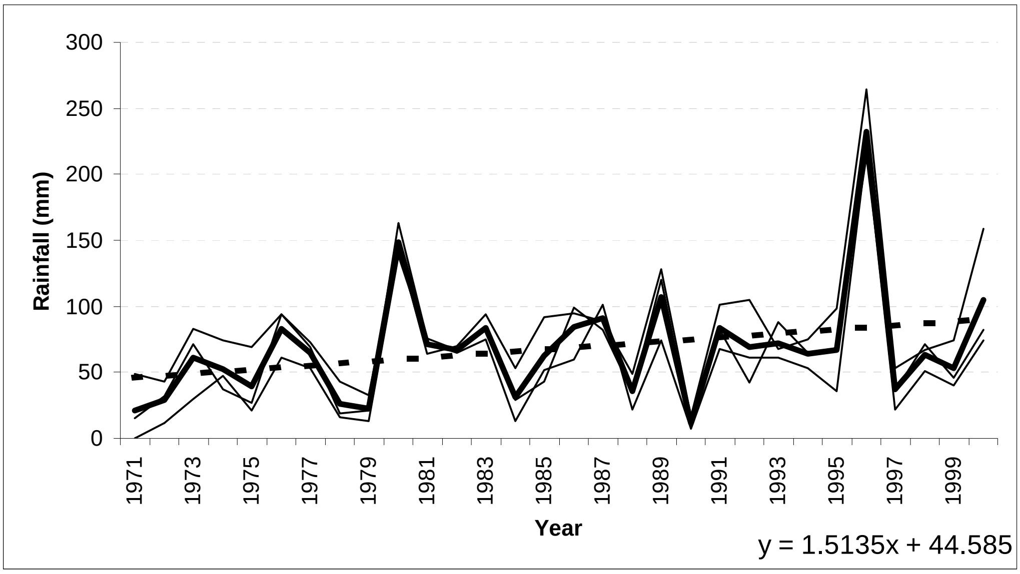


Figure 3.7.15: Rainfall time series for the Kammanassie area (SON season) for stations 1, 3 and 4 (thin black lines). The thick black solid line represents the average for the stations with the associated linear regression line (dashed).

3.4.16 Rainfall anomalies for the SON season over the Kammanassie area

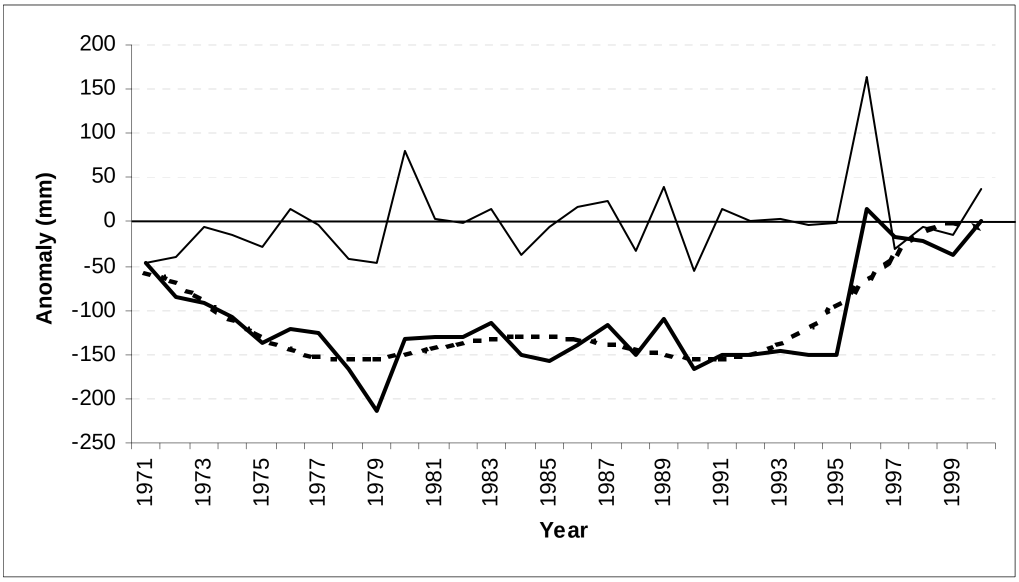


Figure 3.7.16: Rainfall anomalies for the Kammanassie area during the SON season (thin black line). The accumulated anomalies are depicted by a thick black line with the associated polynomial fit (dashed line)

Table 3.2: Slope of the linear regression line (linear trend) fitted through the 30/31-year rainfall record (1971 to 2000/1) of seasonal rainfall over the Little Karoo

Oudtshoorn area (stations 1,3,4)		Kammanassie area (stations 10,24,31)	
Season	**Linear trend**	**Season**	**Linear trend**
DJF	-0.2082	*DJF*	+0.0540
MAM	-0.0626	*MAM*	-1.6468
JJA	-1.3350	*JJA*	-1.0544
SON	+1.0211	*SON*	+1.5135

DJF season (Figures 3.7.1 to 3.7.4)

In both the Oudtshoorn and Kammanassie areas a notable decrease in the amplitude of the rainfall variability occurred over the past thirteen years. This is not unusual and might be regarded as a return of rainfall totals to the longer-term norm (see Hoekplaas analysis – figures 3.4 and 3.5). However, what were somewhat unusual are the extreme wet years that occurred in the 1970s and 1980s. The more recent period of smaller rainfall deviations (1989 to1999) might have contributed to less soil moisture than for the preceding extremely wet period. The period of smaller deviations is not necessarily dry, but compare well with rainfall variability experienced before the 1970s. Linear regression therefore reveals a slight negative trend in rainfall totals over the past 31 years.

MAM season (Figures 3.7.5 to 3.7.8)

Figure 3.3 indicates that the average rainfall totals for the months March and April are higher that for the remaining months. In general deviations from the average rainfall are smaller than for the wet 1981 season. The rainfall totals since 1999 is below normal but was not proceeded by an exceptionally long and severe drought. Similar to the DJF season a gradual negative rainfall trend is present in the time series of both the Oudtshoorn and Kammanassie areas. This trend is not necessarily indicative of a dry period.

JJA season (Figures 3.7.9 to 3.7.12)

Similar to the rest of the summer rainfall region, winter rainfall does not drop significantly over the Little Karoo (figure 3.3). As a matter of fact winter rainfall totals (season JJA) compares well with summer rainfall totals (season DJF). The rainfall for JJA become very close to average over the past five years and even dropped to below normal in the year 2000. Note that much larger fluctuations occurred in the rainfall variability in the historical record of 30 years. A gradual and somewhat stronger negative trend in rainfall than calculated for the DJF and MAM seasons appear in both the Oudtshoorn and Kammanassie areas.

SON season (Figures 3.7.13 to 3.7.16)

The SON period is the only season where a slight positive rainfall trend could be identified. This might be attributed to a high rainfall event that occurred in 1996. Apart from 1996 no exceptionally high rainfall values were recorded.

3.5 CONCLUSION

The Little Karoo is regarded as a dry region with average monthly totals of less than 31mm per month. Rainfall over the region does not exhibit a distinctive bimodal seasonal cycle.

A long rainfall record (1925 to 2000) reveals that the Little Karoo experienced unusually high rainfall during 1981, 1985 and 1996. These high rainfall values contribute to a general positive rainfall trend since 1925. If the shorter period of the recent 30/31 years (1971 to 2000/1) is considered, a general negative trend appears, implying that in both the Oudtshoorn and Kammanassie areas a decrease in the amplitude of the rainfall variability occurred over the past thirteen years. The trend is most obvious in the DJF, MAM and JJA seasons while rainfall totals increased over the SON season. The negative trends are not unusual and might be regarded as a return of rainfall totals to the longer-term norm (see Hoekplaas analysis – figures 3.4 and 3.5). A strong deviation from the norm was rather the extreme wet years that occurred in the 1970s and 1980s.

The more recent period of smaller rainfall deviations (1989 to1999) might have contributed to less soil moisture than for the preceding extremely wet period. In particular, a sequence of below-normal rainfall years appears in the JJA record (1985 to 2000). The period of smaller deviations does not necessarily point towards a drought, but compare well with rainfall variability experienced before the 1970s.

CHAPTER 4

GEOHYDROLOGY

4.1 INTRODUCTION

4.1.1 Background

The commissioning of a groundwater supply scheme for rural communities in the water-poor Klein Karoo in 1993 was highly controversial and met with much resistance in various quarters. The media and conservation officials all expounded on the negative environmental impacts. The farmers feared that it would influence their existing supplies. Although a number of well fields have been developed in this area, it was the well field in the Vermaaks River Valley at the Western end of the Kammanassie Mountain Range (KMR) that evoked the most opposition as a result of four boreholes been drilled within nature conservation property. Furthermore, the well field was in the recharge area of boreholes and streams used for agricultural purposes.

Although the Vermaaks River well field has been the subject of much research, to date the focus has been predominantly on well field management aspects pertaining to sustainability of water supply. Little attention has been paid to environmental needs. The Water Act (1998) requires that water needed to sustain the environment be taken into account and reserved for this purpose. Implementation of the Act in this respect is hampered by the lack of understanding of groundwater/surface water interactions. This research is a step toward developing the necessary understanding, which will ultimately lead to the responsible management of the groundwater resources of the Kammanassie in harmony with all users. Lessons learned here will inform groundwater developments elsewhere in the region and in particular in the Table Mountain Group Aquifer.

4.1.2. Aims and objectives

This chapter aims to investigate the influence of groundwater abstraction on springs in the Kammanassie Mountain.

The objectives were as follows:

- To better understand the influence of groundwater abstraction on the interface between groundwater and surface water.

- To better understand the threat posed by groundwater abstraction on ecosystems.

- To provide a case study to inform future developments elsewhere in the Table Mountain Group.

- To assist in assessing whether reports of springs drying up and vegetation stress as a result of groundwater abstraction have sound scientific basis.

4.2. METHODS

The research incorporated the following main steps:

- Desk study.
- Field work
- Data analysis
- Evaluation of results

Desk study: This involved the review of relevant available information contained in numerous DWAF hydrogeological reports relating to the Kammanassie as well as WRC reports on the Table Mountain Group hydrogeology, groundwater surface water interaction and groundwater dependent ecosystems.

Particular attention was paid to the remote sensing and satellite lineament mapping and analysis by the Council for Geoscience (Chevallier, 1999). Image processing enhancement methods were used to map the geometry of major lineaments, define tectonic domains as well as classify satellite lineaments in terms of groundwater potential. Geological field mapping by Halbich and Greef, (1995) described the nature of geological structures and their bearing on hydraulic characteristics of features observable via remote sensing. The conceptual model formulation by Kotze, (2001) provided insight into the flow dynamics and included a typical spring classification and an assessment of the radius of influence of the Vermaaks River well field.

Fieldwork:

- Routine monitoring of groundwater levels in existing monitored and production boreholes and of groundwater abstraction volumes (Overberg water).
- Climatic monitoring at an automatic weather station set up by Western Cape Nature Conservation Board (WCNCB) in the Vermaaks River Valley as well as recording rainfall at a number of stations across the mountain range (WCNCB and Overberg Water).
- Flow at v-notches constructed in the Marnewicks and Vermaaks Rivers by the operating agent (Overberg Water).
- Establishment of additional monitoring boreholes specifically at vegetation monitoring sites (DWAF).
- Accurate location of springs with a global positioning system, monitoring flow status and sampling sites (WCNCB).
- Inspection of springs (DWAF).

Data analysis: This part entailed interpretation of field observations in conjunction with hydrogeological data. This included:

- Analysing the influence on surface flow in the Vermaaks River Valley
- Ranking the probability that individual springs would be influenced by abstraction
- Comparing isotopic signatures

4.2.1 Influence on surface flow

The influence of groundwater abstraction on surface water flow was evaluated by interpreting the Vermaaks and Marnewicks Rivers flow hydrographs in conjunction with groundwater abstraction and rainfall data. This involved interpretation by simple visual inspection of composite graphs and statistical analysis (Xu, Wu, and Titus, 2002). The trendline technique built in Microsoft Excel software was used to determine linear relationships between rainfall, abstraction, and flow at the v-notches for the period beginning 1994 to end of 2001.

In addition groundwater levels in the Vermaaks River Valley in response to abstraction were related to spring/surface flow observations.

4.2.2 Vermaaks well field vulnerability ranking - springs

Groundwater level data was only available in the immediate vicinity of the well field, whereas the springs are widely scattered along the mountain range in inaccessible rugged terrain where no boreholes, and therefore no groundwater level data, are available. To make a judgement on the potential influence groundwater abstraction could have on groundwater levels near the surface, an understanding of the factors controlling groundwater flow, the locality of groundwater discharges and factors influencing the degree of interconnectivity with abstracted groundwater is required.

It is necessary to understand each spring occurrence in order to evaluate potential risk posed by abstraction versus other factors such as climatic variations. For example springs fed by the higher storage deep aquifer are less susceptible to drought, but more vulnerable to groundwater abstraction. Compared to these the localised low storage perched systems are vulnerable to drought but would not be affected by abstraction from the main aquifer that occurs at a deeper level. The explanation of the reason for a particular spring occurrence required qualified judgement on the basis of remote sensing including lineament analysis, site inspection, structural interpretation and hydrochemical data.

The various parameters that are likely to affect the potential for a particular spring to be impacted by abstraction were identified. A score/rank/rating was assigned to each parameter in such a way that the higher the score the greater the likelihood of impact. The parameters that influence the potential for a particular spring to be affected by groundwater abstraction are discussed below, and the scores are given in Table 4.1.

Lithological

Springs occurring in the Peninsula formation are were most likely to be influenced by the well field situated in the Peninsula and therefore score highest (10). Springs fed by the Nardouw formation are less likely to be influenced as the limited interconnection, in particular to the North of the well field where the Cedarberg formation aquitard is largely intact, hence a lower score (3) was assigned. In the case of the aquizone to the south of the well field, springs fed by the Nardouw aquifer are far more likely to be impacted because of the high degree of fracture interconnection in this zone. However this is still not as high as within the Peninsula formation due to the presence of feldspathic sandstone and shale bands inhibiting connection to some extent (8).

Bedding planes

No adjustment to the score was made purely on bedding plane considerations. Transmissivity in the bedding plane strike direction can be expected to be higher than average, especially where shale bands cause directional anisotropy, inhibiting flow across bedding. However the rarity of shale bands and the abundance of crosscutting structures in the Peninsula formation are likely to subdue directional anisotropy in this formation. Directional anisotropy caused by the Cedarberg shale and presence of shale within the Nardouw had already been accounted for by assigning lower scores to the Nardouw and Aquizone on a lithological basis.

Table 4.1: Scores used for ranking probability of springs being influenced by Vermaaks well field abstraction

Lineament Connection		Lithology		Altitude of spring relative to baseline groundwater level		Distance of spring from closest wellfield borehole		Spring occurrence	
Direct Domain1*	10 +2	Peninsula	10	Below	10	Within 3 km	10	Direct connection to aquifer	10
Indirect Domain1*	5 +2	Nardouw	3	Within 50 m above	5	Between 3 and10 km	5	Unsure of connection	5
None Domain1*	0 +2	Aquizone	8	> 50 m above	0	Between 10 and 20 km Beyond 20 km	2 0	Perched	0

* Chevallier, (1999) Domain of good connectivity and erratic directional permeability.

Lineaments

Lineaments identified on aerial photographs or satellite imagery can provide evidence of structural connection of the springs to the abstraction zone. A direct connection from well field to a spring resulted in a 10 score, whereas an indirect connection scored 5. Where there was no evidence of connection 0 was assigned. A further 2 was added to the scores of springs occurring in Domain 1 (Figure 2.7) identified by Chevallier (1999) due to the high degree of lineament interconnectivity. A generous buffer of 200 m on either side of each lineament was used to account for any "damage zone" around all lineaments and to cover any potential inaccuracies in lineament position.

Altitude

Springs emanating at a lower altitude than the confirmed original water level in the well field prior to pumping are more likely to be fed by the groundwater system affected by abstraction than those springs emanating well above this elevation. The latter are likely to be fed by perched systems. Springs occurring below the Vermaaks River Valley groundwater level scored 10. Those within 50 m higher elevation scored 5 and more than 50 m higher elevation scored 0.

Spring elevations obtained from 1:50 000 top cadastral sheets were used in preference to GPS elevations as they compared best with accurately surveyed data. The GPS readings were consistently between 25 m and 40 m lower, the error becoming gradationally larger with increasing altitude.

The groundwater gradient is expected to be relatively low due to the high transmissity, and this was confirmed by the very flat (0.14 degree) slope of the original water table below the Vermaaks River Valley prior to abstraction (Mulder, 1991). Assuming a constant groundwater gradient, and extrapolating to the highest point in the valley, the groundwater level would be 692 metres above sea level (or 282 metres below surface). This elevation was used as the baseline groundwater elevation before abstraction

Distance to the spring from the well field

The distance between the closest production borehole and the particular spring was measured using the Arc View GIS programme - in general potential influence would diminish with distance.

Kotze (2001) estimated the radius of influence of the Vermaaks River well field to be 1.05 km from the well field and later revised this to approximately 2 km (Kotze, 2001 – first quarterly report). A theoretical minimum and maximum radius of influence of the well field calculated by Xu *et al*., (2002) indicates that a large range is possible due to the heterogeneity of the rock, varying from a maximum of approximately 50 km to a minimum of 3.6 km. Xu *et al*, (2002) state that a realistic range of influence would be between 3 km and 10 km for the well field. For the purposes of this research the latter estimate is accepted as it concurs, to some extent, with field evidence. Drawdown can be expected to be at a maximum in the well field itself, diminishing with distance. Xu *et al*. (2002) applied a modified Theis equation (Kruseman and De Ridder 1991) to provide an estimate of drawdown of the water table with distance from the well field. After 8 years a drawdown of 13 metres at 3 km distance is predicted, diminishing to 3 metres at 10 km distance.

Scores were chosen taking into account the radius of influence and drawdown predictions of Xu *et al.* (2002), as well as field observations. Springs within 3 km of the closest production borehole score high (10), while those between 3 km and 10 km score 5. Between 10 and 20 km a score of 2 is given because it is theoretically possible to have some influence in this zone in extreme cases. Beyond 20 km the score is zero. Springs are not disqualified on the basis of distance because the theoretical maximum potential influence (50 km) extended to the entire research area.

Groundwater level observations made during the period of operation of the scheme provide some insight into the directional anisotropy and radius of influence. These observations are given below.

4.2.3 Observations along Vermaaks River Fault and at Wagenpadsnek

The Vermaaks River Fault is a highly fractured major structure and judging from the satellite and aerial photographic lineament analysis, the most prominent linear structure on the Kammanassie mountain range. A maximum impact of abstraction would be expected along its length.

Observations up to December 2001 (9 years of well field operation) indicated a groundwater level drop of twenty metres within the well field itself, approximately 3 metres drop 1,5 km north west of the well field at the Cedarberg shale formation contact. There was no noticeable impact of abstraction on a spring (051) 1.5-km further north known to be driven by the piezometric head in the Peninsula formation.

The main impacts were detected soon after abstraction increased from an average of approximately 13 l/sec to 19 l/sec (33 000 m^3 to 49 000 m^3 per month) in October 1997. In the period October 1997 to January 1998 abstraction was particularly high the – average for the 4 months being 27 l/sec (71 000 m^3 per month).

A sharp drop in the groundwater level (9 metres) in borehole WK4 at Wagenpadsnek 3 km west of the well field coincided with the increased well field abstraction - indicating rapid influence over large distances. This indicates a strong directional anisotropy with high transmissivity along bedding strike, probably coinciding with fold axes. It must be noted that WK4 was monitored during the short duration test pumping programme (Jolly, 1998) and no influence was reported.

The influence of increased well field abstraction was detected in WK4 in the Nardouw, even though the supposedly impermeable Cedarberg Formation separates it from the well field. This indicates that the shale is either disrupted in the vicinity or the shale has been penetrated in the borehole.

Exclusion from impact

Parameters, which can exclude a spring from being potentially impacted by abstraction, are <u>disconnection</u> of the spring from the water table / piezometric surface as well as <u>timing</u> of dry up.

Interpretation of a spring's occurrence makes it possible to evaluate whether the spring emanates from a perched system or the deeper aquifer from which the well field abstracts. Springs were classified via field inspection and were combined with structural interpretation, satellite imagery and aerial photography. Many springs are associated with a weathered shale horizon toward the crest of the mountain and are classified as perched. The regional groundwater level is expected to be much deeper below surface given the high transmissivity as was proven by drilling in the Vermaaks River Valley.

A definite disconnection scored a zero and disqualified the spring. On the other hand a definite connection scored 10 and possible connection 5.

Timing – springs drying up before abstraction commenced obviously could not be ascribed to the well field. Those springs still flowing were also excluded.

4.2.4 Comparing isotopic signatures

Environmental isotopes for 9 springs were compared with existing data for the well field. Similarities could indicate groundwater of similar origin and therefore potential connection. The isotope data could not be systematically used in the vulnerability assessment outlined above, as data was only available for a few of the springs.

4.3 RESULTS

4.3.1 Influence on surface flow in the Vermaaks and Marnewicks Rivers

Under natural conditions the Vermaaks River was ephemeral, with surface flow along its length only occurring for short periods after high rainfall events. When not in flood, flow occurred at two perennial springs (numbers 009 and 051) discharging into the river course, with the water disappearing/draining into the alluvial/colluvial material in the riverbed within a hundred or so metres downstream of each spring (Uys, *pers comm.*[1]). Surface flow also occurred at the site of the v-notch, where groundwater was forced to surface at a constriction in the valley.

[1] Mr J Uys. 2001. Overberg Water

Changes in this natural state as a result of abstraction are as follows:

4.3.2 Flow at the v-notches

Flow at the v-notches in comparison to rainfall is given in Figure 4.1. The Marnewicks River monthly flow is consistently higher than the neighbouring Vermaaks River primarily due to the larger catchment area. An overall decrease in low-flow is evident in both catchments. This could largely be attributed to the declining rainfall trend in this period, although it was possible that abstraction could have been responsible to some extent. According to Xu *et al.* (2002), results of the statistical analysis (Figure 4.2) indicated that rainfall decrease was the general cause of flow reduction in both the Vermaaks and Marnewicks Rivers.

The flows mimicked each other closely for the first 7 years. However in December 1999 there was a diversion as flow in the Vermaaks River declined despite increased flow in the Marnewicks in response to rain falling. It is possible that this diversion is a result of abstraction starting to noticeably impact on discharge from the Peninsula formation at the Cedarberg formation contact in the Vermaaks River.

4.3.3 Spring flow in the Vermaaks River Valley – Cedarberg shale contact (spring number 009)

Spring 009, which dried up in September 1999, discharged over an area rather than one specific point, hampering accurate flow measurement. Whittingham (1972) reported a flow of 10 l/sec for this spring, and Kotze (2001) accepted this as the best estimate of flow prior to abstraction. A “concrete flume” placed in the stream bed in 1992 indicates the flow to be variable ranging between 5 and 8 l/sec. However this measurement is unreliable due to losses as a result of diffuse discharge from the area around the structure. Measurements stopped after the flood in November 1996 when the parshall weir/flume became clogged and the streambed altered with large losses as a result of the wide seepage area. The spring dried up within 3 years of the flood - no record is available showing the drying.

Three main stages that culminated in the drying up of a spring at the Cedarberg shale contact can be identified. The stages are shown in Figure 4.3, Figure 4.4 and Figure 4.5.

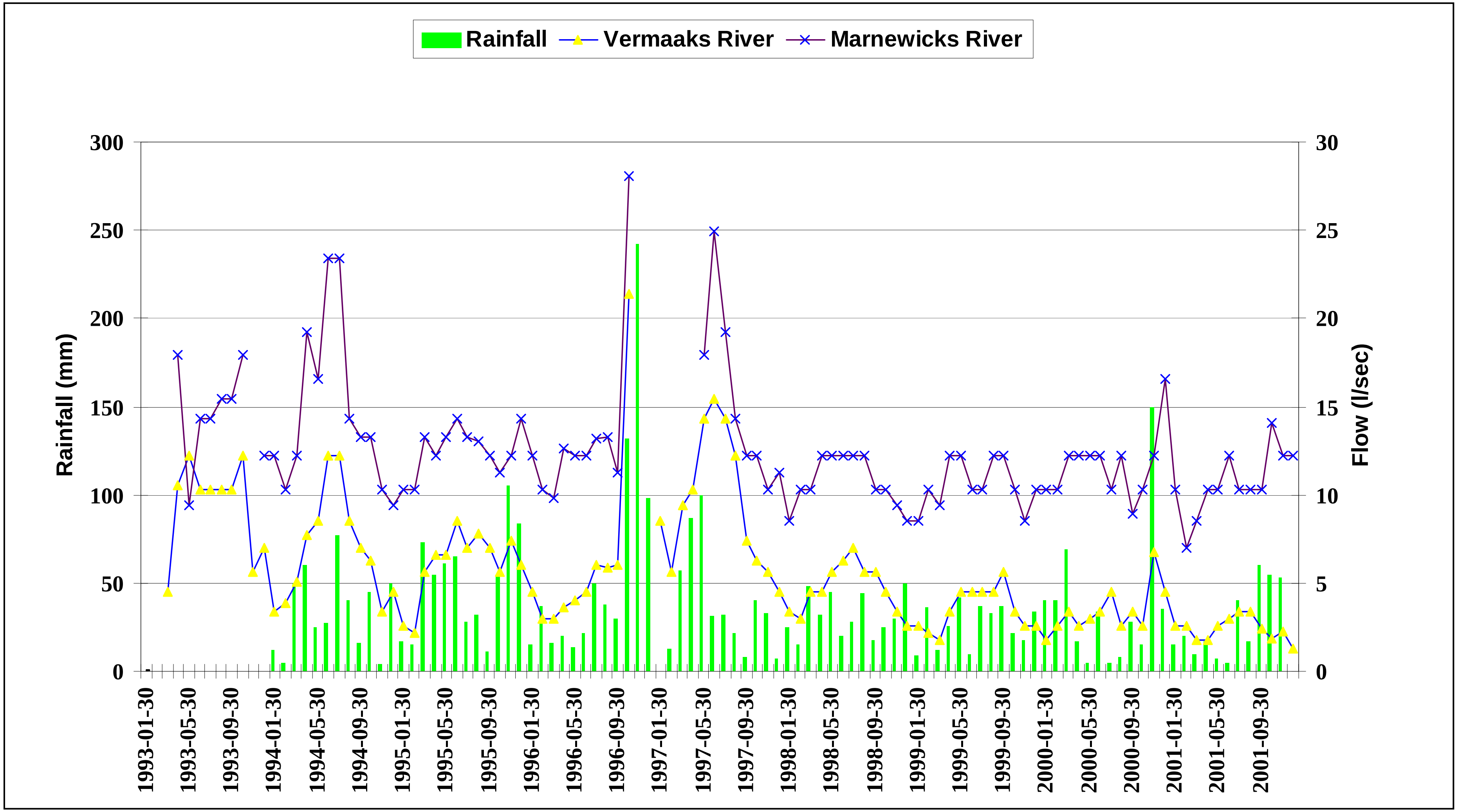


Figure 4.1: Flow at the V-notches in comparison to rainfall (Wildebeesvlakte : KKRWSS station)

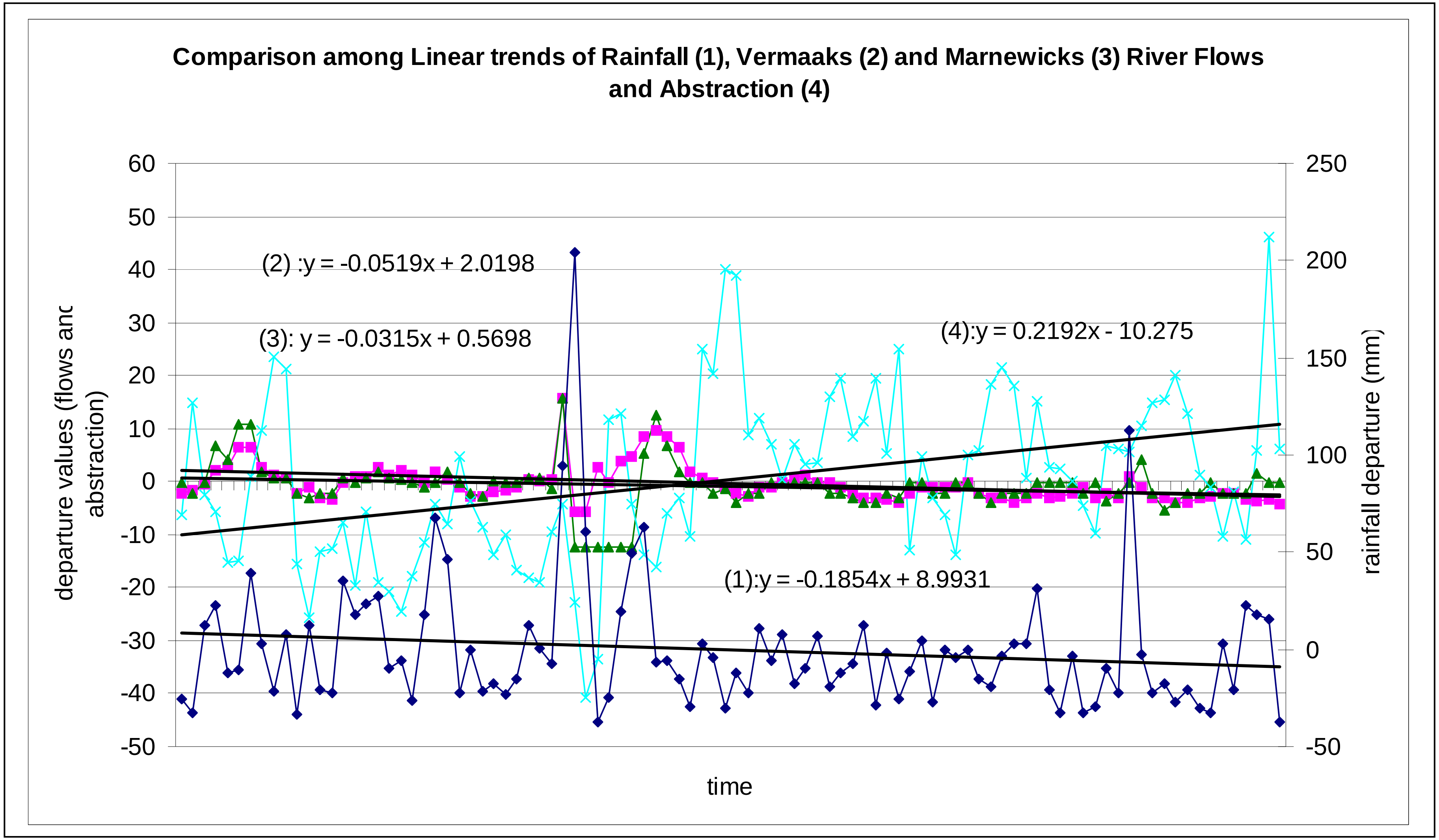


Figure 4.2: Comparison of rainfall, hydrographs and abstraction (Xu *et al*., 2002)

Stage 1: From the start of the scheme in January 1993 to end December 1997. The radius of influence of the well field is slowly expanding but well field groundwater levels are higher, maintaining a gradient toward the spring. The high storage in the saturated alluvium is likely to provide a buffer to influences of abstraction in this stage.

Stage 2: January 1997 till end of October 1998. A sharp increase in abstraction in December 1997 plus to some extent reduced rainfall, r

Stage3: November 1998 till end December 2001. A critical point reached when the groundwater levels in the wellfield drop to below that of VG16, causing a flow direction reversal from this area to the well field and drying up of the spring. This happened despite wellfield groundwater levels still being higher than spring elevation. The well field groundwater level subsequently drop to spring elevation and the soils in the discharge zone become dry.

An attempt to "kickstart" this spring in November 2001 by digging a pit into the dry soil proved unsuccessful. The lack of response was subsequently explained when the dry spring elevation had been surveyed. The groundwater level at the time had declined to approximately 4 metres below surface or 1.5 metres below the base of the excavation.

4.3.4 Spring 051 near artesian borehole hole (G46077)

This consistent spring flow of approximately 2 l/sec was originally ascribed to the river channel intercepting the water table but it is now understood to be discharging from a pressured system. The revised interpretation stems from the fact that the flow reduced noticeably when a monitoring borehole drilled 250 m north of the spring intercepted an artesian flow of 11 l/sec when the Cedarberg formation was penetrated. The spring flow stopped after 5 days. The soils remained wet and the groundwater level dropped to 0.3 m below surface at the discharge point. The flow returned to the pre-impact rate in June 2002 within one month of sealing this artesian borehole.

4.3.5 Vermaaks well field vulnerability ranking - springs

Schematic diagrams in Figure 4.6 (A – D) depict the variety of spring types identified and which spring belonged to a particular category. The results of the vulnerability ranking are shown in Table 4.2 and summarised in Table 4.3.

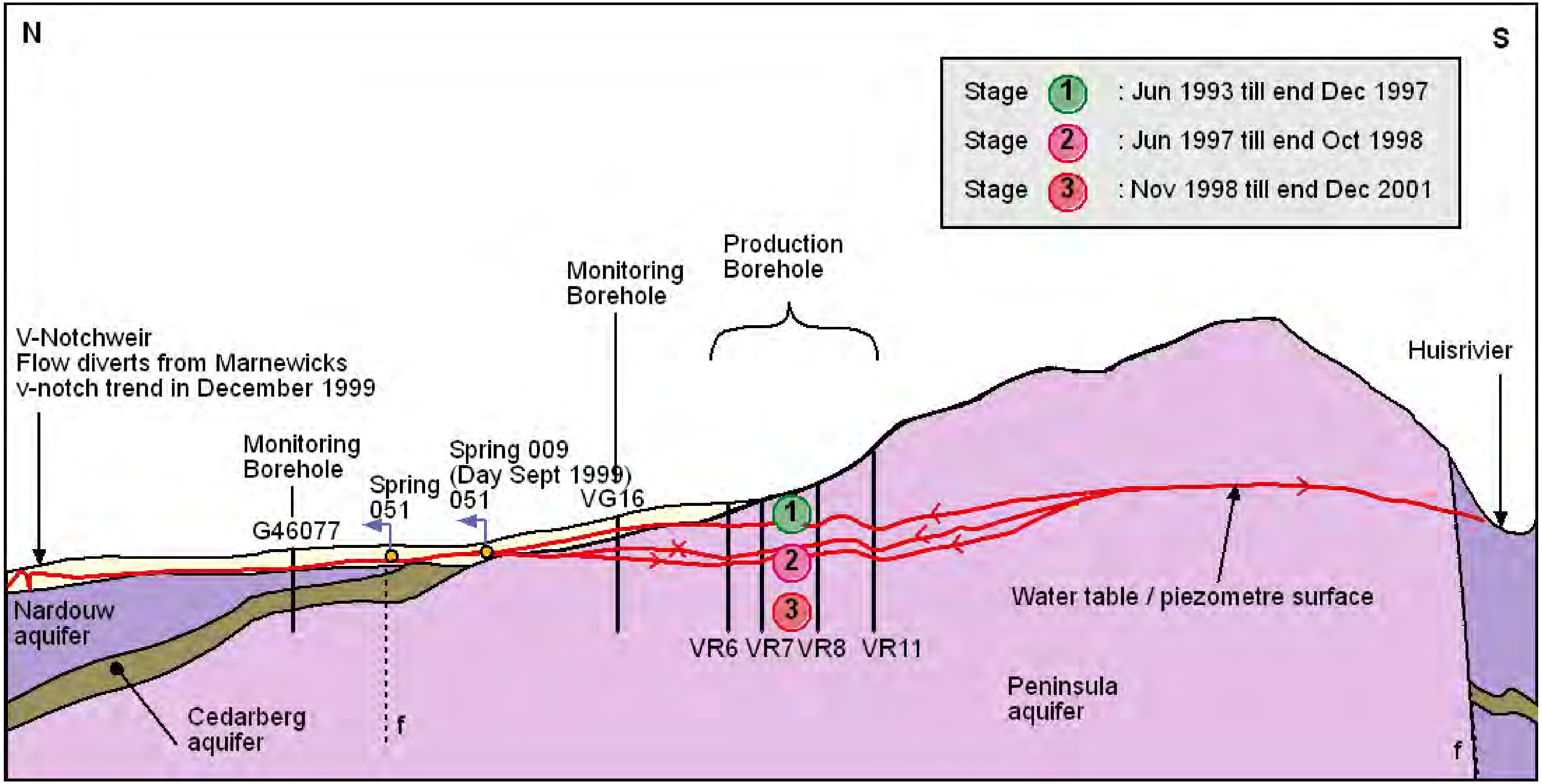


Figure 4.3: **Three stages leading to the drying up of the spring at the Cedarberg shale contact in the Vermaaks River Valley**

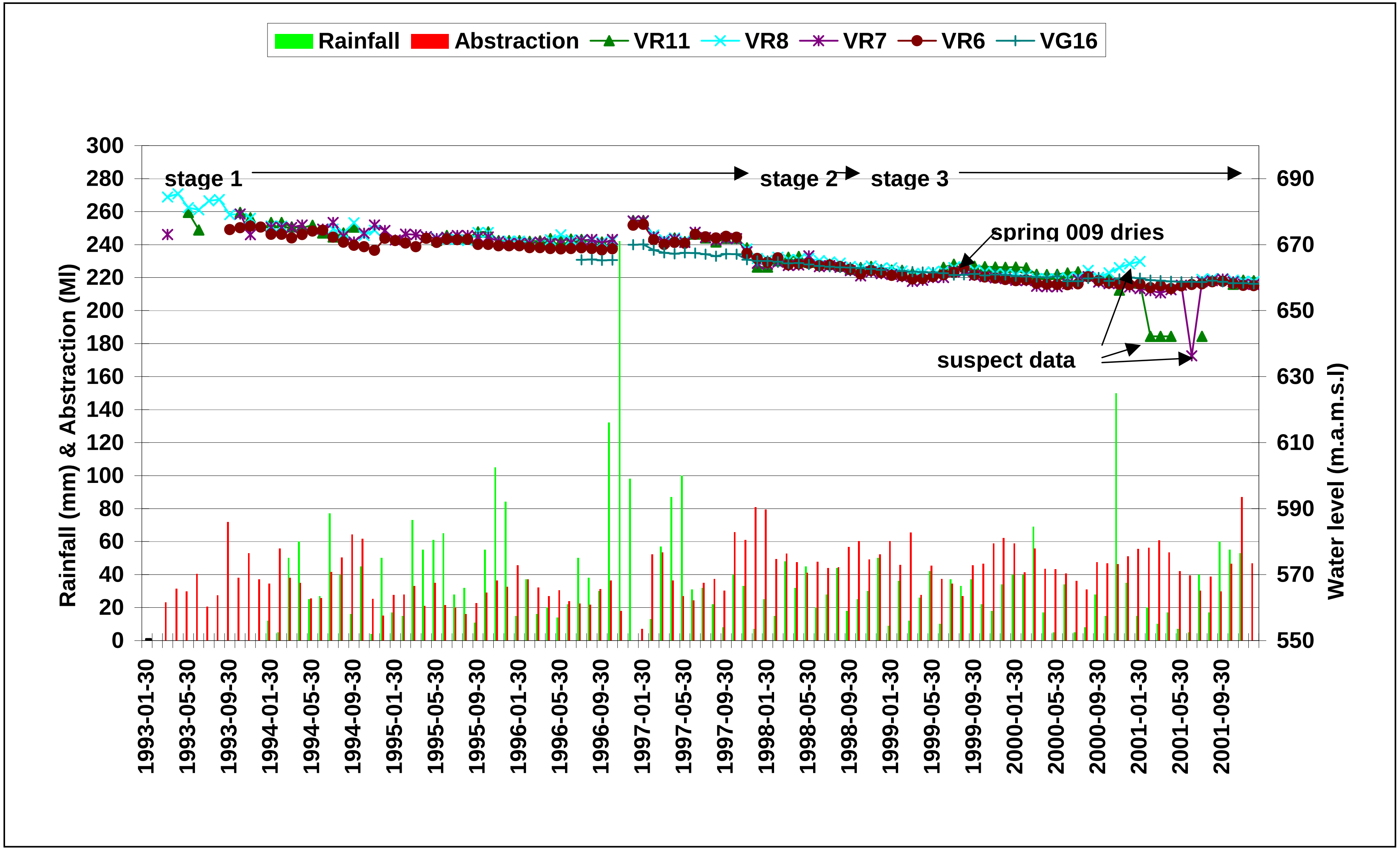


Figure 4.4: Groundwater level in Vermaaks River: Production boreholes

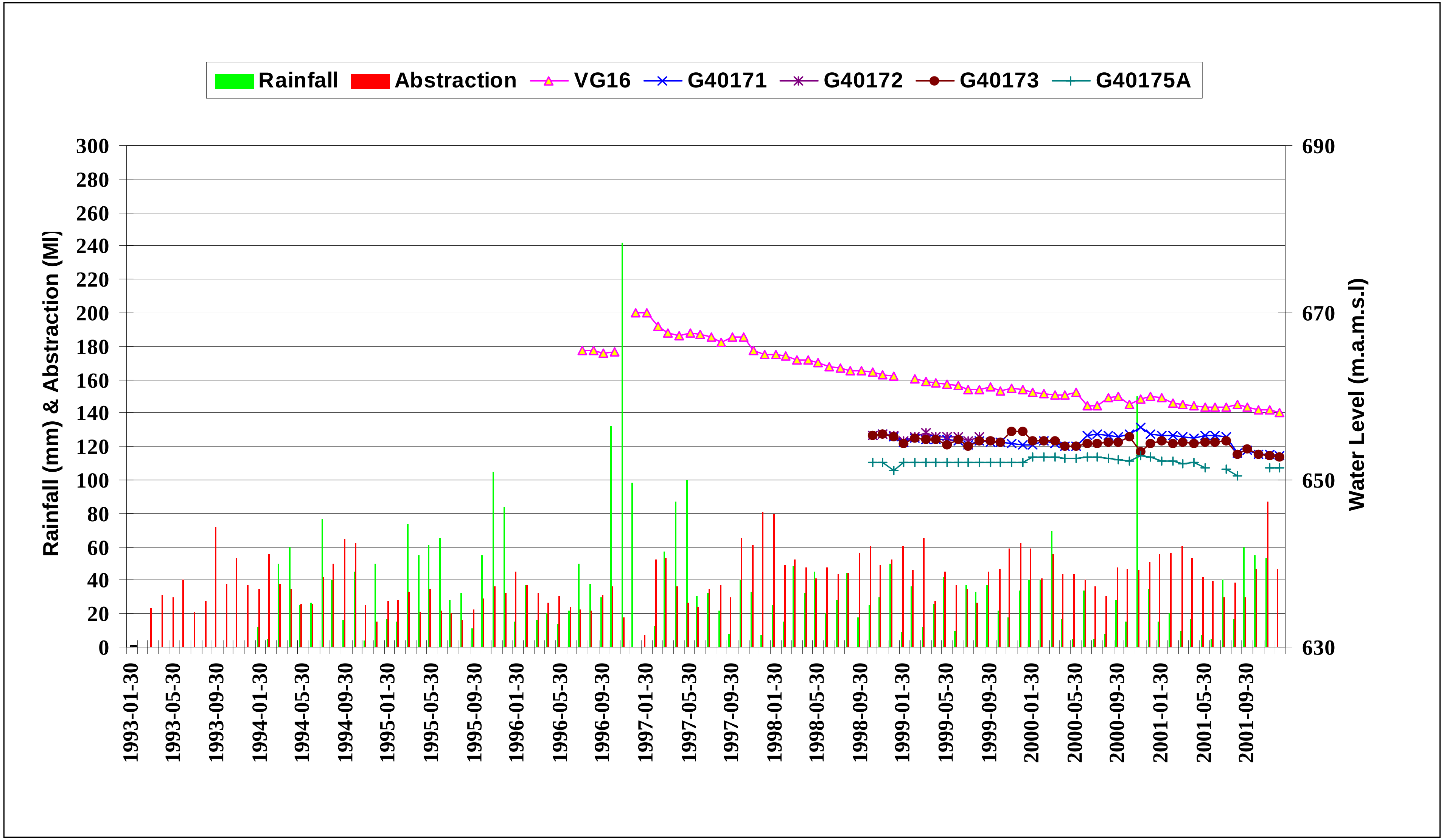
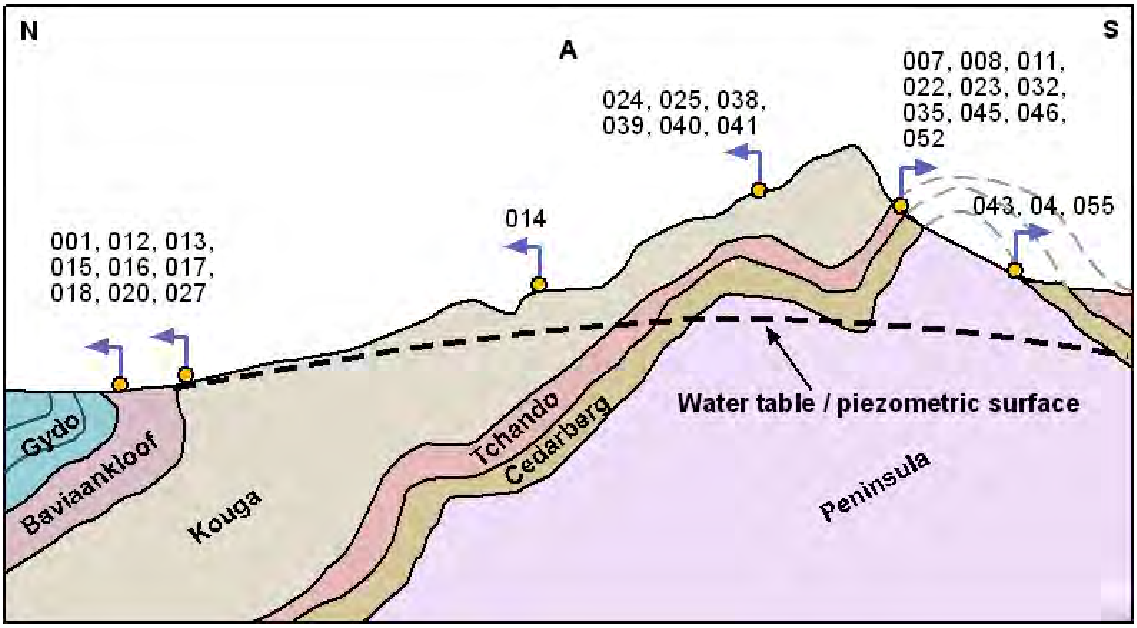


Figure 4.5: Groundwater level in Vermaaks River: Monitoring boreholes



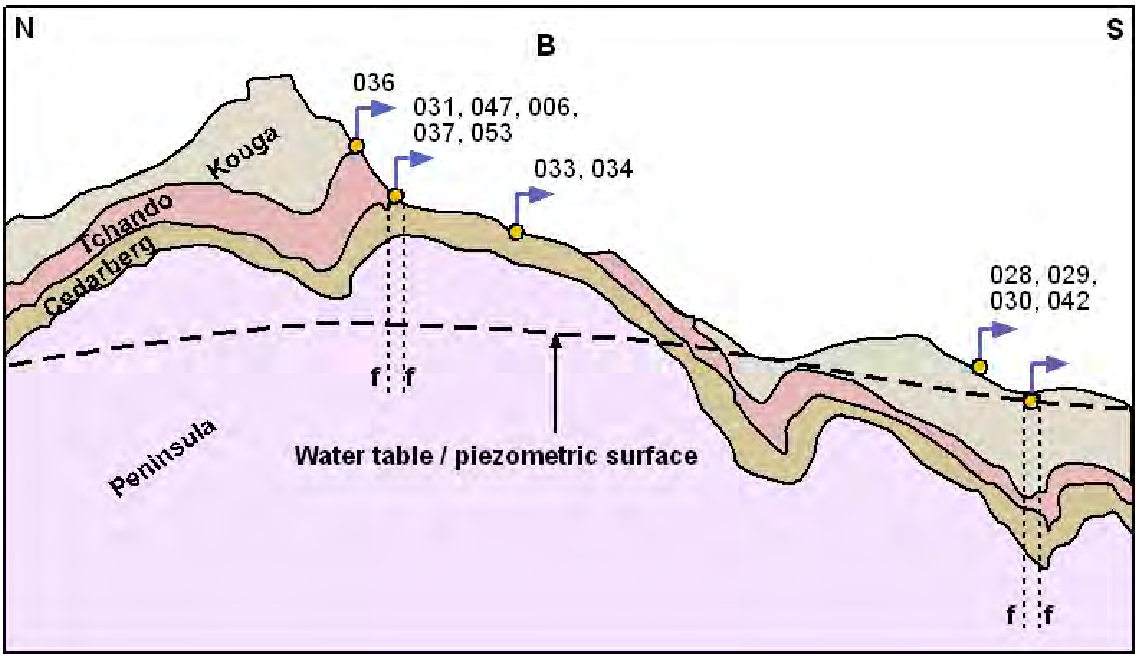
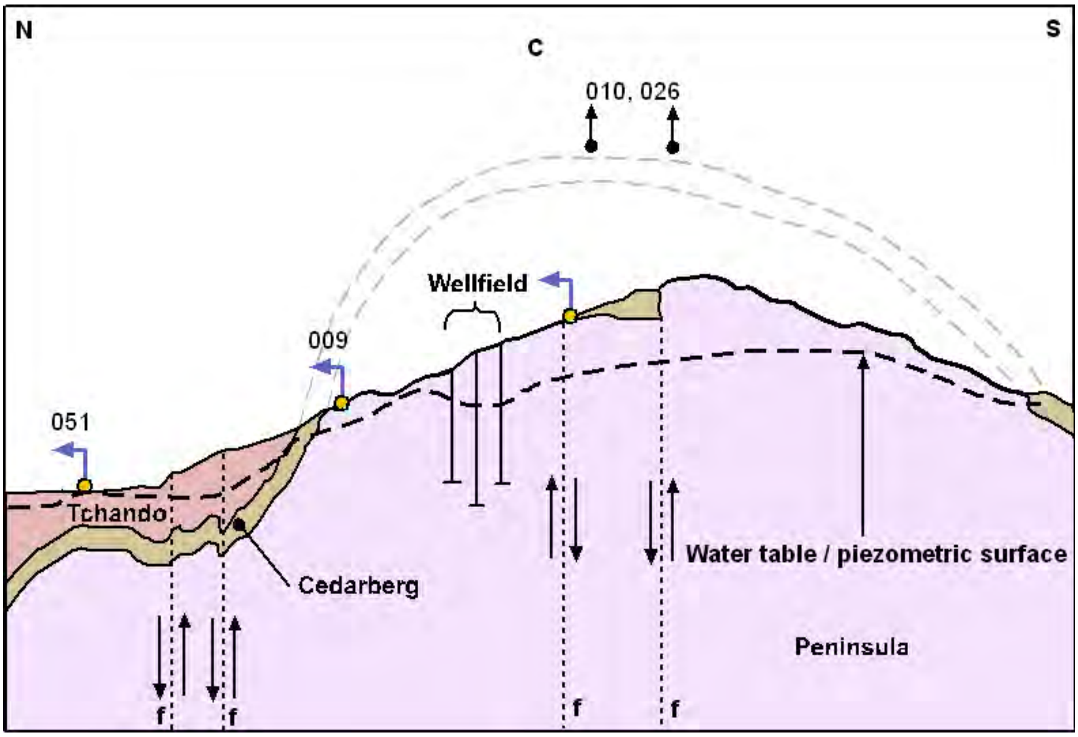


Figure 4.6(A & B): Schematic diagrams showing the various spring types identified on the Kammanassie Mountain



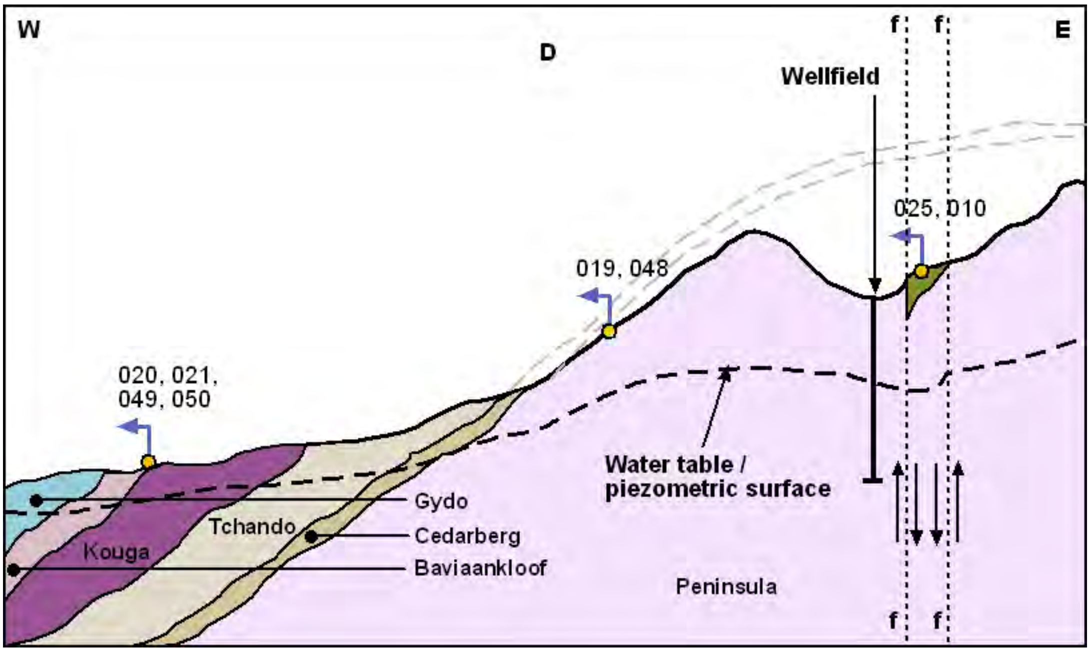


Figure 4.6(C &D): Schematic diagrams showing the various spring types identified on the Kammanassie Mountain

Table: 4.2 Results of spring vulnerability ranking

Spring No.	Score Lithology	Score Lineament	Score Altitude	Score Distance	Score Perched (Structural interpretation)	Timing Exclusion	Perch Exclusion	TOTAL
Kamm/W/001	3	0	0	0	10	NO	NO	13
Kamm/W/002	3	0	0	0	5	YES (1978)	NO	8
Kamm/W/003	3	0	0	0	5	NO	NO	8
Kamm/W/004	3	0	0	2	5	NO	NO	10
Kamm/W/005	10	0	0	2	5	NO	?	17
Kamm/W/006	3	5	0	2	0	NO	YES	10
Kamm/W/007	3	5	0	2	0	FLOWING	YES	10
Kamm/W/008	3	5	0	2	0	NO	YES	10
Kamm/W/009	10	12	10	10	10	NO	NO	52
Kamm/W/010	8	12	0	10	0	YES (1983)	YES	30
Kamm/W/011	3	0	0	2	0	NO	YES	5
Kamm/W/012	3	0	5	2	5	NO	?	15
Kamm/W/013	3	0	5	2	5	NO	?	15
Kamm/W/014	3	7	0	5	5	NO	?	20
Kamm/W/015	3	5	10	2	10	NO	NO	30
Kamm/W/016	3	0	10	2	10	NO	NO	25
Kamm/W/017	3	0	10	5	10	NO	NO	28
Kamm/W/018	3	0	10	5	10	YES (1973)	NO	28
Kamm/W/019	10	7	0	10	0	NO	YES	27
Kamm/W/020	8	2	10	5	10	FLOWING	NO	35
Kamm/W/021	8	7	10	5	10	YES (1988)	NO	40
Kamm/W/022	3	5	0	0	0	NO	YES	8
Kamm/W/023	3	5	0	0	0	FLOWING	YES	8
Kamm/W/024	3	0	0	0	0	NO	YES	3
Kamm/W/025	3	0	0	0	0	YES (1986)	YES	3
Kamm/W/026	8	12	0	10	0	NO	YES	30
Kamm/W/027	3	2	10	5	10	NO	NO	30
Kamm/W/028	3	5	0	5	5	NO	?	18
Kamm/W/029	3	5	0	5	5	NO	?	18
Kamm/W/030	3	5	0	2	5	NO	?	15
Kamm/W/031	3	5	0	2	0	FLOWING	YES	10
Kamm/W/032	3	5	0	2	0	FLOWING	YES	10
Kamm/W/033	3	0	0	2	0	NO	YES	5
Kamm/W/034	3	0	0	2	0	NO	YES	5
Kamm/W/035	3	5	0	0	0	FLOWING	YES	8
Kamm/W/036	3	5	0	0	0	FLOWING	YES	8
Kamm/W/037	3	5	0	0	0	FLOWING	YES	8
Kamm/W/038	3	5	0	0	0	YES (1977)	YES	8
Kamm/W/039	3	5	0	0	0	YES (1983)	YES	8
Kamm/W/040	3	0	0	2	0	NO	YES	5
Kamm/W/041	3	0	0	2	0	YES (1986)	YES	5
Kamm/W/042	3	5	5	2	5	NO	?	20
Kamm/W/043	10	5	0	0	5	NO	?	20
Kamm/W/044	10	0	0	0	5	NO	?	15
Kamm/W/045	3	0	0	2	0	RUN	YES	5
Kamm/W/046	3	0	0	2	0	RUN	YES	5
Kamm/W/047	3	5	0	2	0	NO	YES	10
Kamm/W/048	3	7	0	10	0	NO	?	20
Kamm/W/049	10	7	10	10	10	NO	NO	47
Kamm/W/050	3	7	10	10	10	NO	NO	40
Kamm/W/051	3	7	10	10	10	NO	NO	40
Kamm/W/052	3	5	0	5	0	RUN	YES	13
Kamm/W/053	3	5	0	0	0	RUN	YES	8
							Mean	**16.83**
							Std deviation	**12.21**

Table 4.3: Summarised results of spring vulnerability ranking

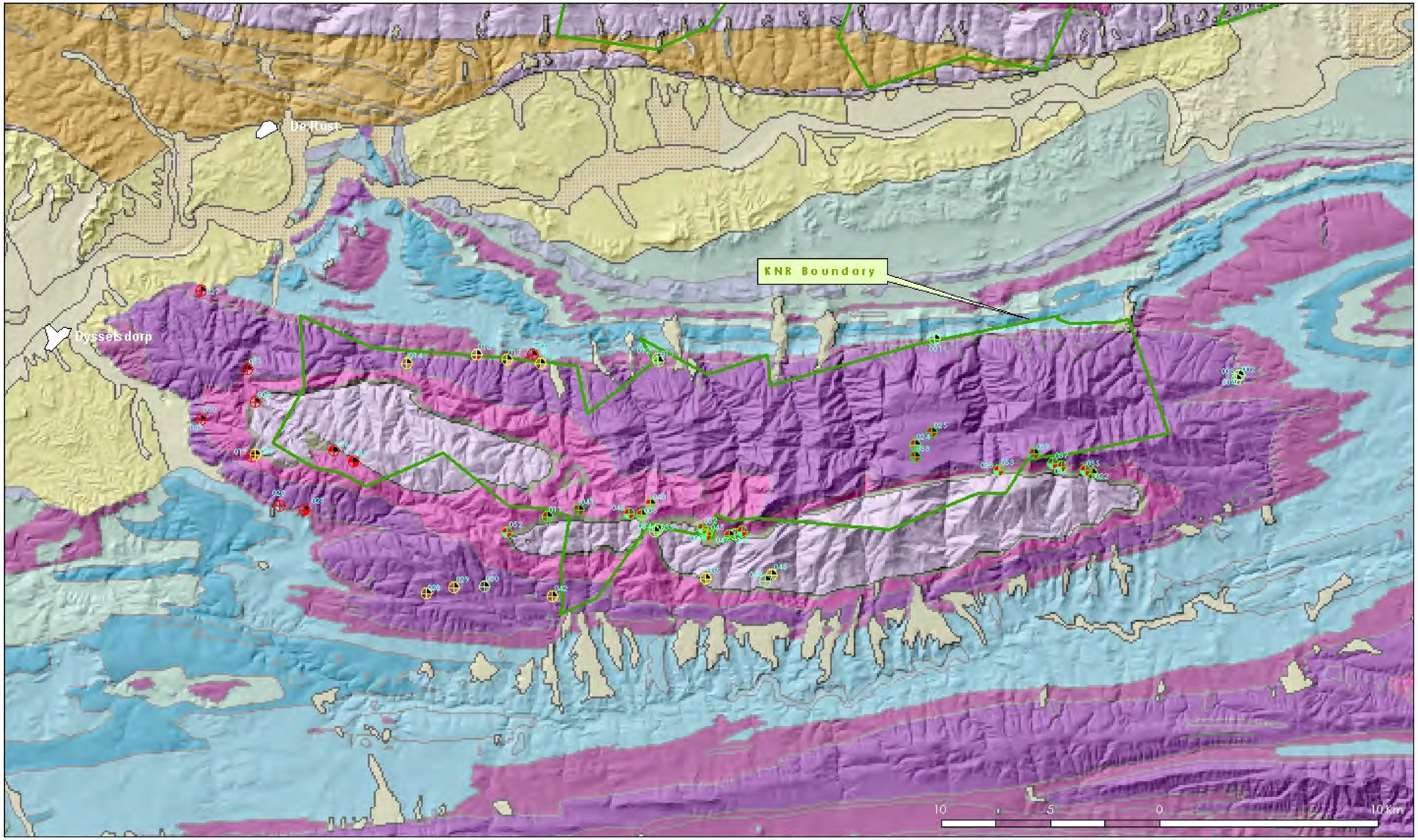
Spring vulnerability	Number of springs	Perched exclusion	Timing exclusion	Total Remaining*
Most likely	9	3	2	6
Intermediate	10	1	3	6
Least likely	34	23	15	8
Total	**53**	**27**	**19**	**20**

*** Thirteen springs are excluded on the basis of both timing as well as being perched.**

The springs identified by Western Cape Nature Conservation Board on the Kammanassie Mountain are shown in Figure 4.7 and are categorised according to vulnerability on the basis of the scores obtained. Those disqualified on the basis of timing of dry up or being perched are indicated.

A mean value 17 was obtained with a standard deviation 12. Those springs scoring in excess of one standard deviation above the mean (29) are considered "most vulnerable". Springs exceeding the mean but one standard deviation above the mean are classified as "intermediate" vulnerability, and those less than the mean "least vulnerable".

Of the 53 springs, 9 fall into the most vulnerable category, 12 into the intermediate vulnerable category and the remaining 32 least vulnerable to the influence of abstraction. No matter what the vulnerability ranking, springs can be disqualified from influence. It is notable that 33 springs (62%) were disqualified from influence on the basis of their being classified as draining perched systems, timing of dry up, or both.



Department: Water Affairs and Forestry
Departement: Waterwese en Bosbou

FIGURE 4.7 : Vulnerability Of Springs Identified By Cape Nature Conservation

REFERENCE

Vulnerability	Exclusion	Flow Status - 2002
Most	Perched	Dry/Standing
Intermediate	Timing	Flowing
Least	Refer to fig. 5.2 for Stratigraphy	

Date	April 2003
Compiler	Q.P. Wolmarans
Projection	Transverse Mercator (Wgs84)
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4.3.6 Comparing isotopic signatures

Table 4.4 shows isotopic analyses for the well field boreholes (Kotze, 2000a) together with data for spring samples analysed in this study (Figure 4.8).

Table 4.4: Tritium analysis for the well field boreholes and springs

Borehole Number	**Tritium (TU)**
VR11	0.3 +/- 0.1
VR8	0.4 +/- 0.1
VR7	1.0 +/- 0.2
VR6	0.4 +/- 0.1
VG3	1.3+/- 0.2
Spring Number	**Tritium (TU)**
020	0.1 +/- 0.3
023	5.4 +/- 0.4
036	2.7 +/- 0.3
037	2.5 +/- 0.3
045	1.2 +/- 0.3
046	1.0 +/- 0.3
048	3.1 +/- 0.4
049	3.5 +/- 0.4
050	2.5 +/- 0.3

The significant tritium in most of the springs is indicative of much younger water associated with the high altitude recharge area as opposed to the low tritium - older groundwater signature of discharge from the aquifer in which the well field was established. The high tritium values occur in springs disqualified on the basis of being perched. These values provide some backing for the interpretation that they are not sustained from the deeper groundwater system, which has lower tritium. A notable exception is low tritium value in spring 020 situated at low altitude in the discharge zone, probably discharging from the deeper aquifer.

Further evidence for this spring representing discharge from the deeper system is observed by examination of the 0xygen 18 versus Deuterium relationship for this spring, in comparison to the general signature of the Klein Karoo area (Kotze 2001). Spring 020 is the only spring that plots within the Peninsula aquifer cluster, indicating that it is sustained by discharge from this aquifer. The remaining springs which were interpreted as being perched are less depleted, approximating the rainfall signature. This indicated that these springs were sustained by rainfall, not the deeper aquifer.

4.4 DISCUSSION

4.4.1 Influence on discharge to the north (Vermaaks and Marnewicks Rivers)

It is clear that groundwater abstraction in the Vermaaks River Valley has reduced groundwater discharging from the catchment, but the superimposed effect of a declining rainfall trend is also evident. In the adjoining Marnewicks catchment there is no evidence of direct impact of groundwater abstraction on flow but the influence of reduced rainfall is observed.

There appears to be a lag period (7 years) between the start of abstraction, and significant impact on surface flow in the Vermaaks River. This is partially explained by the relatively low initial abstraction rate not significantly altering the hydraulic gradient to spring 009, as well as the buffering effect of alluvium with a high saturated storage in the river course. A sharp abstraction volume increase in November 1997 resulted in a groundwater level decline to a critical point causing flow direction reversal, and a reduction in discharge from the catchment of approximately 1.5 l/sec and the spring drying up. The impact on surface water is localised as spring 009 only sustained a localised surface water body that disappeared into the alluvium further downstream. Groundwater levels in December 2001 had declined to approximately two metres below surface at this site.

Abstraction had not impacted surface flow at the second spring (number 051, emanating 1.5 km further downstream) until November 2002 when flow noticeably declined almost immediately after drilling an artesian monitoring borehole (G46077 situated 250 m away). Details of this event are given in section 4.3.4. Once this artesian borehole was properly sealed the spring flow returned. A localised

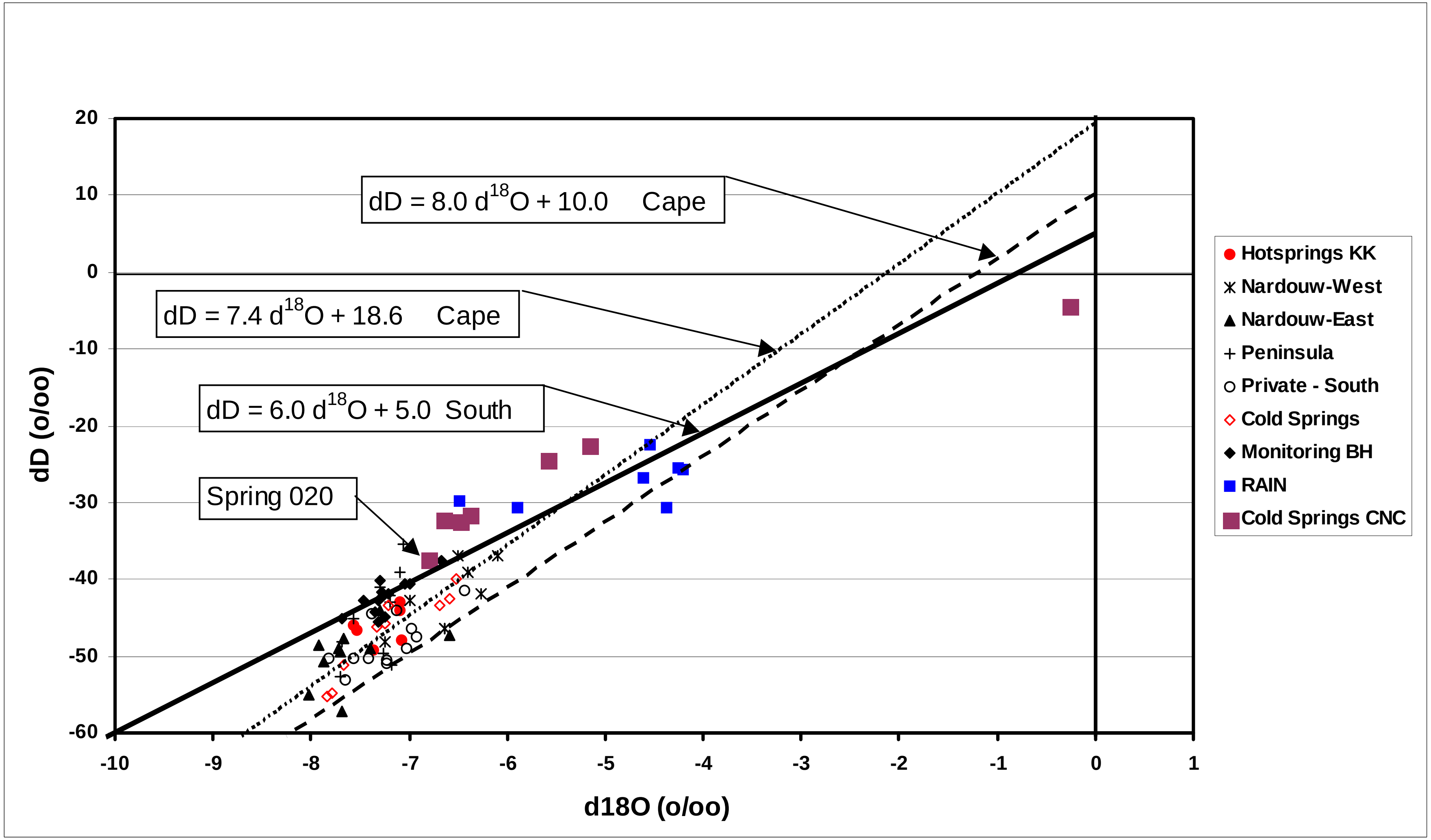

Figure 4.8: Isotopic signatures for groundwater and springs in the Klein Karoo (adapted from Kotze, 2001)

interruption in the perennial surface flow over a short stretch of river was experienced for approximately 6 months.

4.4.2 Influence on discharge to the south (Huis River and Diepekloof River)

There are no surface water monitoring devices and therefore no record of flow in rivers draining the southern side of the Kammanassie Mountain (e.g. the Huis River). Kotze (2001), for purposes of water balance calculation, claimed the flow of the Huis River to be 40 l/sec. Farmers report a gradual decline in Huis River flow since the commissioning of the well field in the Vermaaks River Valley. In 2002 the flow ceased. It is possible that there has been some influence of abstraction on the base flow, but the lower rainfall would also have contributed to flow reduction. The deduction that river flow could have been affected is based on the fact that:

- these rivers occur in the "aquizone"
- the Vermaaks River Fault directly connects the well field to the course of the Huis River
- the Huis River is within the theoretical well field radius of influence.

Direct impacts of well field abstraction on groundwater associated with the Vermaaks river fault could be expected to diminish, and is unlikely to extend much further than its intersection with the Huis River, approximately 9 km from the well field. This deduction was based on mapping by Halbich *et al.*, (1995) which revealed the Vermaaks River Fault dwindled to "almost nothing" and was virtually non-existent where it coincides with the Huis River. This also indicates that, even under unimpacted conditions, direct groundwater contributions from the fault to the discharge of the Huis River are likely to be limited. Similarly the Brillkloof and Leeublad faults diminish to nothing only 6 km south of the Vermaaks River. The Leeublad Fault does intersect the course of the Huis River but the extent of influence would also be restricted by the fading out of the fault in this vicinity.

Evidence for limited effects of abstraction in the Huis River area comes from the fact that:

- Leeublad springs 020 and 021 both had water (although standing) till 2000, despite the low rainfall. The former was running in 2002. Spring 021 was reported as dry in 1981 prior to any development in the Vermaaks River indicating that this spring is susceptible to natural drying up.

- Impact on the groundwater gradient toward the river (elevation 600mamsl) could be limited. This is indicated by the shallow groundwater level (10.5 metres below surface or approx. 630 mamsl) in monitoring boreholes drilled about 1 km north of the course of the Huis River.

The Diepekloof River is less likely to be directly influenced than the Huis River because it is situated even further east of the well field. Furthermore there is a low general degree of lineament interconnection between the well field and the headwaters of the Diepekloof River, limiting the potential for impact even further.

4.4.3 Influence on springs

It has been long recognised that the Cedarberg shale plays a prominent role in the occurrence of springs emanating from the Table Mountain Group aquifer (Meyer, 2001). These springs have usually been considered vulnerable to groundwater abstraction. However it has become clear from this research that the Cedarberg Formation is responsible for occurrence of a large proportion of springs emanating from perched water tables, which are not vulnerable to influences of abstraction from the main/deeper aquifer.

Twenty-seven springs (50%) on the Kammanassie Mountain clearly emanated from perched groundwater systems (type1), which can not be influenced by groundwater abstraction and were excluded from potential influence. Sixteen (30%) “water table” (type 1) springs occurr and are potentially vulnerable to the effects of abstraction if all other hydrogeological parameters permit. In a further 10 cases (19%) there is a possibility that the springs emanate from perched systems but there is an element of doubt.

Fifteen of the perched springs have dried up (5 before well field establishment) indicating susceptibility to low/irregular recharge from rain and/or snow.

This research only focused on the impacts of abstraction of 19 l/sec (0.6 million m^3/a) from the Vermaaks River well field and vulnerability ranking was carried out considering only the well field's potential influence. It has to be recognised, though, that other groundwater users tapping this resource would also impact the aquifer, thus potentially influencing surface/near surface flow. In areas of highly interconnected fracturing - such as the aquizone - private boreholes abstract 29 l/sec (0.9M m^3/a) for agriculture (Kotze, 2001) and could also influence base flow in the Huis River for example. Springs that reportedly used to flow in the vicinity of initially artesian agricultural boreholes (LD6, RF2, RF8, RF9) (Whittingham, 1972) have dried up. So too have 5 low-yielding springs at the Western extremity of the Mountain at Dysselsdorp (Meyer and Dyason*,* 1989) where an additional 0.4M m^3/a (12 l/sec) was abstracted by the Scheme. Even this instance 0.4M m^3/a (12 l/sec)was abstracted for agriculture (Rietfontein 142) at this site till 1998 and 0.2M m^3/a (6 l/sec) subsequently. Clearly this abstraction also contributed to groundwater level decline and drying up of springs as noted by Meyer and Dyasan *(*1989).

Those springs classified as having "most" and "intermediate" vulnerability are considered below. Attention is drawn to cases where there is strong potential for influence by abstraction other than that of the Vermaaks River well field.

Spring 009 (Vermaaks – Figure 4.6C) which flowed at approximately 10 /sec under natural conditions has certainly dried up as a result of abstraction. (Section 4.3.3.)

The reason why a further two which have dried up **(019 and 048)** is not fully understood but it is unlikely to be well field related. There are indications that these springs are perched and therefore should be excluded from consideration for influence. Evidence is as follows:

- These two "springs" (Figure 4.6D and Figure 4.9) occur at elevations of 758 and 775 metres respectively. These elevations are 66 and 83 metres higher than the highest estimated baseline water level at the catchment's divide at the head of the Vermaaks River Valley. Purely on this basis there were indications of a perched source for these springs.

- It would appear that the groundwater discharged even higher up on the slopes and merely collects in depressions in the river course situated at 019 and 048. Likely sources of this water were seen where concentrations of restoid fynbos.
- The high tritium (3.1 TU) for 048 taken during a very dry period.

One would usually expect to find a piezometric pressure driven springs in the valley floor in this and structural setting (at the Peninsula aquifer / Cedarberg Formation contact). Such springs would be vulnerable due to close proximity to the well field, structural connection via lineaments, and would be sustained by the main aquifer from which abstraction took place.

However there are indications that this type of spring does not occur at this site because the Cedarberg Formation is not an aquitard at this locality. Evidence that the Cedarberg Formation is not an aquitard was provided by a highly transmissive direct connection between the well field and borehole WK4 situated 1.6 km west of these springs. This is demonstrated by close resemblance of the groundwater levels recorded in the well field to the WK 4 groundwater level, and in particular a “step” in November 1997 coinciding with the increased abstraction in the well field.

There are two possibilities, both indicating 019 and 048 are not pressure driven springs:

- If 019 and 048 were pressure driven, WK4 would be artesian if the Cedarberg shale was penetrated in the borehole (no geological logs available). In reality the groundwater level in this borehole was 70 m below surface, and has been since records started in 1996, well before the springs dried up.
- Second, if WK4 drilled into Nardouw aquifer only, the direct connection with the Peninsula aquifer (from groundwater level response) would indicate that the intervening Cedarberg Formation freely transmits groundwater at Wagenpadsnek. If this is the case it is unlikely that the springs were pressure driven. Extrapolating between the well field water level and WK4, the

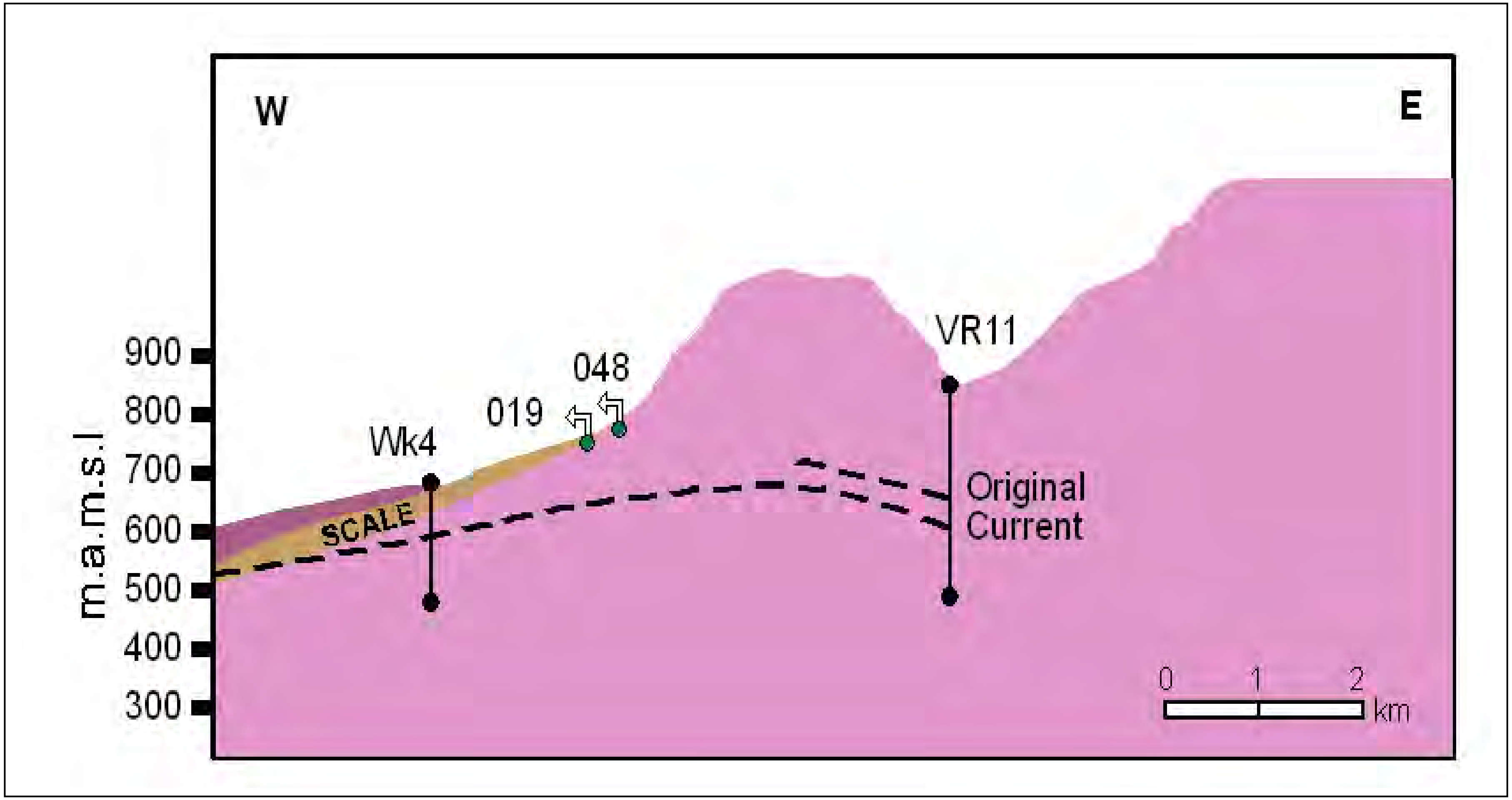

Figure 4.9: Wagenpadsnek linkage

groundwater level was estimated to be 45 metres below surface at the “spring” sites.

Springs 026 and 010

These perched springs occur near the origin of the Vermaaks River close to the topographic divide. They coincide with the Vermaaks River Fault but owe their origin to the fact that the Cedarberg Shale is down faulted as illustrated in Figures 4.6C and 4.6D. As a result this aquitard occurs at surface, inhibiting downward percolation. The deep aquifer groundwater is expected to be of the order of 200 metres below land surface in the vicinity of these springs and therefore can not be responsible for their occurrence.

Spring 051 (Figure 4.6C)

This spring is situated in the Vermaaks River 1.5 km north of the Cedarberg shale. Although occurring in the Nardouw, it is fed under pressure from the Peninsula aquifer. It was not influenced till Nov 2001 when it was impacted by the drilling of an artesian monitoring hole (G46077), and not abstraction per se. After successfully sealing the borehole spring flow returned in June 2002 and the groundwater returned to the pre-impact level.

Springs 014, 015, 016, 017 and 018 (Figure 4.6A)

This series of vulnerable springs occur on the northern slopes of the Kammanassie Mountain at the Kouga / Bavianskloof formation contact toward the base of the Nardouw aquifer. The likely reason for their occurrence is the higher feldspar content and hence clay products inhibiting transmissivity of the Baviaanskloof formation, forcing groundwater occurring in the Nardouw aquifer to surface in the stream channel. Spring 018 dried up in 1973 prior to the establishment of the Vermaaks River well field and is excluded from having been influenced on this basis. The timing of the dry up of 015 and 016 is “unknown”.

Although these springs are vulnerable, it is unlikely that abstraction in the Vermaaks River well field are the cause of any impact for the following reasons:

They occur to the east of the Marnewicks River that was likely to act as a recharge boundary. Any impact on groundwater levels is therefore likely to significantly influence flow in the Marnewicks River before influencing the springs. There is however no evidence of an impact on the flow. The possibility that the Marnewicks River acts as a recharge boundary stems from the fact that there is permanent flow in the river, and probably a good connection between the stream and fractured bedrock aquifer. It is unlikely that a low transmissivity clayey seal would form on the riverbed because of the relatively high flow rate in the river and scarcity of clayey parent rocks. Groundwater levels in boreholes drilled next to the Marnewicks River are at river level.

Further argument that these springs are unlikely to be influenced by Vermaaks well field abstraction comes from the fact that spring 051 (discussed above), much nearer to the well field, had not been influenced by abstraction. If, as in the case of 051, the series of springs were fed by fractures under pressure from the deeper Peninsula aquifer one would expect them to be influenced after 051 as they are further away and importantly at a much lower elevation. There is a much higher pressure-head differential between the series of springs and the head in the well field, compared to 051.

The possibility that abstraction from other Scheme wellfields and for agriculture from the Nardouw aquifer near Dysselsdorp has caused these springs to dry up is also slight. Reasons include:

- Groundwater levels at the Marnewicks River remain at river level, indicating abstraction has not caused a regional decline in water levels east of this point.
- The Nardouw Aquifer groundwater level at Dysselsdorp has been on a rising trend since 1993 – recovering approximately 30 metres.
- Spring 018 dried up in 1973 before groundwater development at Dysselsdorp and therefore this spring was excluded from influence.

Spring 027 (Figure 4.6A)

This spring occurrence is hydrogeologically similar to that of the above series. A similar argument as expounded for 051 could be made to show that it is unlikely that groundwater abstraction from the Peninsula aquifer has influenced this spring. It is further from the well field and at a lower elevation than 051, which has not been influenced. However 027 is likely to have been influenced by abstraction from the Nardouw aquifer well fields at Dysselsdorp. Here dramatic declines in the groundwater level occurred in the 1970s and 1980s. The fact that this spring only dried in 1994 and has not recovered despite the 30 m recovery of groundwater levels, which started at about that time, is somewhat puzzling.

Springs 020 and 021 (Figure 4.6D)

Spring 020 (1.26 l/sec [Meyer & Dyason, 1989]) was still flowing in 2002. Based on both isotopic evidence and the hydrogeological setting, this spring is likely to be fed by the Peninsula aquifer. Although vulnerable to abstraction from the Vermaaks River well field, to date this spring does not appear to have been affected. Spring 021 was reported dry in November 1988 (Meyer & Dyason, 1989) prior to Vermaaks development indicating a natural tendency for this spring to dry up.

Springs 049 and 050 (Figure 4.6D)

These occur at the Kouga/Baviaanskloof Formation contact. Based on the influence of well field abstraction on borehole WK4, these springs could be highly vulnerable because they also occur down plunge of the anticline axis relative to the well field. These springs dried up in 2001/2002, which could be in part related to abstraction, indicating a relatively long period before impact (8 years). It was important to note though that a farmer's irrigation borehole is situated within 300 m of this site.

Springs 028, 029 042, 005 and 043

These springs all dried up between 1997 and 2001. Although classified as "intermediate" vulnerability these springs all scored relatively low (20 or less). All are distant from the well field (between 10 and 20 km) and were beyond the "realistic" radius of influence (Xu *et al*., 2002). Nevertheless the possibility that these springs could have been influenced, even if only slightly, is not excluded entirely.

It is far more likely though that agricultural abstraction is responsible for any impacts on these springs. The springs occurred along a prominent east-west trending set of lineaments directly connected to an area where extensive use of groundwater is made by agriculture. On the other hand the Vermaaks well field is separated from these spring localities by a zone of relatively low fracture frequency and interconnectivity, in the vicinity of the Huis River. The closest spring was approximately 3 km east of the farms whose combined abstraction is nearly double that of the Vermaaks well field.

4.4.4 Climatic influences on groundwater recharge / spring flow

Climatic analysis for the Oudtshoorn Region is given in Chapter 3. The extreme rainfall events that occurred in 1981, 1985 and 1996, as well as the recent period of dry conditions from 1986 to 1992 and again from 1997 to 2000 (Figure 3.4) is significant. These events are likely to have negatively influenced recharge in this area.

The extreme rainfall events are, according to Rautenbach in part responsible for the gradual positive trend in the rainfall time series over a 75 year period. However flood events are not optimal for groundwater recharge as there is not adequate opportunity for water to soak in. For example the 1996 event when 240 mm rain fell in 2 days causing extensive runoff and flood damage in the Vermaaks river valley. It is deceptive therefore to consider rainfall totals such as these when estimating effective recharge to the aquifer. The positive rainfall trend therefore does not necessarily reflect a positive recharge trend. Sustained rainfall over a longer period of days or weeks is preferable for groundwater recharge.

The recent period of dry conditions from 1986 to 1992 and again from 1997 to 2000 will have resulted in lower recharge coinciding with the establishment of the KKRWSS. This is likely to have resulted in decreased soil moisture and recharge of aquifers. Declining flow of springs and base flow in rivers can be expected under such circumstances.

Chapter 3 does not provide an analysis of the short-term change in localised rainfall or snow on the Kammanassise Mountain. These may exert an important influence on the observed flow of perched springs in particular. Flows cannot be sustained for long periods as there is limited storage capacity, which does not receive regular replenishment to sustain flow.

Examination of rainfall records from a gauging station in the Vermaaksriver valley (Figure 4.5) reveals important information from a groundwater perspective. Prior to the flood in 1996 rainfall commonly exceeded 40 mm, but subsequently this amount is rarely attained. Generally lower recharge since the flood can be expected as a result.

Snow is particularly important for recharging perched springs on the topographically high terrain. Slow release of melt water provides adequate time for effective water penetration into the soil and fractured rock. Records of snow on the Kammanassie (Mannetjiesberg) show that snow fell from 1992 to 1998 but during the course of this study (1998 to 2002) no snow fell. It is possible that this played a role in dry up of perched springs 008 and 022 for example.

The overall impact of all the above is likely to have negatively influenced groundwater recharge on the Kammanassie during the period of the establishment and operation of the KKRWSS. This has complicates unravelling the impact abstraction versus climatic influences. These climatic influences are most likely to be first noticed in drying up of shallow / perched systems dependent on regular replenishment. Decreased soil moisture is also likely to result in less water being available to plants.

4.5 CONCLUSION

- Abstraction has impacted on the low flow discharging into the Vermaaks River.

- Superimposed on the abstraction effects is a declining precipitation trend since commissioning the well field.

- Under natural conditions permanent water occurs at two localities in the Vermaaks River Valley where springs emanated in the river course. These support localised ecosystems.

- Abstraction dried up one of these “permanent water” localities (spring 009) causing localised impact. The other spring (051) was temporarily affected and stopped flowing for 6 months.

- There appear to be a lag period (7 years) between the start of abstraction and significant impact on surface flow in the Vermaaks River.

- Of the 53 springs on the Kammanassie Mountain Range, 9 fall into the most vulnerable category, 12 into the intermediate vulnerability and the remaining 32 are the least vulnerable to the influence of abstraction.

- Twenty-seven springs (50%) on the Kammanassie Mountain clearly emanated from perched groundwater systems (type1), which can not be influenced by groundwater abstraction and are excluded from potential influence. Sixteen (30%) "water table" (type 2) springs occur and are potentially vulnerable to the effects of abstraction if all the other hydrogeological parameters permit. In a further 10 cases (19%) there is a possibility that the springs emanate from perched systems but there is an element of doubt.

- Thirteen (48%) of the perched groundwater table springs have dried up since the well field was established indicating their susceptibility to low/irregular recharge from rainfall and snow.

- Of the 9 most vulnerable springs, 3 are excluded from influence, as they are perched. Only one has definitely dried up as a result of abstraction (009). A further two of these springs are still flowing (051 and 020). In the remaining 4 cases there is a strong case to suggest other factors (agricultural, other scheme well fields and climate) played a significant role in springs drying up.

- Of the 10 intermediate vulnerability springs 3 are disqualified on the basis of timing of dry up and one on the basis of being perched. In the remaining 6 cases there are strong indications that other influences played a major role in spring dry up.

- Base flow in the Huis River is likely to have been influenced by abstraction from the well field but the volume cannot be quantified.

- This research only focused on the impacts of abstraction of 19 l/sec (0.6 million m^3/a) from the Vermaaks River well field. It has to be recognised that other groundwater users tapping this resource would also impact on the aquifer and potentially influence surface/near surface flow.

- It has been long recognised that the Cedarberg shale plays a prominent role in the occurrence of springs (Meyer, 2001). It has become clear that a large proportion of these springs emanates from perched groundwater tables and are not vulnerable to influences of abstraction.

4.6 RECOMMENDATIONS

It is recommended that:

- The ecological status of the system be classified, the environmental reserve be determined and resource quality objectives established in consultation with the community.

- The ecological value of the Vermaaks River ex-spring site (009) be evaluated to determine whether an environmental release of groundwater at this site is warranted.

- An environmentally acceptable water level should be determined for the well field. This should be done in consultation with the various stakeholders to address their respective needs.

- Additional monitoring boreholes and flow gauging be designed and established to provide the necessary data to assist with holistic investigation, including impacts of agricultural abstraction and peripheral well fields.

- Farming methods should be adapted to accommodate the changing rainfall pattern.

CHAPTER 5

VEGETATION

5.1. INTRODUCTION

There is a paucity of information in literature on relationships between vegetation and groundwater abstraction, pertaining to examples from Southern Africa. The limited nature of water resources in South Africa and the reality that surface water and groundwater cannot be separated, as water used in one form or from one source, will reduce the availability of water elsewhere (Scott and Le Maitre, 1998).

As early as 1989 farmers in the Klein Karoo suggested that groundwater exploitation was having a detrimental effect on karoo veld productivity (Landelike Water Skema Klein Karoo, 1989). According to Scott and Le Maitre (1998) the abstraction of groundwater may affect vegetation that is reliant on that groundwater body, where it discharges in springs, streams, rivers or wetlands or where it occurs near the ground surface and is directly tapped by plants.

According to Scott and Le Maitre (1998) the following generalised interactions between vegetation types and groundwater are relevent to present biomes:

- In the thicket biome groundwater interactions are probably limited to riparian situations, although many shrubs and trees are likely to be able to develop deep root systems where rocks are deeply weathered or fractured.

- In the fynbos biome, which is dominated by shrub species, shrubs are likely to be able to develop deep roots where possible but because groundwater resources are very limited in the shales, interactions with groundwater are probably minimal.

Riparian zones, especially in semi-arid to arid areas are important for biodiversity as they offer habitat and refuge for a variety of organisms (Milton, 1990). In nonperennial riparian zones, many are supported by alluvial aquifers and the perennial systems receive a substantial proportion of local groundwater fed baseflow (Colvin *et al.,* 2001).

Exploitation of groundwater resources can have a negative impact on both riparian and wetland communities, especially where wetlands depend on access to groundwater (Scott and Le Maitre, 1998). The impacts can be subtle, by lowering water tables seedling recruitment can be prevented and ultimately vegetation dynamics can be altered, but with little impact in the short term (Scott and Le Maitre, 1998). Community responses can be delayed until droughts or high abstraction rates, or both, lower the water table to a point where it passes the threshold of community resilience and there is mass mortality (Scott and Le Maitre, 1998).

Where groundwater is accessible, ecosystems will develop some degree of dependence on it and that dependence is likely to increase with increasing aridity of the associated environment (Hatton and Evans, 1998). Hatton and Evans (1998) identified four kinds of ecosystem dependence on groundwater, namely: terrestrial vegetation, river base flow systems, wetlands and spring systems and aquifer and cave ecosystems (subterranean living organisms). These types focus on direct users of groundwater but there are examples where the ability of these species to access groundwater maintains other species in that ecosystem (Colvin *et al.,* 2001). An example is “hydraulic lift” where deep-rooted plants absorb water during the day and then release it from their shallow root systems at night (Richards and Caldwell, 1987; Caldwell, Dawson and Richards 1998). The additional water released into the surface soil layers may be critical for maintaining shallow-rooted plants and any other dependent organisms in this kind of system (Colvin *et al.*, 2001). According to Colvin *et al.* (2001) the loss of deep-rooted species through, for example, lowering of the water table, may therefore result in a collapse or major transformation of such ecosystems.

5.2 METHODS

5.2.1 The vegetation of the Vermaaks, Marnewicks and Buffelsklip Valleys of the Kammanassie Nature Reserve

In order to distribute sample plots efficiently and effectively so that all relevant variation in vegetation would be sampled, the research area was stratified into physiognomic-physiographic units, by using 1:50 000 stereo aerial photographs and 1:30 000 non-stereo aerial photographs. These physiognomic-physiographic units were then verified in the field and the necessary changes effected to ensure that all variations in the vegetation were considered and sampled. A total of 92 sample plots were randomly located within these units at Vermaaks River, 18 at Marnewicks River and 19 at Buffelsklip.

The "nested plot" method was used to determine the minimum plot size. This can be defined as the area that on average contains at least 95% of the flora in a plot (Technikon SA, 1993). The quadrat size was determined to be 20 x 20 meters.

For the purpose of this research canopy cover-abundance of each species was assessed according to the Braun-Blanquet cover-abundance scale: r = >1%; 1 = 1-5%; 2a = 6-12%; 2b = 13-24%; 3 = 25-49%; 4 = 50-74% and 5=75-100% (Mueller-Dombois and Ellenberg, 1974). Fieldwork was carried out between May to August 2000 and May to July 2001.

Plant taxon names mostly conform to those given by Goldblatt and Manning (2000). These names may therefore differ from the plant species list used by the TURBOVEG database (Hennekens, 1996a), which is based on the PRECIS database of the National Botanical Institute (NBI) in Pretoria, as on date 1997. Dr J Vlok (Regalis Environmental Services) identified most of the plant species.

The percentage cover of grasses and herbaceous plants, shrubs (woody species varying in height between >0-3 m) and trees (woody species higher than 3 m) were also estimated.

The locality of each plot was determined using the Global Positioning System (GPS). Readings were taken using a Garmin III GPS. Environmental data recorded included aspect, altitude, slope, geology, soil, rock cover (%) and rock size (small, small/medium, medium, medium/large and large).

The floristic data was analysed according to Braun-Blanquet procedures using TURBOVEG (Hennekens, 1996a). A first approximation of the main plant communities was derived by applying the two-way indicator species analysis (TWINSPAN) (Hill, 1979b) to the floristic data. Further refinement of the classification was achieved by Braun-Blanquet procedures (Bredenkamp, Joubert and Bezuidenhout, 1989; Kooij, Bredenkamp and Theron, 1990; Bezuidenhout, 1993; Eckhart 1993; Brown and Bredenkamp, 1994). Results are presented in a phytosociological table by using MEGATAB (Hennekens, 1996b).

5.2.2 The vegetation of the springs on the Kammanassie Mountain

The vegetation at 52 of the known springs on the Kammanassie Mountain was surveyed. Spring number Kamm/w/027 (Dysselsberg) was the only spring that was not surveyed due to time constraints. This spring dried up in 1994.

Spring localities were identified by Kammanassie Nature Reserve Staff, who monitor these springs (flow rates and water samples) annually during February/March. Spring monitoring (flow rates) was initiated on the Kammanassie Mountain in 1999. To facilitate this monitoring, each individual spring was given a number, beginning at 001. The prefix Kamm is the standard Western Cape Nature Conservation Board (WCNCB) monitoring code used for the Kammanassie Nature Reserve (Van der Walt, 1993). The standard WCNCB code for water monitoring is indicated by the letter **w** (Van der Walt, 1993).

Floristic composition of springs was surveyed using the Braun-Blanquet cover scale (See 5.2.1), at the origin of the spring. The area sampled varied from spring to spring and was determined to include at least 95% of all flora species. Care was taken to sample only homogeneous spring vegetation and not include adjacent drier communities. Fieldwork was carried out between February and April 2002.

Plant taxon names mostly conform to those given by Goldblatt and Manning (2000), (See 5.2.1). The National Botanical Institute (Pretoria) identified mosses.

The percentage cover of grasses and herbaceous plants, shrubs (woody species varying in height between >0-3 m) and trees (woody species higher than 3 m) was also estimated.

The co-ordinates of each spring were determined using an Omnistar Global Positioning System (GPS). Environmental data recorded included aspect, altitude, slope, geology, soil, rock cover (%) and rock size (small, small/medium, medium, medium/large and large).

The floristic data was analysed according to Braun-Blanquet procedures (See 5.2.1). Results are presented in a phytosociological table. Springs showing similar plant communities were plotted on an ArcView (Version 3.2) Geographical Information System (GIS) generated map, to show their localities.

5.3 RESULTS

5.3.1 The vegetation of the Vermaaks, Marnewicks and Buffelsklip Valleys of the Kammanassie Nature Reserve

5.3.1.1 Classification

The analysis resulted in the following twenty-seven plant communities, which can be grouped into 13 major community types. The results are presented in a phytosociological table (Table 5.1). See Figure 5.1 and Figure 5.2.

General: *Dodonaea angustifolia-Rhus pallens* vegetation type

A: *Gymnosporia buxifolia-Osyris compressa* bush

1. *Elegia capensis-Miscanthus capensis* wet stream scrub
2. *Calopsis paniculata-Cliffortia strobilifera* wet streambank scrub

3. *Calopsis paniculata-Cliffortia strobilifera* wet streambank scrub
   3.1. *Calpurnia intrusa-Acacia karroo* streambank woodland
      3.1.1. *Heteromorpha arborescens* variant.
      3.1.2. Typical variant
   3.2. *Calpurnia intrusa-Diospyros dichrophylla* valley woodland
4. *Tarchonanthus camphoratus-Osyris compressa* streambank bush
5. *Euclea polyandra-Ficus burtt-davyi* valley and kloof woodland
   5.1. Typical sub-community
   5.2. *Euclea polyandra-Lachnostylos bilocularis* valley woodland
6. *Clutia alaternoides-Euclea polyandra* kloof (cliff) woodland
7. *Carrisa haematocarpa-Acacia karroo* river valley woodland
8. *Pentaschistis malouinensis-Rhus pallens* open slope scrub
9. *Osyris compressa-Rhus pallens* dense valley bush

B: *Euclea undulata-Portulacaria afra* succulent scrub

10. *Pteronia incana-Portulacaria afra* succulent scrub on shale
   10.1. *Euclea undulata-Portulacaria afra* succulent of steeper/higher slopes
   10.2. *Passerina obtusifolia-Portulacaria afra* succulent scrub of lower slopes

C: *Pteronia incana-Eriocephalus africanus* karroid scrub

11. *Pteronia incana-Eriocephalus africanus* karroid scrub

D: *Ischyrolepis ocreata-Elytropappus adpressus* fynbos

12. *Ischyrolepis ocreata-Protea nitida* open scrubby fynbos
   12.1. *Elytropappus adpressus-Protea nitida* open scrubby fynbos
   12.2. *Pentaschistis tortuosa-Dodonaea angustifolia* open scrubby fynbos
      12.2.1. Typical variant
      12.2.2. *Osyris compressa* variant
   12.3. *Metalasia pungens-Leucadendron salignum* scrubby fynbos
      12.3.1. *Phylica imberbis* variant
      12.3.2. *Chironia baccifera* variant
13. *Eragrostis plana-Ehrharta erecta* karroid grassland

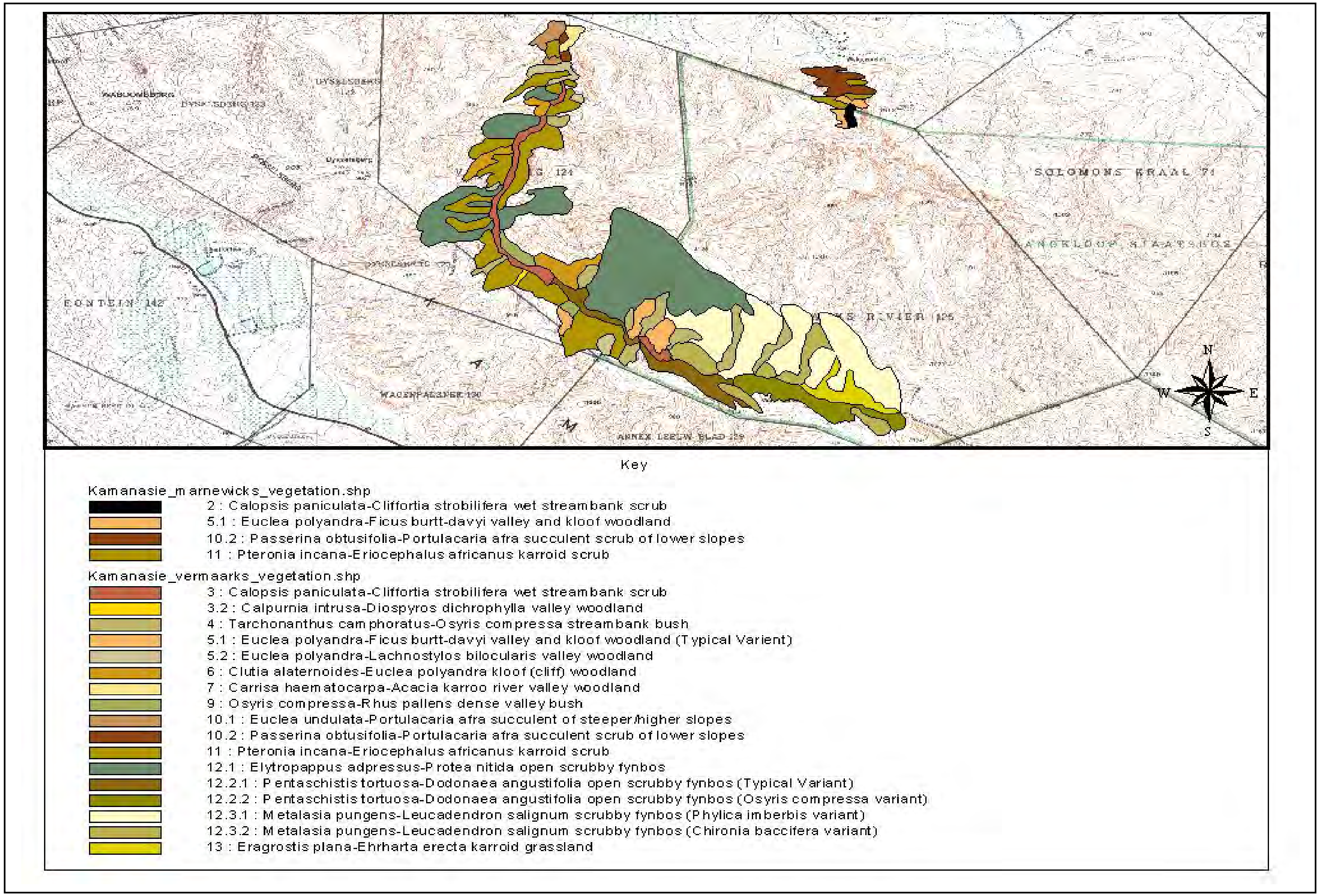

Figure 5.1: Vegetation Map of the Vermaaks and Marnewicks Valley sections of the Kammanassie Nature Reserve

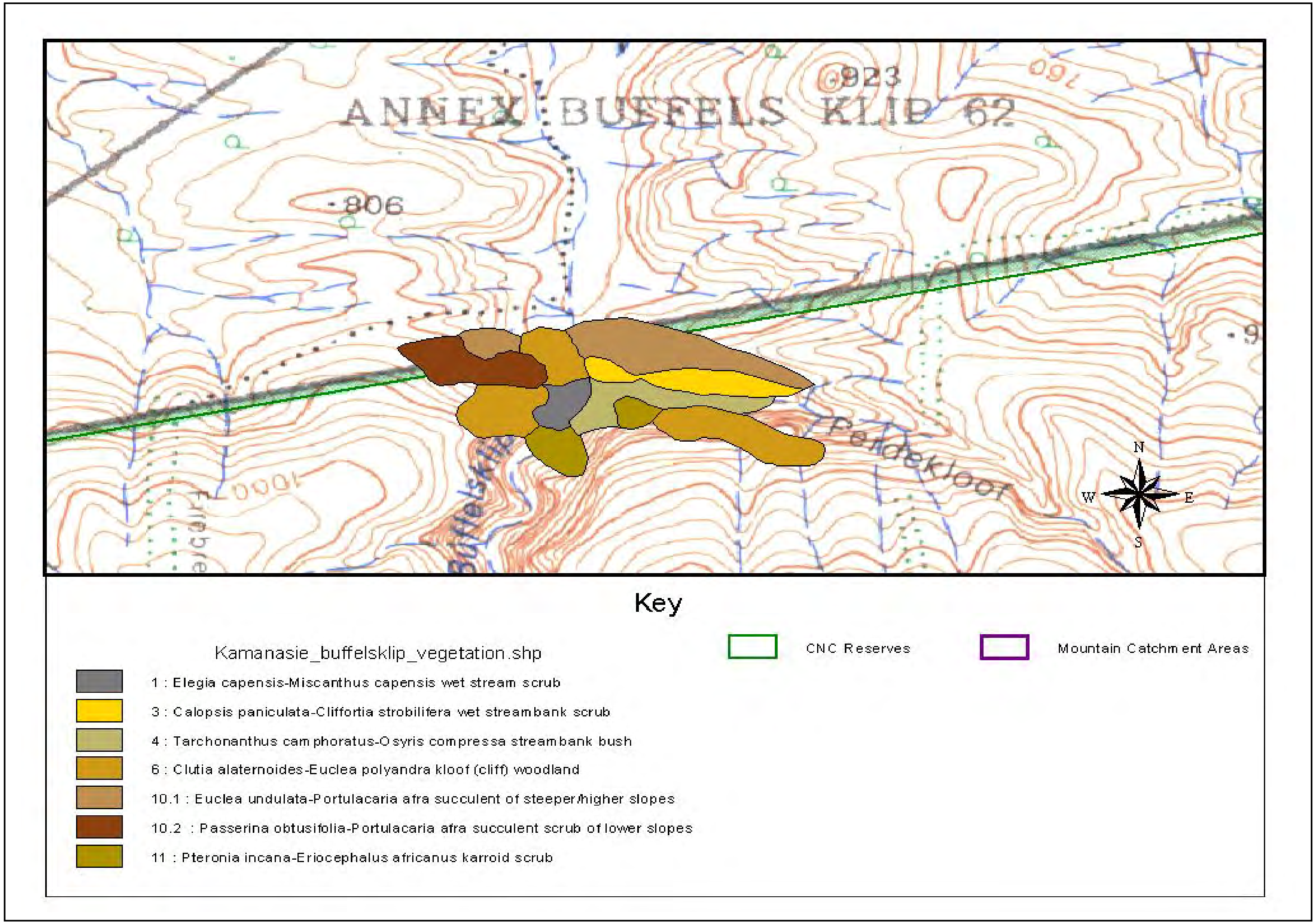

Figure 5.2: Vegetation Map of the Buffelsklip Valley section of the Kammanassie Nature Reserve

5.3.1.2 Description of the plant communities

Refer to Table 5.1 and Figures 5.1 and 5.2 for the descriptions of the different communities.

General: *Dodonaea angustifolia-Rhus pallens* vegetation type

A: *Gymnosporia buxifolia-Osyris compressa* bush

1. *Elegia capensis-Miscanthus capensis w*et stream scrub

Locality

This vegetation is found in patches in the streambed of the Buffelsklip River.

Environmental data

This wet stream scrub is restricted to the streambed of the Buffelsklip River at altitudes ranging from 698 to 732 m above sea level. The slope is between 4-15° with a western aspect. The alluvial soil is sandy with a 10% rock cover. Upstream of these relevés all flow of the river is channelled into a furrow causing the water at this site to flow only after heavy rains.

Vegetation cover

The total cover of this vegetation is 80%, of which the tree layer covers 0%, the shrub layer 5% and the herbaceous layer 70%.

Diagnostic and prominent taxa

The diagnostic species of the *Elegia capensis-Miscanthus capensis* stream scrub is listed in species group A. The diagnostic restio *Elegia capensis*, grass *Miscanthus capensis* and shrubs *Athanasia vestita* and *Stoebe burchellii* are dominant.

Other conspicuous species include the creeper *Dipogon lignosus* (species group C), shrubs *Tarchonanthus camphoratus* (species group G), *Morella humilis* (species group K) *Osyris compressa* (species group O), restio *Ischyrolepis ocreata* (species group U) and *Cliffortia ilicifolia* (species group Y). Other prominent shrubs (species group CC) include: *Rhus pallens*, *Nymania capensis*, *Dodonaea angustifolia*, *Elytropappus adpressus*, *Euclea undulata* and *Ficinia ramosissima*.

2. *Calopsis paniculata-Cliffortia strobilifera* wet streambank scrub

Locality

This sub-community occurs in the streambed of the Marnewicks River. Water flows permanently through these relevés.

Environmental data

The altitude varies between 548 to 568 m above sea level on a very gentle north to south-western slope. Rock cover is between 5–10% (small-to-medium). Soil in the river is sandy-loam.

Vegetation cover

Tree cover is 20%, shrub cover is 40% and the herbaceous layer is 30%.

Diagnostic and prominent taxa

Diagnostic species for the *Calopsis paniculata-Cliffortia strobilifera* wet streambank scrub include (species group B) the shrubs *Cliffortia strobilifera*, *Pelargonium pseudoglutinosum*, *Morella serrata*, *Helichrysum ordoratissimum*, *Pelargonium hispidum*, *Lobostemon glaucophyllus*, *Athanasia tomentosa*, the resio *Calopsis paniculata*, rush-like *Juncus lomatophyllus* and the fern *Thelypteris confluens*.

The shrubs Cliffortia ilicifolia (species group Y), Osyris compressa and Gymnosporia buxifolia (species group O), Rhus pallens, Dodonaea angustifolia and Elytropappus adpressus (species group CC) dominate this community.

Other prominent species include the trees *Calpurnia intrusa*, *Buddleja salviifolia* (species group C) and *Salix mucronata* (species group E). The shrubs *Conyza scabrida*, *Psoralea affinis* (species group E), *Euclea polyandra* (species group L), *Carissa haematocarpa* (species group P), Salvia *namaensis* (species group S), *Anthospermum aethiopicum* (species group T), *Pelargonium scabrum*, *Hermannia salviifolia* and the grasses *Ehrharta ramosa* and *Ficinia ramosissima* (species group CC) are also to be found.

The sedge *Mariscus thunbergii* is locally dominant with a cover of 50-70%.

3. *Calpurnia intrusa-Rhus pallens* moist streambank woodland.

Diagnostic taxa

This woodland is found on dry-to-moist streambanks scattered along the Vermaaks River. The tree *Calpurnia intrusa,* the shrub *Buddleja salviifolia*, the grass *Dipogon lignosus*, the forbs *Solanum linneanum, Nemesia fruticans, Senecio panduratus* and *Stachys aethiopica* and the fern *Pteridium aquilinum* (species group C) are diagnostic for this community.

This community is divided into two sub-communities of which one has two variants.

*3.1 Calpurnia intrusa-Acacia karoo s*treambank woodland.

Locality

This sub-community occurs in the streambed of the Vermaaks River Valley.

Environmental data

This sub-community occurs at altitudes between 543–675 m above sea level. Aspects of north-east and west with gentle slopes of 3° are dominant.

Soil is sandy-loamy in the alluvial streambed. Small-to-medium rocks occur at a cover of 5-40%.

Diagnostic and prominent taxa

The presence of the tree *Acacia karroo*, the woody vine *Clematis brachiata* and the dwarf shrub *Salvia africana-lutea* (species group D) are diagnostic for this sub-community.

Vegetation cover

Varies between 10 – 50%.

3.1.1 Heteromorpha arborescens variant.

Locality

This variant is found only in the Vermaaks River Valley, in the dry streambed in alluvial soils.

Environmental data

This variant is predominantly found on westerly slopes, with a gradient of between 1-16° at an altitude of 543–668 m above sea level. Rock cover (small-to-medium) varies from less than 5% to 40% with sandy soils dominant.

Vegetation cover

Trees and shrubs dominate the *Heteromporpha arborescens* variant, with 40% cover for each. The herbaceous layer has a cover of 10%.

Diagnostic and prominent taxa

The presence of the tree *Heteromorpha arborescens*, the creepers *Falckia repens* and *Rumex lativalvis*, the shrub *Lycium afrum*, the grass *Cynodon dactylon*, the forbes *Laportea peduncularis*, *Spergularia rubra*, *Aizoon canariense*, *Tetragonia portulacoides* and *Pelargonium grossularioides*, the fern *Histiopteris incisa*, the invasive plants *Gomphocarpus fruticosus* and *Solanum guineense* and the weed *Arctotheca prostrata* (species group F), is diagnostic for this variant.

This variant is dominated by the shrubs *Rhus pallens*, *Asparagus africanus*, *Pelargonium scabrum* and *Cliffortia ruscifolia* (species group CC). Trees *Acacia karroo* and *Clematis brachiata* (species group D), the shrub *Conyza scabrida* (species group E), the forb *Lepidium desertorum* (species group L), the tree *Gymnosporia buxifolia* and shrubs *Pelargonium zonale*, *Osyris compressa* and the forb *Oxalis pes-caprae* (species group O) are dominant species for this variant.

The trees *Cussonia paniculata* (species group G) and *Cassine eucleformis* (species group O) are prominent. Prominent shrubs include *Morella serrata* (species group B), *Buddleja salviifolia* (species group C), *Salvia africana*-lutea (species group D), *Psoralea affinis* and *Rubus pinnatus* (species group E), *Clutia alaternoides* (species group K), *Diospyros lycoides* (species group O). *Euclea schimperi* (species group J), *Clutia alaternoides* (species group K), *Euclea polyandra* (species group L), *Nymania capensis, Chrysocoma ciliata*, *Rhus tomentosa*, *Elytropappus adpressus*, *Galenia africana*, *Phylica paniculata* (species group CC) are present. The aromatic forbs *Mentha longifolia* and *Mentha aquatica*, (species group E) and the grasses *Ehrharta erecta*, *Ehrharta ramosa* (species group CC) and *Pentaschistis tortuosa* (species group V) are also prominent species for this variant.

3.1.2 Typical variant

Locality

This variant occurs in the river valley of the Vermaaks River.

Environmental data

This variant is found on north-east facing gentle slopes of 0–3°. The altitude varies between 577–583 m above sea level. Soil is sandy in the alluvium streambed. A rock coverage, comprising small rocks, of 10% is present.

Vegetation cover

Tree and shrub cover is between 30-50%, with a herbaceous layer of 10-20%.

Diagnostic and prominent taxa

Dominant species for this variant include the tree *Gymnosporia buxifolia* and large shrub *Osyris compressa* (species group O) and the large shrubs *Rhus pallens* and *Nymania capensis* and the succulent *Euphorbia maurianica* (species group CC).

Other prominent species include the trees *Acacia karroo* and *Clematis brachiata* (species group D), *Hetromorpha arborescens* (species group F) and *Lachnostylis bilocularis* (species group J). The shrubs *Pelargonium pseudoglutinosum* and *Morella serrata* (species group B), *Salvia africana-lutea* (species group D), *Psoralea affinis* (species group E), *Euclea polyandra* and *Sutera campanulata* (species group L), *Pelargonium zonale* and *Leonotis ocymifolia* (species group O), *Oedera squarrosa* and *Anthospermum galioides* (species group T), *Asparagus africanus*, *Chrysocoma ciliata*, *Dodonaea angustifolia*, *Elytropappus adpressus*, *Rhus tomentosa*, *Pelargonium scabrum*, *Phylica paniculata*, *Cliffortia ruscifolia* (species group CC) are also prominent for this variant. The grasses *Pentaschistis tortuosa* (species group V) and *Ehrharta erecta* (species group CC) and the forbs *Senecio panduratus* (species group C) and *Oxalis polyphylla* (species group BB) are prominent species for this variant.

3.2. Calpurnia intrusa-Diospyros dichrophylla valley woodland

Locality

The *Calpurnia intrusa-Diospryos dichrophylla* valley woodland sub-community occurs in the river valley of the Vermaaks River.

Environmental data

This valley woodland is found at altitudes between 678–810 m above sea level. Slope varies from gentle (2-3°) to moderate (10-16°) on predominantly north north-westerly slopes. This sub-community occurs in sandy alluvial soils of the streambed. Rock cover varies from either 20-40% medium-to-large or small-to-medium size, or 5% small rocks.

Vegetation cover

All relevés have 70% tree coverage, 25% shrubby layer and 5% herbaceous layer present.

Diagnostic and prominent taxa

Diagnostic species include all species listed in species group H, namely the large shrubs *Diospyros dichrophylla*, *Pterocelastrus tricuspidatus*, the dwarf shrubs *Felicia aethiopica*, *Peucedanum capense*, the forb *Cineraria lobata* and the grass *Pentaschistis* species (297).

Dominant species in species group CC include the shrubs *Rhus pallens*, *Nymania capensis*, *Asparagus africanus*, *Dodonaea angustifolia*, *Euryops rehmannii*, *Rhus tomentosa*, *Hermannia salviifolia*, *Phylica paniculata*, *Selago luxurians*, *Cliffortia ruscifolia* and the grass *Ehrharta ramosa*. The trees *Tarchonanthus camphoratus*, *Myrsine africana*, *Maytenus oleoides* (species group G), *Calpurnia intrusa* (species group C), *Gymnosporia buxifoila* and *Cassine eucleformis* (species group O) are dominant for this sub-community. The shrubs *Euclea crispa* (species group G), *Osyris compressa*, *Pelargonium zonale*, *Diospyros lycoides*, *Leonotis ocymifolia* (species group O), *Chrysanthemoides monilifera* (species group U) and the forb *Nemesia fruticans* (species group C) are dominant species for the *Calpurnia intrusa*-*Diospyros dichrophylla* valley woodland sub-community.

The trees *Cussonia paniculata* (specie group G), *Heteromorpha arboresens* and the invasive shrub *Solanum guineense* (species group F) are locally dominant. Species that occur prominently include the shrubs *Freylinia* densiflora (species group G), *Euclea polyandra* (species group L), *Oedera squarrosa* (species group T), *Elytropappus adpressus*, *Pelargonium scabrum*, and *Ficinia ramosissima* (species group CC). Other prominent species include the the weed *Solanum linnaeanum* (species group CC), the restio *Ischyrolepis ocreata* (species group U), the forbs *Senecio panduratus* (species group C) and *Cineraria alchemilloides* (species group G), the fern *Pteridium aquilinum* (species group C), the grasses *Eragrostis plana* (species group BB) and *Ehrharta erecta* (Species group CC) and succulent *Crassula tetragona* (species group CC).

4. *Tarchonanthus camphoratus-Osyris compressa* streambank bush

Locality

This community occurs in the Vermaaks and Buffelsklip River Valleys.

Environmental data

This streambank bush occurs at altitudes of 572–901 m above sea level. Aspect varies greatly but is dominant on western slopes. The gradient varies from gentle slopes (1-2°), moderate (8-15°) to steep (26-31°). A high rock coverage of 20-60% occurs with mostly medium-to-large rocks present. Sandy soil occurs in all relevés.

Vegetation cover

This plant community has a tree cover of 50%, shrub cover of 30% and a herbaceous cover of 10%.

Diagnostic and prominent taxa

The trees *Tarchonanthus camphoratus*, *Myrsine africana*, *Maytenus oleiodes*, *Cussonia paniculata*, the shrubs *Euclea crispa*, *Feylinia densiflora*, the forb *Cineraria alchemilloides* and the climber *Kedrostis nana* (species group G) are diagnostic for this plant community.

Other dominant plant species include the trees *Euclea polyandra* (species group L), *Gymnosporia buxifolia* (species group O), the shrubs *Sutera campanulata* (species group L), *Pelargonium zonale*, *Osyris compressa*, *Leonotis ocymifolia* (species group O), *Rhus pallens*, *Nymania capensis*, *Asparagus africanus*, *Dodonaea angustifoilia*, *Euryops rehmannii*, *Asparagus retrofractus*, *Rhus tomentosa*, *Pelargonium scabrum*, *Chrysocoma ciliata*, Elytropappus *adpressus*, *Euclea undulata*, *Hermannia salviifolia*, *Ficinia ramosissima*, *Phylica paniculata*, the forb *Selago luxurians*, the fern *Cheilanthes parviloba*, the grass *Ehrharta ramosa* and the climber *Cissampelos capensis* (species group CC).

Prominent species include the shrubs *Athanasia vestita* (species group A), *Pelargonium pseudoglutinosum* (species group B), *Salvia africana-lutea* (species group D), *Oedera squarrosa*, *Chysanthemoides monilifera* (species group U), *Chironia baccifera* (species group AA), the climber *Dioscorea hemicrypta*, the forb *Cyphia sylvatica* (species group L), the fern *Pteridium aquilinum* (species group C) and the grasses *Themedra triandra* (species group T) and *Cymbopogon plurinodis* (species group BB).

The trees *Acacia karroo* (species group D), *Cassine eucleformis* (species group O), the shrubs *Buddleja salviifolia* (species group C), *Diospyros dichrophylla*, *Pterocelastrus tricuspidatus* (species group H), *Euclea natalensis* (species group J), *Clutia alaternoides* (species group K), *Carissa haematocarpa* (species group P), *Pteronia incana* (species group R) and the restio *Ischryrolepsis ocreata* (species group U) are conspicuous locally.

5. *Euclea polyandra-Ficus burtt-davyi* valley and kloof woodland

Locality

The *Euclea polyandra-Ficus burtt-davyi* valley and kloof woodland is confined to the western part of the Kammanassie Mountain and is found on screes under steep cliff faces.

Diagnostic taxa

Diagnostic species of this sub-community include the trees *Ficus burtt-davyi*, the shrubs *Withania somnifera*, the invasive shrub *Solanum tomentosum*, the succulent *Cotyledon woodii*, the forb *Pelargonium trifidum* and the creeper *Kedrostis capensis* (species group I).

This community is divided into two sub-communities,

5.1 Typical sub-community

Locality

This sub-community is found on screes in the Vermaaks and Marnewicks Valleys.

Environmental data

Areas belonging to this kloof woodland are relatively steep with a gradient that varies between 8-35º. Altitude varies between 515-770 m above sea level on predominantly north-west and north-east slopes. Soils are sandy with small-to-large rocks, with coverage of 10-90%.

Vegetation cover

Tree cover is between 50-70%, shrub coverage is 10-40% and the herbaceous cover varies between 10-20%.

Diagnostic and prominent taxa

Diagnostic species of this sub-community included species listed in Group I.

The trees *Euclea polyandra* (species group L), the shrubs *Diospyros lycoides* (species group O), *Salvia namaensis* (species group S), *Rhus pallens*, *Nymania capensis*, *Euryops rehmannii*, *Asparagus* *retrofractus*, *Rhus tomentosa*, *Hermannia salviifolia*, *Phylica paniculata* (species group CC), the succulents *Tylecodon paniculatus*, *Aloe comptonii* (species group S), *Crassula ruprestris*, *Euphorbia mauritanica*, *Crassula rubricaulis* (species group CC) the creeper *Cissampelos capensis*, the fern *Cheilanthes parviloba* (species group CC) and the grasses *Digitaria eriantha* (species group S), *Ehrharta erecta* and *Ehrharta ramosa* (species group CC) are dominant locally.

Other prominent species include the trees *Gymnosporia buxifolia* and *Cassine eucleformis* (species group O) and the shrubs *Pelargonium zonale* and *Osyris compressa* (species group O).

The tree *Maytenus oleoides* (species group G), the shrubs *Euclea crispa* (species group G), *Euclea schimperi* (species group J), *Clutia alaternoides* (species group K), *Euclea undulata* (species group CC) and the grass *Cymbopogon plurinodis* (species group BB) are locally conspicuous.

5.2. Euclea polyandra-Lachnostylos bilocularis valley woodland

Locality

This valley woodland sub-community is found on screes in the Vermaaks Valley.

Environmental data

The altitude varies between 504-772 m above sea level on steep slopes (17-42º), and aspect varies greatly. Soil is sandy and rock cover is high, 30-50% (medium-large), found on screes, under cliff faces.

Vegetation cover

Tree coverage is 60-80%, with shrub cover between 5-25% and herbaceous cover between 5-15%.

Diagnostic and prominent taxa

The tree *Lachnostylos bilocularis*, the shrubs *Euclea schimperi*, *Melianthus comosus*, *Euclea natalensis*, the bulb *Haemathus albiflos*, the succulent *Crassula capitella* and the forb *Centella eriantha* (species group J) are diagnostic species for this sub-community.

Other dominant species for this sub-community include the trees *Ficus burtt-davyi* (species group I), *Euclea polyandra* (species group L), the shrubs *Clutia alaternoides* (spcies group K), *Pelargonium zonale* (species group O), *Rhus pallens*, *Nymania capensis*, *Asparagus africanus*, *Euryops rehmannii*, *Asparagus retrofractus*, Ficinia *ramosissima* (species group CC), the creeper *Cissampelos capensis* (species group CC), the fern *Cheilanthes parviloba* (species group CC), the succulents *Cotyledon* *woodii* (species group I), *Tylecodon paniculatus* (species group S), *Crassula rupestris*, *Euphorbia mauritanica*, *Crassula rubricaulis*, *Cotyledon orbiculare* (species group CC) and the grasses *Digitaria eriantha* (species group S) and *Ehrharta erecta* (species group CC).

Prominent species include the invasive shrub *Solanum tomentosum* (species group I), the shrubs *Sutera campanulata* (species group L), *Osyris compressa* (species group O), the climber *Kedrostis capensis* (species group I) and the grass *Ehrharta ramosa* (species group CC).

The trees *Maytenus oleoides*, *Cussonia paniculata* (species group G), *Gymnosporia buxifolia*, *Cassine eucleformis* (species group O), the shrubs *Euclea crispa* (species group G), *Portulacaria afra* (species group P), *Dodonaea angustifolia* and *Rhus tomentosa* (species group CC) are locally present.

6. *Clutia alaternoides-Euclea polyandra* kloof (cliff) woodland

Locality

The *Clutia alaternoides-Euclea polyandra* kloof (cliff) woodland is present in the Vermaaks Valley.

Environmental data

Altitude varies between 534-621 m above sea level, on east to south-west slopes of between 3-34º. Soil is sandy and rock cover of 30% is found on these scree slopes with medium-to-large rocks present.

Vegetation cover

Tree cover is 70%, with shrub cover of 15-25% and herbaceous cover of between 5-10%. Succulents dominate the herbaceous layer.

Diagnostic and prominent taxa

Diagnostic species for this plant community are given in species group K, and include the shrubs *Clutia alaternoides*, *Morella humilis*, the forb *Oxalis* species 676 and the succulent *Crassula atropurpurea*.

The tree *Euclea polyandra* (species group L), the shrubs *Euclea crispa* (species group G), *Rhus pallens*, *Nymania capensis*, *Euryops rehmannii*, *Asparagus retrofractus*, *Pelargonium scabrum* (species group CC), the climber *Kedrostis capensis* (species group I), the succulents *Adromischus caryophyllaceus*, *Aloe comptonii*, (species group S), *Crassula rupestris*, *Crassula rubricaulis* (species group CC) and the fern *Cheilanthes parviloba* (species group CC) are prominent.

Other prominent species include the trees *Maytenus oleoides* (species group G), *Ficus burtt-davyi* (species group I), *Gymnosporia buxifolia* (species group O), the shrubs *Pelargonium zonale* (species group O), *Portulacaria afra* (species group P), *Chrysocoma ciliata*, *Dodonaea angustifolia* (species group CC), the climber *Dioscorea hemicryptica* (species group L), the creeper *Cissampelos capensis* (species group CC), the succulents *Tylecodon paniculatus* (species group S), *Euphorbia mauritanica* (species group CC), *Cotyledon orbiculare* (species group CC) and the grasses *Digitaria eriantha* (species group S) and *Ehrharta ramosa* (species group CC).

7. *Carissa haematocarpa-Acacia karroo* river valley woodland

Locality

This community is found in the river valley of the Vermaaks Valley.

Environmental data

The altitude varies between 497-513 m above sea level, on south south-east and east slopes of 2-10º. Soil is sandy with small-to-medium rocks covering less than 5-10% of the soil surface.

Vegetation cover

Tree cover varies between 20-70%, shrub coverage between 25-60% and the herbaceous layer between 5-20%.

Diagnostic and prominent taxa

Diagnostic species for the *Carissa haemetocarpa-Acacia karroo* river valley woodland include the shrubs *Galenia papulosa*, *Lineum telephoides*, the creepers *Drosanthemum* cf. *delicatulum*, *Drosanthemum hispidum* and the grass *Sporobolus africanus* (species group M).

The trees *Acacia karroo* (species group D), *Gymnosporia buxifolia* (species group O), the invasive shrub *Solanum tomentosum* (species group I), the shrubs *Leonotis ocymifolia*, *Diospyros lycoides* (species group O), *Carissa haematocarpa* (species group P), *Rushia multiflora* (species group Q), *Chironia baccifera* (species group AA), *Rhus pallens*, *Nymania capensis*, *Dodonaea angustifolia*, *Galenia africana* (species group CC), the creeper *Cissampelos capensis* (species group CC), the forbs *Pollichia campestris* (species group Q), *Oxalis polyphylla* (species group BB), the succulent *Euphorbia maurianica* (species group CC), the parasite plant *Viscum capensis* (species group CC) and the grasses *Eragrostis plana* (species group BB) and *Ehrharta erecta* (species group CC) are dominant.

Prominent species in this plant community include the shrubs *Grewia robusta* (species group Q), *Pteronia incana* (species group R), *Hibiscus aethiopicus* (species group U), *Asparagus africanus*, *Chrysocoma ciliata*, (species group CC), the forbs *Lepidium desertorum* (species group L) and the succulent *Crassula subaphylla*.

The shrubs *Osyris compressa* (species group O) and *Elytropappus adpressus* (species group CC) are locally conspicuous.

8. *Pentaschistis malouinensis-Rhus pallens* open slope scrub

Locality

This plant community is found in the Buffelsklip Valley.

Environmental data

Steep slopes between 21-30º on south to south-western slopes vary in altitude between 709 -721 m above sea level. Soil is sandy with medium-to-large rocks covering 30-40% of the soil surface.

Vegetation cover

The tree layer is 10%, shrub coverage is 40% and the herbaceous cover is 20%.

Diagnostic and prominent taxa

The ferns *Cheilanthes hastata* and *Cheilanthes capensis*, the forb *Polyxena ensifolia*, the bulb *Spiloxene trifurcillata* and grass *Pentaschistis maloulnensis* (species group N) are the diagnostic species for this plant community.

Species dominant locally include the shrubs *Osyris compressa* (species group O), *Passerina obtusifolia* (species group Q), *Oedera squarrosa*, *Anthospermum aethiopicum* (species group T), *Rhus pallens*, *Nymania capensis*, *Asparagus africanus*, *Euryops rehmannii*, *Eriocephalus africanus*, *Ficinia ramossima* (species group CC), the fern *Cheilanthes parviloba* (species group CC), the succulent *Crassula capitella* (species group J), the forb *Cyphia sylvatica* (species group L), the creeper *Cissampelos capensis* (species group CC), the restio *Ischyrolepis ocreata* (species group U) and the grass *Ehrharta ramosa* (species group CC).

The tree *Maytenus oleoides* (species group G), the shrubs *Euclea crispa* (species group G), *Pterocelastrus tricuspidatus* (species group H) and *Euclea undulata* (species group CC) are prominent species.

9. *Osyris compressa-Rhus pallens* dense valley bush

Locality

This community is found in the Vermaaks and Buffelsklip Valleys.

Environmental data

Altitude varies between 650-775 m above sea level, on north, north-east and north-western aspects on slopes between 1-31º. Soil is sandy with rock cover 10-80% and less than 5% present at certain localities.

Vegetation cover

Shrubs have a cover of between 40-70% and the herbaceous layer has a cover of 10-20%.

Diagnostic and prominent taxa

Diagnostic species for this plant community include the tree *Gymnosporia buxifolia*, the shrubs *Pelargonium zonale*, *Osyris compressa*, *Leonotis ocymifolia*, *Diospyros lycoides* and the forb *Oxais pes-caprae* (species group O).

The shrubs *Clutia alatemoides* (species group K), *Pteronia incana* (species group R), *Oedera squarrosa* (species group T), *Rhus pallens*, *Nymania capensis*, *Asparagus africanus*, *Chrysocoma ciliata*, *Elytropappus adpressus*, *Euclea undulata* (species group CC), the forb *Aizoon canariense* (species group F), the creeper *Cissampelos capensis* (species group CC) and the grass *Ehrharta erecta* (species group CC) are dominant.

Other prominent species include the tree *Acacia karroo* (species group D), the shrubs *Euryops rehmannii*, *Asparagus retrofractus* (species group CC), the forb *Laportea peduncularis* (species group F), the weed *Arctotheca prostrata* (species group F), the parasite plant *Viscum capense* (species group CC), the succulents *Aloe comptonii* (species group S), *Euphorbia mauritanica* (species group CC), the grass *Themedra triandra* (species group T) and the ferns *Ceterach cordatum* (species group U) and *Cheilanthes parviloba* (species group CC).

The shrubs *Dodonaea angustifolia*, *Eriocephalus africanus* (species group CC) and the grass *Cynodon dactylon* (species group F) are conspicuous locally.

B: *Euclea undulata-Portulacaria afra* succulent scrub

10. *Pteronia incana-Portulacaria afra* succulent scrub on shale

Locality

This community is found in the Vermaaks, Marnewicks and Buffelsklip Valleys.

Diagnostic taxa

Diagnostic species for this community include the shrubs *Portularcaria afra*, *Carissa haematocarpa*, *Chaetacanthus setiger*, *Asparagus striatus*, *Putterlickia pyracantha* and the succulent *Pachypodium bispinosum* (species group P).

This community can be divided into the following two sub-communities:

10.1 Euclea undulata-Portulacaria afra succulent of steeper/higher slopes

Locality

This sub-community is found in the Vermaaks and Buffelskip Valleys.

Environmental data

This succulent dominated sub-community is found on steep slopes (23-34º), at altitudes between 524-782 m above sea level. Aspect varies greatly between north-east, north, west and south slopes and is found on shale bands. Soil is sandy with small-to-medium rocks with a coverage of 25-40%.

Vegetation cover

Tree coverage is 10%, shrub cover is 20-60% and the herbaceous layer is 10-40%.

Diagnostic and prominent taxa

The most dominant species in this sub-community include the shrubs *Pteronia incana*, *Helichrysum zeyheri* (species group R), *Rhus pallens*, *Nymania capensis*, *Elytropappus adpressus*, *Euclea undulata*, *Hermannia salviifolia*, *Eriocephalus africanus* (species group CC), the creeper *Cissampelos capensis* (species group CC), the fern *Cheilanthes parviloba* (species group CC), the succulents *Crassula muscosa* (species group R), *Tylecodon paniculatus*, *Adromischus caryophyllaceus*, *Aloe comptonii* (species group S), *Crassula rupestris*, *Euphorbia mauritanica*, *Cotyledon orbiculare*, *Crassula tetragona* (species group CC) and grass *Ehrharta erecta* (species group CC).

Other prominent species include the shrubs *Clutia alaternoides* (species group K), *Asparagus africanus*, *Chrysocoma ciliata*, *Dodonaea angustifolia*, *Euryops rehmannii*, *Galenia africana* (species group CC), the bulb *Drimea capensis* (species group S), the succulent *Crassula subaphylla*, the grasses *Digitaria eriantha* (species group S), *Themedra triandra* (species group T) and *Eragrostis plana* (species group BB).

The succulent *Crassula atropurpurea* (species group K) is present locally.

10.2. Passerina obtusifolia-Portulacaria afra succulent scrub of lower slopes

Locality

The *Passerina obtusifolia-Portulacaria afra* succulent scrub of lower slopes is found predominantly in the Marnewicks Valley, but also in the Vermaaks and Buffelsklip Valleys.

Environmental data

Altitude varies between 494-808 m above sea level, on slopes between 1-30º. Aspect varies greatly. Soils are sandy with small-to-medium rock size, with a rock coverage of 10-30%.

Vegetation cover

Tree coverage is 10%, shrubs cover is between 40-60% and the herbaceous cover is between 10-20%.

Diagnostic and prominent taxa

Diagnostic species for this sub-community include the tree *Grewia robusta*, the shrubs *Passerina obtusifolia*, *Polygala myrtifolia*, *Rushia multiflora* and the forb *Pollichia campestris* (species group Q).

The shrubs *Pteronia incana*, *Helichrysum zeyheri* (species group R), *Salvia namaensis* (species group S), *Felicia filifolia* (species group T), *Rhus pallens*, *Nymania capensis*, *Asparagus africanus*, *Chrysocoma ciliata*, *Dodonaea angustifolia*, *Asparagus retrofractus*, *Elytropappus adpressus*, *Euclea undulata*, *Eriocephalus africanus*, *Galenia africana* (species group CC), the creeper *Cissampelos capensis* (species group CC), the fern *Cheilanthes parviloba* (species group CC) and the succulents *Crassula muscosa* (species group R), *Tylecodon paniculatus*, *Adromischus caryophyllaceus*, *Aloe comptonii*, (species group S), *Crassula rupestris*, *Euphorbia mauritanica*, *Crassula rubricaulis*, *Cotyledon orbiculare* (species group CC) are dominant species for the *Passerina obtusifolia-Portulacaria afra* sub-community.

Other prominent species include the tree *Acacia karroo* (species group D), the shrubs *Diospyros lycoides* (species group O), *Ruschia lineolata* (species group T), *Chironia baccifera* (species group AA), the succulent *Crassula tetragona* (species group CC) and the grasses *Digitaria eriantha* (species group S) and *Eragrostis plana* (species group BB).

The shrubs *Euclea crispa* (species group G), *Clutia alaternoides* (species group K) and *Leonotis ocymifolia* (species group O) are locally conspicuous.

C: *Pteronia incana-Eriocephalus africanus* karroid scrub

11. *Pteronia incana-Eriocephalus africanus* karroid scrub

Locality

This community, which is the dominant plant community in the study area, is found in the Vermaaks, Marnewicks and Buffelsklip Valleys.

Environmental data

The altitude varies between 385-776 m above sea level on dry slopes of 16-33º. Aspect varies greatly. Soils are sandy with rock cover varying between 10-60% (small-medium-large).

Vegetation cover

The shrub cover is 50-70%, dominated by *Eriocephalus africanus* and the herbaceous coverage is 20-40%.

Diagnostic and prominent taxa

The shrubs *Osyris compressa* (species group O), *Asparagus striatus* (species group P), *Pteronia incana*, *Helichrysum zeyheri* (species group R), *Oedera squarrosa*, *Felicia filifolia*, *Rushia lineolata*, *Anthospermum aethiopicum*, *Anthospermum galioides* (species group T), *Rhus pallens*, *Nymania capensis*, *Asparagus africanus*, *Chrysocoma ciliata*, *Dodonaea angustifolia*, *Euryops rehmannii*, *Asparagus retrofractus*, *Elytropappus adpressus*, *Rhus tomentosa*, *Euclea undulata*, *Hermannia salviifolia*, *Eriocephalus africanus*, the bulbs *Drimia capensis* (species group S), *Urginea altissima* (species group T), the forb *Chlorophytum comosum* (species group T), the creeper *Cissampelos* *capensis* (species group CC), the fern *Cheilanthes parviloba* (species group CC), the parasite plant *Viscum capense* (species group CC), the succulents *Crassula muscosa* (species group R), *Tylecodon paniculatus*, *Adromischus caryophyllaceus* (species group S), *Crassula rupestris*, *Euphorbia mauritanica*, *Crassula rubricaulis*, *Cotyledon orbiculare*, *Crassula subaphylla* (species group CC) and the grasses *Digitaria eriantha* (species group S), *Themedra triandra* (species group T) and *Ehrharta ramosa* (species group CC) are the dominant species for this community.

Other prominent species include the shrubs *Passerina obtusifolia* (species group Q), *Pteronia* species 99 (species group S), *Hermannia flammea* (species group BB), *Ficinia ramosissma*, *Selago luxurians* (species group CC), the bulb *Massonia echinata* (species group CC), the forbs *Pelargonium trifidum* (species group I), *Oxalis punctata* (species group T), *Oxalis obtusa* (species group Z), *Selago glomerata* (species group BB), *Leysera tenella* (species group CC), the succulents *Aloe comptonii* (species group S), *Aloe ferox* (species group T), *Crassula tetragona* (species group CC), the restio *Ischyrolepis ocreata* (species group U) and the grass *Cymbopogon plurinodis* (species group BB).

The trees *Lachnostylis bilocularis* (species group J), *Gymnosporia buxifolia* (species group O), *Protea nitida* (species group U), the shrubs *Euclea crispa* (species group G), *Portulacaria afra*, *Chaetacanthus setiger* (species group P), *Salvia namaensis* (species group S) and *Chrysanthemoides monilifera* (species group U) are present locally.

D: *Ischyrolepis ocreata-Elytropappus adpressus* fynbos

12. *Ischyrolepis ocreata-Protea nitida* open scrubby fynbos

Locality

The *Ischyrolepis ocreata-Protea nitida* open scrubby fynbos is found in the Vermaaks River. This plant community is divided into three sub-communities.

Diagnostic and prominent taxa

Species diagnostic for this community include the tress *Protea nitida*, the shrubs *Chrysanthemoides monilifera*, *Montinia caryophyllacea*, *Hibiscus aethiopicus*, *Aspalathus laricifolia*, *Muraltia dispersa*, *Eriospermum capense*, *Helichrysum teretifolium*, the fern *Ceterach cordatum* and the restio *Ischyrolepis ocreata* (species group U).

12.1 *Elytropappus adpressus-Protea nitida* open scrubby fynbos

Locality

This sub-community is found in the Vermaaks River.

Environmental data

Altitude varies between 571-721 m above sea level on moderate to steep slopes (8-32º). Aspect varies greatly. Soil is sandy with a rock coverage of 5-20%, small-to-medium in size.

Vegetation cover

Tree coverage is 5-10%, shrubs cover 60-70% and the herbaceous layer has a coverage of 10-30%.

Diagnostic and prominent taxa

Dominant species include the shrubs *Oedera squarrosa*, *Felicia filifolia* (species group T), *Hermannia holosericea* (species group V), *Rhus pallens*, *Asparagus africanus*, *Dodonaea angustifolia*, *Elytropappus adpressus*, *Rhus tomentosa*, *Eriocephalus africanus*, *Selago luxurians*, *Senecio juniperinus* (species group CC), the bulb *Massonia echinata* (species group CC), the forb *Pelargonium myrrhifolium* (species group AA), the parasite plant *Viscum capense* (species group CC) and the grasses *Themedra triandra* (species group T) and *Ehrharta erecta* (species group CC).

The shrubs *Euclea crispa*, *Freylinia densiflora* (species group G), *Osyris compressa* (species group O), *Rushia multiflora* (species group Q), *Chrysocoma ciliata*, *Euryops rehmannii*, *Asparagus retrofractus*, *Pelargonium scabrum* (species group CC), the bulb *Urginia altissima* (species group T) and the fern *Cheilanthes hastata* (species group N) are prominent species for the *Elytropappus adpressus-Protea nitida* open scrubby fynbos sub-community.

Species present locally include the shrubs *Leucadendron salignum* (species group V), *Chironia baccifera* (species group AA), *Cliffortia ruscifolia* (species group CC) and the grasses *Pentaschistis tortuosa* (species group V) and *Eragrostis plana* (species group AA).

12.2. *Pentaschistis tortuosa-Dodonaea angustifolia* open scrubby fynbos

Locality

The Pentaschistis tortuosa-Dodonaea angustifolia open scrubby fynbos sub-community is found in the Vermaaks River.

Diagnostic taxa

The shrubs *Muraltia ericaefolia*, *Metalasia massonii*, *Polygala microlopha*, *Metalasia pallida*, *Aspalathus hystrix*, *Hermannia holosericea*, the forb *Pelargonium pulverulentum* and the grass *Pentaschistis tortuosa* (species group V) are diagnostic for this sub-community.

12.2.1. Typical variant

Environmental data

This variant occurs on dry steep slopes of 18-28º, at altitudes between 708–954 m above sea level. Aspect varies greatly but south and north north-west slopes are dominant. Soil is sandy with a rock coverage of 5-30% (small-medium-large).

Vegetation cover

Shrubs cover is 30-40% with herbaceous cover of 40-60%, with grasses dominating the herbaceous layer.

Diagnostic and prominent taxa

The shrubs *Osyris compressa* (species group O), *Pteronia* species 99 (species group S), *Oedera squarrosa*, *Felicia filifolia* (species group T), *Rhus pallens*, *Asparagus africanus*, *Dodonaea angustifolia*, *Elytropappus adpressus*, *Rhus tomentosa*, *Euclea undulata*, *Eriocephalus africanus*, *Ficinia ramosissima*, *Pelargonium scabrum*, *Phylica paniculata*, *Cliffortia ruscifolia*, *Senecio juniperinus* (species group CC), the bulbs *Urginea altissima* (species group T), *Massonia echinata* (species group CC), the forbs *Chlorophytum comosum* (species group T), *Printzia polifolia* (species group AA), the succulent *Crassula tetragona* (species group CC), the restio *Rhodocoma ciliata* (species group Y) and the grass *Themedra triandra* (species group T) are dominant species for this variant.

Prominent species include the trees *Myrsine africana*, *Maytenus oleoides* (species group G), the shrubs *Rushia lineolata* (species group T), *Hermannia cunefolia*, *Leucadendron salignum* (species group Y), *Chrysocoma ciliata*, *Asparagus retrofractus*, *Hermannia salviifolia* (species group CC), the bulb *Androcymbium capense* (species group Y), the fern *Cheilanthes hastata* (species group N), the forb *Senecio juniperinus* (species group CC), the succulents *Crassula muscosa* (species group R), *Crassula rupestris*, *Crassula rubricaulis*, *Crassula subaphylla* (species group CC) and the grass *Digitaria eriantha* (species group S).

Conspicuous species locally include the shrubs *Leucadendron rubrum* (species group Z), *Polygala fruticosa*, *Indigofera heterophylla* (species group AA), *Selago dregei* (species group BB), the succulent *Aloe ferox* (species group T), the forb *Oxalis polyphylla* (species group BB) and the grass *Aristida diffusa* (species group BB).

12.2.2. Osyris compressa variant

Environmental data

This variant occurs on north, north-east and north north-west dry steep slopes (11-25º), at high altitudes between 918 -1004 m above sea level. Soils are sandy with a rock coverage of 15-30%, comprising small, medium and large rocks.

Vegetation cover

Shrub coverage is 40-70% and the herbaceous cover is 10-30%.

Diagnostic and prominent taxa

Diagnostic species for this variant includes the shrubs *Pentzia elegans*, *Lobostemon fruticosus*, the fern *Pellaea calomelanos*, the forb *Pelargonium auritum* and the grass *Tribolium uniolae* (species group X).

The shrubs *Oedera squarrosa* (species group T), *Agathosma ovata* (species group Y), *Asparagus africanus*, *Dodonaea angustifolia*, *Asparagus retrofractus*, *Elytropappus adpressus*, *Euclea undulata*, *Eriocephalus africanus* (species group CC), the forb *Pelargonium myrrhifolium* (species group AA), the succulent *Crassula muscosa* (species group R) and the grass *Themedra triandra* (species group T) are dominant for this variant.

Other prominent shrubs include the shrubs *Felicia filifolia* (species group T), *Hermannia salviifolia*, *Senecio junipernus* (species group CC), the forbs *Chlorophytum comosum* (species group T), *Otholobium fruticans* (species group CC) and the succulents *Crassula rubricaulis* and *Crassula subaphylla* (species group CC).

The shrubs *Osyris compressa* (species group O), *Rhus pallens* (species group CC) and the grasses *Eragrostis plana* and *Cymbopogon plurinodis* (species group BB) are present locally.

12.3. Metalasia pungens-Leucadendron salignum scrubby fynbos

Locality

This sub-community is found in the Vermaaks Valley.

Diagnostic taxa

The *Metalasia pungens-Leucadendron salignum* scrubby fynbos diagnostic species include the shrubs *Clutia polifolia*, *Metalasia pungens*, *Cliffortia falcata*, *Erica curvifolia*, *Agathosma affinis*, *Hermannia cunefolia*, *Leucadendron salignum*, *Protea repens*, *Pteronia stricta*, *Elytropappus gnaphaloides*, *Cliffortia ilicifolia*, *Zygophyllum flexuosum*, *Agathosma ovata*, the bulb *Androcymbium capense*, the herb *Othonna auriculifolia*, the forb *Scabiosa columbaria*, the fern *Mohria caffrorum*, the restios *Rhodocoma arida*, *Restio fourcadei* and the grass *Aristea pusilla* (species group Y)

This sub-community has the following two variants:

12.3.1. Phylica imberbis variant

Environmental data

Altitude varies between 901-1004 m above sea level, on south, south south-west and south south-east slopes of 13-29º. Soil is sandy with a rock cover of 10-30% of medium-to-large in size.

Vegetation cover

Tree coverage is 10%, with the shrub layer coverage 65% and the herbaceous cover 10-30%.

Diagnostic and prominent taxa

Diagnostic species for the *Phylica imberbis* variant (species group Z) include the shrubs *Phyica imberbis*, *Muraltia leptorhiza*, *Leucadendron rubrum*, *Pelargonium laevigatum*, the forbs *Oxalis obtusa*, *Chamarea capensis* and the restio *Cannomois scirpoides*.

The shrubs *Clutia alatermoides* (species group K), *Anthospermum aethiopicum* (species group T), *Metalasia massonii* (species group V), *Rhus pallens*, *Dodonaea angustifolia*, *Elytropappus adpressus* and *Phylica paniculata* (species group CC) are dominant species for this variant.

Prominent species include the shrubs *Lobostemon fruticosus* (species group X), *Hermannia flammea* (species group BB), *Asparagus africanus*, *Pelargonium scabrum* (species group CC), the forb *Oxalis punctata* (species group T) and the grasses *Themedra triandra* (species group T) and *Ehrharta ramosa* (species group CC).

The shrubs *Felicia filifolia*, *Anthospermum galioides* (species group T), *Muraltia ericaefolia* (species group V), *Nymania capensis* (species group CC) and *Erica anguliger* are prominent.

12.3.2. Chironia baccifera variant

Environmental data

Altitude varies between 858-1114 m above sea level, on moderate to steep slopes (10-25º), on south, south south-east and south south-west slopes. Soil is sandy with a low rock coverage of 5-10%.

Vegetation cover

Tree cover is 25% with shrub cover varying between 20-60% and herbaceous cover of 20-60%.

Diagnostic and prominent taxa

The shrubs *Polygala fruticosa*, *Indigofera heterophylla*, *Plecostachys polifolia*, *Selago glomerata*, *Sutera denudata*, *Chironia baccifera*, the forbs *Disa bracteata*, *Pritzia polifolia*, *Pelargonium myrrhifolioum* and the bulbous herb *Corymbium africanum* (species group AA) are diagnostic species for the *Chironia baccifera* variant.

Dominant species include the shrubs *Oedera squarrosa* (species group T*), Aspalathus hystrix* (species group V), *Pentzia elegans* (species group Y), *Rhus pallens, Elytropappus adpressus, Rhus tomentosa, Hermannia salviifolia Cliffortia ruscifolia (*species group CC), the bulb *Urginea altissima* (species group T), the forb *Oxalis polyphylla* (species group BB) and the grasses *Themedra triandra* (species group T) and *Pentaschistis tortuosa* (species group V).

The shrubs *Rushia multiflora* (species group Q), *Felicia filifolia* (species group T), *Metalasia massonii* (species group V), *Athanasia trifurcata* (species group BB), *Dodonaea angustifolia, Ficinia ramosissma, Phylica paniculata* (species group CC) and the grass *Pentaschistis maloulnensis* (species group N) are prominent for this variant.

Locally conspicuous are the shrubs *Freylinia densiflora* (species group G), *Muraltia leptorhiza*, *Pelargonium laevigatum* (species group Z), *Eriocephalus africanus* (species group CC), the forb

Pelargonium pulverulentum (species group V) and the grasses *Eragrostis plana*, *Cymbopogon plurinodis*, *Aristida diffusa* (species group BB) and *Ehrharta erecta* (species group CC).

13. *Eragrostis plana-Ehrharta erecta* karroid grassland

Locality

This plant community occurs in the upper reaches of the Vermaaks River Valley.

Environmental data

Altitude varies between 926-990 m above sea level and is found on south south-west to west dry slopes of 1-2º. Soil is sandy with no rocks present.

Vegetation cover

Shrub coverage is 40-60% and the herbaceous cover, dominated by *Ehrharta erecta* is between 40-60%.

Diagnostic and prominent taxa

Diagnostic species for this community include the shrubs *Athanasia trifurcata*, *Hermannia flammea*, the forbs *Oxalis polyphylla*, *Selago dregei*, the bulb *Babania sambucina* and the grasses *Eragrostis plana*, *Cymbopogon plurinodis*, *Aristida diffusa* and *Aristida junciformis* (species group BB).

The shrubs *Rushia multiflora* (species group Q), *Felicia filifolia*, *Anthospermum galioides* (species group T), *Clutia polifolia* (species group Y), *Chrysocoma ciliata*, *Elytropappus adpressus*, *Aspalatus suaveolens* (species group CC), the creeper *Drosanthemum hispidum* (species group M), the forb *Leysera tenella* (species group CC), the restio *Ischyrolepis ocreata* (species group U) and the grasses *Pentaschistis maloulnensis* (species group N), *Themedra triandra* (species group T), *Pentaschistis tortuosa* (species group V) and *Ehrharta erecta* (species group CC).are dominant for this variant.

Prominent species include the shrubs *Erica curviflora* (species group Y), *Muraltia leptorhiza* (species group Z), *Pelargonium scabrum* (species group CC), the forbs *Pelargonium auritum* (species group V), *Chamarea capnsis* (species group Z), *Pelargonium myrrhifolium* (species group AA) and the grass *Ehrharta ramosa* (species group CC).

The shrubs *Lobostemon fruticosus* (species group X), *Leucadendron salignum* (species group Y) and the grass *Tribolium uniolae* (species group X) are prominent.

5.3.1.3 Floristic Analysis of the Vermaaks, Marenwicks and Buffelsklip Valleys of the Kammanassie Nature Reserve

Vermaaks Valley

The plant species total 441 species for the Vermaaks Valley, which represent 229 genera and 76 families (Appendix 2). Flowering plants are represented by Monocotyledoneae with 98 species in 16 families, Eudicotyledoneae with 329 species in 53 families and the Palaeodicotyledons with 1 species and 1 family. The Pteridophytes with 13 species in 9 families represent the non-flowering plants.

Marnewicks Valley

A total of 189 plant species were recorded in the Marnewicks Valley, which represent 120 genera and 57 families (Appendix 2). Flowering plants are represented by Monocotyledoneae with 42 species in 10 families and Eudicotyledoneae with 145 species in 44 families The Pteridophytes with 3 species in 3 families represent the non-flowering plants.

Buffelsklip

A total of 171 plant species were recorded in the Buffelsklip Valley, which represent 118 genera and 55 families (Appendix 2). Flowering plants are represented by Monocotyledoneae with 38 species in 12 families and Eudicotyledoneae with 128 species in 40 families The Pteridophytes (ferns) with 5 species in 3 families represent the non-flowering plants.

Plant species

A summary of where the same plant species were found is as follows:

Vermaaks, Marnewicks and Buffelsklip Valleys:	89 plant species
Vermaaks and Marnewicks Valleys:	75 plant species
Vermaaks and Buffelsklip Valleys:	62 plant species
Marnewicks and Buffelsklip Valleys:	2 plant species
Only found in the Vermaaks Valley:	215 plant species
Only found in the Marnewicks Valley:	22 plant species
Only found in the Buffelsklip Valley:	16 plant species
TOTAL:	**481 plant species**

Dominant plant families

Thirteen families dominate the Vermaaks, Marnewicks and Buffelsklip flora. By far the two largest families are the Asteraceae with 77 species, reflecting 16% of the total flora and the Poaceae with 40 species (8.3%). These families are followed by much smaller, yet significant families. The latter families are represented by the Crassulaceae with 25 species (5%), Fabaceae and Geraniaceae with 19 species (4%), Aizoaceae with 18 species (4%), Ericaceae with 16 species (3%), Scrophulariaceae with 15 species (3%), Restionaceae with 13 species (3%), Polygalaceae with 12 species (2%), Cyperaceae and Malvaceae with 11 species (2%) and Euphorbiaceae with 10 species (2%).

Red data species

The species discussed here are listed "rare-and-endangered" species according to Hilton-Taylor (1996). Six Red Data species were found, representing 1,25% of the Vermaaks, Marnewicks and Buffelsklip flora (Appendix 2). Red data species and the categorisation are indicated in the species list (Appendix 2).

The endangered species *Erica* sp nov (Ericaceae) was collected in the Marnewicks Valley. The following three rare species, namely: *Bobartia macrospatha* (Iridaceae), *Aspalathus suaveolens* (Fabaceae) and *Agathosma affinis* (Rutaceae) where found. The vulnerable species *Otholobium fruticans* (Fabaceae) was collected. The Orchidaceae *Holothrix pilosa* (intermediate) was collected in the Vermaaks and

Buffelsklip Valleys. Additionally one undescribed *Erica* species has been collected in the reserve which probably has a restricted distribution as well.

Alien Species

A total of 7 alien species were found during this survey, these are included in Appendix 2 and indicated by an asterix (***).**

5.3.2 The vegetation of the springs on the Kammanassie Mountain

5.3.2.1 Classification

The results are presented in a phytosociological table (Table 5.2).

The analysis resulted in the identification of the following fourteen plant communities, which can be grouped into 11 major community types (Table 5.2):

1. *Blechnum tabulare-Hippa frutescens* fern community
    - *1.1.* *Hippia frutescens-Helichrysum cymosum* shrubland
    - *1.2.* *Hippia frutescens-Helichrysum petiolare* shrubland
    - *1.3.* *Hippia frutescens-Ehrharta* species grassland
2. *Eragrostis plana-Juncus lomatophyllus* grassland
3. *Berzelia intermedia-Psoralea verrucosa* shrubland
4. *Cliffortia ilicifolia-Stoebe plumosa* shrubland
5. *Ehrharta ramosa-Aspalatus kougaensis* shrubland
6. *Conyza canadensis-Conyza scabrida* shrubland
7. *Phragmites australis* reed community
8. *Ehrharta erecta-Rhus pallens* shrubland
9. *Mentha longifolia-Thelypteris confluens*
10. *Pelargonium radulifolium-Salvia namaensis* shrubland
11. *Species 814-Crassula biplanata*

5.3.2.2 Description of spring plant communities

In the descriptions of the different spring plant communities, all species groups refer to Table 5.2. Figure 5.3 shows the position of the springs (spring numbers) with similar plant communities indicated in with same colour and symbol.

1. *Blechnum tabulare-Hippa frutescens* fern community

Locality

The springs with vegetation belonging to this community are found scattered on southern slopes on the Kammanassie Mountain.

Environmental data

The soils are loamy to clayey with rock cover varying between 5-40%. All the springs of this community are perennial and undisturbed.

Diagnostic and prominent taxa

Diagnostic species include the dwarf shrub *Hippa frutescens* and the ferns *Blechnum tabulare* and *Blechnum inflexum* (species group A).

This community can be sub-divided into the following three sub-communities:

1.1 Hippia frutescens-Helichrysum cymosum shrubland

Locality

The vegetation of springs Kamm/w/022 and 037 (Mannejiesberg), Kamm/w/031 (Elandsvlakte) and Kamm/w/052 (Wildealsvlei) fall within this sub-community.

Environmental data

Altitude varies between 1038-1361 m above sea level. All springs occur on gentle slopes (1-2°) with a south – southwestern aspect. Rock cover varies between 5 to 40%. All four springs were flowing and Kamm/w/022 standing at the time of the survey.

Vegetation cover

The shrub layer comprises 50-60% and the herbaceous layer 30-40%.

TABLE 5.2: Phytociological table of the vegetation of springs on the Kammanassie Mountain

Community number	**1**			**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
	1.1	**1.2**	**1.3**										
Relevè numbers	21 29 35 50	33 34	4 10 31 44	2 3 32 51	5 41 42 6 22 30 38 43 45	7 24 36 37 23 28 39	20 26 27	9 19 40	25 47	13 15 16 48	1 8 49	11 12 14 17	18 46
Species Group A (Diagnostic species of Blechnum tabulare-Hippia frutescens Fern Coomunity)													
Hippia frutescens	b 1 a +	. b	. + + +	. . . .	 1	+	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Blechnum tabulare	. a + .	. +	+ r . .	. . . .	. . . .	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Blechnum inflexum	. . 1 +	. .	. + . .	. . . .	. . . a	r	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Species Group B (Diagnostic species of Hippia frutescens-Helichrysum cymosum Shrubland)													
Helichrysum cymosum	+ + + r	. .	. . 1 1	. . . .	. r . . . . + + .	+ . 1 . . . +	. + .	. r +	. .	. . . .	. . .	. . . .	. .
Racomitrium lamprocarpum	. a a .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Calopsis paniculata	a + . .	. .	. . . .	. . . .	. . . .	. . . . . . +	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Species Group C (Diagnostic species of Hippia frutescens-Helichrysum petiolare Shrubland)													
Helichrysum petiolare	. . 1 .	3 3	. . . .	. . . .	. . . .	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Cliffortia burchellii	. . . .	+ +	. . . .	. . . .	. . . . 1	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Species Group D (Diagnostic species of Hippia frutescens-Ehrharta species Grassland)													
Ehrharta sp (747)	. . . .	. .	. a 3 a	. + . .	. . . .	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Pelargonium cordifolium	. . . .	. .	+ + . +	. . . .	. . . .	+	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Eleocharis limosa	. . . .	. .	b b . .	. . . .	. . 1	. . . .	. . .	. a .	. .	. . . .	. . .	. . . .	. .
Isolepis verrucosula	. . . .	. .	a r . .	. r . .	. . . .	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Rhus tomentosa	. . . .	. .	+ r . .	. . . .	. . . .	. . . .	. a .	. . .	. .	. . . .	. . .	. . . .	. .
Juncus capensis	. . . +	. .	. + . r	. . . .	. + ...	. . . .	. . .	. . .	. .	. . + .	. . .	. . . .	. .

TABLE 5.2 (continued)

Species Group E (Diagnostic species of Eragrostis plana-Juncus lomatophyllus Grassland)

Juncus lomatophyllus	. . . .	. +	+ . . .	a a . 3	. . . a 1 . . + .	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Eragrostis plana	. . . .	. .	. r . .	. r 1 +	+ . + + ... +	. . . . 1 a b	. . +	. . .	. .	. . . .	. . .	. . . .	. .
Pelargonium grossularioides	. . . .	. .	. . r .	r + r .	. . . .	. . . .	. . .	r . .	. .	. . . .	. . .	. . . .	. .
Panicum ecklonii	. . . .	. .	+ . + .	. . + 1	. . 1 . . . + . .	. . 1	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Vellereophyton vellereum	. . . .	. .	. . . .	. 1 . r	. . . .	. . . .	. . .	. . .	. .	. . . .	. . .	. . + .	. .
Pennisetum macrourum	. . . .	. .	. . + .	. + + .	. . . .	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. a
Gunnera perpensa	+ . . .	. .	. . . .	r 1 . .	. . . .	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .

Species Group F (Diagnostic species of Brezelia intermedia-Psoralea plumosa (Shrubland)

Psoralea verrucosa	. . + r	+ +	. r . .	. . . +	1 a 1 + + + + + +	r	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Berzelia intermedia	. . . .	. .	. . . .	. . . .	+ . . + r + 1 + +	r	. . .	. . .	. .	. . . .	. . .	. . . .	. r
Erica curviflora	. . . .	. .	. . . .	. . . .	. 1 1 r + a 1 . .	. . . b . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Watsonia fourcadei	. . . .	. .	a . . +	. . . .	a . b a . + . + .	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Platycaulos callistachyus	. . . .	. .	. . . .	. . . .	. + . . . + + + +	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Elegia filacea	. . . .	. .	. . . .	. . . .	. 1 . r r . . r .	. . . . . r .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Selago glomerata	. . . .	. .	. r . .	. . . .	. 1 + ... 1 .	. . . . . 1 .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Helichrysum anomalum	. . . .	. .	. . . .	. . . .	+ . . + . . . + .	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Centella eriantha	. . . .	. .	. . . .	. . . .	. 1 . r a	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Ischyrolepis ocreata	. . . .	. .	. . . .	. . . .	. . . . . + + . +	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Clutia alaternoides	. . . .	. .	. . . .	. . . .	+ . . + . . + . +	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Species 788	. . . .	. .	. . . .	. . . .	. . r . . + . r .	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Helichrysum zeyheri	. . . .	. .	. . . .	. . . .	1 . . . . . a . .	. + + ...	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Juncus dregeanus	. . . .	. .	. . . .	. . . .	. 1 1	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Melasma scabrum	. . . .	. .	. . . .	. . . .	. 1 + ...	. . . .	. . 1	. . .	. .	. . . .	. . .	. . . .	. .
Hymenophyllum tunbridgense	. 1 . .	. .	. . . .	. . . .	. + . + ...	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .
Plecostachys polifolia	. . . .	. .	. . . .	. . . +	. . . . 1 + . . .	. . . 1 . . .	. . .	. . .	. .	. . . .	. . .	. . . .	. .

Species Group G (Diagnostic species of Cliffortia ilicifolia-Stoebe plumosa Shrubland)

Stoebe plumosa	. . . .	. .	. . . .	. . . .	r . 1	. 1 1 a + . +	. . .	. . a	. .	. . . .	. . .	. . . .	. .
Cliffortia ilicifolia	. . . .	. .	. . . .	. . . .	. . . . + . + . .	r . . r . + b	. . 1	. . .	. .	. . . .	. . .	. . . .	. .
Pentaschistis sp (831)	. . . .	. .	. . . .	. . . .	. . . .	. 3 . . . a .	3 . .	. . .	. .	. . . .	. . .	. . . b	. .

TABLE 5.2 (continued)

Species Group H (Diagnostic species of Ehrharta erecta-Aspalathus kougaensis)

Aspalathus kougaensis	. . . .	. .	. . . .	. . . .	. . . .	. . . . r 1 .	**. 1 1**	r . .	. .	. . . .	. . .	. . . .	. .
Ehrharta ramosa	. . . .	+ .	. . . .	. . . .	r 1 1	. . . .	**1 . b**	. . .	. +	. . . .	. + .	. . . 1	. .
Phylica paniculata	. . . .	. .	. . . .	. . . .	. . . .	. . . .	**1 . +**	. . .	. .	. . . .	. . .	. . . .	. r
Ficinia ramosissima	. . . .	. .	. . . .	. . . .	. . . . r	. . . .	**+ 3 .**	. . +	. .	. . . .	. . .	. . . .	. .

Species Group I (Diagnostic species of Conyza canadensis-Conyza scabrida)

Conyza scabrida	. . . .	. .	. . . .	+ . . r	. . . .	. . . .	. . .	**a 3 3**	. .	. . . .	. b b	. . . .	. .
Conyza canadensis	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	**. 1 r**	. .	. . . .	. r .	. . . .	. .
Helichrysum nudifolium	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	**+ . 1**	. .	. . . .	. r r	. . . .	. .
Anthospermum aethiopicum	. . . .	. .	. . . .	. . r .	. + ... + . .	. . . . . . r	. . 1	**r . +**	. .	. . . .	. . .	. . . .	. .

Species Group J (Diagnostic species of Phragmites australis)

Phragmites australis	. . . .	. .	. . . .	. 3 . .	. . . .	. . . .	. . .	. . .	**5 3**	. . . .	. . .	. . . .	. .

Species Group K (Diagnostic species of Ehrharta erecta-Rhus pallens)

Rhus glauca	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . 1	. a	**. a + a**	r r .	r . a .	. +
Ehrharta erecta	. . + .	. .	. . . .	. 1 . .	. . . .	. . . .	. . 1	. . .	. .	**. b 3 .**	. . +	. . . .	b .
Pollichia campestris	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . .	. .	**r . + .**	. . .	. . + .	. .
Tarchonanthus camphoratus	. r . .	. .	r . . .	. . . .	. . . .	. . . .	. . .	. . .	. .	**. . 3 +**	r . .	. . . .	. .
Salix mucronata	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . .	. .	**1 3 . .**	. . r	. . . .	. .
Sutera campanulata	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . .	. .	**. + . +**	. . .	. . . .	. .

Species Group L (Diagnostic species Mentha longifolia-Thelypteris confluens)

Thelypteris confluens	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . .	. .	. . . .	**+ + a**	. . . .	. .
Mentha longifolia	+ . . .	. .	. . . .	+ . . .	. . . .	. . . .	. . .	. . .	. .	. . 1 .	**. a a**	. . . .	. .
Calpurnia intrusa	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . .	. .	. . . .	**. + +**	. . . .	. .
Pelargonium zonale	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . .	. r	. . . .	**. + +**	. . . .	. .
Stachys aethiopica	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . +	. .	. . . .	**r + .**	. . . .	. .

TABLE 5.2. (continued)

Species Group M (Diagnostic species of Pelargonium radulifolium-Salvia namaensis)

Salvia namaensis	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . .	. .	. . . .	. . .	b b + a	. .
Pelargonium radulifolium	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . +	. .	. . 1 .	. . .	. + . a	. .
Dipogon lignosus	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . .	. .	. . . .	. . .	. . r 1	. .
Cissampelos capensis	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . .	. .	. . . .	. . .	. . + 1	. .
Mariscus congestus	. . . .	. .	. . . .	. 1 . .	. . . .	. . . .	. . .	. . r	. .	. . . .	. . .	r r . .	. .

Species Group N (Diagnostic species of Species 814-Crassula biplanata)

Crassula biplanata	. . . .	. .	r . . .	. . . .	. . . .	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	+ r
Species 814 (forb)	. . . .	. .	. . . .	. . . .	. . . .	. . . .	. . .	. . .	. .	. . . .	. . .	. . . .	+ 1

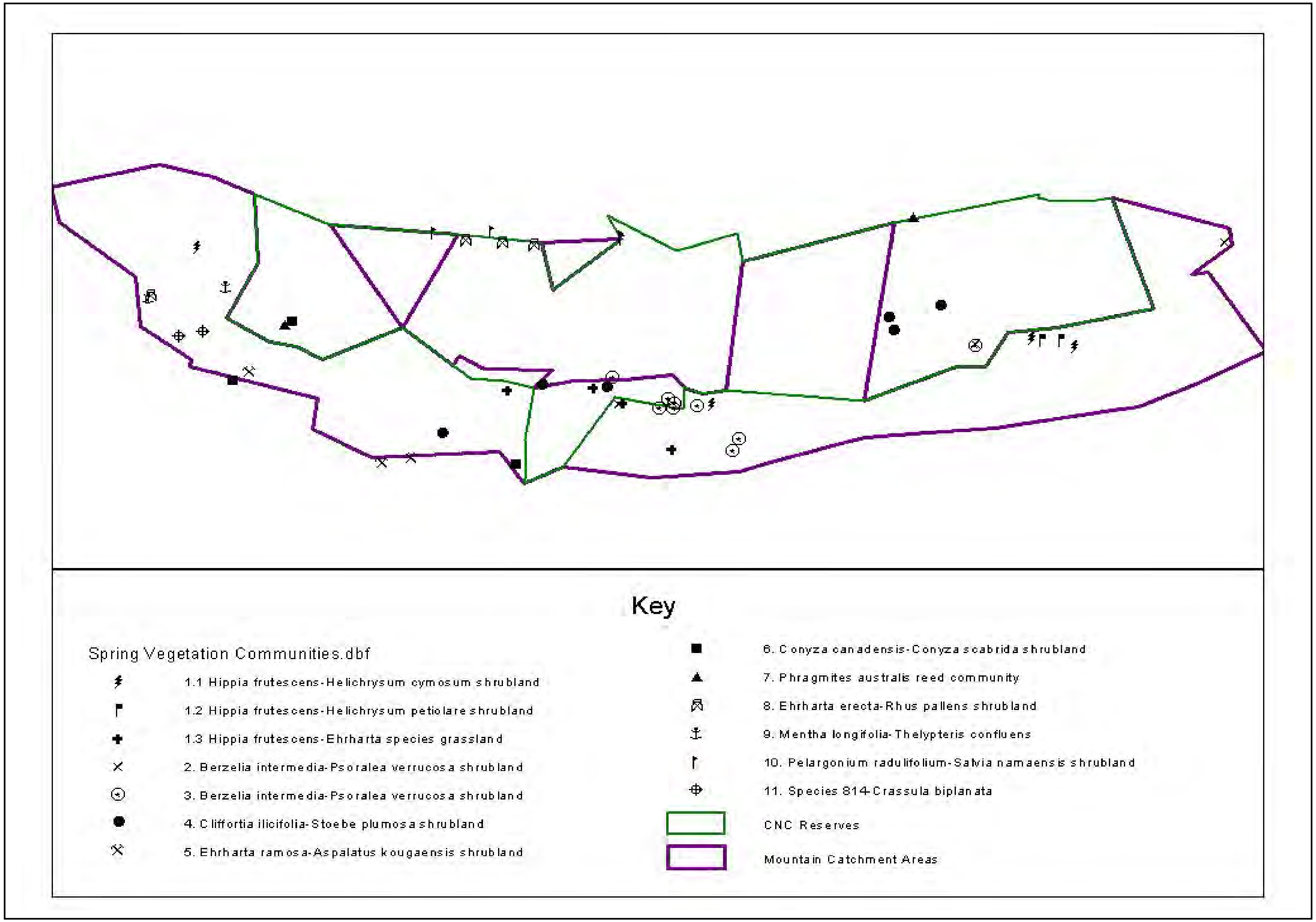

FIGURE 5.3: The vegetation communities of springs on the Kammanassie Mountain

Diagnostic and prominent taxa

Diagnostic species include the shrub *Helichrysum cymosum*, the moss *Racomitrium lamprocarpum* and the restio *Calopsis paniculata* (species group B). The dwarf shrub *Hippia frutescens* (species group A) is dominant while the ferns *Blechnum tabulare* and *Blechnum inflexum* (species group A) are diagnostic in this sub-community. The shrubs *Helichrysum petiolare* (species group C), *Psoralea verrucosa* and small fern *Hymenophyllum tunbridgense* (species group F) are prominent. Other prominent species include the cosmopolitan weed *Spergularia rubra* and moss *Jamesoniella* species 805.

1.2 Hippia frutescens-Helichrysum petiolare shrubland

Locality

The *Hippia frutescens-Helichrysum petiolare* sub-community is found at springs Kamm/w/035 and Kamm/w/036 (Mannetjiesberg) which were both flowing during the period of the survey.

Environmental data

These springs occur on gentle slopes (1-2°) between 1343–1394 m above sea level, where the aspect was south-southwest. Soil is sandy-loamy and with small-to-medium rocks, with a coverage of 30-40% of the soil surface.

Vegetation cover

Shrub cover is 70% and herbaceous cover is 30%.

Diagnostic and prominent taxa

Diagnostic species include the shrubs *Helichrysum petiolare* and *Cliffortia burchelli* (species group C). The shrub *Hippia frutescens* and the fern *Blechnum tabulare* (species group A) are prominantly present. The shrub *Psoralea verrucosa* (species group F) is also conspicuous in this sub-community.

1.3 Hippia frutescens-Ehrharta species grassland

Locality

This sub-community is found at the following springs: Kamm/w/005 (Buffelsdrif), Kamm/w/011 (Wildebeesvlakte), Kamm/w/033 (Elandsvlakte) and Kamm/w/046 (Upper Diepkloof). The spring Kamm/w/005 dried up in December 2001 and Kamm/w/033 dried up in 2000. At the time of the survey Kamm/w/011 was standing and Kamm/w/046 was flowing.

Environmental data

Altitude varies between 837-1154 m above sea level on a gentle slope. All these springs occur on south-facing slopes. Soils are sandy, while rock cover is very low, at most localities less than 5%.

Vegetation cover

Shrubs have a canopy coverage of 60% and the herbaceous layer has a canopy coverage of 40%.

Diagnostic and prominent taxa

Diagnostic species include the shrubs *Pelargonium cordifolium* and *Rhus tomentosa*, *grass Ehrharta* species (747), restios *Isolepsis verrucosula* and *Juncus capensis* and aquatic plant *Eleocharis limosa* (species group D). The shrub *Hippia frutescens*, ferns *Blechnum tabulare* and *Blechnum inflexum* (species group A) are also prominent. Other prominent local species include the shrub *Helichrysum cymosum* (species group B), restio *Juncus lomatophyllus* and grasses *Panicum ecklonii* and *Pennisetum macrourum* (species group E) and bulb *Watsonia fourcadei* (species group F).

2. *Eragrostis plana-Juncus lomatophyllus* grassland

Locality

The vegetation of springs Kamm/w/002 and 003 (Kleinfonteinsberg), Kamm/w/034 (Elandsvlakte) and Kamm/w/053 (Mannetjiesberg) represent this plant community. The springs Kamm/w/002 dried up in 1978, Kamm/w/003 dried up in 1999, Kamm/w/034 dried up in 2000 and Kamm/w/053 was flowing at the time of the survey.

Environmental data

Altitude varies considerably between 867-1405 m above sea level, while slope also varies considerably between 1-11°. The aspect is northeast to north-northeast. Rock cover is low and is less than 5% in most cases while the soil is loamy-clay.

Vegetation cover

Shrub cover is between 10-40% and the herbaceous layer between 40-60%.

Diagnostic and prominent taxa

Diagnostic species include grasses such as *Eragrostis plana*, *Panicum ecklonii*, *Pennisetum macrourum*, restio *Juncus lomatophyllus*, shrub *Gunnera perpensa* and the forbs *Pelargonium grossularioides* and *Vellereophyton vellereum* (species group E). Other prominent species that occur locally include grasses *Ehrharta* species 747 (species group D) and *Ehrharta erecta* (species group K), the tall reed *Phragmites australis* (species group J), and sedge *Mariscus congestus* (species group M).

3. *Berzelia intermedia-Psoralea verrucosa* shrubland

Locality

A total of nine springs, namely; Kamm/w/006 (Buffelsdrif), Kamm/w/007, 032 and 045 (Elandsvlakte), Kamm/w/023 (Mannetjiesberg), Kamm/w/040 (Kleinberg), Kamm/w/043 and 044 (Groenplaat) and Kamm/w/047 (Kleinrivier) form the habitat of the *Berzelia intermedia-Psoralea verrucosa* shrubland. The spring Kamm/w/006 dried up at the end of 2001, Kamm/w/040 and 043 dried up in 2000 and Kamm/w/047 is dry but the year its spring dried up is unknown. The springs Kamm/w/007, 032, 045 and 023 were all flowing at the time of this survey.

Environmental data

Altitude ranges between 927–1404 m above sea level. These springs occur on a slope between 1-17° and aspect varies greatly. Rock size is small to medium with a soil cover of between 5-40%. All these springs are situated on the southern slopes of the Kammanassie Mountain.

Vegetation cover

Shrubs and herbs have a canopy cover of 50%.

Diagnostic and prominent taxa

The diagnostic species from group F include: the shrubs *Psoralea verrucosa*, *Berzelia intermedia*, *Erica curviflora*, *Helichrysum anomalum*, *Clutia alaternoides*, *Helichrysum zeyheri* and *Plecostachys polifolia*., the bulb *Watsonia fourcadei*, restios *Platycaulos callistachyus*, *Elegia filacea*, *Ischyrolepis ocreata* and *Juncus dregeanus*, the forbs *Selago glomerata*, *Centella eriantha*, *Melasma scabrum*, Species 788 and the small fern *Hymenophyllum tunbridgense*.

Other locally dominant species are the shrubs *Ficinia nigrescens* (species group H) and *Helichrysum cymosum* (species group B), the grasses, *Eragrostis plana* and *Panicum ecklonii* (species group E) and *Ehrharta ramosa* (species group H) and the restio *Juncus lomatophyllus* (species group E). Further conspicuous species locally present include the shrubs *Stoebe plumosa* and *Cliffortia ilicifolia* (species group G) and *Anthospermum aethiopicum* (species group I). The mosses *Symphyogyna podophylla*, *Riccardia* species 790, *Sematophyllum* species 798 and *Campylopus* species 789 are prominent locally.

4. *Cliffortia ilicifolia-Stoebe plumosa* shrubland

Locality

The vegetation of springs Kamm/w/008 (Elandsvlakte), Kamm/w/024, 025 and 038 (Paardevlakte), Kamm/w/039 (Mannetjiesberg), Kamm/w/030 (Bergplaas) and Kamm/w/041 (Upper Diepkloof) represents a *Cliffortia ilicifolia-Stoebe plumosa* shrubland. All these springs were dry during the survey period. Most of these springs, excluding Kamm/w/008 (2000) and Kamm/w/030 (2001)), dried up before 1993.

Environmental data

Springs belonging to this shrubland are relatively flat with a slight gradient that varies between 1-2°. Altitude varies between 758 m–1475 m above sea level and aspect varies greatly. Soil is sandy-loam, while the rock cover varies between 40-50% with little to no rocks present in certain localities.

Vegetation cover

The shrub and herbaceous layer has a cover of 50%.

Diagnostic and prominent taxa

Diagnostic species include the shrubs *Stoebe plumosa*, *Cliffortia ilicifolia* and the grass *Pentaschistis* species 831, which grows in large tufts (species group G). Other locally dominant species include the shrubs *Helichrysum cymosum* (species group B), *Helichrysum zeyheri* (species group F), *Aspalathus kougaensis* (species group H) and the grass *Eragrostis plana* (species group E). The large shrub *Chrysanthemoides monilifera*, tree *Protea nerifolia* and succulent *Crassula ericoides* also occur locally.

5. *Ehrharta ramosa-Aspalatus kougaensis* shrubland

Locality

This plant community occurs at the following three springs: Kamm/w/021 (Leeuwblad) and Kamm/w/028 and 029 (Bergplaas). All these springs dried up between 1999 and 2000.

Environmental data

This community is found at lower altitudes (612m–797 m above sea level) with south or west facing aspects. The soil is very coarse gravel. Medium-to-large rocks with coverage of between 70-80% are common.

Vegetation cover

Shrub and herbaceous coverage is between 30-40%.

Diagnostic and prominent taxa

Species group H is diagnostic for this community and includes the shrubs *Aspalathus kougaensis*, *Phylica paniculata*, *Ficinia ramosissima* and grass *Ehrharta ramosa*. *Eragrostis plana* (species group E) is a dominant species. Another locally prominent species is the grass *Pentaschistis sp* 831 (species group G). The following species are locally present: the shrubs *Dodonaea angustifolia*, *Pteronia stricta Anomalanthus anguliger*, the grasses *Panicum repens*, *Pentameris* species 888, the restios *Tetraria capillacea*, *Juncus oxycarpus* and forbs *Ursinia anthemoides* and *Senecio ilicifolius*.

6. *Conyza canadensis-Conyza scabrida* shrubland

Locality

The vegetation of springs Kamm/w/010 (Wildebeesvlakte), Kamm/w/020 (Leeuwblad) and Kamm/w/042 (Ylandsrivier) represents the *Conyza canadensis-Conyza scabrida* shrubland.

Environmental data

This plant community occurs at a lower altitude (586–927 m above sea level), with slopes between 1-3°. The soils vary from sandy, loamy to clay, while rock cover varies between 0-50%.

Vegetation cover

The shrub cover varies between 30-50% and the herbaceous layer coverage is between 30-40%.

Diagnostic and prominent taxa

Species diagnostic for this community include the invader *Conyza scabrida*, the shrubs *Conyza canadensis*, *Helichrysum nudifolium* and *Anthospermum aethiopicum* (species group I). The shrubs *Stoebe plumosa* (species group G) and *Rhus pallens* (species group K) are locally prominent.

7. *Phragmites australis* reed community

Locality

The dominant vegetation of two springs Kamm/w/026 (Wildebeesvlakte) and Kamm/w/049 (Rietfontein) is *Pragmites australis*. At present these springs are both dry. Kamm/w/026 dried up in 1999 and Kamm/w/049 in 2001.

Environmental data

Altitude is between 624-862 m above sea level. Both have an aspect of west, with gentle slopes (1-3°). Soil varies from clay to gravel and rock cover varies 60% to no rocks present in certain localities.

Vegetation cover

The herbaceous layer is dominated by the reed *Phragmites australis* and has a cover of 70%. Shrub coverage varies between 10-30%.

Diagnostic and prominent taxa

This community has the reed *Phragmites australis* as the diagnostic and dominant species (species group J). The tree *Rhus pallens* (species group K) is locally prominent.

8. *Ehrharta erecta-Rhus pallens* shrubland

Locality

The four springs, Kamm/w/014 (Slawedam I) and Kamm/w/016 (Slawedam II) and Kamm/w/017 (Rooielskloof) and Kamm/w/050 (Rietfontein), are the habitat of the *Ehrharta erecta-Rhus pallens* shrubland. The spring Kamm/w/014 dried up in 1994, Kamm/w/017 dried up in 1999 and Kamm/w/016 is dry but the date it dried up is unknown. Spring Kamm/w/050 was standing during the period of the survey.

Environmental data

Altitude is between 553 –602 m above sea level. Aspect varies between north to north-east and west. Soil is coarse gravel, with medium-to-large rocks present with a coverage of between 60-80%.

Vegetation cover

This shrubland has a tree coverage of 10-50%, a shrub coverage of 30-50% and herbaceous coverage of 10-20%.

Diagnostic and prominent taxa

Species from species group K are diagnostic for this community and include the trees *Tarchonanthus camphoratus* and *Salix mucronata*, the large shrub *Rhus pallens*, the small shrub *Sutera campanulata*, the grass *Ehrharta erecta*, and forb *Pollichia campestris*. The aromatic forb *Mentha longifolia* (species group L) is prominently present.

9. *Mentha longifolia-Thelypteris confluens*

Locality

The vegetation of springs Kamm/w/001 (Buffelsklip), Kamm/w/009 and 051 (Vermaaks River) represent this plant community. The spring Kamm/w/001 was standing at the time of the survey, Kamm/w/009 dried up in 1999 and Kamm/w/051 dried up at the end of 2001.

Environmental data

Altitude is between 569-711 m above sea level and aspect varies between west, south and north-northwest on a gentle slope. Soil is loamy-sandy with rock cover between 30-60% and less than 5% in certain areas.

Vegetation cover

The shrub and herbaceous layer have a 50% coverage.

Diagnostic and prominent taxa

The tree *Calpurnia intrusa*, the shrubs *Pelargonium zonale* and *Stachys aethiopica*, the forb *Mentha longifolia* and fern *Thelypteris confluens* (species group L) are diagnostic species of this community. *Conyza scabrida* (species group I) and grasses *Ehrharta ramosa* and *Ehrharta erecta* (species group H and K) are locally dominant.

10. *Pelargonium radulifolium-Salvia namaensis* shrubland

Locality

This plant community occurs at the following springs: Kamm/w/012 and 013 (Kleingeluk), Kamm/w/015 (Slawedam II) and Kamm/w/018 (Solomanskraal). All the springs dried up before 1996. They are found on the northern slopes of the Kammanassie Mountain.

Environmental data

These springs occur at altitudes between 533-684 m above sea on north to north-east gentle slopes (2°). Soil is predominantly sandy to coarse gravel, with rock cover between 20-50% (medium-to-large).

Vegetation cover

Shrub coverage varies between 50-70% and the herbaceous laver has a cover between 10-30%.

Diagnostic and prominent taxa

Diagnostic species include the shrub *Salvia namaensis*, the forb *Pelargonium radulifolium*, the creepers *Dipogon lignosus* and *Cissampelos capensis* and the sedge *Mariscus congestus* (species group M). The grass *Ehrharta ramosa* (species group H) and tree *Rhus pallens* (species group K) occur locally while the sedge *Mariscus thunbergii* is locally conspicuous.

11. *Species 814-Crassula biplanata*

Locality

The vegetation of the springs (Kamm/w/019 and 048) at Wagenpadnek represent this plant community. Kamm/w/019 dried up 1999 and Kamm/w/048 was standing at the time of the survey.

Environmental data

These springs occur on gentle west or south slopes at an altitude between 718–732 m above sea level. Soil is sandy with small-to-medium rocks with a cover of 10-20%.

Vegetation cover

Shrub cover is 60% and the herbaceous layer has a coverage of 30%.

Diagnostic and prominent taxa

The forb Species 814 and succulent *Crassula biplanata* are diagnostic species (species group N). The grasses *Pennisetum macrourum* and *Ehrharta erecta* (species group E and K) are locally prominent.

5.3.2.3 Floristic Analysis of springs on the Kammanassie Mountain

A total of 244 plant species were recorded for springs, which represent 145 genera and 71 families (Appendix 3). Flowering plants are represented by Monocotyledoneae with 63 species in 7 families and Eudicotyledoneae with 156 species in 43 families The Pteridophytes with 12 species in 8 families represent the non-flowering plants. A total of 12 species in 12 families of Bryophytes (Mosses) were found. One species of Gymnosperm was found.

Dominant plant families

Seven families dominate the flora found at springs on the Kammanassie Mountain. By far the two largest families are the Asteraceae with 41 species, reflecting 14.5% of the total flora and the Poaceae with 25 species (8.8%). These are followed by much smaller, yet significant families, represented by the Cyperaceae with 19 species (6.7%), Restionaceae with 8 species (2.8%), Juncaceae with 6 species (2.1%), Rosaceae with 6 species (2.1%) and Scrophulariaceae also with 6 species (2.1%).

Red data species

Two red data species representing 0.7% of the flora of springs on the Kammanassie Mountain were found to be present. The endangered *Erica* sp *nov* (Ericaceae) was sampled at sample plot 18 (Kamm/w/019) and rare *Agathosma affinis* (Rutaceae) in sample plot 24 (Kamm/w/025). Both these two springs dried up before the KKRWSS started abstraction. Red data species and the categorisation are indicated in the species list (Appendix 3)

Alien Species

A total of 11 Alien species or cosmopolitan weeds were found at springs on the Kammanassie Mountain. These species are indicated by an asterix (*) in Appendix 3.

5.4 DISCUSSION

5.4.1 The vegetation of the Vermaaks, Marnewicks and Buffelsklip Valleys of the Kammanassie Nature Reserve

From the floristic analysis and phytosociological study of the Vermaaks, Marnewicks and Buffelsklip Valleys it was established that a large number of species (19%) were present in all three Valleys, which was indicative of similar vegetation. The Vermaaks and Marnewicks Valleys have 75 of the same plant species present (16%) and the Vermaaks and Buffelsklip have 62 of the same plant species present (13%). The vegetation of the Marnewicks and Buffelsklip Valleys were found to be similar to the Vermaaks Valley and suitable control sites for plant water stress tests.

A total of two plant communities, namely the *Passerina obtusifolia-Portulacaria afra* succulent scrub of lower slopes (10.2) and *Pteronia incana-Eriocephalus africanus* karroid scrub (11) were found in all three valleys. The plant community *Euclea* *polyandra-Ficus burtt-davyi* valley and kloof woodland (5.1) was found in both the Vermaaks and Marnewicks Valleys. The *Osyris compressa-Rhus pallens* dense valley bush (9) and *Euclea undulata-Portulacaria afra* succulent of steep/higher slopes (10.1) plant communities were found in both the Vermaaks and Buffelsklip Valleys.

During the phytosociological survey of the vegetation of the Buffelsklip Valley a new *Erica* species was discovered. This species is to be named by Prof. TE Oliver (NBI). A further possible four species are awaiting identification at the NBI in Pretoria and are thought to be new species.

5.4.2. The vegetation of springs on the Kammanassie Mountain

Flowing springs have very different plant communities to those that are dry. A difference between how long a spring has been dry also determines the plant community present. A comparison between spring origin and vegetation communities is given in Table 5.3. Very strong differences occur in plant species in flowing springs with ferns, mosses and water plants dominating these springs (species group A, B and C – Table 5.2). Springs, that have been dry for a number of years, have a shrub, grass and restio dominance (species group G, K and M – Table 5.2). Springs that have dried up recently (within the last 3 years) show a distinct difference once again, with the herbaceous layer being dominant (species group D, E, F, H, J, L and N – Table 5.2).

TABLE 5.3: A SUMMERY OF SPRING VEGETATION AND GENERAL INFORMATION

Site No.	LocalityName	DS	MS	SS	DE	ME	SE	Alt	Asp	Slp	Soil	Perch	Status	S/A	CMZ	1999	2000	2001	2002	Year Dry
1	***Blechnum tabulare*-*Hippa frutescens* fern community (Species Group A)**																			
1.1	***Hippia frutescens*-*Helichrysum cymosum* shrubland (Species Group B)**																			
Kamm/W/022	Mannetjiesberg	33	37	34	22	56	50	1307	SW	0	L	Yes	LV		No	R	D	D	S	1999
Kamm/W/052	Wildealsvlei	33	35	22	22	31	41	1038	S	0	S	Yes			Yes				R	
Kamm/W/031	Elandsvlakte	33	39	11	22	46	28	1304	S	0	S	Yes			No	R	R	R	R	
Kamm/W/037	Mannetjiesberg	33	37	21	22	55	36	1361	S	0	S	Yes			No	R	R	R	R	
1.2	***Hippia frutescens*-*Helichrysum petiolare* shrubland (Species Group C)**																			
Kamm/W/035	Mannetjiesberg	33	37	24	22	56	25	1343	SSW	0	L	Yes			No	R	S	S	R	2000
Kamm/W/036	Mannetjiesberg	33	37	25	22	55	53	1394	SSW	0	S	Yes			No	R	S	S	R	
1.3	***Hippia frutescens*-*Ehrharta* species grassland (Species Group D)**																			
Kamm/W/011	Wildealevlei	33	38	54	22	40	40	1037	S	0	S	Yes			Yes	R	R	R	S	
Kamm/W/046	Upperdiepkloof	33	38	48	22	43	7	1115	S	1	S	Yes			Yes		R	R	R	
Kamm/W/005	Buffelsdrif	33	40	21	22	45	22	837	S	0	S	?	IV	A	No	R	R	R	D	12/2001
Kamm/W/033	Elandsvlakte	33	39	11	22	43	56	1154	S	1	CL	Yes			Yes	S	S	D	D	2000
2	***Eragrostis plana*-*Juncus lomatophyllus* grassland (Species Group E)**																			
Kamm/W/034	Elandsvlakte	33	39	14	22	43	50	1145	NE	1	S	Yes			Yes	S	S	D	D	2000
Kamm/W/053	Mannetjiesberg	33	37	33	22	54	0.1	1405	NE	0	L	Yes			Yes				R	
Kamm/W/002	Kleinfonteinsberg	33	35	15	22	0	56	867	NNE	3	S	No			No	D	D	D	D	1978
Kamm/W/003	Kleinfonteinsberg	33	34	50	23	1	3.7	868	NNE	11	CL	No			No	S	D	D	D	1999
3	***Berzelia intermedia*-*Psoralea verrucosa* shrubland (Species Group F)**																			
Kamm/W/040	Kleinberg	33	38	32	22	43	39	1325	NW	17	S	Yes			?	D	D	D	D	1995
Kamm/W/007	Elandsvlakte	33	39	18	22	45	24	1176	N	0	S	Yes			No	R	R	R	R	
Kamm/W/032	Elandsvlakte	33	39	11	22	45	25	1192	SWW	0		Yes			Yes	R	R	R	R	
Kamm/W/045	Elandsvlakte	33	39	4	22	45	15	1180	W	0	S	Yes			Yes	0	R	R	R	
Kamm/W/023	Mannetjiesberg	33	37	34	22	54	0.5	1404	NNE	0	S	Yes			No	R	R	R	R	
Kamm/W/043	Groenplaat	33	40	3	22	47	17	1011	S	0	L	?	IV	A	No	R	R	D	D	2000
Kamm/W/044	Groenplaat	33	40	22	22	47	8	927	S	0	L	?			No	S	R	D	D	2000
Kamm/W/047	Kleinrivier	33	39	14	22	46	4	1279	S	0	S	Yes			No	0	D	D	D	Unknown
Kamm/W/006	Buffelsdrif	33	39	18	22	45	0	1284	S	0	S	Yes			?	D	D	D	D	Unknown

TABLE 5.3: Continued

Site No.	LocalityName	DS	MS	SS	DE	ME	SE	Alt	Asp	Slp	Soil	Perch	Status	S/A	Red D	1999	2000	2001	2002	Year Dry
4	***Cliffortia ilicifolia*-*Stoebe plumosa* shrubland (Species Group G)**																			
Kamm/W/024	Perdevlakte	33	36	55	22	51	30	1475	E	0	CL/L	Yes			No	D	D	D	D	Unknown
Kamm/W/025	Perdevlakte	33	36	35	22	52	58	1448	E	0	S	Yes			No	D	D	D	D	1986
Kamm/W/038	Perdevlakte	33	37	14	22	51	38	1462	NW	0	L	Yes			No	D	D	D	D	1977
Kamm/W/039	Mannetjiesberg	33	37	8	22	55	5	1772	NE	0	GR	Yes			?	D	D	D	D	1983
Kamm/W/041	Upperdiepkloof	33	38	46	22	41	38	1159	E	0	S	Yes			Yes	D	D	D	D	1986
Kamm/W/008	Elandsvlakte	33	38	48	22	43	28	1135	SW	0	S	Yes			Yes	R	R	D	D	2000
Kamm/W/030	Bergplaas	33	40	3	22	38	48	758	S	0	GR	?			No	R	R	R	D	2001
5	***Ehrharta ramosa*-*Aspalatus kougaensis* shrubland (Species Group H)**																			
Kamm/W/028	Bergplaas	33	40	49	22	37	7.1	745	W	0	GR	?	IV	A	No	S	S	D	D	2000
Kamm/W/029	Bergplaas	33	40	42	22	37	56	797	S	0	GR	?	IV	A	No	S	D	D	D	1999
Kamm/W/021	Leeublad	33	38	32	22	33	15	613	S	0	GR	No	MV	S/A	Yes	S	S	D	D	2000
6	***Conyza canadensis*-*Conyza scabrida* shrubland (Species Group I)**																			
Kamm/W/042	Elandsrivier	33	40	49	22	40	55	652	SW	0	CL	?	IV	A	Yes	D	D	D	D	1997
Kamm/W/020	Leeublad	33	38	45	22	32	45	586	S	0	L	No	MV	S/A	Yes	S	S	S	R	
Kamm/W/010	Wildebeesvlakte	33	37	13	22	34	27	927	NWW	3	S	Yes			?	D	D	D	D	1983
7	***Phragmites australis* reed community (Species Group J)**																			
Kamm/W/049	Rietfontein	33	34	19	22	52	7	600	W	0	GR	No	MV	A	Yes			S	D	2001
Kamm/W/026	Wildebeesvlakte	33	37	19	22	34	13	862	W	3	CL	Yes			No	S	D	D	D	1999
8	***Ehrharta erecta*-*Rhus pallens* shrubland (Species Group K)**																			
Kamm/W/016	Slawedam II	33	35	6.6	22	40	24	553	N	0	GR	No			Yes	D	D	D	D	Unknown
Kamm/W/017	Rooielskloof	33	35	5	22	39	20	576	NE	0	GR	No			Yes	S	D	D	D	1999
Kamm/W/050	Rietfontein	33	36	36	22	30	23	602	W	0	GR	No	MV	A	Yes			S	S	
Kamm/W/014	Slawedam I	33	35	10	22	41	18	565	N	0	GR	?			Yes	D	D	D	D	1994
9	***Mentha longifolia*-*Thelypteris confluens* (Species Group L)**																			
Kamm/W/001	Buffelsklip	33	55	10	22	37	60	711	NNW	0	S	No			No	R	R	R	S	
Kamm/W/009	Voorzorgpoort	33	36	22	22	32	32	635	W	0	L	No	MV	S	Yes	R	R	D	D	Sep-99
Kamm/W/051	Voorzorg	33	36	40	22	30	20	569	E	0	L	No	MV	S	No			R	D	02-Dec

TABLE 5.3: Continued

Site No.	LocalityName	DS	MS	SS	DE	ME	SE	Alt	Asp	Slp	Soil	Perch	Status	S/A		1999	2000	2001	2002	Year Dry
10 *Pelargonium radulifolium* -*Salvia namaensis* shrubland (Species Group M)																				
Kamm/W/012	Kleingeluk	33	34	55	22	43	50	684	N	0	S	?			Yes	D	D	D	D	1996
Kamm/W/013	Kleingeluk	33	34	59	22	43	53	703	N	0	S	?			Yes	D	D	D	D	1996
Kamm/W/015	Slawedam II	33	34	52	22	40	8.3	533	N	0	GR	No	MV	-	Yes	D	D	D	D	Unknown
Kamm/W/018	Solomonskraal	33	34	55	22	38	28	646	NE	0	GR	No			Yes	D	D	D	D	1973
11 Species 814-*Crassula biplanata* (Species Group N)																				
Kamm/W/019	Wagenpadsnek	33	37	30	22	31	55	718	W	0	S	Yes			Yes	S	D	D	D	1999
Kamm/W/048	Wagenpadsnek	33	37	38	22	31	13	732	S	0	S	?			Yes		S	S	S	

KEY

Soil	Status	S/A	Red D (Red data species present)	Flow
S=Sandy	MV=Most Vulnerable	S=KKRWSS abstraction likely to affect spring	End=Endangered	R=Running
L=Loamy	IV=Intermediate vulnerability	A=Agriculture abstraction likely to affect spring	Thr=Threatened	D=Dry
CL=Clay	LV=Least vulnerable			S=Standing
GR=Gravel				

5.5 CONCLUSIONS

- Since no similar vegetation descriptions have previously been done on the valleys and springs of the Kammanassie Mountains, this research provides valuable data on these ecosystems.

- This study has allowed for a comprehensive plant species list to be completed for the Vermaaks, Marnewicks and Buffelsklip Valley sections of the Kammanassie Nature Reserve. The plant species list can now be included into the Kammanassie Nature Reserve Management Plan and will result in the plant species list for the reserve being much more comprehensive.

- A new *Erica* species was discovered as a result of this survey.

- The localities of rare and vulnerable plant species previously unknown were identified during this survey.

- Herbarium specimens were collected for all of the plant species collected in this survey. These are stored at the Kammanassie Nature Reserve and duplicate material was sent to the Southern Cape Herbarium in George and Technikon SA, Florida, Johannesburg.

- The floristic account, together with the descriptions of the plant communities serves as a basis to develop a habitat management plan for the Kammanassie Mountains.

- If further springs dry up on the Kammanassie Mountain, plant communities at these springs will change over time and species diversity is expected to decrease. Important water dependent plants will be lost and wet plant communities will be transformed into dry shrub and grass dominated areas.

5.6 RECOMMENDATIONS

- These vegetation surveys and descriptions provide baseline information that allows similar surveys to be conducted in future. These data could then be compared with this study to determine if changes/shifts in plant communities have occurred.

- A change in habitat conditions could result in the loss of "wetland" plant communities, and a host of other organisms that depend on these plants such as invertebrates, frogs and fish species

- The WCNCB should continue to monitor rare and vulnerable species found during this survey to ensure their survival by applying the correct management strategies (for example it could include changing the burning policy for the Vermaaks Valley area).

- Monitoring of spring vegetation should continue to determine changes in plant communities over time related to springs drying up. This could form part of a long-term monitoring programme on the Kammanassie Nature Reserve.

CHAPTER 6

PLANT WATER STRESS

6.1 INTRODUCTION

Plant water stress tests are used to detect imbalances in the plant-water status or plants and indicate the degree of plant water stress in different seasons. A high Plant water stress occurs when a deficit of water exists in the plant either due to an unreplenished loss of water or the limited uptake of water by the plant. A number of factors are responsible for plant water stress in plants. However, under certain conditions, this can reflect deficiencies in soil moisture due to groundwater abstraction (Kemper, 1994). With long-term monitoring this methodology can act as an early warning system to indicate the impact of groundwater abstraction on riverine vegetation and corrective steps can be taken timeously.

The stomata, as well as permitting the entry of carbon dioxide, allow the evaporation of water from the plant, a phenomenon called (Roberts, 1986). Although transpiration can take place through the stems, the leaves with their large surface area and abundant stomata are the main source of water loss (Roberts, 1986). External conditions affecting transpiration include: temperature, relative humidity, air movements, atmospheric pressure, light and water supply (Raven, Evert and Eichhorn, 1986). Transpiration depends on the walls of the mesophyll cells being thoroughly wet. For this to be so the plant must have adequate water supply from the soil. If for some reason the plant cannot take up water from the soil (for example if it is too dry), sooner or later the stomata close, thus reducing the rate of transpiration (Roberts, 1986).

According to Roberts (1986), when a plant loses more water through transpiration than it can take up into its roots, it wilts and is said to suffer from water stress. The loss of water from the leaves raises the tension of the water columns in the xylem, and the water potential gradient from the soil to the xylem increases. As a result the roots remove more and more water from the soil. If this situation continues the stomata close rapidly, thereby cutting down water loss to a minimum. The closing of the stomata reduces photosynthesis, which is one of the most notable side-effects of water stress. According to Raven *et al.* (1986), the main function of transpiration is to cool the leaves, an important effect particularly in hot conditions. Transpiration also provides a pathway through which mineral elements are transported.

An increase in water stress as groundwater availability decreases (e.g. lowering the water table) would indicate groundwater dependence and could be a good indicator of when the stress is approaching the stage of plant die-back or mortality (Colvin, Le Maitre and Hughes, 2001).

6.2 METHODS

6.2.1 Site selection

Experimental sites to determine plant water stress were located at selected sites, based on the following requirements:

- at the site of water abstraction (Vermaaks 1);

- at the site where a spring existed (Kamm/w/009) but dried up (Vermaaks 2) downstream of Vermaaks 1. This is also the site of three monitoring boreholes (to monitor water table heights) and the automatic weather station (See section 4.3.3);

- a site further downstream (Vermaaks 3) further from the water abstraction site. This site also had spring number Kamm/w/051 flowing at this site, but it had dried up in December 2001 (see section 4.3.4). However this spring started flowing again in June 2002;

- a control site in a Valley similar to and close to the experimental sites in the Vermaaks River. This site had to be similar to the Vermaaks River experimental sites in terms of climate, geology, topography, stream and vegetation. Marnewicks River Valley was selected as the control site.

A comparison of the four selected sites is given in Table 6.1 and 6.2.

Site selection was also dependent on plant species present in all 4 sites. The following species were selected for plant water stress tests, namely *Rhus pallens*, *Dodonaea angustifolia*, *Acacia karroo*, *Nymania capensis* and *Osyris compressa*. At least 5 individuals (replicates) of each of the above plant species had to occur within each site.

Five individual plants of each species were randomly selected at each site. These plants were then permanently marked for the duration of the project. Plants were marked with an iron stake inserted near the individual with a 4 m reed attached to this pole. Danger tape was tied to the top of the reed to assist the project team find the marked plants at night. A silver tag with the individual number of the plant was tied to the plant with string. The same individual plants were used throughout the study period. Plants that died during the research period were replaced for study purposes by the nearest living individual of the same species and marked accordingly. A record was kept of these changes.

Plant water stress experiments were conducted over two years during the beginning of the growing season, end of the growing season and the dormant period.

Due to various factors that cause mixing of water from different origins, (water from Peninsula and Nardouw formations and rainwater) before as at the time of water-uptake by plants, it is expected that a fingerprint-test using radio-isotopes will not give an indication of which water plants are using. (Kotze pers. comm[1]. and Van Wyk pers. comm.[2])

The plant water stress tests were carried out in October 2000, February 2001, June 2001, October 2001, end January 2002 and end May 2002.

[1] Dr JC Kotze, 2001. SRK Consulting, Cape Town.
[2] Mr E van Wyk, 2001. Department of Water Affairs and Forestry, Pretoria.

Table 6.1: A comparision of the three experiential sites in the Vermaaks Valley and control sites at Marnewicks and Buffelsklip Valleys

Site	Site 1	Site 2	Site 3	Site 4
Area	Vermaaks 1	Vermaaks 2	Vermaaks 3	Marnewicks
Experimental/ Control	Experimental Site	Experimental Site	Experimental Site	Control
Co-ordinates	33°36'42.9"S 22°32'43.4"E	33°36'11.2"S 22°31'56.2"E	33°35'21.6"S 22°31'42.2"E	33°34'33.8"S 22°34'57.0"E
Altitude (m.a.s.l)	718.3	660	646	550
Aspect	W	W	NNE	N
Geology	Table Mountain Sandstone	Table Mountain Sandstone	Table Mountain Sandstone	Table Mountain Sandstone
Soil	Sandy	Loamy	Loamy	Loamy
Location	Situated at the WCNCB gate in the Vermaaks River.	Situated at the spring (009), that dried up during August 1999. The automatic weather station is also located at this site.	Situated at spring (051), this spring is still flowing.	Situated above the weir in the Marnewicks River. Site extends 30m above the fenceline.
Production Boreholes	VR6 is situated within this study site.	None	None	None
Monitoring Boreholes	None	G40171 G40172 G40173	None	G3854 BH15A
First Water level (m)	34.64	G40171 = ? G40172 = 5 G40173 = 3	-	?
Average water level For study period (m)	60	G40171 = 5.085 G40172 = 5.125 G40173 = 4.925	surface	G3854 = 2.873 BH15A = 1.978
Amount of abstraction Per annum	257 457 kilolitre	-	-	-

Table 6.1 continued

Site	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Vegetation Unit according to Southwood et al (1991)		Kloof shrubland	Kloof shrubland	Kloof shrubland
General Vegetation type (See section 3.3.1.1)	*Dodonaea angustifolia-Rhus pallens*	*Dodonaea angustifolia-Rhus pallens*	*Dodonaea angustifolia-Rhus pallens*	*Dodonaea angustifolia-Rhus pallens*
Structural community	*Gymnosporia buxifolia-Osyris compressa* bush	*Gymnosporia buxifolia-Osyris compressa* bush	*Gymnosporia buxifolia-Osyris compressa* bush	*Gymnosporia buxifolia-Osyris compressa* bush
Major community type (See section 3.3.1.1)	*Osyris comressa-Rhus pallens* (9)	*Calopsis paniculata-Cliffortia strobilifera* (3)	*Calopsis paniculata-Cliffortia strobilifera* (3)	*Calopsis paniculata-Cliffortia strobilifera* (2)
Plant community		*Calpurnia intrusa-Acacia karoo* (3.1) Streambank woodland	*Calpurnia intrusa-Acacia karoo* (3.1) Streambank woodland	
Variant (See section 3.3.1.1)		*Heteromorpha arborescens* (3.1.1)	*Heteromorpha arborescens* (3.1.1)	
Vegetation Description	Dense Valley Bush	Wet streambank scrub	Wet streambank scrub	Wet streambank scrub

Table 6.2: A comparison of the detailed geology, geohydrology and geomorphology for the four sites

Site 1 Vermaaks Experimental	At site 1 there is a 16 m thick unconsolidated valley fill consisting of quartzite boulders set in a clayey sand matrix. This is underlain by fractured Peninsula formation bedrock. No permanent surface water occurs naturally at this site. The 1989 groundwater level (unimpacted) was 34 metres below surface (Mulder,1995). By 2001 the groundwater level had dropped to 60 m below surface at this site as a result of abstraction.
Site 2 Vermaaks Experimental	At site 2 the geology the alluvium/colluvim is 20m thick and is also underlain by Peninsula formation. The Cedarberg formation shale sub outcrops in the palaeovalley within 100m down gradient of this site. Prior to abstraction the groundwater level at this site was at surface at point where spring 009 emanated in the river course. The depth to groundwater level across the remainder of the site varies as a result of topography, and was probably as deep as 5 metres below surface at some localities before any abstraction took place. A detailed description of the drying up of the spring at this site is given in section 5.5.3. The groundwater level is unlikely to have been significantly impacted until mid 1998. Subsequently the groundwater level across the site gradually dropped by approximately 3 metres.
Site 3 Vermaaks Experimental	At site 3 the alluvium/colluvium is also 20 m thick but is underlain in this instance by fractured Nardouw bedrock. The groundwater level is shallow, discharging at spring 051 in the river course. The groundwater level may be a deep as 4 m below surface at some localities on this site, depending on topography. Impacts of abstraction on groundwater levels at this site are negligible, except for the period between December 2001 and June 2002 when a decline of 0.3 metres was recorded.
Site 4 Marnewicks Control	The geology and hydrogeology is similar to the sites in the Vermaaks river valley. It is alluvium/colluvium filled valley - these unconsolidated sediments being 12 metres thick. Nardouw fractured rock aquifer (Baviaanskloof formation) occurs beneath the alluvium. The groundwater level across this site varies from being at surface along the Marnewicks river to approximately 5 metres below surface depending on the topographic height above river level. The groundwater level measured in a borehole on this site during the course of this study varied between 0.132 meters and 2.205 metres below surface.

6.2.2 24-hour plant water stress tests

Initially, before any experiments were conducted, the time of the day/night most suitable for the experiments had to be determined. Two plant water stress tests were carried out every hour on each of the marked individuals in Site 2 (Vermaaks 2) namely plant moisture stress (see section 6.2.3) and stomata resistance, light, relative humidity, temperature and time (see section 6.2.5). Results were used to establish the optimum time to conduct these two experiments (Kemper, 1994).

6.2.3 Plant moisture stress

A research team consisting of 2-3 people was assigned to each of the 4 sites. To ensure that experiments were conducted under similar environmental conditions the 4 sites were assessed simultaneously. Each research team started the assessments at exactly the same time (23:00, see section 6.2.2) at their assigned sites. A total of 6 tests were carried out over a two-year period.

Two healthy branch tips of approximately the same size (± 20 cm long and 3-4 mm in diameter) of each marked individual was randomly selected and cut with pruning sheers. These branches were then placed in a plastic bag marked with the same number as the plant. All plants from each site were then placed into a cooler box and transported to the laboratory in Uniondale where plant moisture stress and leaf water content tests were carried out.

Plant moisture stress was measured using a Schölander pressure gauge. One of the branch tips collected was placed into the pressure cylinder, with a small section (1cm) protruding through the pressure cylinder lid. The branch tip was then put under put under pressure using nitrogen gas. This pressure forced water from the protruding section of the stem. When a droplet of water formed on the protruding section of the stem the pressure reading was measured (bar). The higher the pressure needed to force a droplet of water from the plant, the higher the plant moisture stress.

6.2.4 Leaf water content (LWC)

Leaf water content was determined using the leaf disc method (Saayman, 1987) on the second of the branches collected (see section 6.2.3).

A predetermined number of healthy leaves was randomly selected from collected branches from each individual in order to have a suitable mass of leaves to determine fresh, saturation and dry mass. The following number of leaves was used per species: *Rhus pallens* (4 leaves); *Dodonaea angustifolia* (10 leaves); *Acacia karroo* (2 compound leaves); *Nymania capensis* (20 leaves) and *Osyris compressa* (4 leaves).

The fresh weight (FW) of each sample was determined using a Mettler AM/PM balance scale and the samples were then placed in petri dishes with 10 cm^3 distilled water. The petri dishes were covered with lids and the leaves left in the water for 24 hours. The leaves of each sample were removed from the petri dishes and dried surficially with blotting paper. The samples were weighed to obtain the weight at saturation (SW). Leaf samples were placed in dry petri dishes in a drying oven at 65°C for 48 hours. Samples were removed from the oven and weighed to obtain dry weight (DW).

Formula for calculating leaf water content (Saayman, 1987):

Leaf water content (Ww) = FW - DW
Leaf water content at saturation (Ws) = SW – DW
Leaf water content = Ww as a percentage of Ws
The higher the leaf water contents (%) the less plant water stress the plant experiences.

6.2.5 Stomata resistance (SR)

An AP4 porometer was used to measure the stomatal resistance of plant leaves. This is a measure of the resistance to loss of water vapour through the stomata, which is an indicator of the physiological state of the plant (Webb, 1999).

The porometer measures the time it takes for a leaf to release sufficient water vapor to change the relative humidity in a small chamber by a fixed amount. This is compared with a calibration plate of known resistance in order to derive the stomatal resistance of the leaf. Porometer readings are taken in seconds per centimeter (s.cm^{-1}) and measure stomata resistance. Other readings taken include light (µmol.m^{-2}.s^{-1}), relative humidity (%), temperature (°C) and time (hh:mm). Readings were taken between 10:00 and 14:00 (see section 6.2.2). The sites were always surveyed in sequential order, namely: Site 1, Site 2, Site 3 and Site 4.

The data obtained from the porometer readings was varied. This can be ascribed to the dependency of stomata closure on light intensity, wind and temperature (Saayman 1987, Webb 1999 and Raven *et al.*, 1986). Statistical analysis between stomata resistance and light intensity confirmed this correlation. Due to the limitations of equipment available, porometer readings could not be measured simultaneously at all sites. This caused great variation in the environmental factors, which in turn caused great variation in the porometer readings. It was therefore decided to discard these results.

6.2.6 Statistical analysis

ANOVA, t-test (parametric), Mann-Whitney and Kruskal Wallis tests (non-parametric) were used to ascertain whether there were significant differences (p-value<0.05), per season, per species, per test between the following sites: Vermaaks 1 and Marnewicks; Vermaaks 2 and Marnewicks; Vermaaks 3 and Marnewicks (t-tests and Mann-Whitney) and all 4 sites (ANOVA and Kruskal Wallis). Boxplots (Box-and-whisker diagram) were used to graphically depict the results of the test results obtained.

Pearson’s Product Moment correlation coefficients were calculated to determine whether there were any correlations between the plant water stress tests (plant moisture stress, stomata resistance and leaf water content) per season, per species. If the p-value was < 0.05, it was concluded that there was a significant correlation between the tests. The sign of the correlation coefficient was used to determine the direction (either positive or negative) of the relationship. Pearson Correlations were also calculated to determine whether there were any correlations between porometer and light readings. Scatter diagrams and Boxplots were used to illustrate the degree of correlation.

6.2.7 Groundwater abstraction

6.2.7.1 Klein Karoo Rural Water Supply Scheme (KKRWSS)

Monthly groundwater abstraction figures for the four pumps in the Vermaaks River, namely VR6, VR7, VR8 and VR11 were obtained from Overberg Water for the period May 2000 to April 2002. These figures were used to determine the amount of groundwater being abstracted by the KKRWSS during the plant water stress test period.

Annual groundwater abstraction figures were obtained from the Department of Water Affairs and Forestry.

6.2.7.2 Farmer abstraction

The amount of groundwater abstracted by farmers around the Kammanassie Nature Reserve was obtained from the Department of Water Affairs and Forestry. These abstraction amounts were obtained from the completed Water Registration Forms, a process completed by landowners during 2000/2001. These abstraction amounts must still be verified.

6.3 RESULTS

6.3.1 24-hour plant water stress test

From the results of the 24-hour test, using the Schölander Pressure gauge, it was apparent that plant moisture stress seemed to stabilize for the five species at approximately 22:00 to 03:00 (Figure 6.1). The 24-hour test measure with the porometer indicated that stomata resistance was most stable between 10:00 and 16:00 (Figure 6.2). Light, relative humidity and temperature were also relatively stable between 10:00 and 14:00 (Figures 6.3, 6.4 and 6.5). For this reason it was decided to collect plant specimens for plant moisture stress and leaf water content between 23:00 and 02:00 and perform the stomata resistance test between 10:00 and 14:00.

6.3.2 Plant Water Stress per season

A comparison between the four sites of plant water stress in the five species for the spring (October surveys), summer (January/February surveys) and winter (May/June surveys) periods is summarised in Figures 6.6, 6.7 and 6.8.

The results are as follows:

Spring

In spring, at the beginning of the growing season all plant species tested, except *Nymania capensis* showed a higher plant moisture stress at Vermaaks 1 than at Marnewicks. The indication is that the vegetation at Vermaaks 1, the site of water abstraction, was more stressed than at the control site. Some plant species also indicated greater stress at Vermaaks 2 and Vermaaks 3 than the control.

The results of the leaf water content for all species indicated lower values at Vermaaks 1 than at the control, confirming that the vegetation at Vermaaks 1 was more stressed than at Marnewicks.

Generally it seemed that the vegetation at the site of water abstraction was most stressed, while the stress was somewhat less at Vermaaks 2. The vegetation at Vermaaks 3 and at the control site showed the least stress (Figure 6.6).

Summer

In summer, in the middle of the growing season, results of both tests (plant moisture stress and leaf water content) showed a similar trend, though more pronounced than in spring (Figure 6.7).

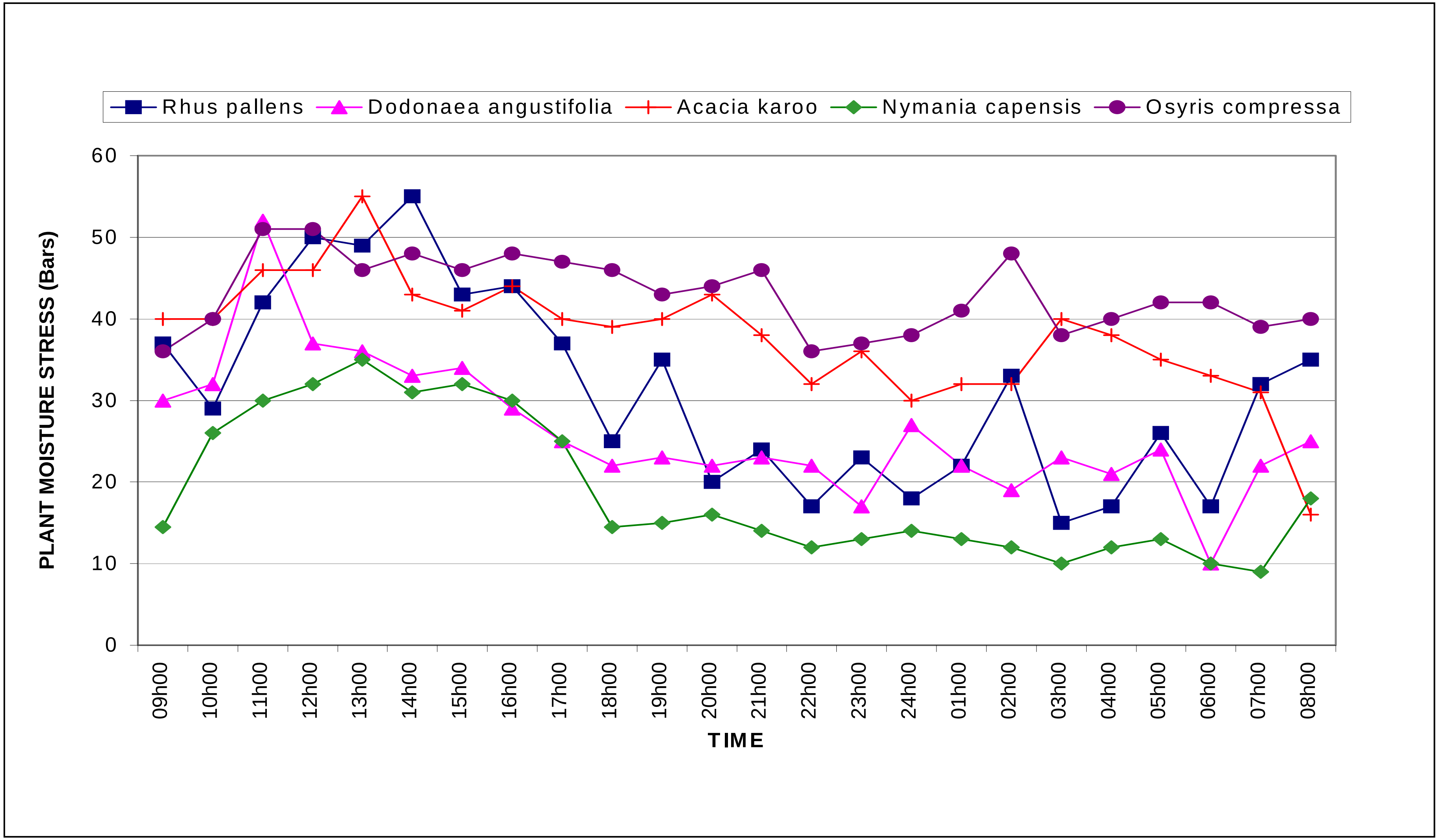

Figure 6.1: 24-hour test: plant moisture stress

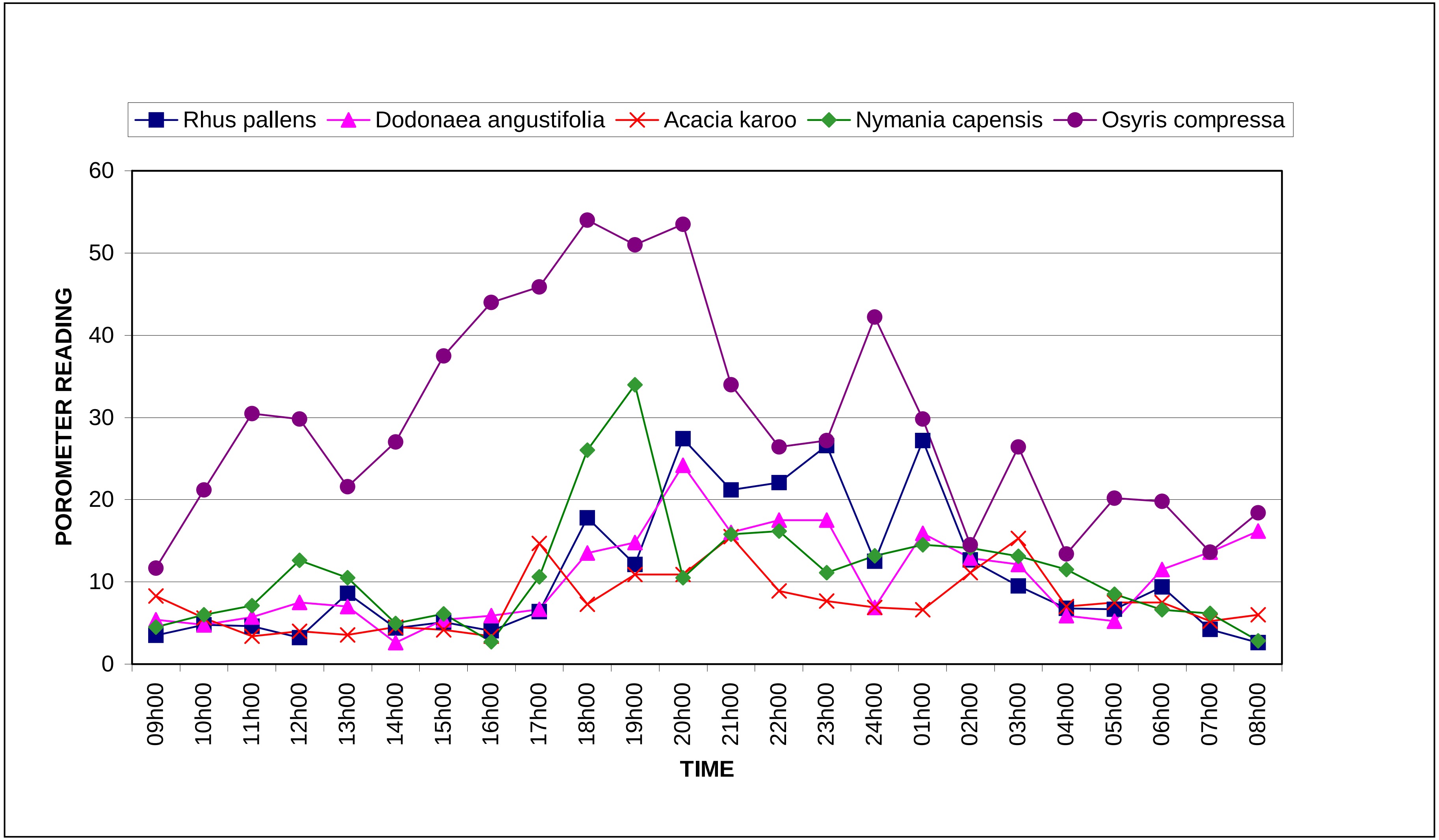

Figure 6.2: 24-hour test: stomata resistance

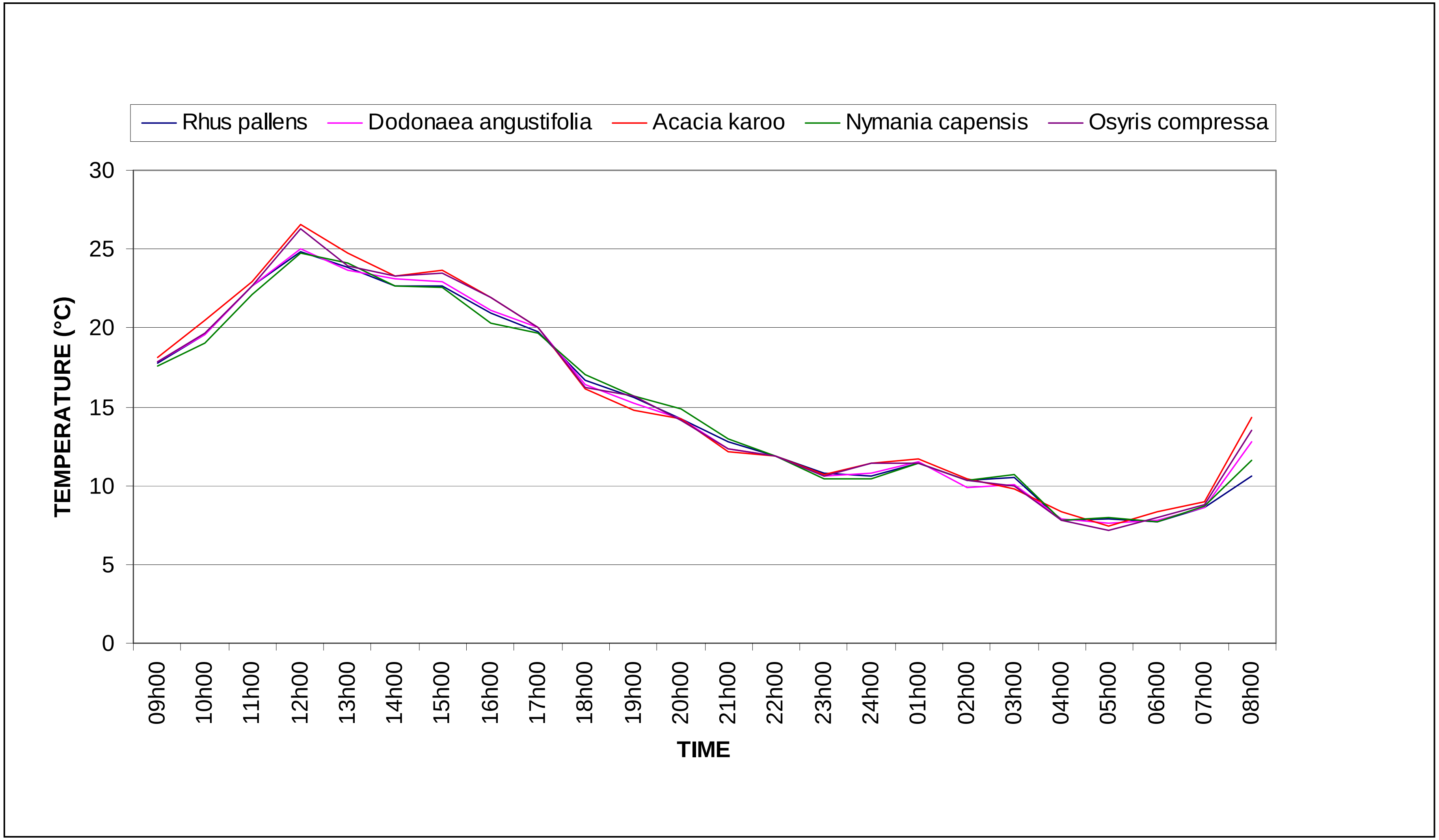

Figure 6.3: 24-hour test: temperature

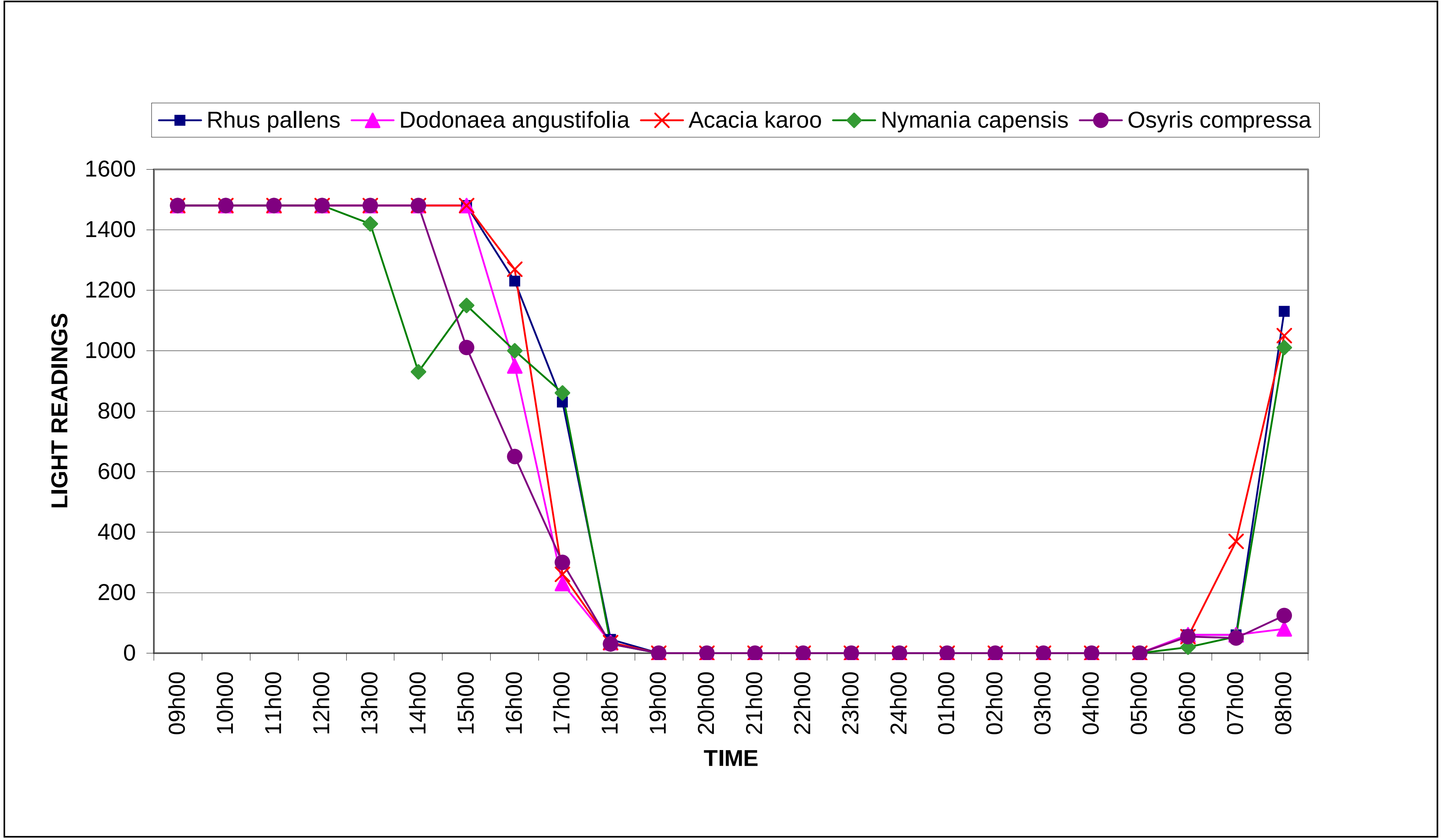

Figure 6.4: 24-hour test: light readings

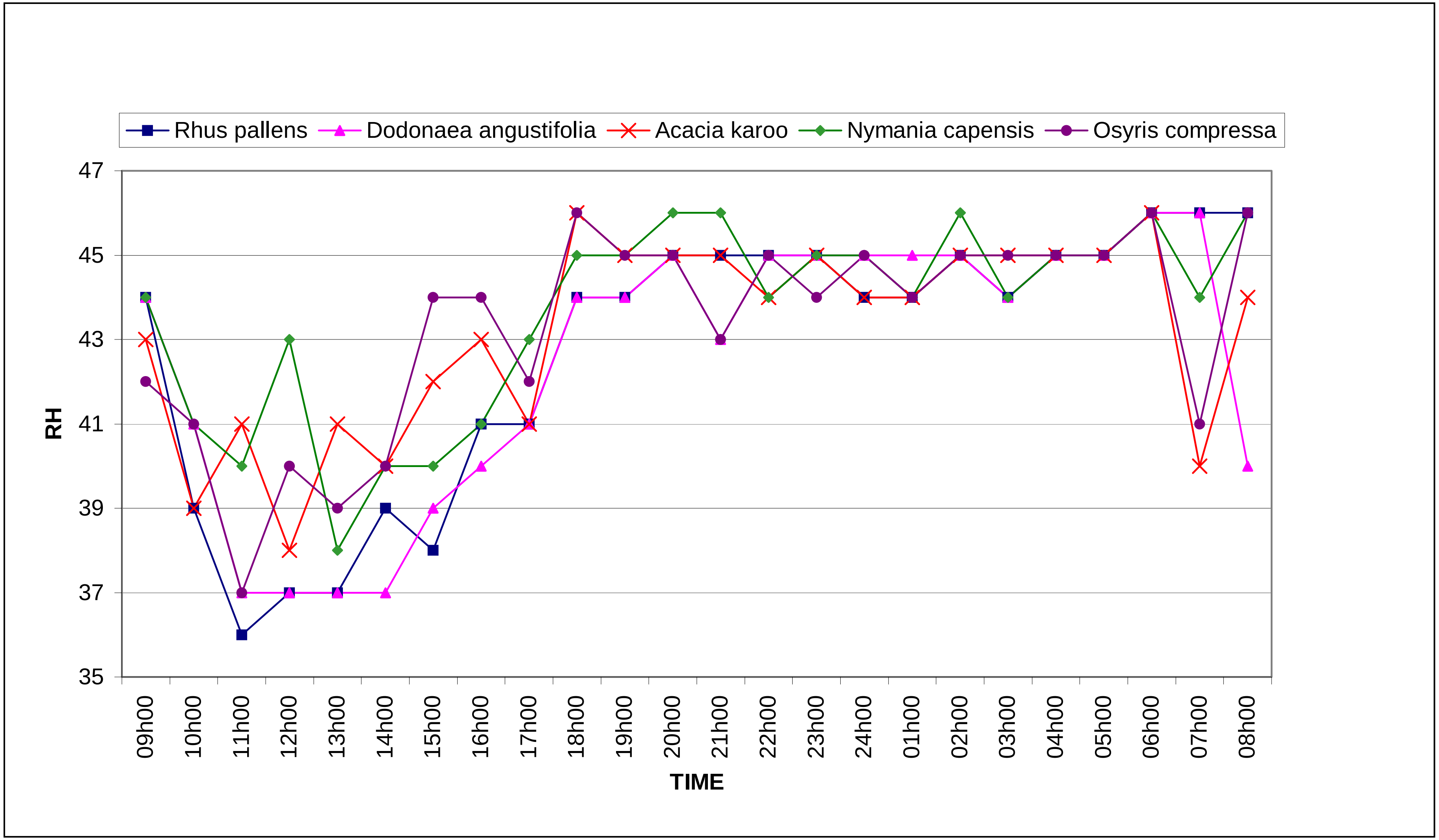

Figure 6.5: 24-hour test: relative humidity

Winter

In winter, in the most dormant and dry period, results of both tests (plant moisture stress and leaf water content) showed a similar trend to those experienced in spring and summer (Figure 6.8).

6.3.3 Results from statistical analyses

6.3.3.1 Plant moisture stress

Table 6.3 summarises the differences between the plant moisture stress of all four sites.

Vermaaks 1 & Marnewicks:

For spring, summer and winter significant differences were found for the species *Rhus pallens* and *Dodonaea angustifolia*. Both *Acacia karroo* and *Osyris compressa* showed significant differences for winter as well as for spring and summer. This indicated that the vegetation of Vermaaks 1 (site of water abstraction) was significantly more stressed than that of the control site at Marnewicks*.* *Nymania capensis* appeared to be the only species with higher plant moisture stress at Marnewicks than Vermaaks 1 in spring and summer. In winter however this species was more stressed at Vermaaks 1 than Marnewicks, similar to the other four plant species.

The results of the tests on *Nymania capensis* could be explained by this species being a karroid plant probably with anatomical or physiological adaptations to drought especially summer drought. This most probably resulted in the Sholander Pressure Gauge giving higher values than expected. In winter this plant was probably not dormant. This however was not investigated and further research is needed to give a better understanding of the water relationships of the species.

Vermaaks 2 & Marnewicks:

There are no significant differences between these sites for *Rhus pallens* in spring. There are significant differences for winter and differences in summer for *Rhus pallens*. *Dodonaea angustifolia* and *Osyris compressa* both show significant differences for spring and winter and differences for summer. *Acacia karroo* and *Nymania capensis* are more stressed at Marnewicks in spring, however in winter

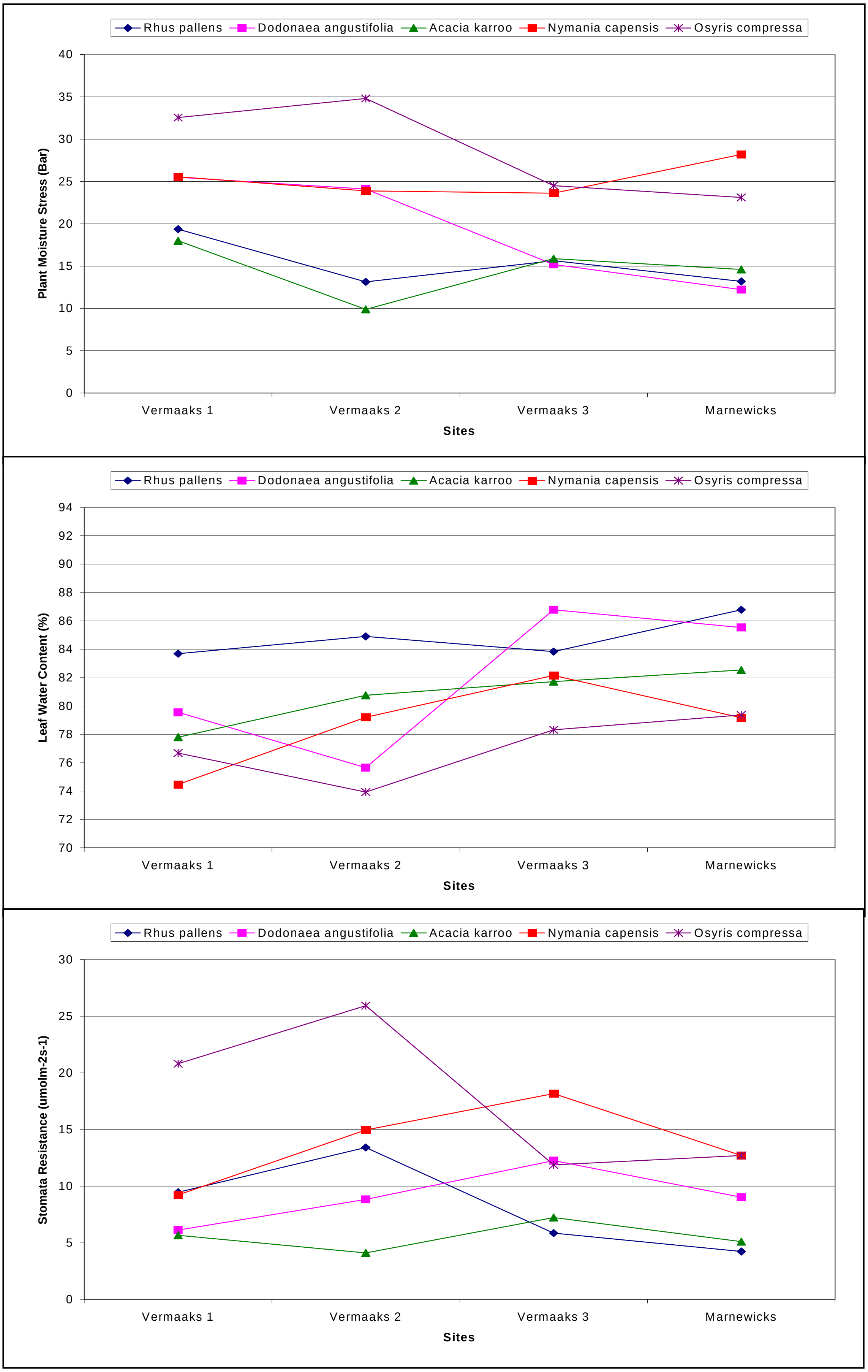

Figure 6.6: Plant water stress at the 4 sites for spring

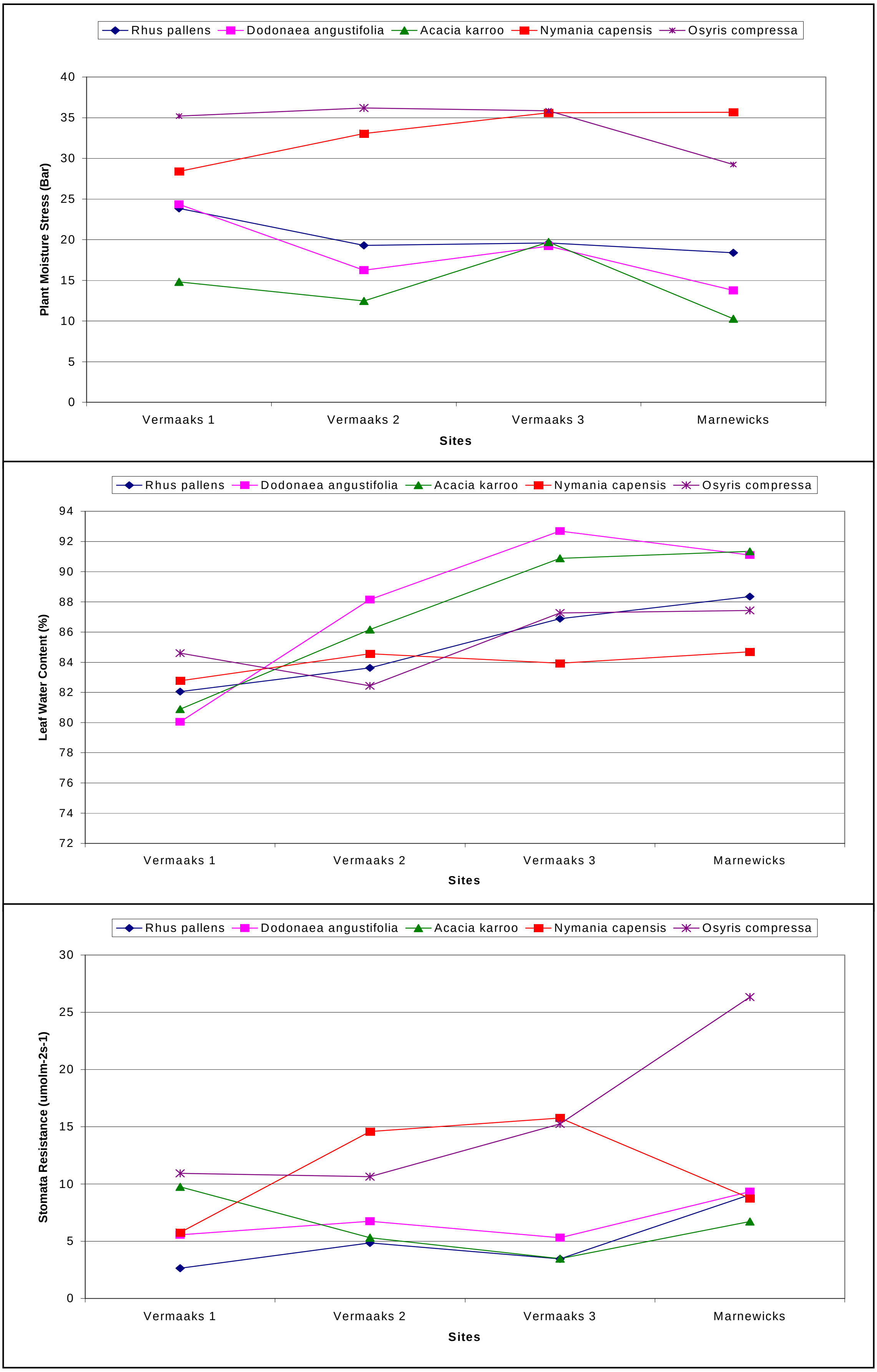

Figure 6.7: Plant water stress at the 4 sites for summer

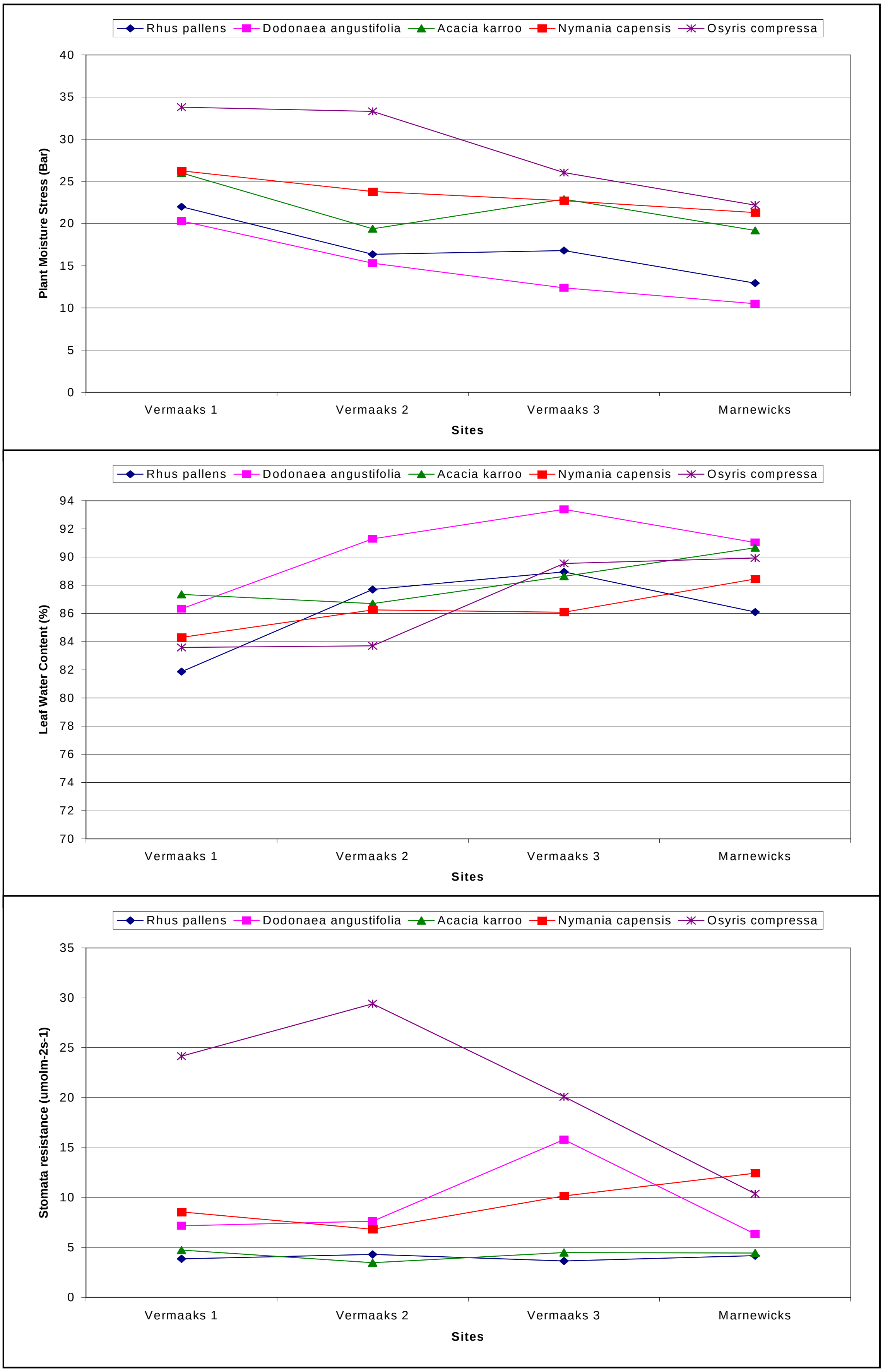

Figure 6.8: Plant water stress at the 4 sites for winter

TABLE 6.3: A summary for Plant Moisture Stress between the 4 sites per season (including statistical values)

SPECIES	VERMAAKS 1 vs. MARNEWICKS			VERMAAKS 2 vs. MARNEWICKS			VERMAAKS 3 vs. MARNEWICKS		
	Spring	Summer	Winter	Spring	Summer	Winter	Spring	Summer	Winter
Rhus pallens	S p=0.025	S p=0.015	S p=0.000	- p=0.980	D p=0.750	S p=0.017	D p=0.999	D p=0.602	S p=0.01
Dodonaea angustifolia	S p=0.002	S p=0.000	S p=0.001	S p=0.04	D p=0.351	S p=0.020	S p=0.032	S p=0.001	D p=0.177
Acacia karroo	D p=0.262	D p=0.052	S p=0.000	M p=0.980	D p=0.164	D p=0.941	D p=0.732	S p=0.003	D p=0.104
Nymania capensis	M p=0.703	M p=0.060	D p=0.122	M p=0.479	M p=0.552	D p=0.508	M p=0.420	- p=0.990	D p=0.786
Osyris compressa	D p=0.071	D p=0.081	S p=0.000	S p=0.014	D p=0.086	S p=0.000	D p=0.585	S p=0.033	S p=0.036

S = Vermaaks significantly more stressed than Marnewicks ($p<0.05$)
D = Vermaaks more stressed than Marnewicks (not significantly)
M = Marnewicks more stressed than Vermaaks (not significantly)
\- = No differences between Vermaaks and Marnewicks

there are significant differences with Vermaaks 2 being more stressed than Marnewicks.

Vermaaks 3 & Marnewicks:

Rhus pallens showed differences for spring and summer and significant differences for winter between these sites. *Dodonaea angustifolia* showed significant differences for spring and summer and differences for winter. *Acacia karroo* showed significant difference for summer and differences for spring and winter. *Osyris compressa* had significant differences for summer and winter and differences for spring. This would indicate that the vegetation at Vermaaks 3 was more stressed than the control site at Marnewicks. As observed at Vermaaks 1 and Marnewicks *Nymania capensis* differed from all other species showing that it was more stressed at Marnewicks in spring.

6.3.3.2 Leaf water content

Table 6.4 summarises the differences between the leaf water content of all four sites.

Vermaaks 1 & Marnewicks:

Rhus pallens and *Nymania capensis* showed differences for spring, summer and winter. *Dodonaea angustifolia* and *Acacia karroo* showed differences for spring and winter and significant differences for summer. *Osyris compressa* showed differences in spring and summer and significant differences in winter. Thus the vegetation at Vermaaks 1 seemed to be more stressed than that at Marnewicks.

Vermaaks 2 & Marnewicks:

Rhus pallens and *Acacia karroo* were more stressed at Vermaaks 2 in spring, summer and winter. *Dodonaea angustifolia* and *Osyris compressa* were significantly different in spring and different in winter. *Nymania capensis* was different for summer and winter but showed no differences for spring.

Vermaaks 3 & Marnewicks:

Rhus pallens showed differences for spring and summer with Marneiwcks more stressed in winter. *Acacia karroo* showed no differences for spring but differences for summer and winter. *Osyris compressa* showed differences for spring but no differences for summer and winter. There were no differences for *Dodonaea* *angustifolia* for spring, with Marnewicks more stressed in summer and Vermaaks 3 more stressed in winter. Marnewicks was more stressed for *Nymania capensis* in spring but less stressed in summer and winter.

6.3.4 Correlation between Plant Water Stress Tests

The correlation between the three different plant water stress tests is illustrated in Figure 6.9.

- *Rhus pallens*: There was a negative correlation (p=0.07) between plant moisture stress and leaf water content.

- *Dodonaea angustifolia*: There was a significant negative correlation between plant moisture stress and leaf water content.

- *Acacia karroo*: There was a significant negative correlation between stomata resistance and leaf water content.

- *Nymania capensis*: There was a significant negative correlation between plant moisture stress and leaf water content.

- *Osyris compressa*: There was a significant negative correlation between stomata resistance and leaf water content..

6.3.5 Groundwater Abstraction

The total amount of groundwater abstracted by the Klein Karoo Rural Water Supply Scheme and registered agriculture is reflected in Table 6.5 and Figure 6.10.

TABLE 6.4: A summary for leaf water content between the 4 sites per season (including statistical values)

SPECIES	VERMAAKS 1 vs. MARNEWICKS			VERMAAKS 2 vs. MARNEWICKS			VERMAAKS 3 vs. MARNEWICKS		
	Spring	Summer	Winter	Spring	Summer	Winter	Spring	Summer	Winter
Rhus pallens	D p=0.098	D P=0.072	D p=0.334	D p=0.531	D p=0.084	D p=0.673	D p=0.97	D p=0.466	M p=0.403
Dodonaea angustifolia	D p=0.117	S P=0.014	D p=0.145	S p=0.011	D p=0.194	- p=0.924	- p=0.646	M p=0.372	D p=0.447
Acacia karroo	S p=0.033	S P=0.013	D p=0.275	D p=0.231	D p=0.141	D p=0.078	- p=0.779	D p=0.872	D p=0.348
Nymania capensis	D p=0.269	D P=0.686	D p=0.389	- p=0.996	D p=0.971	D p=0.623	M p=0.395	D p=0.856	D p=0.623
Osyris compressa	D p=0.120	D P=0.397	S p=0.034	S p=0.021	D p=0.124	D p=0.079	D p=0.633	- p=0.955	- p=0.874

S = Vermaaks significantly more stressed than Marnewicks ($p<0.05$)
D = Vermaaks more stressed than Marnewicks (not significantly)
M = Marnewicks more stressed than Vermaaks (not significantly)
\- = No differences between Vermaaks and Marnewicks

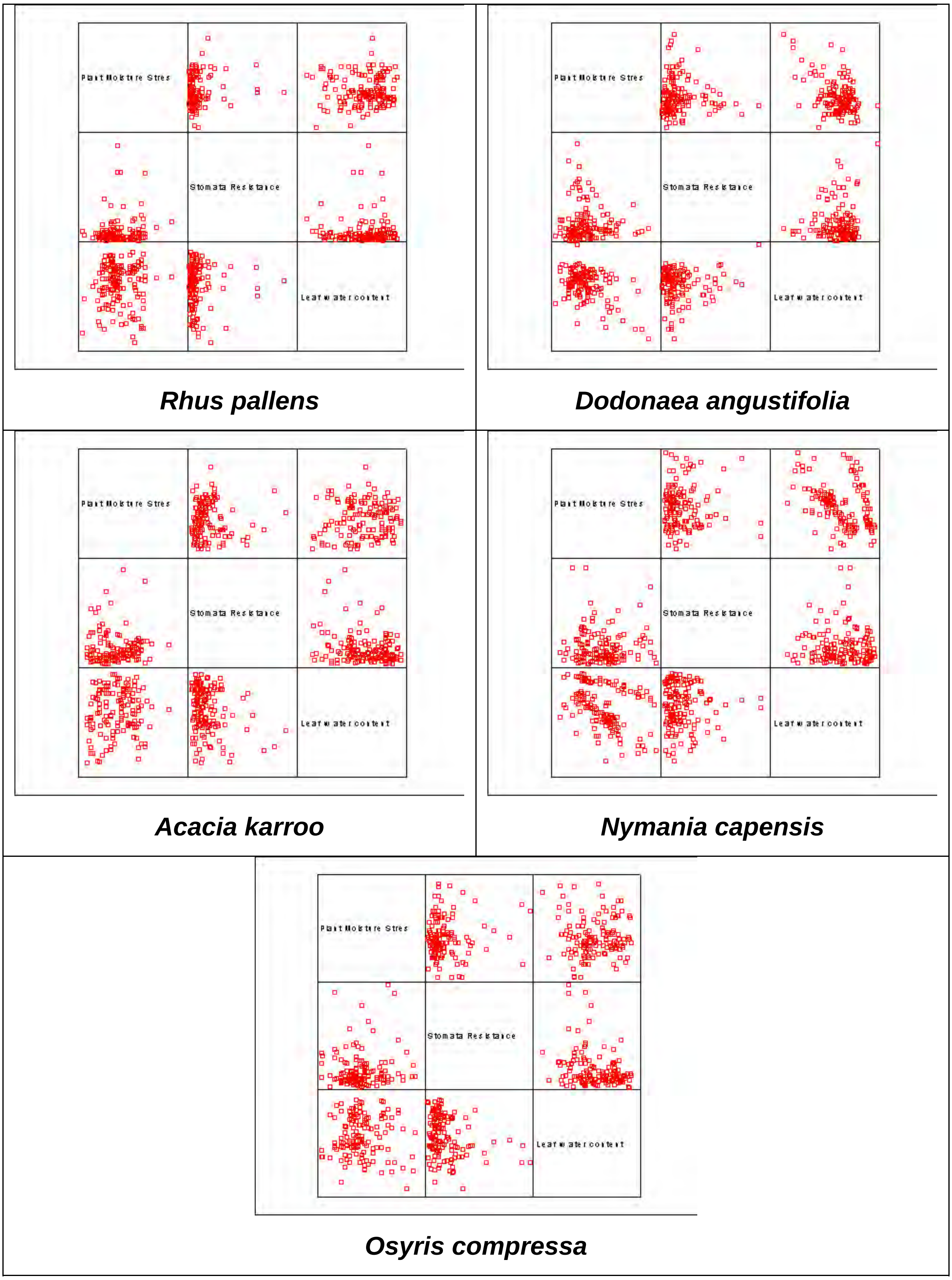

Figure 6.9: Correlation between plant moisture stress, stomata resistance and leaf water content

TABLE 6.5: Water abstraction from the Kammanassie Mountain area

Farm Name	Local Farm	Farm no	Latitude	Longitude	Map no	Drainage Reg	Groudwater m³/a	Surface m³/a
Dysselsdorp	Varkieskloof (DP12)		-33.57440	22.45420	3322CB	J33E	115 935	0
Dysselsdorp	De Brug (DP18)		-33.56970	22.42080	3322CB	J33E	169 993	0
Dysselsdorp	Bokkraal (DP28)		-33.58110	22.45670	3322CB	J33E	104 426	0
Dysselsberg	Droekloof (DG110)	123	-33.56610	22.47080	3322CB	J33E	29 713	0
Voorsorg	VG3	124	-33.56690	22.53860	3322DA	J33E	106 229	0
Vermaaks Rivier	VR6	125	-33.61170	22.54640	3322DA	J33E	542 615	0
						Scheme	1 068 911	0
						Agriculture Registered	8 501 482	20 224 400

KKRWSS ,Abstraction for the year 2001

The amount of groundwater abstraction from the KKRWSS and rainfall in the Vermaaks River Valley is given in Figure 6.11.

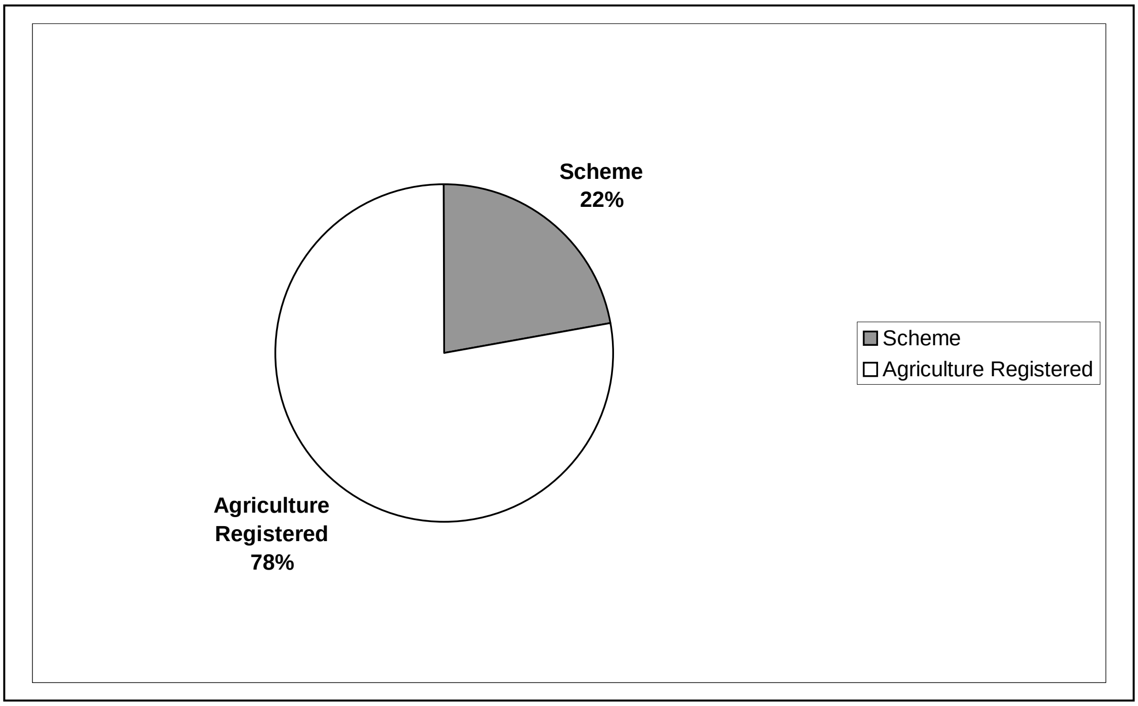

Figure 6.10: Groundwater abstraction around the Kammanassie Mountain

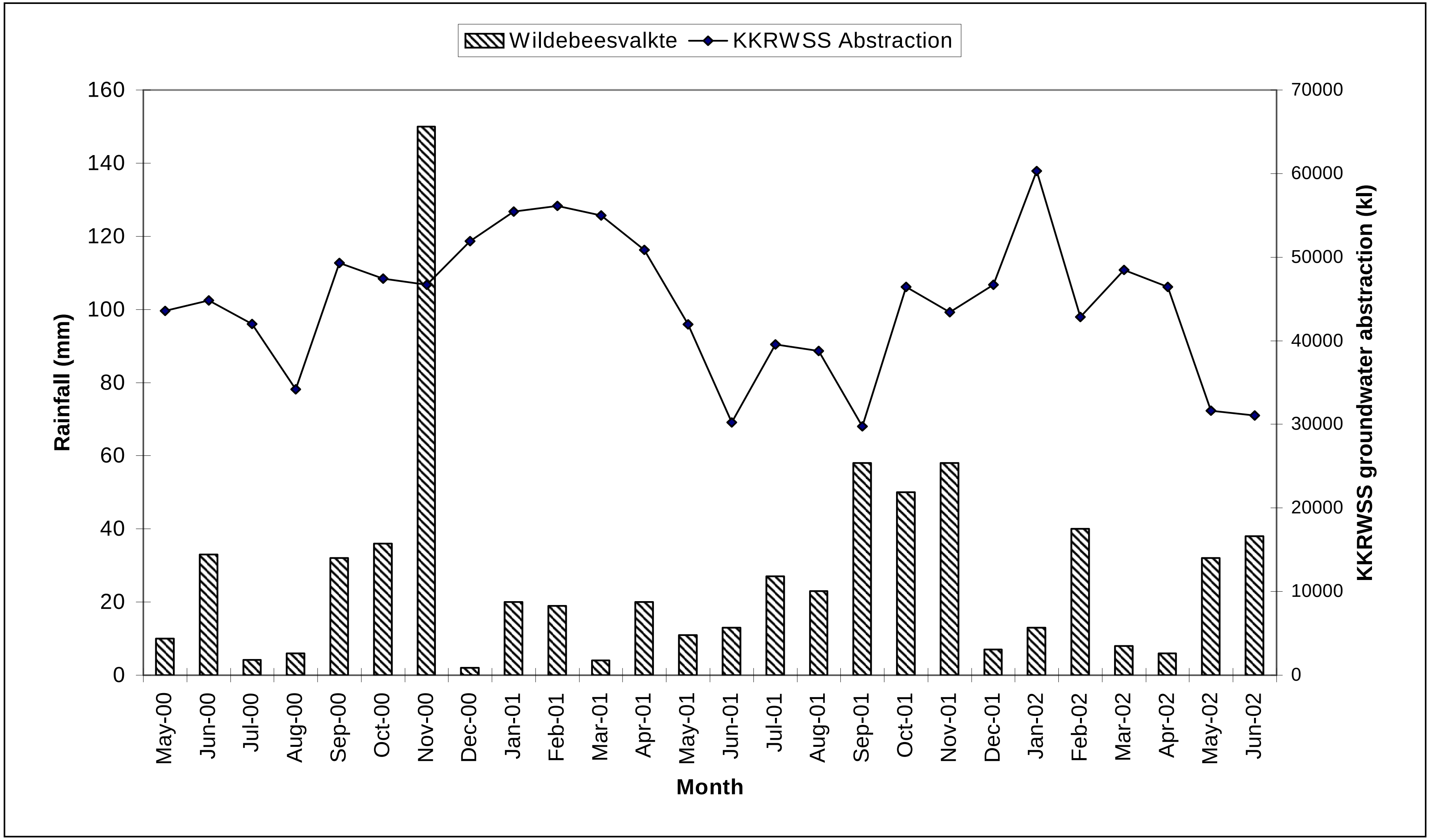

Figure 6.11: Rainfall for Wildebeesvlakte and KKRWSS groundwater abstraction during the plant water stress test period

6.4 DISCUSSION

6.4.1 Site selection

The method of marking plants for the duration of the project proved to be very effective and can be recommended for similar studies.

All test species except *Nymania capensis*, showed similar trends in plant moisture stress and leaf water content stress tests for the different seasons (spring, summer and winter). This is indicated in Figures 6.8, 6.9 and 6.10. *Nymania capensis* readings for the three plant water stress tests, per season, varied significantly from *Rhus pallens*, *Dodonaea angustifolia*, *Acacia karroo* and *Osyris compressa*.

Nymania capensis, being a karroid plant, probably with anatomical or physiological adaptations to drought especially summer drought, can therefore not be considered suitable for plant water stress tests. Porcupine damage to the base of the stem of this species could also effect plant water stress results of this species, which makes it unreliable for these tests. *Rhus pallens*, *Dodonaea angustifolia* and *Acacia karroo, Osyris compressa* can be considered suitable species for plant water stress tests.

Plant water stress tests only need to be carried out in the summer months as this proved to be the time when the most pronounced differences were found, since high groundwater abstraction and low rainfall put additional stress on the plants.

The leaf water content and plant moisture stress (Shölander) methods produced the most accurate results. The Porometer (stomata resistance) did not render very good results as there were too many variables such as light, wind, relative humidity and temperature that caused readings to vary considerably. To achieve comparable data, it is recommended that a porometer is available at each test site. This will enable tests to commence at precisely the same time. As this equipment is expensive it was not possible to purchase additional equipment for the purpose of this study.

6.4.2 24-hour stress tests

The 24-hour stress tests were carried out to determined the optimum time to collect plant specimens for plant moisture stress and leaf water content tests. It was determined that the optimum time to collect plant material for the plant moisture stress and leaf water content tests was between 23:00 and 02:00.

In a study by Kemper (1994), it was recommended that plant material for plant moisture stress tests be collected between 24:00 and 03:00, when plant moisture is at its minimum. The results for the 24-hour stress tests carried out in the Vermaaks Valley at site 2, therefore were similar to Kemper (1994) findings.

6.4.3 Plant moisture stress per season

Vermaaks 1 was significantly more stressed than Marnewicks, the control site. Vermaaks 2 was more stressed than Marnewicks, but not as stressed as Vermaaks 1. Vermaaks 3 was in turn also more stressed than Marnewicks but less stressed than Vermaaks 2. It would therefore appear that plant water stress in the Vermaaks Valley decrease further away from the point of abstraction.

Vermaaks 1, the study site where abstraction is taking place, had its original water level at 34.64m (Kotze, 2001) prior to starting abstraction in 1993. The water level in VR6 is currently and for the purpose of this study at 60m (Kotze, 2001). This is a total drop in water level of approximately 30m since the start of the KKRWSS in 1993.

The higher stress at Vermaarks 1 is caused by drier conditions of the ecosystem at this site. This is not due to differences in rainfall as the rainfall over the period of the experiment was essentially similar. The dryness could be due to:

1. The drainage pattern at this site which is situated higher up in the valley. Runoff and ground water accumulation lower down could cause these sites (Vermaarks 2 and 3) to be more moist.
2. The woody vegetation at Vermaarks 1 is generally more open which is normally ascribed to altitude and associated cooler conditions. However this area is more

exposed to wind and sunshine (less shade) which could cause higher evapo-transpiration rates and therefore drier conditions.

3. Water abstraction, causing a drop in the water table, resulting in general desiccation of the site. However, the original water table depth and associated capillary fringe (34.64 m) were too deep for utilisation by plants. Therefore a further lowering of the water table at this site will not have a negative effect on vegetation present. Furthemore, at Vermaarks 2 and 3 the original water table was shallower (surface – 5 m) and this water was available to plants. Here the lowering of the water table could result in less water being available to plants.
4. Although the sites were carefully selected to be relatively homogeneous in terms of environmental factors and vegetation, it is realized that variations in micro-tography and microclimate and soil moisture could also influence differences in water stress at the various sites.

According to the statistical analysis there is significant plant water stress in Vermaaks 2 compared to the control site at Marnewicks. Vermaaks 3 also shows higher plant water stress than Marnewicks (the control), especially in the summer months, though less than Vermaaks 2. Vermaaks 3 is further away from abstraction than Vermaaks 2 and also falls within the alluvium basin.

Plant water stress at Vermaaks 2 and 3 is partially due to groundwater abstraction as these sites receive similar rainfall to Marnewicks, which was the least stressed site. The significant plant water stress results for summer, showing Vermaaks 2 & 3 significantly more stressed than Marnewicks seems to indicate that groundwater abstraction (elevated during the summer months) is placing additional water stress on vegetation during their growing season.

The data from Vermaaks 2 & 3 seem to indicate that groundwater abstraction, superimposed by decreased rainfall and recharge, is having a significant negative impact on plant water stress at the experimental sites in the Vermaaks River Valley. Changes in the water abstraction management could maybe improve the situation.

6.5 CONCLUSIONS

- The Vermaaks River (abstraction) sites within the alluvium basin had higher plant water stress than at the control site at Marnewicks, which has similar rainfall. This indicated stress probably related to groundwater abstraction.

- *Nymania capensis*, being a karroid plant, probably with anatomical or physiological adaptations to drought especially summer drought, is not considered suitable for plant water stress tests.

- *Rhus pallens*, *Dodonaea angustifolia* and *Acacia karroo*, *Osyris compressa* proved suitable species for plant water stress tests.

- Plant water stress tests only need to be carried out in the summer months as this proved to be the time when the most pronounced differences were found, since high groundwater abstraction and low rainfall put additional stress on the plants.

- The leaf water content and plant moisture stress (Shölander) methods were found to give the most accurate results.

- The Porometer (stomata resistance) did not produce very good results as there were too many variables such as light, wind, relative humidity and temperature that caused readings to vary considerably.

- The best time to collect plant material for the plant moisture stress and leaf water content tests is between 23:00 and 02:00.

- The negative trend in rainfall over the past 13 years, especially in Dec/Jan/Feb, combined with increased groundwater abstraction which co-incided with the growing season of plants has negatively impacted ecosystems in the Vermaaks River.

- Vegetation in the Vermaaks River Valley area from site 2 (Kamm/w/009), in the alluvium basin, to Middleplaas can be considered the most vulnerable to groundwater abstraction. Vegetation that relies on surface water is affected the most when the water table drops as a result of groundwater abstraction, superimposed by low recharge rates due to the negative trends in rainfall since 1985.

6.6 RECOMMENDATIONS

- Groundwater abstraction by the KKRWSS in the Vermaaks River should not be allowed to increase more than the current abstraction of 0.6 million m^3/a without further monitoring of plant water stress in the Vermaaks/Marnewicks Valleys.

- Accurate determination of water use by farmers should be seen as a priority and groundwater use from the same aquifer should be monitored and controlled.

- If the negative trend in rainfall continues, which will result in less recharge, the amount of groundwater abstraction from this aquifer will have to be re-evaluated.

- If necessary, additional source of water (surface) must to be sourced to supplement the KKRWSS, to alleviate the stress on ecosystems in the Vermaaks River Valley.

- Long term monitoring to determine plant moisture stress, using the Shölander pressure gauge and leaf water content, using the leaf disc method, should be continued at the three experimental sites in the Vermaaks River and the control site at Marnewicks River. These tests need only be done annually during the summer months.

- By conducting long-term annual plant water stress tests, it will be possible to determine whether plant moisture stress is increasing/decreasing over time and whether changes in the ecosystem occur (e.g. stable or degrading).

- Soil moisture tests should also be done as part of long-term.

- These tests could be expanded to additional areas lower in the Valley, below Site 3.

- Species to be used for these tests should include *Rhus pallens*, *Dodonaea angustifolia*, *Acacia karroo* and *Osyris compressa*.

- These surveys have supplied a baseline to determine the current state of the ecosystem. Future surveys will enable all parties involved to have a better understanding of the effects of groundwater abstraction on ecosystems.

- Spring Kamm/w/051 in the Vermaaks River Valley at Site 3, should be kept flowing naturally at all costs.

- Improved management of surface and groundwater by all parties is necessary to ensure the sustainable utilization of the resource.

- The WCNCB should continue to monitor accurate rainfall, min/max temperatures, relative humidity, wind speed and wind direction at the Automatic Weather Station in the Vermaaks River Valley. This data should be provided for further research on the Kammanassie Mountain.

- The monitoring of snowfall on the Kammanassie Mountain is important, as this would have a direct effect on recharge.

- An additional automatic weather station should be installed at the "top" of the recharge area for better climate data for comparison with the various water level readings in the production boreholes, monitoring boreholes and v-notch.

CHAPTER 7

MONITORING CAPE MOUNTAIN ZEBRA MOVEMENTS RELATED TO DRINKING WATER

7.1 INTRODUCTION

The Cape mountain zebra (*Equus zebra zebra*) once inhabited the entire mountain region south of the Karoo in South Africa. By 1950, hunting, habitat destruction and agricultural competition had reduced the number of Cape mountain zebra to 91 individuals occurring in five, isolated populations. A further two of these populations have gone extinct without contributing to the gene pool of the metapopulation. Thus the entire Cape mountain zebra population in present existence consists of descendants of no more than 58 animals in the remaining three locations. Intensive protection and reintroduction programs initiated by conservation authorities have resulted in an increase in the number of animals to approximately 1200 in 6 National Parks, 10 provincial reserves and 14 private game farms. Most of the Cape mountain zebra today, live in these seeded populations, most of which were derived from the largest and most successful of the relict populations – the Cradock population of Mountain Zebra National Park. According to Moodley (2002) not all seeded populations have been successful and, more alarmingly, the two smallest relict populations in the Kammanassie and Gamka Mountains, both reduced to critically small numbers, may not have recovered from the extreme genetic bottlenecking. In the last 30 years, both these populations have increased in number from 10 to 30 animals each The Cape mountain zebra thus remains at the status of "endangered" in the IUCN's red data book of threatened species (Moodley, 2002).

Severe population bottlenecks, such as the one experienced by the Cape mountain zebra, have serious genetic consequences since they drastically reduce genetic variation and leave populations open to the effects of inbreeding with continuing loss of genetic diversity due to genetic drift. If left uncontrolled, inbreeding may reach levels where fitness is compromised thereby leading to the extinction of the sub-species (Moodley, 2002).

The Wildlife Genetics Unit, University of Cape Town, obtained genetic samples (in the form of blood, tissue, skin or faeces) from over 100 Cape mountain zebras, including 9 animals from Kammanassie and 9 from Gamka. They researched the hypervariable microsatellite DNA of these animals and compared these populations to a) each other and b) to closely related Hartmann's mountain zebra (*E. z. hartmannae*) which are still free ranging in Namibia (Moodley, 2002).

According to Moodley (2002) the results show that all three Cape mountain zebra stocks are grossly inbred, with low numbers of alleles/locus and low heterozygosity. By comparison, the nine Hartmann's mountain zebra populations investigated show no loss of genetic variation and therefore do not appear to have undergone any genetic bottlenecking. However as a consequence of inbreeding, genetic drift and marked reduction of genetic variation, all three relict Cape mountain zebra stocks are significantly differentiated from each other. Thus the entire Cape mountain zebra metapopulation has still maintained much of it's historical genetic variation, albeit in three separate and very inbred stocks. Each stock population therefore represents one third of the entire Cape mountain zebra gene pool. This is alarming given that two thirds of the gene pool exists in only 5% of the metapopulation, i.e. 38 animals at Kammanassie Nature Reserve and 24 at Gamka Mountain Nature Reserve (Moodley, 2002).

In terms of conservation management, these two reserves are critically important in the maintenance of genetic diversity of Cape mountain zebra. A loss of one of these populations will reduce the genetic variation by a third. It is suggested that instead of only extending the Mountain Zebra National Park, which conserves one third of the Cape mountain zebra gene pool, new smaller reserves should also be obtained and restocked with mixed herds from each of the three relict stocks. In the meantime, every imaginable precaution should be taken to protect the two most vulnerable stock populations at Kammanassie and Gamka (Moodley, 2002).

The Kammanassie Nature Reserve was established in 1978 since the conservation and preservation of this pure Cape mountain zebra population was considered a priority. When the reserve was established in 1978 the estimated number of Cape mountain zebra was six (Odendal, 1978). The earliest record of Cape mountain zebra on the Kammanassie mountain dates back to 1949, with a total of 15 animals recorded. Today 24 years later the population consists of 38 confirmed Cape mountain zebra. Although the Kammanassie Nature Reserve and declared mountain catchment comprise 44 000 hectares the Cape mountain zebra utilse a small percentage of the protected area as a whole. They are mainly found in areas where the required type of grazing, a plentiful water supply and shelter in the form of kloofs and ridges are readily available (Skinner & Smithers, 1990). During winter they prefer low-lying areas whilst moving into the higher lying areas in the summer (Skinner & Smithers, 1990). In the past these animals were free to roam where they chose, but today their movements are limited by fences which contain them within the protected area for their own safety.

According to Skinner & Smithers (1990), Cape mountain zebra must drink water daily, normally during the late morning and again in the afternoon. They have a distinct preference for clear water, avoiding murky water and would in such cases usually wade a few paces into the water before drinking (Penzhorn 1984). Penzhorn (1975) states that Cape mountain zebras were observed drinking daily. This observation has been confirmed by reserve staff who closely monitor the Kammanassie population of Cape mountain zebra. The major water source utilised by Cape mountain zebra on the Kammanassie Nature Reserve is from natural springs situated on the mountain. These springs supply a constant source of clean drinking water for numerous different animal species on the Kammanassie Nature Reserve. When springs on the reserve started drying up, within the last five years, it lead to the Western Cape Nature Conservation Board becoming concerned for the continued survival of the Kammanassie population of Cape mountain zebra. Without easy access to clean drinking water, the Kammanassie population of Cape mountain zebra, is under threat of extinction. Intervention in the form of artificial watering points has become necessary to ensure the survival of this population and ultimately of the sub species as a whole. For the first time in the history of the Kammanassie mountain’s naturally occurring Cape mountain zebra population these animals are no longer able to rely on natural springs for drinking water and are forced to rely on artificial water points.

7.2 METHODS

7.2.1 Census methods

7.2.1.1 Foot patrols

Only two roads lead into the Kammanassie mountain region, which means that access into the reserve is on foot. Foot patrols are carried out at regular intervals throughout the year. The Kammanassie Nature Reserve staff, working in groups of two or more, search for Cape Mountain Zebra on foot. The groups maintain contact with one another with IRC or KEY hand-held radios. Staff use Tasco 8 x 40 binoculars to find the Cape Mountain Zebra. Once a group of Cape Mountain Zebra has been located its position is recorded using a Garmin III Geographical Positioning System (GPS). If possible, animals are then photographed using an automatic Minolta 7000 camera with a 70-210 mm AF lens. The following information is then recorded, namely: total number of animals in the group; number of adults, sub-adults and juveniles; and the sex of each individual, if possible. Cape Mountain Zebra are classified into the various age classes using the method as described by Penzhorn (1982).

A summary of all Cape Mountain Zebra sightings on the Kammanassie Nature Reserve is provided, based on all the data available on the Kammanassie Nature Reserve.

All Cape Mountain Zebra sightings from 1993-2001 were mapped onto the ArcView Geographical Information System (GIS) Version 3.1 (Environmental Systems Research Institute Inc., 1998) computer program. Maps showing Cape Mountain Zebra locations on the Kammanassie Mountain were then reproduced using this software. The 1:50 000 Topographical maps used in the ArcView program were supplied by the Western Cape Nature Conservation Board, Working for Water Section.

7.2.1.2 Aerial census

Aerial censuses were carried out in 1983, 1985, 1986, 1987, 1988, 1990 and 1995. A Bell Jet Ranger helicopter was used for the 1983-1988 and 1995 surveys. The occupants of the helicopter included the pilot and three observers. The survey was done from 09:00 to 16:00 over a period of two days. Flying altitude was approximately 50 feet in order to flush out the Cape Mountain Zebra. The helicopter flight path followed the contours, in and out of valleys. Photographs were taken of the right hand side of each zebra seen. Zebras seen from the helicopter were sexed and family groups recorded. Despite using two helicopters for the surveys in 1990, the surveys yielded poor results.

On 14 October 2000 the South African National Parks Board (SANPARKS) assisted the Kammanassie Nature Reserve with an aerial census. The main aim of this operation was to dart as many Kammanassie Cape Mountain Zebra as possible for blood and tissue samples for genetic study purposes by the Wildlife Genetics Unit, Department of Chemical Pathology, University of Cape Town. While looking for suitable animals to dart, an aerial census was carried out. The SANPB Eurocopter was used for this survey. Areas where groups were known to occur were concentrated on. The pilot, veterinarian and one field ranger (Kammanassie Nature Reserve) were on board. The helicopter flew along contour lines ensuring valleys were also searched. A total of 6 hours was spent in the air. Zebras seen were photographed, sexed and family groups recorded. One individual in the family group was then marked using a paint ball gun, to ensure the same group was not counted twice.

7.2.1.3 Foot census

On 28 April 1998 a foot census was carried out on the Kammanassie mountain. A total of 17 routes were covered, in areas where Cape Mountain Zebra were known to occur or to have occurred in the past. A total of 38 people took part in this census. Two people walked each route. All groups left the Kammanassie Nature Reserve Uniondale Office at 06:00 on 28 April 1998. The census lasted from sunrise to sunset. Groups were dropped off at various points and afterwards walked to their pick-up points. Groups kept contact via handheld radios. Photographs, ages and sexes were recorded where possible.

7.2.2 The utilisation of springs by Cape Mountain Zebra on the Kammanassie Nature Reserve

All the springs on the Kammanassie Nature Reserve were monitored in February and March 1999-2002. Every spring utilised by Cape Mountain Zebra on the Kammanassie Mountain was monitored with particular emphasis on the flow rates. Cape Mountain Zebra sightings were then overlaid on ArcView generated maps. These maps were used to determine the movements of Cape Mountain Zebra family groups on the Kammanassie Mountain. Where movement was found to have occurred, the reason for these movements was discussed.

7.3 RESULTS

7.3.1 Census methods

7.3.1.1 Foot patrols

A summary of the number of Cape Mountain Zebra found on the Kammanassie Mountain is given in Table 7.1.

Table 7.1: Results from foot patrols on the Kammanassie Mountain

Year	Number of animals	Year	Number of animals
1949	15	1990	20**
1967	16	1991	19
1972	18	1992	25
1973	8*	1994	19
1975	8	1995	20
1978	6	1996	21
1980	9	1997	24
1982	10	1998	32
1984	12	1999	38
1985	13	2000	38
1986	16	2001	34***
1987	18	2002	38
1988	19		

* Drastic reductions in 1972 resulted from capture attempts for translocation purposes.

** Two carcasses were found in May/June 1990. One was a stillborn foal and the other an old stallion who had probably died from a kick in the jaw (signs of dislocated jawbone).

*** Four Cape Mountain Zebra died at Wagenpadsnek in 2001, three foals and one mare.

7.3.1.2 Aerial census

The results of aerial census carried out on the Kammanassie Mountain between 1983 and 1990 are summarised in Table 7.2.

Table 7.2: A summary of aerial census results 1983 – 1990

ANIMAL ID	1983	1985	1986	1987	1988	1990
A1	M		M		M	
A2	F				F	F
A3					JU	
J2	F					
B1	J		M	M	M	
B2		U		F	F	
B3				JU	U	U
C1		M	M	M	M	M
C2		F	F	F	F	F
C3			JU	U	U	
C4						JU
D1	M	M		M	M	M
D2		U		U	F	F
D3					JU	
D4						JU
E2	F	F	F	F	F	
E3		U	U		U	
F2		U	F	F	F	F
F3			JU	U		
F4					JU	
F5						JU
G		U			U	
H			JU	U	U	
F3I					U	
K			U	U		
L			U	U		
D3M2						U
M3						JU
N						F
C30						U
P						JU
TOTAL	**6**	**9**	**12**	**14**	**19**	**16**

M = Male; F = Female; J = Juvenile; U = Unsexed

An aerial census was conducted on the Kammanassie Nature Reserve on 14 November 1995 and the results are summarised in Table 7.3.

Table 7.3: A summary of aerial census results carried out on 14 November 1995

Area	Total	Male	Female	Adult	Sub-adult	Juvenile
Dysselsberg (1)	2			2		
Dysselsberg (2)	3			2		1
Roode Els	3			3		
Wildealsvlei	1			1		
Kleingeluk	2			1		1
TOTAL	**11**			**9**		**2**

On 14 October 2000 an aerial census was carried out in conjunction with the South African National Parks. The main aim of the exercise was to dart as many animals as possible for tissue and blood samples for genetic testing. The aerial census was carried out at the same time. These results are presented in Table 7.4.

Table 7.4: A summary of aerial census results carried out on 14 October 2000

Area	Total	Male	Female	Adult	Sub-adult	Juvenile
Uitkyk/Rooiplaas	2		2	2F		
Leeuwblad	6	2	4	1M 3F	1F 1M	
Dysselsberg (1)	2	2		2M		
Dysselsberg (2)	2	1	1	1M 1F		
Solomonskraal	4	1	3	1M 2F	1F	
TOTAL	**16**	**6**	**10**	**14**	**2**	

7.3.1.3 Foot census

A summary of the results for the foot census carried out on the 29 April 1998 is presented in Table 7.5.

Table 7.5: Cape Mountain Zebra sighted during the foot census carried out on 29 April 1998

Area	Total	Male	Female	Adult	Sub-adult	Juvenile	Other
Kleingeluk (1)	4	1	3	4			
Kleingeluk (2)	1			1			
Dooringkloof	1	1		1			Dead
Kleinberg	7	1	3	4	2	1	
Paardekloof (1)	1			1			
Paardekloof (2)	5			4		1	
Leeuwblad (1)	1			1			
Upper Diepkloof	2			2			
TOTAL	**22**	**3**	**6**	**18**	**2**	**2**	**1 Dead**

The following Cape Mountain Zebra were seen on numerous occasions and were recorded. They were however not seen on the day of the foot census. (Table 7.6).

Table 7.6: Cape Mountain Zebra on the Kammanassie Nature Reserve not counted in the foot census on 29 April 1998

Area	Total	Male	Female	Adult	Sub-adult	Juvenile	Other
Piet se Laagte	2	1	1	2			
Rooiplaas	2		2	2			
Donkerhoek	1		1	1			
Leeuwblad (2)	6	1	3	4	1	1	
TOTAL	**11**	**2**	**7**	**9**	**1**	**1**	

The confirmed total number of Cape Mountain Zebra for 1998 on the Kammanassie Nature Reserve was 32 animals. The total number of Cape Mountain Zebra recorded for 2001 was 38 animals as shown in Table 7.7.

Table 7.7: Cape Mountains Zebra sightings on the Kammanassie Nature Reserve for 2001

Area	Total	Male	Female	Adult	Sub-adult	Juvenile	Other
Piet se Laagte	2	1	1	2			
Rooiplaas	2		2	2			
Upper Diepkloof	2			2			
Kleingeluk (1)	3			2	1		
Kleingeluk (2)	2	1	1	2			
Paardekloof (1)	2			2			
Paardekloof (2)	4			4			
Wagenpads-nek (1)	6	1	2	4	1	1	
Wagenpads-nek (2)	3	1	1	2		1	
Wagenpads-nek (3)	1	1		1			
Leeuwblad (1)	1	1		1			
Leeuwblad (2)	6	1	3	4	1	1	
Dysselsberg (1)	2	2		2			
Dysselsberg (2)	2	1	1	2			
TOTAL	**38**	**10**	**11**	**32**	**3**	**3**	

7.3.2 The utilisation of springs by Cape Mountain Zebra on the Kammanassie Nature Reserve

There are currently 38 Cape Mountain Zebra on the Kammanassie Mountain that depend on springs for drinking water. Springs that are currently used by the CMZ or were used in the past are shown in Table 7.8.

Leeuwblad/Wagenpadsnek/Dysselsberg

The most western section of the Kammanassie Mountain has the highest number of Cape Mountain Zebra. Twenty-one (7 family groups) of the thirty-eight zebra utilise the Leeuwblad/Wagenpadsnek/Dysselsberg area (Table 7.7). The two Dysselsberg family groups were recorded utilising water at spring Kamm/w/051 and the V-notch in the Vermaaks River in 2001. (Highly vulnerable – Section 4.4.3).

The three groups at Wagenpadsnek utilised springs Kamm/w/019, 020, 021, 048, 049 and 50. Only Kamm/w/020 is still flowing, Kamm/w/048 and 050 are standing

Table 7.8: Spring localities and current status, indicating those utilised by Cape Mountain Zebra on the Kammanassie Mountain

LocalityName	Site No.	1999	2000	2001	2002	Year Dry	Utilised by Cape Mountain Zebra
Buffelsklip	Kamm/W/001	Run	Run	Run	Standing		No
Kleinfonteinsberg	Kamm/W/002	Dry	Dry	Dry	Dry	1978	No
Kleinfonteinsberg	Kamm/W/003	Standing	Dry	Dry	Dry	1999	No, but utilised by other game
Kleinfonteinsberg	Kamm/W/004	Standing	Dry	Dry	Dry	12/04/1999	No, but utilised by other game
Buffelsdrif	Kamm/W/005	Run	Run	Run	Dry	12/2001	No, but utilised by other game
Buffelsdrif	Kamm/W/006	Dry	Dry	Dry	Dry	Unknown	Unknown
Elandsvlakte	Kamm/W/007	Run	Run	Run	Run		Yes
Elandsvlakte	Kamm/W/008	Run	Run	Dry	Dry	2000	Yes
Voorzorgpoort	Kamm/W/009	Run	Dry	Dry	Dry	Sep-99	Yes
Wildebeesvlakte	Kamm/W/010	Dry	Dry	Dry	Dry	1983	Unknown
Wildealevlei	**Kamm/W/011**	**Run**	**Run**	**Run**	**Standing**		**Yes**
Kleingeluk	Kamm/W/012	Dry	Dry	Dry	Dry	1996	Yes
Kleingeluk	Kamm/W/013	Dry	Dry	Dry	Dry	1996	Yes
Slawedam I	Kamm/W/014	Dry	Dry	Dry	Dry	1994	Yes
Slawedam II	Kamm/W/015	Dry	Dry	Dry	Dry	Unknown	Yes
Slawedam II	Kamm/W/016	Dry	Dry	Dry	Dry	Unknown	Yes
Rooielskloof	Kamm/W/017	Standing	Dry	Dry	Dry	1999	Yes
Solomonskraal	Kamm/W/018	Dry	Dry	Dry	Dry	1973	Yes
Wagenpadsnek130	Kamm/W/019	Standing	Dry	Dry	Dry	1999	Yes
Leeublad	**Kamm/W/020**	**Standing**	**Standing**	**Standing**	**Run**		**Yes**
Leeublad	Kamm/W/021	Standing	Standing	Dry	Dry	2000	Yes
Mannetjiesberg	Kamm/W/022	Run	Dry	Dry	Standing	1999	No
Mannetjiesberg	Kamm/W/023	Run	Run	Run	Run		No
Perdevlakte	Kamm/W/024	Dry	Dry	Dry	Dry	Unknown	No, but utilised by other game
Perdevlakte	Kamm/W/025	Dry	Dry	Dry	Dry	1986	No, but utilised by other game
Wildebeesvlakte	Kamm/W/026	Standing	Dry	Dry	Dry	1999	No, but utilised by other game
Dysselsberg	Kamm/W/027	Dry	Dry	Dry	Dry	1994	Yes
Bergplaas	Kamm/W/028	Standing	Standing	Dry	Dry	2000	No
Bergplaas	Kamm/W/029	Standing	Dry	Dry	Dry	1999	No
Bergplaas	Kamm/W/030	Run	Run	Run	Dry	2001	No
Elandsvlakte	**Kamm/W/031**	**Run**	**Run**	**Run**	**Run**		**Yes**
Elandsvlakte	**Kamm/W/032**	**Run**	**Run**	**Run**	**Run**		**Yes**
Elandsvlakte	Kamm/W/033	Standing	Mud Pools	Dry	Dry	2000	Yes
Elandsvlakte	Kamm/W/034	Standing	Mud Pools	Dry	Dry	2000	Yes
Mannetjiesberg	Kamm/W/035	Run	Standing	Standing	Run	2000	No, but other game
Mannetjiesberg	Kamm/W/036	Run	Standing	Standing	Run		No, but other game
Mannetjiesberg	Kamm/W/037	Run	Run	Run	Run		No, but other game
Perdevlakte	Kamm/W/038	Dry	Dry	Dry	Dry	1997	Yes in the past
Mannetjiesberg	Kamm/W/039	Dry	Dry	Dry	Dry	1983	Unknown
Kleinberg	Kamm/W/040	Dry	Dry	Dry	Dry	1995	Unknown
Upperdiepkloof	Kamm/W/041	Dry	Dry	Dry	Dry	1986	Yes
Elandsrivier	Kamm/W/042	Dry	Dry	Dry	Dry	1997	Yes
Groenplaat	Kamm/W/043	Run	Run	Dry	Dry	2000	No, but other game
Groenplaat	Kamm/W/044	Standing	Run	Dry	Dry	2000	No, but other game
Elandsvlakte	Kamm/W/045	0	Run	Run	Run		No, but utilised by other game
Upperdiepkloof	**Kamm/W/046**	**0**	**Run**	**Run**	**Run**		**Yes**
Kleinrivier	Kamm/W/047	0	Dry	Dry	Dry	Unknown	No
Wagenpadsnek	**Kamm/W/048**	**0**	**Standing**	**Standing**	**Standing**		**Yes**
Rietfontein	Kamm/W/049	0	0	Standing	Dry	2001	Yes
Rietfontein	**Kamm/W/050**	**0**	**0**	**Standing**	**Standing**		**Yes**
Voorzorg	**Kamm/W/051**	**0**	**0**	**Run**	**Dry**	**Dec-02**	**Yes**
Wildealsvlei	**Kamm/W/052**	**0**	**0**	**0**	**Run**		**Yes**
Mannetjiesberg	Kamm/W/053	0	0	0	Run		No

and the rest have dried up within the last three years. Surface flow in the Huis River has decreased over the past few years and is now dry for long periods (Section 4.4.1). Cape Mountain Zebra at Leeuwblad were also known to use this river for drinking water. The spring at Leeuwblad (Kamm/w/020) is vulnerable to abstraction from the wellfield (Section 4.4.3). This spring is utilised by seven Cape Mountain Zebra, and although still flowing it is recommended that it should be monitored closely.

Four Cape Mountain Zebra died at Wagenpadsnek between November 2000 and August 2001. One foal was aborted in the Wagenpadsnek area in November 2000. In January 2001 a foal (1 month old) was separated from its mother when she came to drink at the farm dam at Wagenpadsnek, on returning the foal to its mother it was later found dead. It is possible that the mother rejected the foal and hence without its mother to feed it, resulted in its death. During August 2001 an adult mare with a month old foal, died after drinking water at the farm dam at Wagenpadsnek. She was spooked, ran through a closed gate and broke her neck. Her month-old foal died a week later after attempts by WCNCB to rear the foal by hand.

Kleingeluk/Paardekloof

A total of 11 Cape Mountain Zebra of the Kammanassie Mountain is found on the north-western slopes at Kleingeluk and Paardekloof. A total of four springs have dried up in this area between 1994-1999 namely at Kleingeluk (Kamm/w/012 & 013), Slawedam I (Kamm/w/014) and Rooielskloof (Kamm/w/017). Of these Kamm/w/014 and Kamm/w/017 were classified as vulnerable (Section 4.4.3). These springs are not likely to have been impacted by the KKRWSS but probably as a result of the negative trend in rainfall since 1985.

Upper Diepkloof

Two adults utilised this section of the Kammanassie Mountain. One was however found dead during February 2002. The age of the animal determined from its skull showed it was 15+ years old. This group have also been known to move over to the Kleingeluk/Paardekloof area from time to time.

Zebra in this area utilised springs Kamm/w/007, 008, 031, 032, 033, 034, 041 and 042. Only Kamm/w/007, 031 and 032 are still flowing, while Kamm/w/011 is currently standing. These three springs were classified as “least likely” to have been influenced by groundwater abstraction (Section 4.4.3). Before it dried up in 2000, the Cape Mountain Zebra preferred these areas (Kamm/w/033 and 034) for drinking water. The spring vulnerability of Kamm/w/042 was classified as “intermediate”. It is probably more likely that agricultural abstraction has impacted on this spring than KKRWSS groundwater abstraction (Section 4.4.3).

Piet se Laagte/Rooiplaas

Two zebra move between Piet se Laagte and Kleinfonteinsberg while two adult mares are found at Rooiplaas. The Cape Mountain Zebra in the most eastern section of the Kammanassie Mountain drink water mainly from the Piet se Laagte River, and the Lands and Notsom Rivers at Rooiplaas. Spring Kamm/w/023 feeds the Lands River and was classified “least vulnerable” to groundwater abstraction, but a decrease in rainfall could impact upon spring flow.

7.4 DISCUSSION

It would appear that mares heavy in foal or with young foals cannot easily reach springs Kamm/w/019 and 048. Kamm/w/049 is one of the only standing springs in the area and Kamm/w/019 dried up in 1999 (Table 7.8), one of the remaining standing springs in the area. This spring is situated far up a kloof and access is difficult. As a result mares (with foals) then used the local farm dam at Wagenpadsnek 130 to access drinking water easier. This directly caused the death of one mare and the indirect deaths of the two foals in this area. Records on the reserve also show a foal once drowned at this same dam in the 1990’s. Although the aborted foal cannot directly be linked to a shortage of accessible drinking water, it would indeed indicate stress to the mother. The loss of Cape Mountain zebra in this area is cause for great concern for WCNCB staff and neighbouring landowners.

After the loss of the four Cape Mountain Zebra at Wagenpadsnek a joint project was launched by WCNCB, DWAF, Overberg Water and Mr B Terblanche (farmer-

Leeuwblad), to install an artificial watering point at Wagenpadsnek. A temporary artificial water point was installed during September 2001 and is being utilised by the Wagenpadsnek family groups. This consists of a rain tank, which WCNCB have to full manually every two weeks, connected to a stock drinking trough. From observations it was determined that the Wagenpadsnek groups started utilising the artificial watering point within two weeks of being installed. They utilise approximately 2500 – 4000 litres of water every two weeks. WCNCB staff fills the tank manually with water from the KKRWSS in Dysselsdorp. A more permanent solution such as the installation of a borehole with a solar pump should be considered.

Kamm/w/020 at Leeuwblad was vulnerable to abstraction from the wellfield (Section 4.4.3). This spring was utilised by 7 CMZ, and although still flowing it will have to be monitored closely, since surface flow in the Huis River has declined and dry at certain times of the year. If this spring should dry up the WCNCB would have to consider an artificial watering point at this site.

WCNCB with assistance from Overberg Water, installed a second artificial watering point at the Forestry Huts at Kleingeluk in August 2002, to provide animals in this area with a constant water supply. This watering point provides a more permanent solution as four rain tanks at the forestry huts provide a collection point for rainwater, which are then connected to the crib with a long pipe (gravity fed). This watering point does not need to be manually filled.

From observations it can be determined that the Kammanassie Cape mountain zebra only utilise specific areas on the Kammanassie Mountain. These zebra seem to prefer the western section and northern slopes of the Nature Reserve. Zebra groups concentrate in specific areas and the installation of artificial water points at these preferred areas should be considered.

Regardless of whether springs dried up because of groundwater abstraction or the negative trend in rainfall and decreased amount of snow on the Kammanassie Mountain, the WCNCB should continue monitoring water sources and zebra movement closely.

A helicopter census should be carried out annually on the Kammanassie Mountain to enable WCNCB staff to manage this zebra population more effectively.

7.5 CONCLUSIONS

- Without artificial watering points at strategic places on the Kammanassie Mountain the 38 endangered Cape Mountain Zebra risk extinction as a result of natural water sources (springs) drying up.

7.6 RECOMMENDATIONS

- Permanent artificial watering points for the endangered Cape Mountain Zebra must be installed at Wagenpadsnek, Kleingeluk and Vermaaks River, to ensure the future survival of this species.

- Regardless of whether springs dry up due to groundwater abstraction or the negative trend in rainfall and decreased amount of snow on the Kammanassie Mountain, the WCNCB will have to monitor water sources and zebra movement closely and install artificial watering points timeously to prevent the unnecessary loss of any Cape Mountain Zebra.

- An annual helicopter census is required on the Kammanassie Mountain.

- The non-aquatic ecosystems must be taken into consideration when determining the amount of groundwater abstraction allowed around the Kammanassie Mountain.

CHAPTER 8

CONCLUSIONS

THE MAIN CONCLUSIONS BASED ON THIS RESEARCH ARE:

- The Little Karoo is regarded as a dry region as it has an average monthly total of less than 31 mm of rain per month.

- Rainfall over the region does not exhibit a distinctive bimodal seasonal cycle.

- Climatologically the seasons MAM and SON appear to be the wettest while drier conditions prevail during the austral mid-summer (DJF) and mid-winter (JJA).

- A long rainfall record (1925 to 2000) reveals that the Little Karoo experienced unusually high rainfall in 1981, 1985 and 1996. These high rainfall values contribute to a general positive rainfall trend since 1925.

- If the shorter period of the recent 30/31 years (1971 to 2000/1) is considered, a general negative trend appears implying that in both the Oudtshoorn and Kammanassie areas a decrease in the amplitude of the rainfall variability occurred over the past thirteen years.

- The trend is most obvious in the DJF, MAM and JJA seasons while rainfall totals increased over the SON season.

- The negative trends are not unusual and might be regarded as a return of rainfall totals to the longer-term norm.

- A strong deviation from the norm was rather the extreme wet years that occurred in the 1970s and 1980s.

- The more recent period of smaller rainfall deviations (1989 to 1999) might have contributed to less soil moisture than for the preceding extremely wet period. In particular, a sequence of below-normal rainfall years appears in the JJA record (1985 to 2000).

- The period of smaller deviations does not necessarily point towards a drought, but compares well with rainfall variability experienced before the 1970's.

- Abstraction has impacted on the low flow discharging into the Vermaaks River.

- Superimposed on the abstraction effects, is a declining precipitation trend since commissioning the well field.

- Abstraction dried up one of these "permanent water" localities (spring 009) causing localised impact. The other spring (051) was temporarily affected and stopped flowing for 6 months.

- The combined effect of the negative rainfall trend over the past 13 years is, in the majority of cases, the probable cause of springs drying up.

- There appears to be a lag period (7 years) between the start of abstraction and significant impact on surface flow in the Vermaaks River.

- Of the 53 springs on the Kammanassie Mountain Range, 9 fall into the most vulnerable category, 10 into the intermediate vulnerability and the remaining 34 are the least vulnerable to the influence of abstraction.

- Twenty-seven springs (50%) occurring on the Kammanassie Mountain clearly emanate from perched groundwater systems (type1), which cannot be influenced by groundwater abstraction and are excluded from potential influence. Sixteen (30%) "water table" (type 2) springs occur and are potentially vulnerable to the effects of abstraction if all the other hydrogeological parameters permit. In a further 10 cases (19%) there is a possibility that the springs emanate from perched systems but there is an element of doubt.

- Thirteen (48%) of the perched groundwater table springs have dried up since the well field was established indicating their susceptibility to low/irregular recharge from rainfall and snow.

- Of the 9 most vulnerable springs, 3 are excluded from influence, as they are perched. Only one has definitely dried up as a result of abstraction (009). A further two of these springs are still flowing (051 and 020). In the remaining 4 cases there is a strong indication that other factors (agricultural, other well field schemes and climate) have played a significant role in springs drying up.

- Of the 10 intermediate vulnerability springs 3 are disqualified on the basis of timing of dry up and one on the basis of being perched. In the remaining 6 cases there are strong indications that influences other than Vermaaks wellfield abstraction have played a major role in spring dry-up.

- Base flow in the Huis River is likely to have been influenced by abstraction from the well field but the volume cannot be quantified.

- This research has only focused on the impact of abstraction of 0.6 million m3/a from the Vermaaks river well field. It has to be recognised though that other groundwater users tapping this resource will also impact the aquifer and potentially influence surface/near surface flow.

- It has been long recognised that the Cedarberg shale plays a prominent role in the occurrence of springs (Meyer, 2002). It has become clear that a large proportion of these springs emanate from perched groundwater tables, and are not vulnerable to influences of abstraction.

-

- Since no similar vegetation descriptions have previously been done on the valleys and springs of the Kammanassie Mountains, this research provides valuable data on these ecosystems.

- This study has allowed for a comprehensive plant species list to be completed for the Vermaaks, Marnewicks and Buffelsklip Valley sections of the Kammanassie Nature Reserve. The plant species list can now be included into the Kammanassie Nature Reserve Management Plan and will result in the plant species list for the reserve being much more comprehensive.

- A new *Erica* species was discovered as a result of this survey.

- The localities of rare and vulnerable plant species previously unknown were identified during this survey.

- Herbarium specimens were collected for all of the plant species collected in this survey. These are stored at the Kammanassie Nature Reserve and duplicate material was sent to the Southern Cape Herbarium in George and Technikon SA, Florida, Johannesburg.

- The floristic account, together with the descriptions of the plant communities serves as a basis to develop a habitat management plan for the Kammanassie Mountains.

- If further springs dry up on the Kammanassie Mountain, plant communities at these springs will change over time and species diversity is expected to decrease. Important water dependent plants will be lost and wet plant communities will be transformed into dry shrub and grass dominated areas.

- The Vermaaks River (abstraction) sites within the alluvium basin had higher plant water stress than at the control site at Marnewicks, which has similar rainfall. This indicated stress probably related to groundwater abstraction.

- *Nymania capensis*, being a karroid plant, probably with anatomical or physiological adaptations to drought especially summer drought, is not considered suitable for plant water stress tests.

- *Rhus pallens*, *Dodonaea angustifolia* and *Acacia karroo*, *Osyris compressa* proved suitable species for plant water stress tests.

- Plant water stress tests only need to be carried out in the summer months as this proved to be the time when the most pronounced differences were found, since high groundwater abstraction and low rainfall put additional stress on the plants.

- The leaf water content and plant moisture stress (Shölander) methods were found to give the most accurate results.

- The Porometer (stomata resistance) did not produce very good results as there were too many variables such as light, wind, relative humidity and temperature that caused readings to vary considerably.

- The best time to collect plant material for the plant moisture stress and leaf water content tests is between 23:00 and 02:00.

- The negative trend in rainfall over the past 13 years, especially in Dec/Jan/Feb, combined with increased groundwater abstraction which co-incided with the growing season of plants has negatively impacted ecosystems in the Vermaaks River.

- Vegetation in the Vermaaks River Valley area from site 2 (Kamm/w/009), in the alluvium basin, to Middleplaas can be considered the most vulnerable to groundwater abstraction. Vegetation that relies on surface water is affected the most when the water table drops as a result of groundwater abstraction, superimposed by low recharge rates due to the negative trends in rainfall since 1985.

- Without artificial watering points at strategic places on the Kammanassie Mountain the 38 endangered Cape Mountain Zebra risk extinction as a result of natural water sources (springs) drying up.

CHAPTER 9

RECOMMENDATIONS

THE MAIN RECOMMENDATIONS EMANATING FROM THIS RESEARCH ARE:

The following **research priorities** to be funded by WRC were identified by this project:

- Determination of the environmental reserve for the Kammanassie Mountain. This should be done by specialists in consultation with the community.

- The effect of ground water release from Production Borehole VR6 into the Vermaaks River on adjacent plant and animal communities and micro habitats.

- A holistic investigation of the impact of agricultural abstraction and peripheral well fields on the Vermaaks River keystone aquifer (Additional monitoring boreholes and flow gauging should be designed and established to provide the necessary data).

- A long-term research project to determine if shifts/changes in plant communities have occurred in the Vermaaks River Valley as a result of changes in the environmental conditions (long term rainfall patterns, water abstraction etc.).

These research projects will assist in addressing industry’s needs while offering previously disadvantaged students at higher tertiary institutions opportunities to become involved in research.

Monitoring

- With further monitoring by WCNCB, DWAF and KKRWSS an environmentally acceptable water level could be determined for the well field. This should be done in consultation with the various stakeholders to address their respective needs.

- The WCNCB should continue to monitor rare and vulnerable species found during this survey to ensure their survival by applying the correct management strategies (for example it could include changing the burning policy for the Vermaaks Valley area).

- Monitoring of spring vegetation should continue to determine changes in plant communities over time related to springs drying up. This could form part of a long-term monitoring research programme on the Kammanassie Nature Reserve as listed above.

- Plant water stress monitoring at experimental sites 2 and 3 as well as Marnewicks (control) should be continued in order to collect long-term data that will allow for more informed decisions regarding abstraction in the Vermaaks River well field. This should be done using the plant moisture stress method (Shölander pressure gauge) and the leaf water content (leaf disc method). These tests need only be conducted annually during the summer months. These tests could be expanded to additional areas lower in the Valley, below Site 3. This could also become a research project undertaken between WRC, WCNCB and tertiary institutions.

- The WCNCB should continue to monitor accurate rainfall, min/max temperatures, relative humidity, wind speed and wind direction at the Automatic Weather Station in the Vermaaks River Valley. This data should be provided for further research on the Kammanassie Mountain.

- The monitoring of snowfall on the Kammanassie Mountain is important, as this would have a direct effect on recharge.

- An additional automatic weather station should be installed at the “top” of the recharge area for better climate data for comparison with the various water level readings in the production boreholes, monitoring boreholes and v-notch.

- The WCNCB will have to monitor water sources and zebra movement closely and install artificial watering points timeously to prevent the unnecessary loss of any Cape Mountain Zebra.

Actions

- Farming methods should be adapted to accommodate the changing rainfall pattern. Western Cape Agriculture should be consulted for assistance in this regard.

- An ecological study (Environmental Impact Assessment) should be conducted before any further well fields are developed.

- Groundwater abstraction by the KKRWSS in the Vermaaks River should not be allowed to increase more than the current abstraction of 0.6 million m^3/a without further monitoring of plant water stress in the Vermaaks/Marnewicks Valleys.

- Re-evaluation of the amount of groundwater abstraction from this aquifer as a result of the negative trend in rainfall and therefore less recharge will have to be conducted an annual basis by DWAF, WCNCB, KKRWSS and local community.

- If necessary, additional source of water (surface) must to be sourced to supplement the KKRWSS, to alleviate the stress on ecosystems in the Vermaaks River Valley.

- Spring Kamm/w/051 in the Vermaaks River Valley at Site 3, should be kept flowing naturally at all costs.

- Improved management of surface and groundwater by all parties is necessary to ensure the sustainable utilization of the resource.

- Permanent artificial watering points for the endangered Cape Mountain Zebra must be installed at Wagenpadsnek, Kleingeluk and Vermaaks River, to ensure the future survival of this species.

- Annual helicopter censuses should be carried out on the Kammanassie Mountain.

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APPENDICES

APPENDIX 1

DRAFT: Western Cape Nature Conservation Board's policy with regard to bulk water supply utilising underground water sources.

By

Wietsche Roets

1. Introduction

Utilisation of underground water sources was highlighted as one of the activities that could have a detrimental impact on the environment, when it was listed by the Minister of Environmental Affairs under section 21 of the Environmental Conservation Act (Act 73 of 1989). This substantiates the fact that the utilisation of underground water sources always was, and still is a controversial issue on which no-one has yet been able to reach consensus. The full implication of underground water abstraction, is still not clearly understood. The utilisation of underground water for bulk supply in the Kammanassie, recently became an example of this controversial issue.

According to Dr Tom Hatton of the CSIRO in Australia, who visited the area to advise Geo-hydrologists of Department of Water Affairs and Forestry, there were no single environmental parameters that could be utilised as an indicator of the possible impacts of underground water utilisation. Measuring change in the environment can be attributed to so many divergent aspects, that assessment of impacts of underground water utilisation cannot be assessed properly within a decade or even longer.

2. Aims and objectives

The aim of this research was to investigate the influence of groundwater abstraction on ecosystems in the Kammanassie Nature Reserve and Environs.

The objectives were as follows:

- To better understand the influence of groundwater abstraction on the interface between groundwater and surface water.
- To better understand the threat posed by groundwater abstraction on ecosystems.
- To provide a case study to inform future developments elsewhere in the Table Mountain Group.
- To assist in assessing whether reports of springs drying up and vegetation stress as a result of groundwater abstraction have any scientific basis.

The Western Cape Nature Conservation Board's (WCNCB) policy has and will always be, that as long as insufficient information is available, a conservative approach must be maintained. The Board does not want to be held responsible 40 years down the line that it, as the custodian of biodiversity in the Cape Floristic Kingdom, approved underground water utilisation, at a time too little was understood of the dynamics of underground water sources.

3. Policy statement

The Western Cape Nature Conservation Board will not support any underground water supply schemes for bulk supply purposes (including underground water abstraction for agricultural activities), unless each individual application has been properly assessed by a stringent Environmental Impact Assessment (EIA). If no clear-cut recommendations on the potential impacts and mitigation thereof are forthcoming the Western Cape Nature Conservation Board will take the precautionary approach, that is, the application will not be approved.

All present and future utilisation of underground water for bulk supply purposes (including abstraction for agricultural activities) must be managed according to the following guidelines:

- Operating rules must be drawn up for each scheme that must be approved by the Department of Environment, Culture and Sport, Western Cape Nature Conservation Board, Department of Water Affairs and Forestry and Department of Agriculture.

- Volumes of water abstracted and water levels must be monitored and recorded accurately on a weekly basis.

- A team of specialists from all relevant disciplines (Geo-hydrologists, ecologists, botanists, etc.) should determine the operating rules for such a scheme, stipulate the upper and lower water levels where abstraction rates should be adjusted or cease all together for both wet and dry years. These thresholds of acceptability should be assessed through an integrated environmental approach.

- These figures should be available for public inspection at any time.

- If, at any time, any new information becomes available to suggest that the scheme should stop any further abstraction, such abstraction should be ceased immediately.

- Any rehabilitation and removal of structures that become redundant as a result of such a decision should be done at the cost of the developer.

Any reference to this document should take note of the fact that the Western Cape Nature Conservation Board is no longer part of the Provincial Administration Western Cape's: Department of Environmental and Cultural Affairs and Sport. The Western Cape Nature Conservation Board is now a separate statutory board. It is therefore no longer responsible for the issuing of permits in terms of the Environmental

Conservation Act No.73 of 1989. The Western Cape Nature Conservation Board is no longer the regulating authority in terms of the above legislation but hope that its policy will influence the relevant authorities as an important interested and affected party in terms of its role as custodian of the Flora Cape Floral Kingdom.

APPENDIX 2

PLANT SPECIES LIST FOR THE VERMAAKS, MARNEWICKS AND BUFFELSKLIP VALLEYS OF THE KAMMANASSIE NR

E	Endangered – taxa in danger of extinction if causal factors continue operating
Ex	Extinct – taxa which are no longer known to exist in the wild
I	Intermediate – taxa known to be extinct, endangered, vulnerable or rare but information is insufficient to categorise them
K	Insufficiently known – taxa that are suspected to belong to any of the above categories but information is lacking
R	Rare - taxa with small world populations, presently not endangered or vulnerable but at risk that a threat could cause a critical decline
V	Vulnerable – taxa believed likely to move into the endangered category in the near future if the factors causing decline continue operating
nt	Not threatened – taxa previously threatened but are no longer in any of the above categories due to an increase in population size or to subsequent discoveries
*	Introduced species

FAMILIES	SPECIES	RED DATA	VERMAAKS	MARNEWICKS	BUFFELSKLIP
PTERIDOPHYTES					
ANEMIACEAE	Mohria caffrorum (L.) Desv.		x		x
ASPLENIACEAE	Asplenium aethiopicum (Burm.f.) Bech.		x		
ASPLENIACEAE	Asplenium platyneuron (L.) Oakes		x		
ASPLENIACEAE	Ceterach cordatum (Thunb.) Desv.		x		
DENNSTAEDTIACEAE	Histiopteris incisa (Thunb.) J.Sm.		x		
DENNSTAEDTIACEAE	Pteridium aquilinum (L.) Kuhn		x		x
GLEICHENIACEAE	Gleichenia polypodioides (L.) Sm.		x	x	
PTERIDACEAE	Cheilanthes capensis (Thunb.) Sw.		x		x
PTERIDACEAE	Cheilanthes hastata (L.f.) Kunze		x		x
PTERIDACEAE	Cheilanthes parviloba (Sw.) Sw.		x	x	x
PTERIDACEAE	Cheilanthes viridis (Forssk.) Sw.		x		
PTERIDACEAE	Pellaea calomelanos (Sw.) Link		x		
THELYPTERIDACEAE	Thelypteris confluens (Thunb.) Morton		x	x	
PALAEODICOTYLEDONS					
LAURACEAE	Cassytha ciliolata Nees		x		
MONOCOTYLEDONEAE					
ALLIACEAE	Tulbaghia violacea Harv.			x	

AMARYLLIDACEAE	Brunsvigia striata (Jacq.) Aiton	Nt	x	x	
AMARYLLIDACEAE	Haemanthus albiflos Jacq.		x	x	x
AMARYLLIDACEAE	Haemanthus species 645		x	x	
AMARYLLIDACEAE	Nerine humilis (Jacq.) Herb.		x		x
ANTHERICACEAE	Chlorophytum comosum (Thunb.) Jacq.		x	x	
ANTHERICACEAE	Chlorophytum crispum (Thunb.) Baker		x		
ANTHERICACEAE	Chlorophytum species 651		x	x	
ASPARAGACEAE	Asparagus africanus Lam.		x	x	x
ASPARAGACEAE	Asparagus asparagoides (L.) W.Wight		x		
ASPARAGACEAE	Asparagus burchellii Baker		x		
ASPARAGACEAE	Asparagus densiflorus (Kunth) Jessop		x	x	
ASPARAGACEAE	Asparagus recurvispinus (Oberm.) Fellingham & N.L.Mey.		x		x
ASPARAGACEAE	Asparagus retrofractus L.		x	x	x
ASPARAGACEAE	Asparagus striatus (L.f.) Thunb.		x	x	x
ASPARAGACEAE	Asparagus suaveolens Burch.		x	x	x
ASPHODELACEAE	Aloe comptonii Reynolds		x	x	x
ASPHODELACEAE	Aloe ferox Mill.		x	x	
ASPHODELACEAE	Bulbinella cauda-felis (L.f.) T.Durand & Schinz		x		
ASPHODELACEAE	Haworthia decipiens Poelln.		x		x
COLCHICACEAE	Androcymbium capense (L.) K.Krause		x		
COLCHICACEAE	Androcymbium longipes Baker		x		
CONVALLARIACEAE	Eriospermum capense (L.) Thunb.		x		x
CONVALLARIACEAE	Eriospermum pubescens Jacq.		x		
CYPERACEAE	Cyperus laevigatus L.				x
CYPERACEAE	Eleocharis limosa (Schrad.) Schult.			x	
CYPERACEAE	Ficinia deusta (P.J.Bergius) Levyns		x		
CYPERACEAE	Ficinia filiformis (Lam.) Schrad.		x		
CYPERACEAE	Ficinia nigrescens (Schrad.) J.Raynal		x		x
CYPERACEAE	Ficinia oligantha (Steud.) J.Raynal		x	x	
CYPERACEAE	Ficinia ramosissima Kunth		x	x	x
CYPERACEAE	Mariscus congestus (Vahl) Schrad.				x
CYPERACEAE	Mariscus thunbergii (Vahl) Schrad.		x	x	
CYPERACEAE	Tetragonia portulacoides Fenzl		x		
CYPERACEAE	Tetraria cuspidata (Rottb.) C.B.Clarke		x		

DIOSCOREACEAE	Dioscorea hemicrypta Burkill		x		x
HYACINTHACEAE	Albuca cooperi Baker		x		x
HYACINTHACEAE	Drimea ciliata (L.f.) Baker		x		
HYACINTHACEAE	Drimia capensis (Burm.f.) Wijnands	Nt	x	x	x
HYACINTHACEAE	Drimia haworthioides Baker		x		x
HYACINTHACEAE	Massonia echinata L.f.		x	x	
HYACINTHACEAE	Polyxena ensifolia (L.f.) Schönland		x	x	x
HYACINTHACEAE	Urginea altissima (L.f.) Baker		x	x	
HYACINTHACEAE	Urginea species 242		x		
HYACINTHACEAE	Veltheimia capensis (L.) DC.			x	
HYPOXIDACEAE	Spiloxene trifurcillata (Nel) Fourc.		x		x
HYPOXIDACEAE	Stachys aethiopicus L.				x
IRIDACEAE	Aristea pusilla (Thunb.) Ker Gawl.		x		
IRIDACEAE	Babiana sambucina (Jacq.) Ker Gawl.		x		
IRIDACEAE	Bobartia macrospatha Baker	R	x		
IRIDACEAE	Ferraria divaricata Sweet		x	x	x
IRIDACEAE	Freesia refracta (Jacq.) Klatt		x		
IRIDACEAE	Tritoniopsis antholyza (Poir.) Goldblatt		x		
IRIDACEAE	Watsonia marlothii L.Bolus		x		
JUNCACEAE	Juncus lomatophyllus Spreng.		x	x	
JUNCACEAE	Juncus oxycarpus E. May. Ex Kunth			x	
JUNCACEAE	Juncus species 567			x	
ORCHIDACEAE	Disa bracteata Sw.		x		
ORCHIDACEAE	Holothrix pilosa (Burch. ex Lindl.) Rchb.f.	I	x		x
POACEAE	Aristida diffusa Trin.		x		x
POACEAE	Aristida junciformis Trin. & Rupr.		x		
POACEAE	Bromus catharticus Vahl	*	x		
POACEAE	Cymbopogon plurinodis (Stapf) Stapf ex Burtt Davy		x	x	x
POACEAE	Cynodon dactylon (L.) Pers.		x		
POACEAE	Digitaria eriantha Steud.		x	x	x
POACEAE	Digitaria sanguinalis (L.) Scop.		x	x	
POACEAE	Ehrharta bulbosa Sm.		x		
POACEAE	Ehrharta erecta Lam.		x	x	x
POACEAE	Ehrharta pusilla Nees ex Trin.		x		

POACEAE	Ehrharta ramosa (Thunb.) Thunb.		x	x	x
POACEAE	Ehrharta villosa Schult.f.		x		
POACEAE	Enneapogon desvauxii P.Beauv.			x	
POACEAE	Eragrostis capensis (Thunb.) Trin.		x		
POACEAE	Eragrostis chloromelas Steud.		x		
POACEAE	Eragrostis curvula (Schrad.) Nees			x	
POACEAE	Eragrostis plana Nees		x	x	
POACEAE	Eustachys paspaloides (Vahl) Lanza & Mattei		x		
POACEAE	Merxmuellera arundinacea (P.J.Bergius) Conert		x		x
POACEAE	Merxmuellera species 239		x		
POACEAE	Merxmuellera stricta (Schrad.) Conert		x		
POACEAE	Miscanthus capensis (Nees) Andersson				x
POACEAE	Panicum ecklonii Nees		x		
POACEAE	Panicum repens L.		x		x
POACEAE	Pentameris macrocalycina (Steud.) Schweick.		x		x
POACEAE	Pentameris species 118		x		
POACEAE	Pentaschistis curvifolia (Schrad.) Stapf				x
POACEAE	Pentaschistis eriostoma (Nees) Stapf		x	x	x
POACEAE	Pentaschistis malouinensis (Steud.) Clayton		x	x	x
POACEAE	Pentaschistis species 122		x		
POACEAE	Pentaschistis species 297		x		
POACEAE	Pentaschistis species 675		x		
POACEAE	Pentaschistis tortuosa (Trin.) Stapf		x	x	
POACEAE	Phragmites australis (Cav.) Steud			x	
POACEAE	Sporobolus africanus (Poir.) Robyns & Tournay		x	x	
POACEAE	Themeda triandra Forssk.		x	x	x
POACEAE	Tribolium hispidum (Thunb.) Desv.		x	x	
POACEAE	Tribolium species 274		x		
POACEAE	Tribolium uniolae (L.f.) Renvoize		x	x	
POACEAE	Triraphis andropogonoides (Steud.) E.Phillips		x		
RESTIONACEAE	Calopsis paniculata (Rottb.) Desv.			x	
RESTIONACEAE	Cannomois scirpoides (Kunth) Mast.		x		
RESTIONACEAE	Elegia capensis (Burm.f) Schelpe				x
RESTIONACEAE	Elegia filacea Mast.		x	x	

RESTIONACEAE	Hypodiscus striatus (Kunth) Mast.		x		
RESTIONACEAE	Ischyrolepis capensis (L.) H.P.Linder		x		
RESTIONACEAE	Ischyrolepis ocreata (Kunth) H.P.Linder		x		x
RESTIONACEAE	Restio fourcadei Pillans		x		
RESTIONACEAE	Restio triticeus Rottb.		x		
RESTIONACEAE	Rhodocoma arida H.P.Linder & Vlok		x	x	
RESTIONACEAE	Rhodocoma fruticosa (Thunb.) H.P.Linder		x		
RESTIONACEAE	Thamnochortus rigidus Esterh.		x		
RESTIONACEAE	Willdenowia teres Thunb.		x		
TECOPHILAEACEAE	Cyanella lutea L.f.		x		
DICOTYLEDONEAE					
ACANTHACEAE	Blepharis capensis (L.f.) Pers.			x	
ACANTHACEAE	Chaetacanthus setiger (Pers.) Lindl.		x	x	x
AIZOACEAE	Aizoon canariense L.		x		x
AIZOACEAE	Aizoon rigidum L.f.		x		
AIZOACEAE	Drosanthemum delicatulum (L.Bolus) Schwantes		x		
AIZOACEAE	Drosanthemum hispidum (L.) Schwantes		x		x
AIZOACEAE	Drosanthemum lique (N.E.Br.) Schwantes				x
AIZOACEAE	Galenia africana L.		x	x	x
AIZOACEAE	Galenia papulosa (Eckl. & Zeyh) Sond.		x		x
AIZOACEAE	Lampranthus diffusus (L.Bolus) N.E.Br.		x		
AIZOACEAE	Machairophyllum acuminatum L.Bolus		x		
AIZOACEAE	Mesembryanthemum crystallinum L.		x		x
AIZOACEAE	Mestoklema tuberosum (L.)N.E.Br. Ex Glen			x	
AIZOACEAE	Phyllobolus splendens (L.) Gerbaulet		x		x
AIZOACEAE	Ruschia lineolata (Haw.) Schwantes		x	x	
AIZOACEAE	Ruschia multiflora (Haw.) Schwantes		x	x	x
AIZOACEAE	Ruschia species 310		x	x	
AIZOACEAE	Ruschia species 667		x		
AIZOACEAE	Ruschia species 537				x
AIZOACEAE	Tetragonia nigrescens Eckl. & Zeyh.		x		
AMARANTHACEAE	Atriplex semibaccata R. Br.	*	x		
AMARANTHACEAE	Atriplex vestita (Thunb.) Aellen		x	x	x
ANACARDIACEAE	Rhus glauca Thunb.		x	x	x

ANACARDIACEAE	Rhus incisa L.f.		x		
ANACARDIACEAE	Rhus laevigata L.		x		
ANACARDIACEAE	Rhus pallens Eckl. & Zeyh.		x	x	x
ANACARDIACEAE	Rhus tomentosa L.		x	x	
APIACEAE	Anginon difforme (L.) B.L.Burtt		x		
APIACEAE	Chamarea capensis (Thunb.) Eckl. & Zeyh.		x		
APIACEAE	Heteromorpha arborescens (Thunb.) Cham. & Schltdl.		x		x
APIACEAE	Peucedanum capense (Thunb.) Sond.		x		x
APIACEAE	Sanicula elata Buch.-Ham. ex D.Don		x		
APOCYNACAEA	Carissa haematocarpa (Eckl.) A.DC.		x	x	x
APOCYNACEAE	Cynanchum obtusifolium L.f.		x		
APOCYNACEAE	Fockea edulis (Thunb.) K.Schum.		x		
APOCYNACEAE	Gomphocarpus cancellatus (Burm.f.) Bruyns		x		
APOCYNACEAE	Gomphocarpus fruticosus (L.) Aiton f.		x		
APOCYNACEAE	Pachypodium bispinosum (L.f.) A.DC.		x		x
APOCYNACEAE	Quaqua mammillaris (L.) Bruyns		x	x	
APOCYNACEAE	Stapelia hirsuta L.		x		
ARALIACEAE	Centella eriantha (A. Rich.) Drude		x		
ARALIACEAE	Cussonia paniculata Eckl. & Zeyh.		x		
ASTERACEAE	Arctotheca prostrata (Salisb.) Britten		x		
ASTERACEAE	Athanasia tomentosa Thunb.			x	
ASTERACEAE	Athanasia trifurcata (L.) L.		x	x	
ASTERACEAE	Athanasia vestita (Thunb.) Druce				x
ASTERACEAE	Berkheya cruciata (Houtt.) Willd.		x		
ASTERACEAE	Chrysanthemoides monilifera (L.) Norl.		x	x	
ASTERACEAE	Chrysocoma ciliata L.		x	x	x
ASTERACEAE	Cineraria alchemilloides DC.		x		x
ASTERACEAE	Cineraria lobata L'Hèr.		x		x
ASTERACEAE	Conyza scabrida DC.		x	x	
ASTERACEAE	Corymbium africanum L.		x		
ASTERACEAE	Cotula heterocarpa DC.		x		
ASTERACEAE	Cotula leariloba (DC.) Hilliard		x		
ASTERACEAE	Cullumia bisulca (Thunb.) Less.		x		
ASTERACEAE	Dicoma spinosa (L.) Druce		x		

ASTERACEAE	Dimorphotheca nudicaulis (L.) B.Nord.		x		
ASTERACEAE	Elytropappus adpressus Harv.		x	x	x
ASTERACEAE	Elytropappus gnaphaloides (L.) Levyns		x	x	
ASTERACEAE	Eriocephalus africanus L.		x	x	x
ASTERACEAE	Eriocephalus ericoides (L.f.) Druce		x		x
ASTERACEAE	Euryops rehmannii Compton		x	x	x
ASTERACEAE	Felicia aethiopica (Burm.f) Adamson & T.M. Salter		x		
ASTERACEAE	Felicia amoena (Sch.Bip) Levyns			x	x
ASTERACEAE	Felicia filifolia (Vent.) Burtt Davy		x	x	x
ASTERACEAE	Garuleum bipinnatum (Thunb.) Less.		x		x
ASTERACEAE	Helichrysum anomalum Less.		x		x
ASTERACEAE	Helichrysum cylindriflorum (L.) Hilliard & B.L.Burtt		x		
ASTERACEAE	Helichrysum cymosum (L.) D.Don.		x		x
ASTERACEAE	Helichrysum felinum Less.		x		
ASTERACEAE	Helichrysum nudifolium (L.) Less.		x		
ASTERACEAE	Helichrysum odoratissimum (L.) Sweet		x	x	
ASTERACEAE	Helichrysum rosum (P.J. Bergius) Less.		x		
ASTERACEAE	Helichrysum rotundifolium (Thunb.) Less.		x		
ASTERACEAE	Helichrysum species 445		x		
ASTERACEAE	Helichrysum teretifolium (L.) D.Don		x	x	
ASTERACEAE	Helichrysum zeyheri Less.		x	x	x
ASTERACEAE	Helichrysum zwartbergense Bolus		x		
ASTERACEAE	Leysera gnaphalodes (L.) L.		x		
ASTERACEAE	Leysera tenella DC.		x	x	x
ASTERACEAE	Metalasia massonii S.Moore		x		x
ASTERACEAE	Metalasia pallida Bolus		x		
ASTERACEAE	Metalasia pungens D.Don		x		
ASTERACEAE	Oedera imbricata Lam.		x		
ASTERACEAE	Oedera squarrosa (L.) Anderb. & K.Bremer	Nt	x	x	x
ASTERACEAE	Osteospermum dregei (D.C.) Norl.		x		
ASTERACEAE	Othonna alba Compton		x		
ASTERACEAE	Othonna auriculifolia Licht. ex Less.		x	x	
ASTERACEAE	Othonna cylindrica (Lam.) DC.			x	
ASTERACEAE	Othonna filicaulis Jacq.		x	x	

ASTERACEAE	Othonna lobata Schltr.		x		
ASTERACEAE	Othonna protecta Dinter		x		x
ASTERACEAE	Pegolettia retrofracta (Thunb.) Kies		x		
ASTERACEAE	Pentzia dentata (L.) Kuntze		x		
ASTERACEAE	Pentzia elegans DC.		x		
ASTERACEAE	Plecostachys polifolia (Thunb.) Hilliard & B.L.Burtt		x	x	
ASTERACEAE	Printzia polifolia (L.) Hutch.		x	x	
ASTERACEAE	Pteronia fasciculata L.f.		x	x	x
ASTERACEAE	Pteronia flexicaulis L.f.		x	x	
ASTERACEAE	Pteronia incana (Burm.) DC.		x	x	x
ASTERACEAE	Pteronia species 99		x	x	
ASTERACEAE	Pteronia species 534				x
ASTERACEAE	Pteronia stricta Aiton.		x		
ASTERACEAE	Senecio cotyledonis DC.		x	x	
ASTERACEAE	Senecio denudata		x		
ASTERACEAE	Senecio dissidens Fourc.		x		
ASTERACEAE	Senecio ilicifolius L.		x		
ASTERACEAE	Senecio juniperinus L.f.		x		x
ASTERACEAE	Senecio panduratus Less.		x		x
ASTERACEAE	Senecio paniculatus P.J.Bergius		x	x	
ASTERACEAE	Senecio pinifolius (L.) Lam.		x	x	
ASTERACEAE	Senecio species 168		x		
ASTERACEAE	Stoebe burchellii Levyns		x		x
ASTERACEAE	Stoebe plumosa (L.) Thunb.		x	x	
ASTERACEAE	Syncarpha canescens (L.) B.Nord.		x		
ASTERACEAE	Tagetes minuta L.	*	x		
ASTERACEAE	Tarchonanthus camphoratus L.		x		x
ASTERACEAE	Ursinia chrysanthemoides (Less.) Harv.	Nt	x		x
BORAGINACEAE	Lobostemon fruticosus (L.) H.Buek		x		
BORAGINACEAE	Lobostemon glaucophyllus (Jacq.) H.Buek		x	x	
BRASSICACEAE	Lepidium desertorum Eckl. & Zeyh.		x		
BUDDLEJACEAE	Buddleja salviifolia (L.) Lam.		x	x	
CAMPANULACEAE	Cyphia sylvatica Eckl.		x	x	x
CAMPANULACEAE	Lobelia linearis Thunb.		x		

CAMPANULACEAE	Lobelia patula L.f.				x
CAMPANULACEAE	Prismatocarpus candolleanus Cham.		x		
CAMPANULACEAE	Wahlenbergia guthriei L.Bolus		x		x
CAMPANULACEAE	Wahlenbergia nodosa (H.Buek) Lammers		x		
CARYOPHYLLACEAE	Dianthus caespitosus Thunb.		x		
CARYOPHYLLACEAE	Dianthus thunbergii Hooper		x		
CARYOPHYLLACEAE	Pollichia campestris Aiton		x	x	
CARYOPHYLLACEAE	Spergularia rubra (L.) J.& C.Presl	*	x		
CELASTRACEAE	Cassine eucleiformis (Eckl. & Zeyh.) Kuntze		x	x	
CELASTRACEAE	Gymnosporia buxifolia (L.) Szyszyl.		x	x	x
CELASTRACEAE	Maytenus oleoides (Lam.) Loes.		x	x	x
CELASTRACEAE	Pterocelastrus tricuspidatus (Lam.) Sond.		x		x
CELASTRACEAE	Putterlickia pyracantha (L.) Szyszyl.		x	x	
CONVOLVULACEAE	Convolvulus capensis Burm.f.		x		
CONVOLVULACEAE	Cuscuta cassytoides Nees ex Engelm.		x		x
CONVOLVULACEAE	Falckia repens L.f.		x		
CRASSULACEAE	Adromischus caryophyllaceus (Burm.f.) Lem.		x	x	x
CRASSULACEAE	Adromischus triflorus (L.f.) A.Berger		x		
CRASSULACEAE	Cotyledon orbiculata L.		x	x	x
CRASSULACEAE	Cotyledon woodii Schönland & Baker f.		x	x	x
CRASSULACEAE	Crassula arborescens (Mill.) Willd.		x	x	
CRASSULACEAE	Crassula atropurpurea (Haw.) Dietr.		x		
CRASSULACEAE	Crassula biplanata Haw.		x		
CRASSULACEAE	Crassula capitella Thunb.		x	x	x
CRASSULACEAE	Crassula capitella Thunb. ssp. thyrsiflora (Thunb.) Toelken		x	x	
CRASSULACEAE	Crassula cotyledonis Thunb.		x		
CRASSULACEAE	Crassula expansa Dryand.			x	
CRASSULACEAE	Crassula mollis Thunb.		x		x
CRASSULACEAE	Crassula muscosa L.		x	x	x
CRASSULACEAE	Crassula pellucida L.		x		
CRASSULACEAE	Crassula rubricaulis Eckl. & Zeyh.		x	x	x
CRASSULACEAE	Crassula rupestris Thunb.		x	x	x
CRASSULACEAE	Crassula saxifraga Harv.		x		
CRASSULACEAE	Crassula species 530				x

CRASSULACEAE	Crassula species 608		x		
CRASSULACEAE	Crassula subaphylla (Eckl. & Zeyh.) Harv.		x	x	x
CRASSULACEAE	Crassula tetragona L.		x		x
CRASSULACEAE	Crassula tetragona L. ssp. lignescens Toelken		x	x	
CRASSULACEAE	Crassula umbella Jacq.		x	x	x
CRASSULACEAE	Tylecodon paniculatus (L.f.) Toelken		x	x	x
CRASSULACEAE	Tylecodon ventricosus (Burm.f.) Toelken		x		
CUCURBITACEAE	Kedrostis africana (L.) Cogn.		x	x	x
CUCURBITACEAE	Kedrostis capensis (Sond.) A.Meeuse		x	x	
CUCURBITACEAE	Kedrostis nana (Lam.) Cogn.		x	x	x
DIPSACACEAE	Scabiosa columbaria L.		x		
EBENACEAE	Diospyros dichrophylla (Gand.) De Winter		x		
EBENACEAE	Diospyros lycioides Desf.		x	x	x
EBENACEAE	Euclea crispa (Thunb.) Guerke		x	x	x
EBENACEAE	Euclea linearis Zeyh. ex Hiern	Nt	x		
EBENACEAE	Euclea natalensis A.DC.		x		
EBENACEAE	Euclea polyandra (L.f.) E.Mey. ex Hiern		x	x	
EBENACEAE	Euclea schimperi (A.DC.) Dandy		x		
EBENACEAE	Euclea undulata Thunb.		x	x	x
ERICACEAE	Erica anguliger (N.E.Br.) E.G.H. Oliv.		x		
ERICACEAE	Erica cristata Dulfer		x		
ERICACEAE	Erica curvifolia Salisb.		x		
ERICACEAE	Erica glandulosa Thunb.		x		
ERICACEAE	Erica glomiflora Salisb.		x		
ERICACEAE	Erica granulosa H.A.Baker		x		
ERICACEAE	Erica leucopelta Tausch		x		
ERICACEAE	Erica melanthera L.		x		
ERICACEAE	Erica passerinae Montin		x		
ERICACEAE	Erica petraea Benth.		x		
ERICACEAE	Erica quadrangularis Salisb.		x		
ERICACEAE	Erica rosacea (L. Guthrie) E.G.H. Oliv.		x		
ERICACEAE	Erica sp nov	E		x	
ERICACEAE	Erica tragulifera Salisb.		x	x	
ERICACEAE	Erica vlokii E.G.H. Oliv.		x		

ERICACEAE	**Erica NEW SPECIES**				x
EUPHORBIACEAE	Clutia alaternoides L.		x		x
EUPHORBIACEAE	Clutia ericoides Thunb.		x		x
EUPHORBIACEAE	Clutia laxa Eckl. ex Sond.		x		
EUPHORBIACEAE	Clutia polifolia Jacq.		x		x
EUPHORBIACEAE	Euphorbia arceuthobioides Boiss.		x		
EUPHORBIACEAE	Euphorbia heptagona L.		x	x	
EUPHORBIACEAE	Euphorbia mauritanica L.		x	x	x
EUPHORBIACEAE	Euphorbia silenifolia (Haw.) Sweet		x		
EUPHORBIACEAE	Lachnostylis bilocularis R.A.Dyer	Nt	x		
EUPHORBIACEAE	Ricinus communis L.	*	x		
FABACEAE	Acacia karroo Hayne		x	x	x
FABACEAE	Aspalathus granulata R.Dahlgren			x	
FABACEAE	Aspalathus hystrix L.f.		x		
FABACEAE	Aspalathus kougaensis (Garab. ex R.Dahlgren) R.Dahlgren		x		
FABACEAE	Aspalathus laricifolia P.J. Bergius		x		
FABACEAE	Aspalathus suaveolens Eckl. & Zeyh.	R	x		x
FABACEAE	Calpurnia intrusa (R.BR. Ex W.T. Aiton) E. Mey		x	x	
FABACEAE	Cyclopia intermedia E.Mey.		x		
FABACEAE	Dipogon lignosus (L.) Verdc.		x	x	x
FABACEAE	Indigofera denudata L.f.		x		
FABACEAE	Indigofera heterophylla Thunb.		x	x	
FABACEAE	Indigofera species 618		x		
FABACEAE	Lebeckia sericea Thunb.			x	
FABACEAE	Lebeckia species 70		x		
FABACEAE	Otholobium fruticans (L.) C.H.Stirt.	V	x	x	x
FABACEAE	Podalyria burchellii DC.	Nt	x		
FABACEAE	Psoralea affinis Eckl. & Zeyh.		x	x	
FABACEAE	Psoralea species 278		x		
FABACEAE	Tephrosia capensis (Jacq.) Pers.		x		
GENTIANACEAE	Chironia baccifera L.		x	x	
GERANIACEAE	Pelargonium auritum (L.) Willd.		x		
GERANIACEAE	Pelargonium exstipulatum (Cav.) L'Hèr.				x
GERANIACEAE	Pelargonium glutinosum (Jacq.) L'Hèr.		x		

GERANIACEAE	Pelargonium grossularioides (L.) L'Hèr.		x		
GERANIACEAE	Pelargonium hispidum (L.f.) Willd.			x	
GERANIACEAE	Pelargonium laevigatum (L.f.) Willd.		x		
GERANIACEAE	Pelargonium luteolum N.E.Br.		x		
GERANIACEAE	Pelargonium myrrhifolium (L.) L'Hèr.		x	x	
GERANIACEAE	Pelargonium ovale (Burm.f.) L'Hèr.		x		
GERANIACEAE	Pelargonium pseudoglutinosum R.Knuth		x	x	x
GERANIACEAE	Pelargonium pulverulentum Colvill ex Sweet		x		
GERANIACEAE	Pelargonium radulifolium (Eckl. & Zeyh.) Steud.		x		
GERANIACEAE	Pelargonium scabrum (Burm.f.) L'Hèr.		x	x	x
GERANIACEAE	Pelargonium sp. nov		x		
GERANIACEAE	Pelargonium species 628		x		
GERANIACEAE	Pelargonium suburbanum Clifford ex C.Boucher		x		
GERANIACEAE	Pelargonium tetragonum (L.f.) L'Hèr.			x	
GERANIACEAE	Pelargonium trifidum Jacq.		x	x	x
GERANIACEAE	Pelargonium zonale (L.) L'Hèr.		x	x	x
GUNNERACEAE	Gunnera perpensa L.			x	
LAMIACEAE	Leonotis ocymifolia (Burm.f) Iwarsson		x	x	x
LAMIACEAE	Mentha aquatica L.		x	x	x
LAMIACEAE	Mentha longifolia (L.) Huds.		x	x	x
LAMIACEAE	Salvia africana-lutea L.		x	x	x
LAMIACEAE	Salvia namaensis Schinz.			x	
LAMIACEAE	Stachys aethiopica L.		x		
LAMIACEAE	Teucrium trifidum Retz.		x		
LINACEAE	Linum africanum L.		x		
MALVACEAE	Abutilon sonneratianum (Cav.) Sweet				x
MALVACEAE	Grewia occidentalis L.		x		
MALVACEAE	Grewia robusta Burch.		x	x	
MALVACEAE	Hermannia cernua Thunb.		x	x	
MALVACEAE	Hermannia cuneifolia Jacq.		x		x
MALVACEAE	Hermannia flammea Jacq.		x	x	
MALVACEAE	Hermannia holosericea Jacq.		x	x	x
MALVACEAE	Hermannia salviifolia L.f.		x	x	x
MALVACEAE	Hibiscus aethiopicus L.		x	x	

MALVACEAE	Hibiscus pusillus Thunb.		x		
MALVACEAE	Sida ternata L.f.		x		
MELIACEAE	Nymania capensis (Thunb.) Lindb.		x	x	x
MELIANTHACEAE	Melianthus comosus Vahl		x		x
MENISPERMACEAE	Cissampelos capensis L.f.		x	x	x
MOLLUGINACEAE	Limeum aethiopicum Burm.		x		
MOLLUGINACEAE	Limeum telephioides E.Mey. ex Fenzl.		x		
MOLLUGINACEAE	Morella humilis (Cham. ex Schltdl.) Killick		x	x	x
MOLLUGINACEAE	Morella serrata (Lam.) Killick		x		x
MOLLUGINACEAE	Pharnaceum aurantium (DC.) Druce		x		
MONTINIACEAE	Montinia caryophyllacea Thunb.		x	x	x
MORACEAE	Ficus burtt-davyi Hutch.		x	x	
MYRSINACEAE	Myrsine africana L.		x		x
OLEACEAE	Olea europaea L. ssp. africana (Mill.) P.S.Green		x		
OXALIDACEAE	Oxalis dilatata L.Bolus		x		
OXALIDACEAE	Oxalis obtusa Jacq.		x		x
OXALIDACEAE	Oxalis pes-caprae L.		x	x	x
OXALIDACEAE	Oxalis polyphylla Jacq.		x	x	
OXALIDACEAE	Oxalis punctata L.f.		x	x	
OXALIDACEAE	Oxalis species 616		x		
OXALIDACEAE	Oxalis species 621			x	
OXALIDACEAE	Oxalis species 676		x		
OXALIDACEAE	Oxalis species 710			x	
POLYGALACEAE	Muraltia dispersa Levyns		x		
POLYGALACEAE	Muraltia ericaefolia DC.		x		
POLYGALACEAE	Muraltia leptorhiza Turcz.		x		
POLYGALACEAE	Polygala fruticosa P.J.Bergius		x		
POLYGALACEAE	Polygala illepida E. May. Ex Harv.			x	
POLYGALACEAE	Polygala microlopha DC.		x	x	
POLYGALACEAE	Polygala myrtifolia L.		x	x	x
POLYGONACEAE	Polygonum salicifolium		x		
POLYGONACEAE	Rumex acetosella L.	*	x		
POLYGONACEAE	Rumex lativalvis Meisn.		x		
POLYGONACEAE	Rumex sagittatus Thunb.		x		

POLYGONACEAE	Rumex species 416		x		
PORTULACACEAE	Portulacaria afra Jacq.		x	x	x
PROTEACEAE	Leucadendron rubrum Burm.f.		x		
PROTEACEAE	Leucadendron salignum P.J.Bergius		x		
PROTEACEAE	Leucospermum royenifolium (Salisb. ex Knight) Stapf		x		
PROTEACEAE	Protea neriifolia R.Br.		x		
PROTEACEAE	Protea nitida Mill.		x		
PROTEACEAE	Protea repens (L.) L.		x		
RANUNCULACEAE	Clematis brachiata Thunb.		x	x	x
RANUNCULACEAE	Knowltonia filia (L.f.) T.Durand & Schinz		x		
RHAMNACEAE	Phylica imberbis P.J.Bergius		x		
RHAMNACEAE	Phylica meyeri Sond.		x		
RHAMNACEAE	Phylica paniculata Willd.		x	x	x
ROSACEAE	Cliffortia exilifolia Weim.		x		
ROSACEAE	Cliffortia falcata L.f.		x		x
ROSACEAE	Cliffortia ferruginea L.f.		x		x
ROSACEAE	Cliffortia ilicifolia L.		x	x	x
ROSACEAE	Cliffortia ruscifolia L.		x	x	x
ROSACEAE	Cliffortia strobilifera L.			x	x
ROSACEAE	Rubus pinnatus Willd.		x	x	
RUBIACEAE	Anthospermum aethiopicum L.		x	x	x
RUBIACEAE	Anthospermum galioides Rchb.f.		x		
RUBIACEAE	Galium spurium L.		x		
RUTACEAE	Agathosma affinis Sond.	R	x		
RUTACEAE	Agathosma capensis (L.) Dummer		x		
RUTACEAE	Agathosma ovata (Thunb.) Pillans	Nt	x		
RUTACEAE	Agathosma pungens (E.Mey. ex Sond.) Pillans		x		
RUTACEAE	Diosma apetala (Dummer) I.Williams		x		
SALICACEAE	Salix mucronata Thunb.		x	x	
SANTALACEAE	Osyris compressa (P.J. Bergius)		x	x	x
SANTALACEAE	Thesidium fragile (Thunb.) Sond.		x	x	
SANTALACEAE	Thesidium microcarpum (A.DC.) A.DC.				x
SANTALACEAE	Thesium carinatum A.DC.		x		
SAPINDACEAE	Dodonaea angustifolia L.f.		x	x	x

SCROPHULARIACEAE	Aptosimum procumbens (Lehm.) Steud.		x		
SCROPHULARIACEAE	Freylinia densiflora Benth.		x	x	
SCROPHULARIACEAE	Freylinia lanceolata (L.f.) G.Don		x		x
SCROPHULARIACEAE	Halleria lucida L.		x		
SCROPHULARIACEAE	Jamesbrittenia tortuosa (Benth.) Hilliard		x		x
SCROPHULARIACEAE	Nemesia fruticans (Thunb.) Benth.	Nt	x	x	
SCROPHULARIACEAE	Oftia africana (L.) Bocq.		x		
SCROPHULARIACEAE	Selago dregei Rolfe		x		x
SCROPHULARIACEAE	Selago glomerata Thunb.		x		x
SCROPHULARIACEAE	Selago glutinosa E.Mey.		x		x
SCROPHULARIACEAE	Selago luxurians Choisy		x	x	
SCROPHULARIACEAE	Sutera campanulata (Benth.) Kuntze	Nt	x	x	x
SCROPHULARIACEAE	Sutera denudata (Benth.) Kuntze		x		
SCROPHULARIACEAE	Sutera integrifolia (L.f.) Kuntze		x	x	x
SCROPHULARIACEAE	Sutera species 703			x	
SOLANACEAE	Lycium afrum L.		x	x	
SOLANACEAE	Lycium cinereum Thunb. sensu lato		x		x
SOLANACEAE	Solanum guineense L.		x		
SOLANACEAE	Solanum linnaeanum Hepper & Jaeger		x	x	
SOLANACEAE	Solanum tomentosum L.		x	x	x
THYMELAEACEAE	Passerina obtusifolia Thoday		x	x	x
THYMELAEACEAE	Pegolettia retrofracta (Thunb.) Kies				x
THYMELAEACEAE	Struthiola macowanii C.H.Wright		x		
THYMELAEACEAE	Struthiola species 91		x	x	x
URTICACEAE	Laportea peduncularis (Wedd.) Chew		x	x	x
URTICACEAE	Urtica species 625	*	x		
VISCACEAE	Viscum capense L.f.		x	x	x
ZYGOPHYLLACEAE	Zygophyllum flexuosum Eckl. & Zeyh.		x		x
ZYGOPHYLLACEAE	Zygophyllum retrofractum Thunb.		x	x	x

Species highlighted have not been identified at the time of this report being published.

APPENDIX 3

PLANT SPECIES LIST FOR VEGETATION FOUND AT SPRINGS ON THE KAMMANASSIE MOUNTAIN

Family	Species	Red Data
E	Endangered – taxa in danger of extinction if causal factors continue operating	
Ex	Extinct – taxa which are no longer known to exist in the wild	
I	Intermediate – taxa known to be extinct, endangered, vulnerable or rare but information is insufficient to categorise them	
K	Insufficiently known – taxa that are suspected to belong to any of the above categories but information is lacking	
R	Rare - taxa with small world populations, presently not endangered or vulnerable but at risk that a threat could cause a critical decline	
V	Vulnerable – taxa believed likely to move into the endangered category in the near future if the factors causing decline continue operating	
nt	Not threatened – taxa previously threatened but are no longer in any of the above categories due to an increase in population size or to subsequent discoveries	
*	Introduced species	

Family	Species	Red Data
BRYOPHYTES		
ANEURACEAE	Riccardia species 790	
BARTRAMIACEAE	Philonotis hastata (Duby) Wijk & Margad.	
BRACHYTHECIACEAE	Rhynchostegium brachypterum (Hornsch.) A.Jaeger	
BRYACEAE	Pohlia nutans (Hedw.) Lindb.	
DICRANACEAE	Camphlopus species 789	
FISSIDENTACEAE	Fissidens glaucescens Hornsch.	
GRIMMIACEAE	Racomitrium lamprocarpum (C. Mull.) A.Jaeger	
HEDWIGIACEAE	Braunia secunda (Hook.) Bruch, Schimp. & W.Gumbel	
JUNGERMANNIACEAE	Jamesoniella species 805	
PALLAVICINIACEAE	Symphyogyna podophylla (Thumb.) Nees & Mont.	
POTTIACEAE	Triquetrella tristicha (C. Mull.) C. Mull.	
SEMATOPHYLLACEAE	Sematophyllum species 796	
PTERIDOPHYTES		
ASPLENIACEAE	Asplenium adiantum-nigrum L.	
ASPLENIACEAE	Asplenium platyneuron (L.) Oakes	
BLECHNACEAE	Blechnum inflexum (Kunze) Kuhn	
BLECHNACEAE	Blechnum tabulare (Thunb.) Kuhn	
DENNSTAEDTIACEAE	Histiopteris incisa (Thunb.) J.Sm.	
DRYOPTERIDACEAE	Dryopteris inaequalis (Schltdl.) Kuntze	
GLEICHENIACEAE	Gleichenia polypodioides (L.) Sm.	
HYMENOPHYLLACEAE	Hymenophyllum tunbrigense (L.) Sm.	
PTERIDACEAE	Cheilanthes capensis (Thunb.) Sw.	
PTERIDACEAE	Cheilanthes hastata (L.f.) Kunze	
PTERIDACEAE	Cheilanthes parviloba (Sw.) Sw.	
THELYPTERIDACEAE	Thelypteris confluens (Thunb.) Morton	
GYMNOSPERMS		
TAXODIACEAE	Taxodium distichum	*
MONOCOTYLEDONS		
ARACEAE	Zantedeschia aethiopica (L.) Spreng.	
CYPERACEAE	Carpha glomerata (Thunb.) Nees	
CYPERACEAE	Cyathocoma hexandra (Nees) J.Browning	

CYPERACEAE	Cyperus species 906	
CYPERACEAE	Cyperus sphaerospermus Schrad.	
CYPERACEAE	Eleocharis limosa (Schrad.) Schult.	
CYPERACEAE	Epischoenus gracilis Levyns	
CYPERACEAE	Ficinia nigrescens (Schrad.) J.Raynal	
CYPERACEAE	Ficinia oligantha (Steud.) J.Raynal	
CYPERACEAE	Ficinia ramosissima Kunth	
CYPERACEAE	Isolepis verrucosula (Steud.) Nees	
CYPERACEAE	Isolepsis cernua (Vahl) Roem. & Schult.	
CYPERACEAE	Isolepsis species 767	
CYPERACEAE	Isolepsis species 870	
CYPERACEAE	Isolepsis species 898	
CYPERACEAE	Isolepsis species 901	
CYPERACEAE	Mariscus congestus (Vahl) C.B.Clarke	
CYPERACEAE	Mariscus thunbergii (Vahl) Schrad.	
CYPERACEAE	Tetraria capillacea (Thunb.) C.B.Clarke	
CYPERACEAE	Tetraria cuspidata (Rottb.) C.B.Clarke	
DIOSCOREACEAE	Dioscorea hemicrypta Burkill	
IRIDACEAE	Babiana sambucina (Jacq.) Ker Gawl.	
IRIDACEAE	Bobartia paniculata G.J.Lewis	
IRIDACEAE	Watsonia fourcadei J.W.Mathews & L.Bolus	Nt
JUNCACEAE	Juncus bufonius L.	*
JUNCACEAE	Juncus capensis Thunb.	
JUNCACEAE	Juncus dregeanus Kunth	
JUNCACEAE	Juncus effusus L.	
JUNCACEAE	Juncus lomatophyllus Spreng.	
JUNCACEAE	Juncus oxycarpus E.Mey. ex Kunth	
POACEAE	Aristida junciformis Trin. & Rupr.	
POACEAE	Bromus catharticus Vahl	*
POACEAE	Cymbopogon plurinodis (Stapf) Stapf ex Burtt Davy	
POACEAE	Cynodon dactylon (L.) Pers.	
POACEAE	Ehrharta erecta Lam.	
POACEAE	Ehrharta pusilla Nees ex Trin.	
POACEAE	Ehrharta ramosa (Thunb.) Thunb.	
POACEAE	Ehrharta species 747	
POACEAE	Ehrharta species 762	
POACEAE	Eragrostis plana Nees	
POACEAE	Eragrostis species 825	
POACEAE	Panicum ecklonii Nees	
POACEAE	Panicum repens L.	
POACEAE	Pennisetum macrourum Trin.	
POACEAE	Pentameris species 801	
POACEAE	Pentameris species 888	
POACEAE	Pentaschistis eriostoma (Nees) Stapf	
POACEAE	Pentaschistis species 675	
POACEAE	Pentaschistis species 831	
POACEAE	Pentaschistis species 834	
POACEAE	Pentaschistis species 843	
POACEAE	Phragmites australis (Cav.) Steud.	
POACEAE	Themeda triandra Forssk.	
POACEAE	Tribolium species 833	
POACEAE	Tribolium uniolae (L.f.) Renvoize	

RESTIONACEAE	Calopsis paniculata (Rottb.) Desv.	
RESTIONACEAE	Elegia capensis (Burm.f.) Schelpe	
RESTIONACEAE	Elegia filacea Mast.	
RESTIONACEAE	Ischyrolepis ocreata (Kunth) H.P.Linder	
RESTIONACEAE	Platycaulos callistachyus (Kunth) H.P.Linder	
RESTIONACEAE	Restio triticeus Rottb.	
RESTIONACEAE	Rhodocoma capensis Nees ex Steud.	
RESTIONACEAE	Rhodocoma fruticosa (Thunb.) H.P.Linder	
EUDICOTYLEDONS		
AIZOACEAE	Galenia papulosa (Eckl. & Zeyh) Sond.	
AIZOACEAE	Ruschia multiflora (Haw.) Schwantes	
ANACARDIACEAE	Rhus glauca Thunb.	
ANACARDIACEAE	Rhus pallens Eckl. & Zeyh.	
ANACARDIACEAE	Rhus tomentosa L.	
APIACEAE	Heteromorpha arborescens (Thunb.) Cham. & Schltdl.	
APIACEAE	Peucedanum capense (Thunb.) Sond.	
APOCYNACEAE	Cynanchum obtusifolium L.f.	
ARALIACEAE	Centella eriantha (A. Rich.) Drude	
ARALIACEAE	Cussonia paniculata Eckl. & Zeyh.	
ASTERACEAE	Arctotheca prostrata (Salisb.) Britten	
ASTERACEAE	Athanasia pachycephala DC.	
ASTERACEAE	Athanasia tomentosa Thunb.	
ASTERACEAE	Athanasia trifurcata (L.) L.	
ASTERACEAE	Berkheya cruciata (Houtt.) Willd.	
ASTERACEAE	Chrysanthemoides monilifera (L.) Norl.	
ASTERACEAE	Cineraria lobata L'Hèr.	
ASTERACEAE	Cirsium vulgare (Salv.) Ten.	
ASTERACEAE	Conyza canadensis (L.) Cronquist	*
ASTERACEAE	Conyza scabrida DC.	
ASTERACEAE	Cotula andreae (E.Phillips) Bremer & Humphries	
ASTERACEAE	Cotula nigellifolia (DC.) Bremer & Humphries	
ASTERACEAE	Elytropappus adpressus Harv.	
ASTERACEAE	Euryops rehmannii Compton	
ASTERACEAE	Euryops virgineus (L.f.) DC.	
ASTERACEAE	Helichrysum anomalum Less.	
ASTERACEAE	Helichrysum cylindriflorum (L.) Hilliard & B.L.Burtt	
ASTERACEAE	Helichrysum cymosum (L.) D.Don.	
ASTERACEAE	Helichrysum felinum Less.	
ASTERACEAE	Helichrysum nudifolium (L.) Less.	
ASTERACEAE	Helichrysum odoratissimum (L.) Sweet	
ASTERACEAE	Helichrysum petiolare Hilliard & B.L.Burtt	
ASTERACEAE	Helichrysum zeyheri Less.	
ASTERACEAE	Helichrysum zwartbergense Bolus	
ASTERACEAE	Hippia frutescens (L.) L.	
ASTERACEAE	Plecostachys polifolia (Thunb.) Hilliard & B.L.Burtt	
ASTERACEAE	Plecostachys serpyllifolia (P.J.Bergius) Hilliard & B.L.Burt	
ASTERACEAE	Pteronia stricta Aiton.	
ASTERACEAE	Senecio dissidens Fourc.	
ASTERACEAE	Senecio ilicifolius L.	
ASTERACEAE	Senecio juniperinus L.f.	
ASTERACEAE	Senecio lanifer Mart. ex C.Jeffrey	
ASTERACEAE	Senecio panduratus Less.	

ASTERACEAE	Senecio paniculatus P.J.Bergius	
ASTERACEAE	Senecio species 844	
ASTERACEAE	Senecio species 851	
ASTERACEAE	Senecio species 854	
ASTERACEAE	Stoebe plumosa (L.) Thunb.	
ASTERACEAE	Tarchonanthus camphoratus L.	
ASTERACEAE	Ursinia anthemoides (L.) Poir.	
ASTERACEAE	Ursinia chrysanthemoides (Less.) Harv.	Nt
ASTERACEAE	Vellereophyton vellereum (R.A.Dyer) Hilliard	
BRASSICACEAE	Lepidium bonariense L.	*
BRUNIACEAE	Berzelia intermedia (D.Dietr.) Schltdl.	
CAMPANULACEAE	Grammatotheca bergiana (Cham.) C.Presl	
CAMPANULACEAE	Lobelia linearis Thunb.	
CARYOPHYLLACEAE	Dianthus caespitosus Thunb.	
CARYOPHYLLACEAE	Pollichia campestris Aiton	
CARYOPHYLLACEAE	Polycarpon tetraphyllum L.f.	*
CARYOPHYLLACEAE	Spergularia rubra (L.) J.& C.Presl	*
CELASTRACEAE	Cassine eucleiformis (Eckl. & Zeyh.) Kuntze	
CELASTRACEAE	Maytenus heterophylla (Eckl. & Zeyh.) N.Robson	
CELASTRACEAE	Maytenus oleoides (Lam.) Loes.	
CONVOLVULACEAE	Cuscuta cassytoides Nees ex Engelm.	
CRASSULACEAE	Cotyledon orbiculata L.	
CRASSULACEAE	Crassula biplanata Haw.	
CRASSULACEAE	Crassula ericoides Haw.	
CRASSULACEAE	Crassula rubricaulis Eckl. & Zeyh.	
CRASSULACEAE	Crassula tetragona L.	
DIPSACACEAE	Cephalaria humilis (Thunb.) Roem. & Schult.	
DROSERACEAE	Drosera aliciae Raym.-Hamet	
EBENACEAE	Diospyros dichrophylla (Gand.) De Winter	
EBENACEAE	Diospyros lycioides Desf.	
EBENACEAE	Euclea undulata Thunb.	
ERICACEAE	Erica anguliger (N.E.Br.) E.G.H. Oliv.	
ERICACEAE	Erica cordata Andrews	
ERICACEAE	Erica curviflora L.	
ERICACEAE	Erica curvifolia Salisb.	
ERICACEAE	Erica glandulosa Thunb.	
ERICACEAE	Erica glomiflora Salisb.	
ERICACEAE	Erica granulosa H.A.Baker	
ERICACEAE	Erica maesta	
ERICACEAE	Erica petraea Benth.	
ERICACEAE	Erica sp nov	E
ERICACEAE	Erica speciosa Andrews	
ERICACEAE	Erica species 812	
ERICACEAE	Erica species 822	
EUPHORBIACEAE	Clutia alaternoides L.	
FABACEAE	Acacia karroo Hayne	
FABACEAE	Acacia mearnsii De Wild.	
FABACEAE	Amphithalea violacea (E.Mey.) Benth.	
FABACEAE	Aspalathus granulata R.Dahlgren	
FABACEAE	Aspalathus kougaensis (Garab. ex R.Dahlgren) R.Dahlgren	
FABACEAE	Calpurnia intrusa (R.BR. Ex W.T. Aiton) E. Mey	
FABACEAE	Dipogon lignosus (L.) Verdc.	

FABACEAE	Indigofera heterophylla Thunb.	
FABACEAE	Otholobium prodiens C.H.Stirt.	
FABACEAE	Psoralea affinis Eckl. & Zeyh.	
FABACEAE	Psoralea asarina (P.J.Bergius) Salter	
FABACEAE	Psoralea monophylla (L.) C.H.Stirt.	
FABACEAE	Psoralea verrucosa Willd.	
FABACEAE	Tephrosia capensis (Jacq.) Pers.	
GERANIACEAE	Pelargonium cordifolium (Cav.) Curtis	
GERANIACEAE	Pelargonium grossularioides (L.) L'Hèr.	
GERANIACEAE	Pelargonium radulifolium (Eckl. & Zeyh.) Steud.	
GERANIACEAE	Pelargonium scabrum (Burm.f.) L'Hèr.	
GERANIACEAE	Pelargonium zonale (L.) L'Hèr.	
GUNNERACEAE	Gunnera perpensa L.	
LAMIACEAE	Leonotis ocymifolia (Burm.f) Iwarsson	
LAMIACEAE	Mentha longifolia (L.) Huds.	
LAMIACEAE	Mentha pungens	
LAMIACEAE	Salvia namaensis Schinz	
LAMIACEAE	Stachys aethiopica L.	
LINACEAE	Linum africanum L.	
MALVACEAE	Abutilon sonneratianum (Cav.) Sweet	
MALVACEAE	Hermannia cuneifolia Jacq.	
MALVACEAE	Hermannia flammea Jacq.	
MENISPERMACEAE	Cissampelos capensis L.f.	
MOLLUGINACEAE	Morella humilis (Cham. ex Schltdl.) Killick	
MORACEAE	Ficus burtt-davyi Hutch.	
OROBANCHACEAE	Melasma scabrum P.J.Bergius	
OXALIDACEAE	Oxalis pes-caprae L.	
POLYGALACEAE	Muraltia ericaefolia DC.	
POLYGONACEAE	Polygonum aviculare L.	*
POLYGONACEAE	Polygonum salicifolium	*
PRIMULACEAE	Anagallis arvensis L.	
PRIMULACEAE	Anagallis huttonii Harv.	
PROTEACEAE	Leucadendron salignum P.J.Bergius	
PROTEACEAE	Protea neriifolia R.Br.	
PROTEACEAE	Protea repens (L.) L.	
RANUNCULACEAE	Clematis brachiata Thunb.	
RHAMNACEAE	Phylica paniculata Willd.	
ROSACEAE	Cliffortia burchellii Stapf	
ROSACEAE	Cliffortia falcata L.f.	
ROSACEAE	Cliffortia ilicifolia L.	
ROSACEAE	Cliffortia species 807	
ROSACEAE	Cliffortia stricta Weim.	
ROSACEAE	Rubus pinnatus Willd.	
RUBIACEAE	Anthospermum aethiopicum L.	
RUTACEAE	Agathosma affinis Sond.	R
RUTACEAE	Agathosma ovata (Thunb.) Pillans	Nt
RUTACEAE	Agathosma pungens (E.Mey. ex Sond.) Pillans	
RUTACEAE	Empleurum unicapsulare (L.f.) Skeels	
SALICACEAE	Populus x canescens (Aiton) Sm.	*
SALICACEAE	Salix mucronata Thunb.	
SANTALACEAE	Osyris compressa (P.J. Bergius)	
SAPINDACEAE	Dodonaea angustifolia L.f.	

SCROPHULARIACEAE	Halleria lucida L.	
SCROPHULARIACEAE	Selago dregei Rolfe	
SCROPHULARIACEAE	Selago glomerata Thunb.	
SCROPHULARIACEAE	Selago glutinosa E.Mey.	
SCROPHULARIACEAE	Selago luxurians Choisy	
SCROPHULARIACEAE	Sutera campanulata (Benth.) Kuntze	Nt
SOLANACEAE	Solanum linnaeanum Hepper & Jaeger	
SOLANACEAE	Withania somnifera (L.) Dunal	*
URTICACEAE	Forsskaolea viridis Ehrenb. ex Webb	

Species highlighted have not been identified at the time of this report being published.