

ENVIRONMENTAL FACTORS
AND
THE WATER REGIME OF DE HOOP VLEI

by

SHIRLEY E. BUTCHER

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ABSTRACT

The De Hoop Vlei is an internationally registered wetland of great ecological richness which is situated partly within the first and largest nature reserve established by the Cape Department of Nature and Environmental Conservation.

This vlei has flooded twice and been dry on four occasions this century. There has been speculation that land management practices in the catchment are the cause of such extremes. This claim is investigated with reference to established techniques for modelling runoff from rainfall data. As background to the study the characteristics of the De Hoop catchment have been documented. This information was not previously available and provides an essential basis for further study of conditions in De Hoop Vlei.

It is found that whilst large differences in runoff may occur in localised areas due to changing land management practices, because of the composite hydraulic characteristics of the entire catchment it is not possible at the present time to provide a final answer to the question of whether streamflow to De Hoop has changed significantly due to human impact. Nevertheless, some important environmental changes affecting basin capacity and biological factors at De Hoop have been elucidated by this study.

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1. INTRODUCTION

1.1. THE STUDY AREA

De Hoop Vlei, classified by Noble and Hemens (1978) as an endorheic coastal lake, is situated in the south-western Cape Province, approximately 54 km north-east of Cape Agulhas (see Figure 1). It is presently separated from the coast by 2,5 km of mobile sand dunes. The vlei receives most of its water from the Sout River which rises near Jongensklip and drains the grain farming area of the Bredasdorp district, known locally as the Rûens. A tributary of the Sout River, the Potberg River, rises in the Potberg Mountain towards Cape Infanta and drains eastwards towards the Sout River. This accounts for the shape of the catchment as depicted in Figure 2.

The farm De Hoop in the Bredasdorp district was the first land to be purchased by the Cape Department of Nature Conservation for the establishment of a nature reserve. Since its initial acquisition in 1956 the De Hoop Nature Reserve has been considerably enlarged by land purchases and is currently the largest reserve under the jurisdiction of this department, having a surface area of 17 846 ha (Cape Dept. of Nature and Environmental Conservation, 1981). This reserve includes a variety of ecosystems - mobile sand dunes, rocky shore, coastal fynbos, mountain fynbos, caves and underground streams and, not least, the De Hoop Vlei (although provincial ownership does not extend over the entire waterbody at the present time). De Hoop Reserve thus

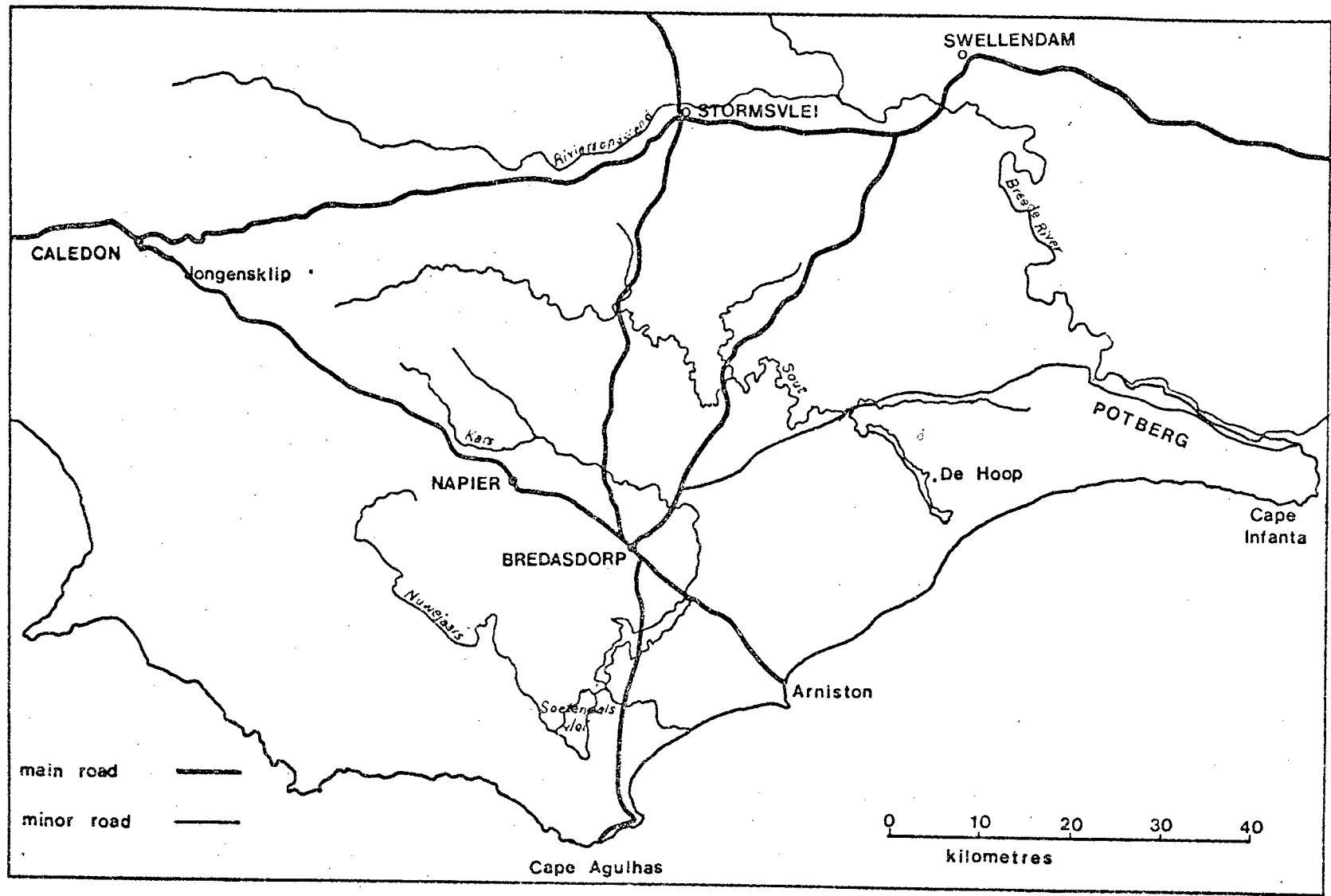


Figure 1: Location of the study area

caters for a wide range of scientific and educational interests. Besides its local importance, De Hoop Vlei also enjoys international status as a registered wetland under the Ramsar Convention, following upon South African participation in the International Conference on the Conservation of Wetlands and Waterfowl held in Ramsar, Iran, in 1971. South Africa became a signatory to this convention in 1975 and registered De Hoop and Barberspan as wetlands of international importance, particularly as wader habitat. Unfortunately there is some dissatisfaction amongst ornithologists regarding the choice of De Hoop Vlei as a registered wader area since the majority of palaeartic waders seem to frequent the estuaries of the West Coast which are not internationally registered (African Wildlife, 1977; Summers et al, 1976) - although some of these areas do now have local conservation status, e.g. Langebaan Lagoon and Rocher Pan. Despite this uncertainty regarding the migrant wader population, De Hoop Vlei does qualify as being of international importance on several other criteria set by the Ramsar convention (Underhill et al, 1980) - including its research and educational value and the practicality of conservation of the area.

A characteristic of De Hoop Vlei is the variability of the water level, particularly in recent years, and the accompanying fluctuations in both the physical and biological components of the ecosystem. In October 1957 a severe flood occurred at De Hoop, causing extensive inundation of the farms Melkkamer and Reimerskraal to the south-west of De Hoop. Both local and migrant avifauna benefited from this event which temporarily enlarged the

wetland considerably and created additional distinct habitat types (Uys and MacLeod, 1967, 1969). Just over a decade later, following exceptionally low local rainfall in three consecutive years (1968 - 1970) almost the entire bed of the vlei was exposed, causing severe disruption of the aquatic ecosystem. A dry state persisted from summer 1972 to June 1976, and again from January 1980 to January 1981.

These changes, the flooding in particular, have caused speculation that there may have been recent environmental changes in the area related to human activities. The most frequently cited examples of human impact upon De Hoop Vlei which could influence flooding are the alleged blockage of a sinkhole in the vlei, and increased agricultural activity in the catchment during the past century. Prior to these impacts it is maintained that there was an annual cycle of dessication and that runoff from the catchment was less. It would appear that periodic droughts are generally accepted as being a natural occurrence and the local people do not link these to human activities in the catchment area.

Landowners on the south-western bank of the vlei understandably feel threatened by the possibility of flooding and would like to be able to control water levels and thereby protect their property. A previous attempt to construct a canal from the vlei to the sea proved unsuccessful largely due to infilling from the large reservoir of mobile sand in the nearby dunes. Today the Cape Department of Nature Conservation is opposed to the vlei being drained and there has consequently been some dissension between farmers and conservationists on this

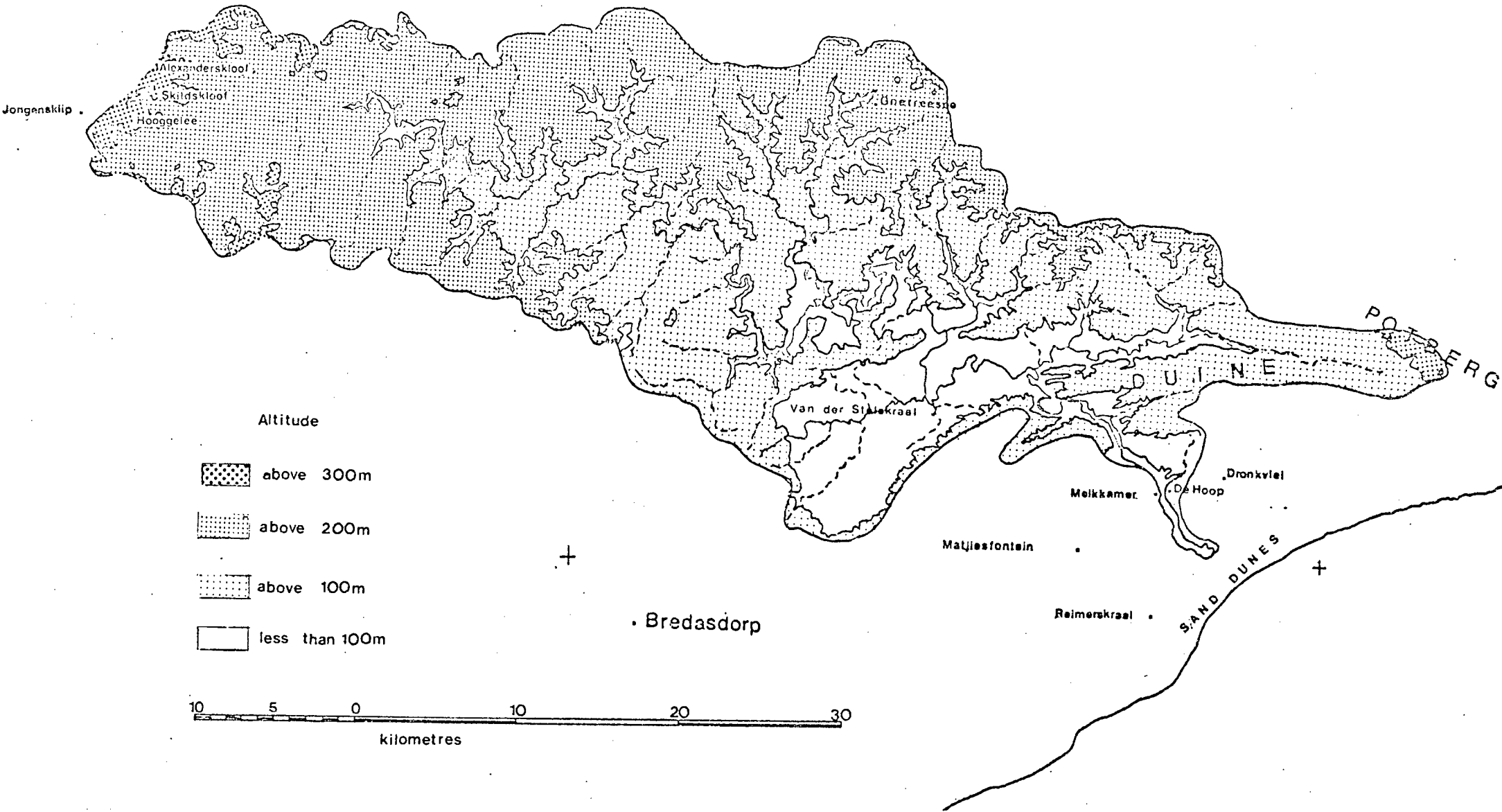


Figure 2: Catchment of De Hoop Vlei

issue.

The study of the water regime of De Hoop Vlei must of necessity encompass a study of its catchment, the state of the vlei being dependent on that of its catchment. The study area as depicted in Figure 2 includes De Hoop Vlei and the catchment area - an area of 1 198 square kilometres.

1.2. PREVIOUS RESEARCH AT DE HOOP

Various research projects have been carried out at De Hoop by officers of the Cape Department of Nature and Environmental Conservation. Most of these are of a biological nature. Since this department stemmed from the former Department of Inland Fisheries, it is to be expected that many of its personnel had a particular interest in the aquatic ecosystem at De Hoop. Siegfried (1963) compiled a report on the Cape kurper, Sandelia capensis, the only indigenous freshwater fish known to have occurred in De Hoop Vlei when it was purchased in 1956. Van Rensburg (1966) was responsible for an investigational report on the Mozambique tilapia, Oreochromis mossambicus (until recently known as Sarotherodon mossambicus) which had been successfully introduced into the area by the Department of Nature Conservation.

The birdlife of the region has been extensively documented (e.g. Uys and MacLeod, 1967, 1969; Smith, 1959; Winterbottom, 1957; Summers et al, 1976; Underhill and Cooper, 1982). These reports are mainly checklists and censuses and highlight the diversity and scientific value of

De Hoop's avifauna.

Several reports have appeared dealing with terrestrial fauna and flora. A report on the De Hoop Reserve appears annually in the Annual Report of the Cape Department of Nature and Environmental Conservation. In the years immediately following the purchase of De Hoop farm some useful material was published in which aspects of the De Hoop Reserve were described. Subsequent annual reports tended to focus on questions of administration and maintenance, with research reports now forming a separate series. The four-page report by Harrison (1957) is the most comprehensive article published by the department dealing specifically with De Hoop Vlei.

A thesis by Brand (1961) deals with the biology and nutrition of the Cape Shoveller and the Cape Teal. As De Hoop Vlei was one of the study sites, this thesis includes a brief description of the vlei and analyses of water quality for the year September 1958 - September 1959. Research by Harrison (1948) on the hydrobiology of the south-western Cape makes brief mention of De Hoop Vlei as one of the alkaline and eutrophic waters of the south-western Cape, although detailed work was not undertaken at this site at the time.

Van der Merwe (1976) compiled a useful introductory work on the De Hoop area, a section of which refers specifically to the vlei. His general description of climate has been used in this study.

Whist these studies have served to highlight some aspects of

the biology and ecology of De Hoop, there is no published research confined specifically to the De Hoop Vlei. In addition both water depth and quality exhibit considerable spatial and temporal variation, which makes the sporadic references which exist difficult to interpret. None of the previous studies have made any attempt to describe the entire hydrological unit of catchment and vlei. This report will supply some data to amend this deficiency.

1.3. APPROACH

This report is concerned primarily with the quantity of water held in De Hoop Vlei. Since the water balance of any impoundment is dynamic, the aquatic ecosystem which it supports will fluctuate in response to the quantity and quality of water available. It is difficult to define an equilibrium state for De Hoop Vlei based on recorded lake levels as there have been wide fluctuations in annual rainfall and the record of lake levels which began in 1958 is incomplete. The variation in lake level shows both seasonal and long-term fluctuation, primarily related to rainfall input.

The two extreme cases, viz. drought and flood, can be isolated as definitive stages in the hydrological history of De Hoop Vlei. The bed of the vlei has been exposed at least four times this century, namely in the years 1903, 1945, 1975 and 1980 (Harrison, 1957 and own observation). In times of flood the vlei overflows its south-western bank and floods the farmlands of Melkkamer, Matjiesfontein and

Reimerskraal. This has occurred twice this century, viz. in 1906 and 1957. Both of these extremes have discernible and immediate effects on the biotic community.

The vlei is in a continual state of fluctuation between these extremes and is therefore subject to frequent environmental changes. Such changes are by definition short term and non-permanent.

Superimposed on these short term fluctuations are longer and more persistent changes. One such change is that brought about by sedimentation, whereby the capacity of the vlei is continually being reduced. In a vlei which is (a) endorheic and often highly eutrophic; (b) supplied from an entirely agricultural catchment and (c) in close proximity to extensive mobile sand dunes in a zone of high wind frequency and velocity, sedimentation is measurable over the timespan of a few decades. Reference is made to this factor in the water regime of De Hoop in Section 4.3 although no quantitative work has been carried out on the phenomenon.

Other environmental factors such as climatic change and geological processes which occur on a different time scale and are not directly related to local land management practices, are beyond the scope of this investigation.

1.4. AIMS OF THIS STUDY

The primary aim of this study is to investigate the allegation that the recent flooding of De Hoop Vlei is a result of human activities both in the catchment and at De

Hoop. This implies a survey of bio-physical and land-use characteristics of the study area over the past century from historical records.

A secondary aim of this study is the documentation of some of the hydrological characteristics of the De Hoop Vlei and its catchment.

The structure of the body of this report is as follows:

Chapter 2 briefly describes the history of land management at De Hoop itself, the site upon which the investigation is centred. Chapter 3 describes the bio-physical and land-use characteristics of the catchment area. Once the region which supplies water to De Hoop Vlei has been described, the physical characteristics of De Hoop Vlei are discussed in more detail in Chapter 4. Finally, in Chapter 5, established hydrological techniques which are in common use in South Africa for modelling runoff and streamflow are applied to the study region with the intention of gaining insight regarding the extent to which the agricultural development of its catchment may have affected the quantity of water which reaches De Hoop Vlei, and providing an estimate of the magnitude of the mean annual runoff from the De Hoop catchment.

2. BRIEF HISTORY OF MAN-LAND RELATIONS AT DE HOOP

Although De Hoop Farm was one of the earliest settlements in the Bredasdorp district, no references to the area have been found in the writings of the early travellers. According to local history the area was colonised in the early 18th century, but as it is some 50 km from the main route to the south-eastern Cape via Swellendam and has the physical obstacle of the Breede River separating it from Swellendam the area was not much frequented by early travellers and therefore receives little attention in early historic records.

2.1. OWNERSHIP RECORD

According to records filed in the office of the Surveyor General in Cape Town, the earliest registered owner of De Hoop Farm was Pieter Lourens Cloete. In 1850 De Hoop, referred to in this instance as Hope Farm, was constituted from sections of four previously recorded land parcels and registered as Bredasdorp farm number 74. The constituent pieces of land, all of which had originally been granted to P.L. Cloete, were the following: De Hoop ("Klipduinen") and section Sw.Q.3 f 10 "adjoining De Hoop" which had been granted to Cloete in 1820; "Klipfontein", granted in 1833, and "Cupidoskraal", granted in 1836. Deed 95 of 10 July 1850 transfers ownership of De Hoop from Pieter Lourens Cloete to Frederik Johannes de Jager.

This farm, with the exception of two portions, passed

through the hands of a succession of owners - the families Human, De Wet, Neethling, Wood and Gardiner - until it was transferred to the Cape Department of Nature Conservation in terms of deed 11958 dd 22 August 1956. The two portions excluded from this transfer were the portion known as Dronkvlei (Klipfontein) which had been transferred to G.F. de Wet in terms of deed 382 of 21 November 1876, and a portion transferred to J.D. Albertyn in terms of deed 181 of 13 January 1926. Both of these pieces of land are currently included in De Hoop Nature Reserve - the latter having been expropriated, and the former purchased during the period 1976 - 1978.

2.2. AGRICULTURE AT DE HOOP

The practice of agriculture at De Hoop has not been easy. The low mean annual rainfall of only 368 mm (25-year average, 1956 - 1980), rocky terrain and very shallow soil on limestone make the area unsuited to grain farming as practised in the surrounding districts. The carrying capacity of the veld is low - although it varies in response to rainfall, which is highly variable - averaging approximately 18 ha per large stock unit (Smit and Goldswain, 1980). An additional problem has been the scarcity of readily available potable water. Water for domestic use was pumped from Grootfontein, a spring on the western side of the vlei just north of the Melkkamer flatland, and piped approximately 6 km to De Hoop.

The highlight of De Hoop's agricultural history was the

successful Spanish horse stud established by the Cloete family. Both Jan Frederick Reitz who owned the Arab horse stud at Rhenosterfontein on the eastern side of the Breede River and Pieter Lourens Cloete of De Hoop were well-known figures in Cape Town in the early 19th century. Pieter Cloete is referred to by Burrows (1952 p.94) as "the turf king who owned The Hope at Potteberg". Indications are that these horse studs were renowned even before the turn of the 19th century since Lady Anne Barnard and her husband, Andrew, paid a visit to Rhenosterfontein in May 1798 to inspect the stud which then boasted some 200 horses (Burrows, 1952 p.150).

Agriculture in the vicinity of De Hoop has always been centred on livestock, the floodplain of the vlei being utilised as grazing during dry periods (Van der Merwe, 1976). During dry seasons the bed of the vlei has also been cultivated, producing valuable vegetable crops (Harrison, 1957). This applies particularly to the northern part of the vlei on the farm Windhoek.

Because of the environmental restraints imposed upon agriculture in the vicinity of De Hoop it would appear that the region is not currently capable of sustaining economically viable agricultural development. Several landowners in the lowland surrounding De Hoop also own other land, either in the grain-producing parts of the district or elsewhere in the country, and from personal observation are not solely dependent on income derived from the De Hoop area.

It is possible that the present-day vegetation which is

responsible for the low carrying capacity of the area is a result of overgrazing in the past. Bateman (1961) made the following remark concerning the rhenosterbos vegetation type:

"The undeveloped areas from Swellendam to Mossel Bay are now mainly worthless renosterbosveld (Elytropappus rhinocerotis), although a hundred years ago they were mainly covered with the rich red grass, Themeda triandra. It is true that much land in the Swellendam and Bredasdorp areas is given over to arable farming, but immediately it is uncropped, or where heavy grazing has occurred, the renoster bush quickly takes over."
(Bateman, 1961 p. 90)

Whilst this does not strictly apply to the De Hoop region which is in a coastal fynbos vegetation zone, it is nevertheless in agreement with the sentiment expressed by a 19th century inhabitant of Melkkamer. Visiting the farm in the 1940's, this elderly lady was asked whether Melkkamer had changed much since her youth. The most striking change, in her opinion, was the appearance of bushy vegetation, since her childhood memories of the region were of a grassland vegetation type (M. Swart, pers. comm.). There may therefore have been rapid environmental change due to human impact over the past century, which has contributed to the decrease in carrying capacity of the region.

A major environmental problem that could possibly be attributed to agriculture is that of infestation by the alien plants Acacia cyclops, and to a lesser extent A. saligna. This problem is not unique, being experienced throughout the fynbos biome. Much of the "bushy vegetation" now found on Melkkamer consists of thickets of these alien plants. It is therefore possible that there has been rapid

environmental deterioration due to overgrazing and unwise use of fire.

2.3. NATURE CONSERVATION AT DE HOOP

In the early days of Nature Conservation at De Hoop the main management objective was to establish an experimental farm for the breeding of rare and endangered wildlife species, especially antelope. It was intended that these animals be used to stock other reserves or sold to private landowners. Grasses and fodder crops were sown in many of the pans and low-lying areas and records kept of the yields of different crops. These were restricted to annual crops such as lucerne, seradella and wheat which would not cause progressive ecological damage.

The aquatic part of the ecosystem was not ignored. Mr H. Wood who owned De Hoop from June 1947 to January 1953, had tried without success to introduce largemouth bass, smallmouth bass and rainbow trout into the vlei. Harrison (1957) commented that these fish were unable to tolerate the wide fluctuations in alkalinity and salinity that occurred. In 1958 the Department of Nature Conservation successfully introduced Oreochromis mossambicus to the vlei (Siegfried, 1963). This is cited as a contributory factor to the establishment of resident breeding pairs of the fish eagle, Haliaeetus vocifer, at De Hoop (Uys and MacLeod, 1967). This is an important development for conservation, since H. vocifer is considered to be a vulnerable and declining species (Noble and Hemens, 1978).

Until 1971 the conservation philosophy at De Hoop was one of "habitat improvement" (Van der Merwe, 1976). This involved the planting of crops, bushcutting, application of fertilizers and trace elements to certain areas, provision of drinking troughs and burning the veld to encourage grasses. Since 1972 management policy has placed greater emphasis on the concept of ecosystem conservation. Species of animals not considered indigenous to the area, such as springbuck and black wildebeest, were removed. Cultivation of fodder crops ceased and management plans focussed on the rehabilitation of a natural coastal fynbos community. This involved activities such as eradication of invasive alien plants, controlled burning of selected plots and the re-establishment of an indigenous animal community. To date the bontebok, Damaliscus dorcas dorcas, and the Cape mountain zebra, Equus zebra zebra, have been reintroduced to De Hoop (Cape Department of Nature Conservation, 1956 - 1981).

2.4. DE HOOP VLEI

It is, however, the waterbody that is the main focus of this report. The surface area (as determined by planimetry from the 1:50 000 topographic map 3420AD WYDGELEË) is 6,2 sq.km. This map was drawn from aerial photography in 1962 and shows the full extent of the vlei. It is thus a sizeable waterbody by local standards and particularly noteworthy because of its setting in semi-arid environs. The first farmers of the district settled close to the vleis Zoetendalsvlei and De Hoop (originally known as

Soutriviersvally). The waterbody thus played a role in attracting initial human settlement to De Hoop and subsequently in arousing the interest of conservationists (particularly as the Department of Nature Conservation stemmed from the former Department of Inland Fisheries). It would thus be reasonable to state that the vlei was initially the focal point of the De Hoop Nature Reserve.

Some controversy surrounds the drainage mechanism of the vlei. The vlei has not opened directly into the sea within living memory. The earliest maps and sketches of the vlei are not more than 130 years old, but indicate a surface separation from the coast much as can be seen today. It is possible that the extent of the mobile sand dunes has increased during this century (Dreyer, 1938).

The current view is that the vlei is depleted mainly by evaporation and underground seepage. But local oral tradition is firm that De Hoop Vlei did have a direct subterranean outlet to the sea via a sinkhole near the centre of what is now the vlei. This hole is reputed to have been situated just south of the stone wall which enters the vlei from Melkkamer. It is said that this hole was not situated at the lowest point of the bed and only served to drain the vlei directly once the water level had risen sufficiently (M. Swart, pers. comm.). It is claimed that by this means the vlei could drain in about three months and it was uncommon for much standing water to remain from one winter to the next (M. Swart, pers. comm.).

During a dry spell (possibly 1902/3) this sinkhole is claimed to have been deliberately blocked in an attempt to

reduce drainage from the vlei and to prevent cattle from falling into the hole. Another version of the story states that a wall surrounding the hole (to keep cattle out) collapsed inward and it was thereafter decided to block the hole completely ("behoorlik toegestop" - to use the local idiom). Shortly afterward (in December 1906) the Sout River came down in flood, further filling this hole with mud and debris, and since then it has not been possible to locate the legendary sinkhole. Judging from rainfall records, the water level in the vlei must have remained high for at least three years after this flood (see Section 4.4).

To compensate for the supposed blockage of the original sinkhole, two channels were dug. The timing and sequence of these attempts is uncertain. A channel known as "Cloete's sloop" was dug in an easterly direction near to Die Mond to drain into another sinkhole which, it is claimed, is connected to the same underground watercourse as others in the area (and possibly the original sinkhole) (J. Blacquiere, pers. comm.). It is even possible that "Cloete's sloop" was dug many years previously for irrigation purposes during a period of high water levels, as Cloete was no longer associated with De Hoop at the time of the 1906 flood. The remains of this channel are still evident and "Cloete's sloop" is now operated by a sluice gate in the dyke constructed by the Cape Department of Nature Conservation in 1958 (Van der Merwe, 1976). It is still regarded as an overflow outlet and its last recorded use was during the winter of 1962 according to the diary kept by the Nature Conservation Officer at De Hoop. The channel does not have an even downward gradient and it is

doubtful whether this ineffectual-looking ditch could play any significant role in flood control.

The other drainage attempt involved digging an open channel to the sea. It was a cause which gained the practical support of almost all the local farmers at the time. A channel was dug in a south-westerly direction towards the beach just west of the extensive mobile sand dunes. This effort was not a success and the channel became filled with sand in a very short time (within a matter of days). Some remains of this channel can still be detected on recent aerial photographs (C. Burgers, pers. comm.).

The question of controlling water levels was again raised during the 1940's. Consultant engineers suggested laying two pipes of 6 ft diameter to follow the course of "Cloete's sloop", but underground. These were to be operated by a sluice gate. The estimated cost of £40 000 was beyond what the farmers could afford at the time and the matter was dropped (H. Wood, M. Swart, pers. comm.). (It is not certain whether this was an official investigation or not, as there does not seem to be any documentation relating to it.)

As far as can be ascertained, the water in the vlei has never been directly utilised. The vlei is classified as alkaline and eutrophic by Harrison (1948). Because of the variability of the water level, measurements of water quality are likewise highly variable. Total dissolved solids range from 5 - 11 ppt and pH from 8,5 - 9,5 (Van der Merwe, 1976; Noble and Hemens, 1978; Brand, 1961; Harrison, 1957). The water quality is thus poor due to the

very high alkalinity and salinities that prevail. Attempts to introduce game fishing have also been unsuccessful for this reason, as mentioned in Section 2.3.

3. CATCHMENT CHARACTERISTICS

In this chapter the focus is on those aspects of the physical, biological and human geography of the catchment that are relevant to its hydrology. Brief mention of macrofauna is made in the section on land use for the sake of completeness. Although not directly related to the hydrology of the region, the fauna has suffered severe impact as a result of human occupation of the catchment. It is a matter of concern that further changes in the biotic community at De Hoop might be occurring as a result of human impacts upon the entire catchment (see Section 3.2.2).

The limestone ridge known locally as the "duine" (or sometimes referred to as "hardeduine" to distinguish them from the coastal sand dunes) separates the study area into distinct geological, soil, vegetational and land-use types. Since the greater part of the catchment falls to the north of the "duine" and for convenience in writing, the word "catchment" shall hereafter in this chapter be used to refer only to this inland region. The coastal region south of the "duine" shall be referred to as the De Hoop region. The phrase "entire catchment" includes both sections.

3.1. PHYSICAL CHARACTERISTICS

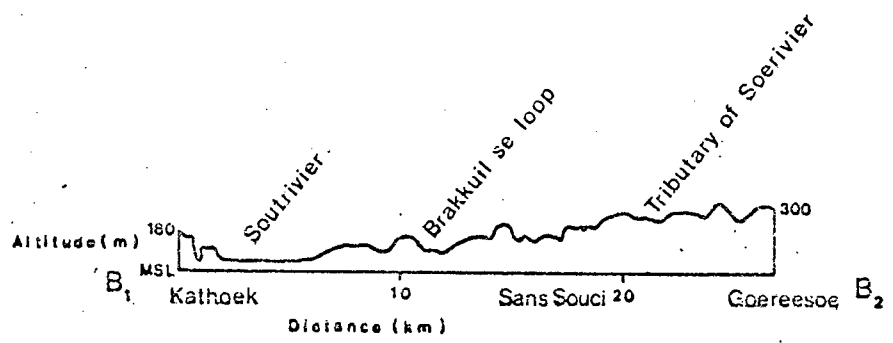
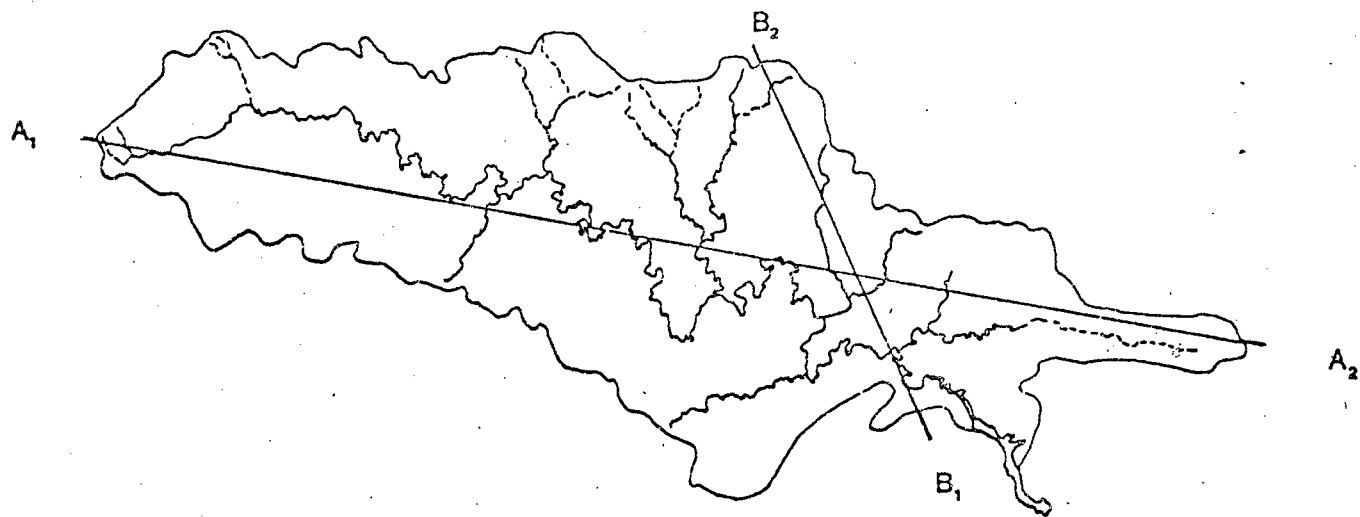
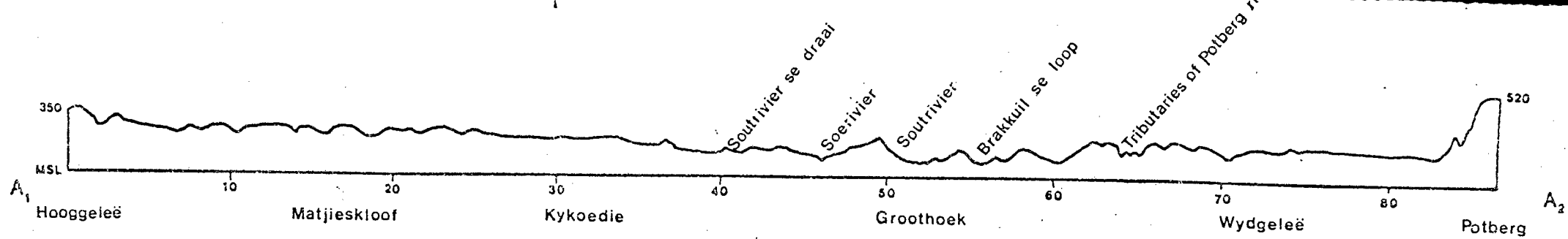
3.1.1. Climate

The climate of an area depends primarily upon its situation and elevation, particularly as this relates to atmospheric and oceanic circulation. Other factors such as surface characteristics, vegetal cover and aspect, which affect the local radiation budget and atmospheric turbulence, are of secondary importance (Schulze, 1965). In this section the primary determinants and the meteorological variables precipitation, temperature and wind are discussed.

3.1.1.1. Situation and Elevation

The study area is situated in the temperate latitudes between $34^{\circ} 12'$ and $34^{\circ} 30'$ south, towards the eastern boundary of the winter rainfall region of the south-western Cape. The catchment falls within a region bounded to the south and south-west by the "duine" and Bredasdorp mountains respectively and to the north and north-east by the Langeberg mountains. The Kars, Breede and Riviersonderend rivers drain the perimeters of the region, and the Sout River the centre.

The topography of the study area and its surrounds is shown in Figure 2. The region is of low relief, aptly described



VERTICAL EXAGGERATION = 10

Figure 3: Catchment elevation

by Lichtenstein (1928 Vol. 1, p.198) in the following words:

"This is called a plain, because there are no high hills, but there are perpetual risings and unevenness of ground."

The catchment exhibits an overall upward slope to the WNW, reaching an altitude of 355 m above mean sea level at Hooggelee. To the east there is a rapid rise to the Potberg mountain (611 m above MSL). This is depicted as the section A₁A₂ in Figure 3. The section B₁B₂ in the same figure extends inland across the point at which the Sout River enters De Hoop Vlei, starting from the summit of the "duine" on the western side of the vlei.

The entire catchment is thus close to the coast and is subject to maritime influence, the remotest point (near Alexanderskloof) being only 65 km inland.

3.1.1.2. Precipitation

Some rainfall occurs throughout the year, the maximum mean monthly rainfall occurring in August and minimum in December and January. (See Figure 6a and Table 3-2.) When this distribution is compared with that for Cape Town (Figure 6b) it is seen that, whilst the mean annual total is lower, the catchment monthly rainfall is more evenly distributed than that of Cape Town and that the summer rainfall is slightly higher. The average catchment rainfall pattern as disclosed by these figures is well suited to the production of winter grain crops, which are sown during the period March to May and harvested between October and December; but due to the variability and relatively low annual rainfall, heavy crop

losses can be incurred in years in which rainfall is low or unfavourably distributed. Summer rains, often associated with cloudbursts, can cause severe erosion since the soil is bare during the period immediately following the harvest.

Rainfall is predominantly cyclonic, associated with the eastward advance of cells of low pressure across the south-western and southern Cape. The winter rains advance mostly from south-west to north-west. There can be large differences in the amount of rain measured by neighbouring gauging stations due to local effects in the hilly terrain; this is particularly so in the vicinity of the "duine".

It would seem that orographic influences exist at the extremities, viz. Jongensklip and Potberg. This is suggested by the isohyetal map of the region (Figure 4) which shows no gradient of mean annual precipitation except at the extremities. The correlation between mean annual precipitation and altitude is not significant if rainfall stations bordering on the catchment are included in the analysis, and stronger ($r = 0,804$) but still not statistically significant at the 95% level if the analysis is limited to those stations that are actually within the catchment (Figure 5). This could be due to the scarcity of data, or might reflect differences due to some other factor, such as aspect.

The mean annual precipitation of individual rainfall stations in the study region ranges from 330 to 410 mm. When the individual means are aggregated a figure of 369 mm is obtained for the mean annual catchment precipitation (see Section 5.2). The data for Tables 3-1 and 3-2 were derived

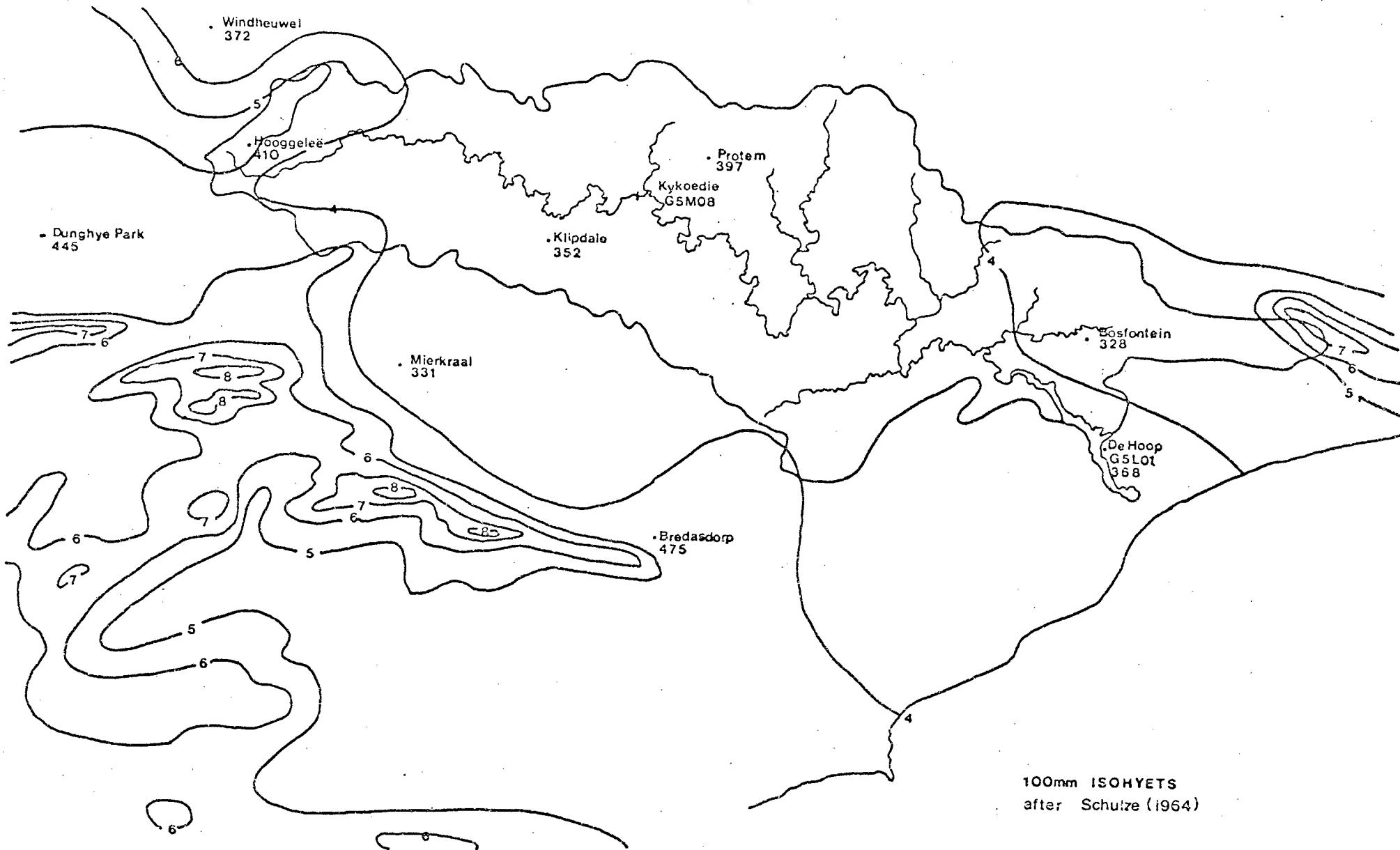
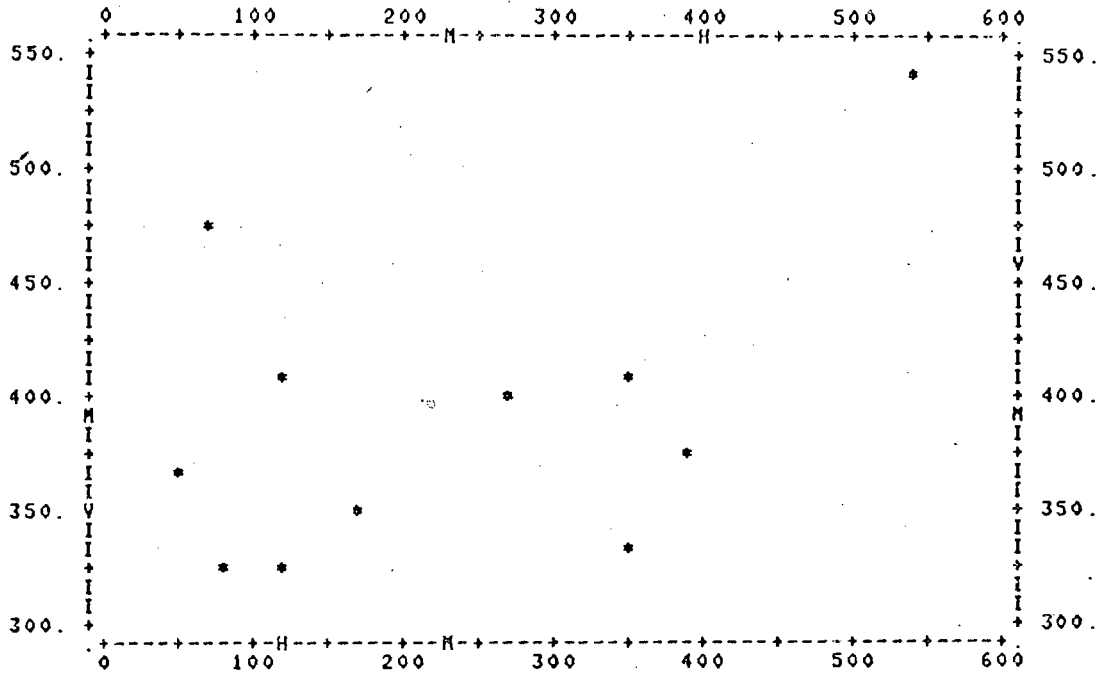


Figure 4: Isohyetal map showing distribution of rain gauges and MAP

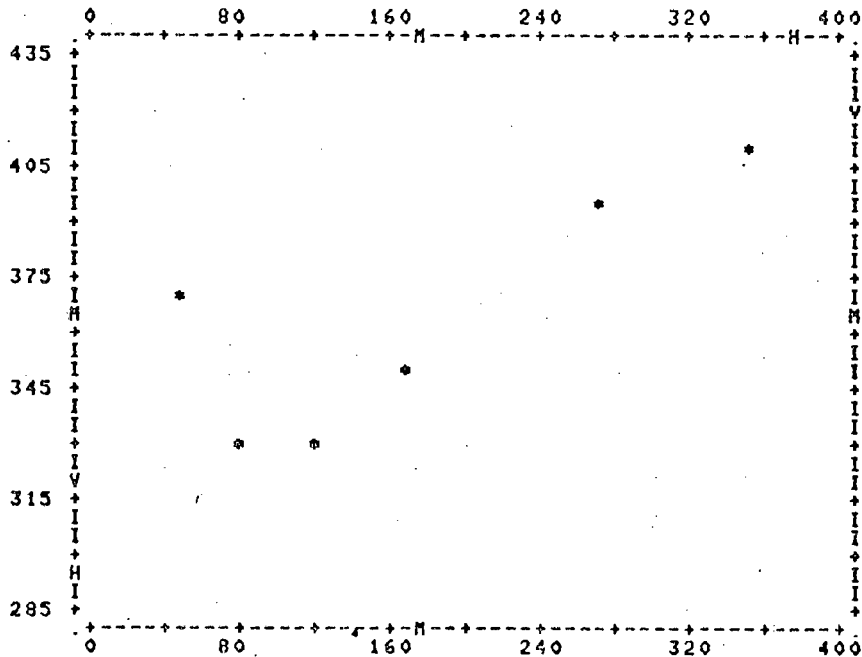
MADISON ACADEMIC COMPUTING CENTER PROGRAM PICT1
MEAN ANNUAL PRECIPITATION VS HEIGHT ABOVE SEA LEVEL
FOR RAINFALL MEASURING STATIONS IN DE HOOP CATCHMENT
FIRST DATA SET

SCAT 1
HORIZONTAL: HEIGHT (VAR. 2)
HEIGHT ABOVE MEAN SEA LEVEL (M)
VERTICAL: RAIN (VAR. 1)
MEAN ANNUAL PRECIPITATION (MM)



11 POINTS ARE INCLUDED IN THE SCALED PLOT
CORRELATION R = .435, T(9) = 1.45, SIG. PROB. = .181

HORIZONTAL: HEIGHT (VAR. 2)
HEIGHT ABOVE MEAN SEA LEVEL (M)
VERTICAL: RAIN (VAR. 1)
MEAN ANNUAL PRECIPITATION (MM)



6 POINTS ARE INCLUDED IN THE SCALED PLOT
CORRELATION R = .804, T(4) = 2.71, SIG. PROB. = .054

Figure 5: Correlation of rainfall and height above sea level

using this mean and output from the computer programme AVRAIN (Pitman, 1973) (Appendix B). In respect of its relatively low mean annual precipitation this catchment resembles the adjacent Breede River Valley (M.A.P. 250 mm). By comparison with the figures for Cape Town (M.A.P. 626 mm) and George (M.A.P. 860 mm) this south-western Cape region is seen to exhibit a typical rain shadow effect, attributable to the presence of the Hottentots Holland and Langeberg mountain ranges (Schulze, 1965 p.313).

Table 3-1. MEAN ANNUAL PRECIPITATION

Time period	\bar{x} (mm) (M.A.P.)	s(mm) (%M.A.P.)	range(mm) min.(yr) max.(yr)	Relative variability (%)
1882 - 1980	369	95,42 (25,85%)	214 (1973) 1015 (1909)	16,69
1882 - 1908	368	70,48	214 (1973)	14,94
1910 - 1980		(19,15%)	557 (1907)	
1965 - 1980	346	77,98 (22,54%)	214 (1973) 518 (1977)	16,71

* Relative variability = $\frac{\sum_{i=1}^n |x_i - \bar{x}|}{n} \cdot \frac{\bar{x}}{100}$
(after Schulze, 1965 p. 265)

x_i = annual precipitation

n = number of years

\bar{x} = M.A.P.

** The average catchment rainfall for the hydrological year 1909 (i.e. October 1908 to September 1909) is the highest on record. This is largely due to the extremely high rainfall figures recorded by the Bredasdorp station in that year.

Table 3-2. MONTHLY DISTRIBUTION OF ANNUAL RAINFALL

Month:	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
\bar{x} (mm)	21,2	25,5	30,9	35,4	43,5	44,6	43,5	47,7	37,3	37,6	29,9	21,1
s (mm)	14,1	21,0	21,4	21,0	24,6	23,7	21,6	27,7	22,7	25,1	21,8	22,7
s/ \bar{x} (%)	66,5	82,4	69,3	59,3	56,6	53,1	49,7	58,1	60,9	66,8	72,9	107,6
min	0,4	1,6	0,2	0,9	4,8	8,7	1,7	3,2	5,5	3,0	1,5	0,7
(yr)	(1958)	(1887 & 1950)	(1979)	(1979)	(1928)	(1950)	(1958)	(1918)	(1887)	(1912)	(1961)	(1957)
max	66,8	112,3	148,9	119,0	116,2	122,1	128,9	206,5	149,1	169,2	98,2	188,0
(yr)	(1943)	(1979)	(1909)	(1967)	(1890)	(1921)	(1909)	(1909)	(1909)	(1948)	(1952)	(1906)

These data (with the exception of the values for s/ \bar{x}) are represented graphically in Figure 6a.

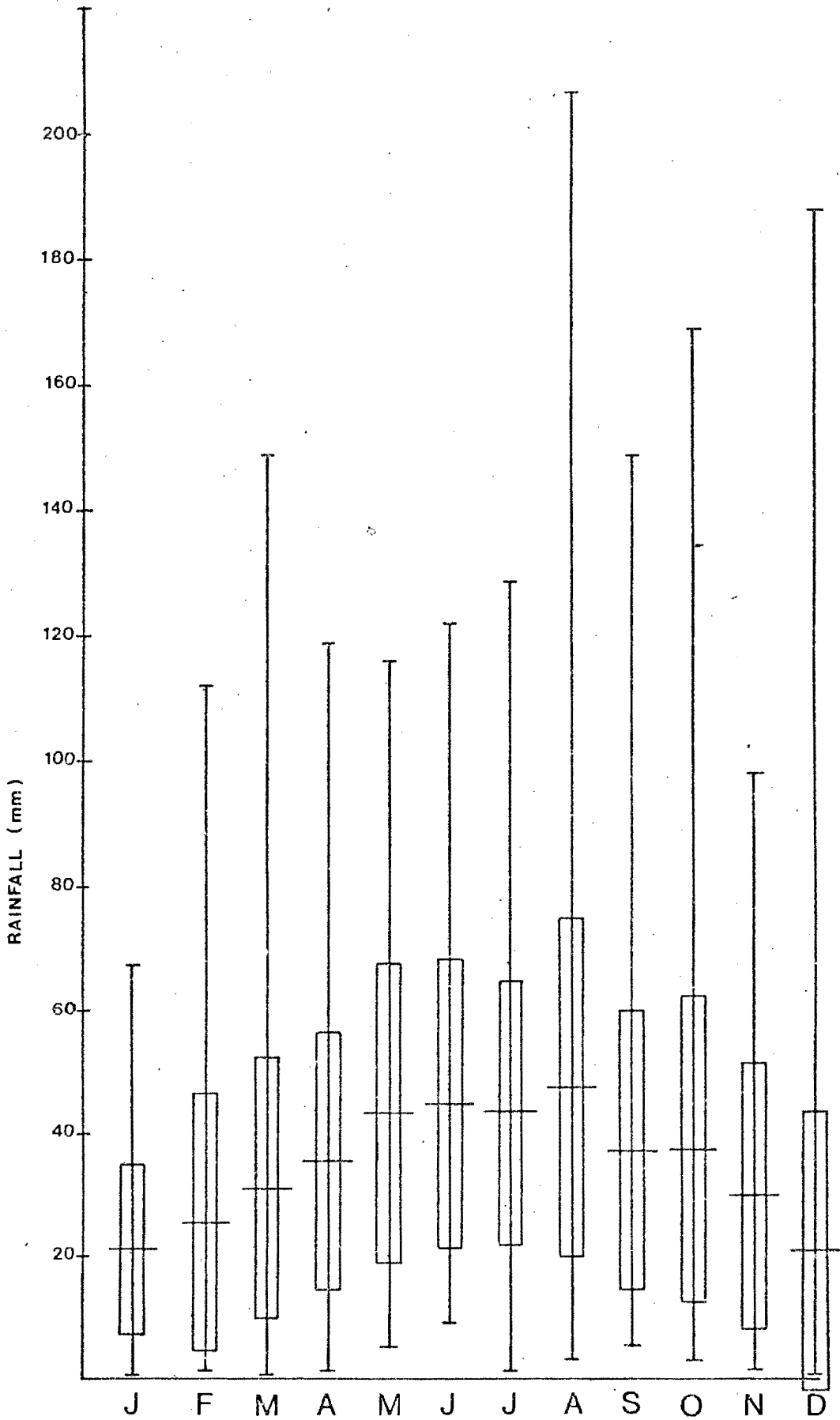


Figure 6a: Monthly distribution of catchment rainfall (\bar{x} , s and range from Table 3-2)

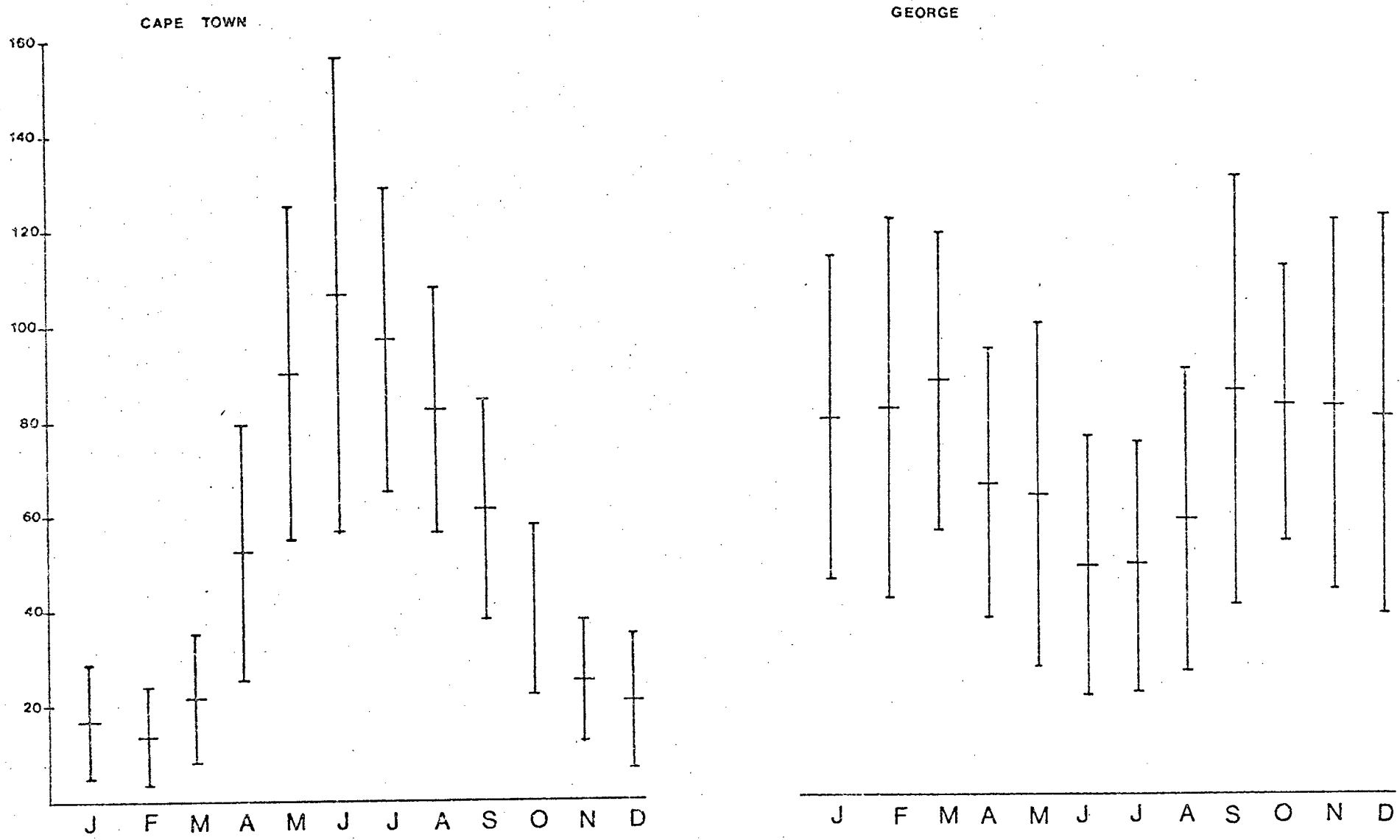


Figure 6b: Average monthly rainfall for Cape Town and George
 (\bar{x} and s from Schulze (1965))

Although the relative rainfall variability of 15 - 17% is not high by South African standards (cf. 20 - 25% for the Highveld and over 40% for Central Karoo and Namaqualand - Schulze, 1965 p. 265), it is evident from Table 3-2 or Figure 6a that there is a large amount of local variation in the seasonal distribution of annual rainfall. This is an important factor which, seen in conjunction with the low mean annual precipitation and poor quality of groundwater, limits the range of agricultural crops that can be produced.

Precipitation in the form of mist or frost occurs in the winter months. A feature of winter weather in the Rûens is the dense mist or fog that occurs overnight, particularly in the valleys. The ground mist often persists until mid-morning. Frost is a less common occurrence and on average is limited to the month of July (Schulze, 1965 p. 135) when average temperature is also at a minimum. Snow is only known to have occurred once this century in the Rûens, viz. on 8 August 1906 (Van Breda diary):

- 1906: August 8: "Rained well during the night. Bredasdorp Mountain capped by snow."
- August 10: "It is reported that in the Ruggens snow fell half a foot thick during last rain."

It was in December of the same year that the first known flood occurred at De Hoop (see Section 4.4).

3.1.1.3. Temperature

The region is characterised by warm summers and relatively mild winters, with a mean annual temperature of

approximately 17,5°C (Schulze, 1965 p. 79). Due to the proximity of the sea and the warm Agulhas current, the southern and south-western coastal areas of the Cape display an amplitude of only 7 - 8 C° in the mean diurnal temperature curve (Schulze, 1965 p. 141). Approximate seasonal mean air temperatures are shown in Table 3-3 below.

Table 3-3. SEASONAL MEAN AIR TEMPERATURES

	Mean temperature (°C) *

January	22,5
March	20,0
May	14,0
July	11,5
September	15,0
November	20,0

(after Schulze, 1965 p.94-6)

* where mean temperature = $0,5 (Tx + Tn)$

Tx = mean maximum temperature

Tn = mean minimum temperature

3.1.1.4. Wind

De Hoop is notorious for windy conditions, particularly during the summer. In this region the prevailing winds are also the strongest winds. The summer resultant wind is southerly, with average speed 35 km/h (Schulze, 1965 p. 239), although the most frequent wind directions at Cape Agulhas are west, east and south-west (in order of frequency of occurrence) (Walsh, 1968). The July resultant wind at Cape Agulhas is the strongest along the coastline, viz. 60 km/h westerly, which is a true reflection of the prevailing air movement. Mean wind velocity reaches a maximum in the mid-afternoon (about 15h00) (Walsh, 1968 p. 22).

Land and sea breezes are common and are funnelled between the "duine" following the course of the Sout River. The farm Windhoek is accordingly not misnamed. Occasional berg winds are experienced, particularly during late summer and autumn. These hot, dry winds from the interior increase evaporation from the vlei.

Wind off the sea is moisture-laden and thus plays a lesser role in promoting evaporative loss. The strong southerly winds do, however, affect water levels in the vlei as they transport water northward towards Windhoek. With the diurnal change to land breezes at night southward return of surface water is effected. This water movement is in some cases sufficient to be recorded as a fluctuation of water level by the gauge at De Hoop. The amplitude of this variation is of the order of 10 - 20 mm (records of gauge G5L01, Department of Water Affairs).

3.1.2. Geology, Soils and Vegetation

3.1.2.1. Geology

Two main geological formations are represented in the study area, namely the Bokkeveld shales of the Rûens and the Tertiary Limestones near the coast (Figure 7).

The Bokkeveld series is of Palaeozoic age (c. 300 million years), is up to 730 m thick, and lies conformably on the Table Mountain series in this region (Frommurze, 1937 p. 116). The African and post-African erosion cycles during the Tertiary period formed upper and lower landsurfaces respectively, into which the valleys were further incised during the Quaternary period (King, 1972 p. 247). The divide between these two landsurfaces can be seen north-west of Potberg where the silcrete-capped hilltops of Goerreesoe stand some 30 m above the adjacent rolling landscape.

The Bokkeveld shales are impermeable but relatively soft and easily eroded (King, 1942 p. 307). Dunne and Leopold (1978 p. 202) quote the average porosity of shales as being the second lowest for sedimentary rocks - only old crystalline limestone is less porous. This has the hydrological effect of increasing the interflow component of runoff. It also means that downward percolation is slow, which results in groundwater being highly mineralised, in this case with sodium and magnesium salts. In many places these shales are

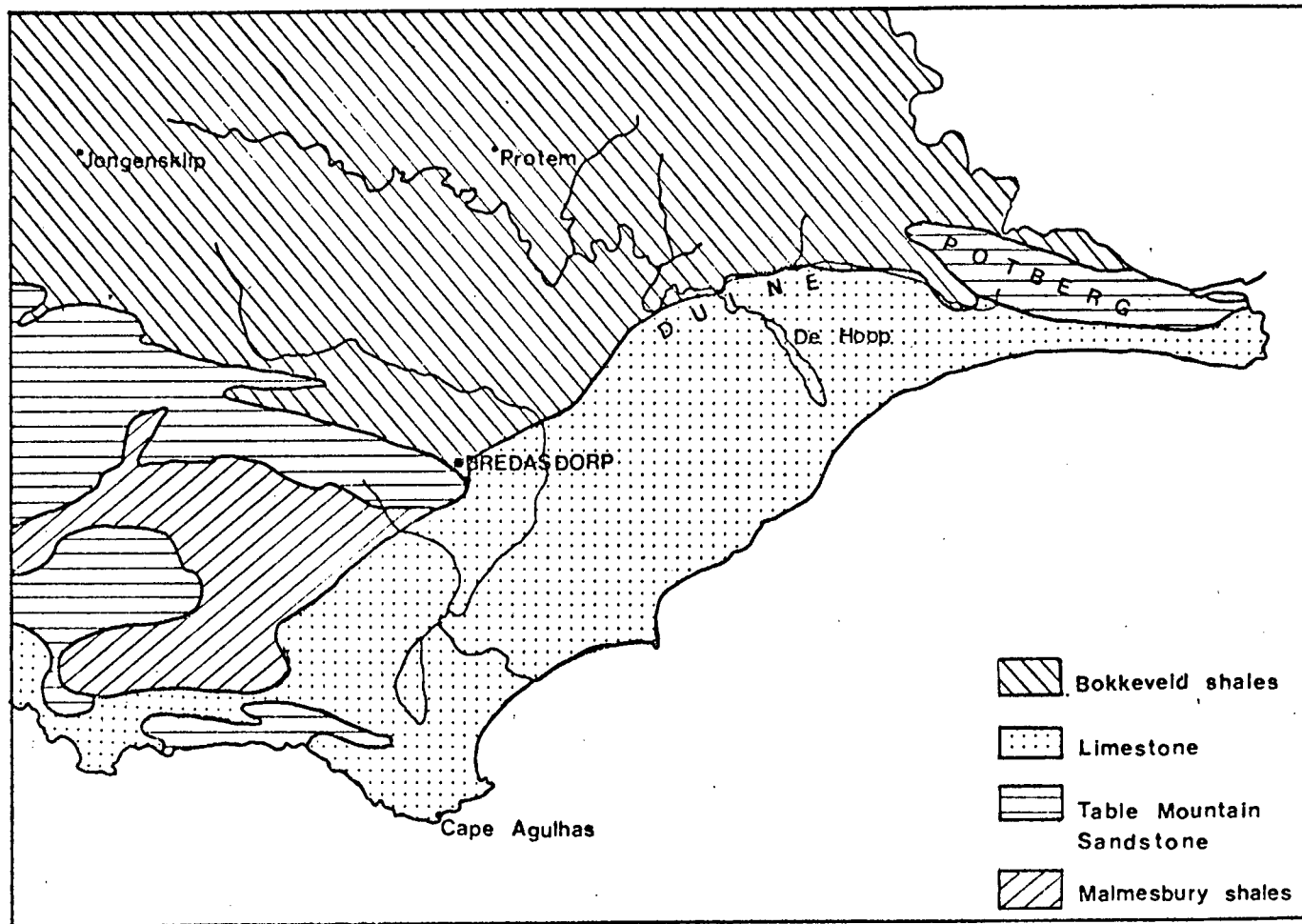


Figure 7: Geology of the study area after Jordaan (1946)

tilted and fissured so that bedding planes are near vertical. In such cases percolation is more rapid. Groundwater is not lacking in quantity, but is of poor quality (Frommurze, 1937 p. 116) - hence the name "Sout River". Farmers in this region rely on rainfall for their domestic water supply. In times of deficient rainfall they are forced to purchase drums of water for domestic use due to the non-utility of the groundwater. Groundwater is not used for irrigation purposes.

The limestone karst of the De Hoop area is generally considered to be a Tertiary feature, although the deposition and reworking of limestones on the southern and southeastern Cape coast could have spanned most of the Cainozoic era from early Eocene to Pleistocene and Recent epochs, according to the work done in the eastern Cape by Houghton, Siesser and Parr (Russell, 1981 p. 51). In the De Hoop area the limestone overlies impermeable shales and sandstone of the Table Mountain series, the thickness of limestone varying from less than 20 m near the coast to approximately 200 m on the "duine" (Russell, 1981).

The limestones were deposited then reworked, planed and lithified during a series of three Tertiary marine transgressions and regressions. The first of these transgressions is estimated to have occurred during the early Eocene epoch (about 50 million years ago) and to have extended inland well north of the "duine". This corresponds to the African landsurface referred to by King (1972 p. 247). Of this surface only residual limestone cappings remain on some catchment hilltops.

The limestone of the "duine" was laid down during the late Eocene marine transgression, and later exposed and lithified during the subsequent regression. The third transgression/regression sequence occurred in the Miocene to Pliocene epochs, forming the footslopes of the "duine" and the coastal foreland. This has since been planed to four distinguishable levels at 100 - 90 m, 60 m, 40 - 30 m and 20 - 15m above mean sea level. These surfaces are of descending age and correspond to eustatic changes in sea level during the Pleistocene interglacial periods as evidenced generally along the South African coastline (Russell, 1981 pp. 51 - 63).

The Bredasdorp limestones vary greatly in hardness and therefore permeability (Spies et al, 1963 p. 24). Weathering takes place by solution - the solubility of De Hoop limestones falling within the range 82 - 97% (Russell, 1981 p. 98).

The surface features on the limestone are typical of a Mediterranean karst environment, namely shallow pans of various dimensions formed mainly by solution. Most of these are shallow, almost circular hollows (known as dolines). Deeper, irregular shaped hollows (uvalas) occur in the "duine" and a large flat plain (rand polje) lies in the region between the "duine" and the Potberg mountain. Sinkholes occur occasionally on the lower surfaces. The De Hoop region abounds with caves, both on the lower surfaces and in the "duine". Although these have long attracted the attention of the Western Cape speleologists, relatively few detailed surveys have been made as almost all entrances are

jealously guarded by large swarms of aggressive bees or are inhabited by baboons. Some caves on the Dronkvlei section, namely Hot Pot and Onmeetbare Diepgat, have been surveyed, as well as the guano cave in the eastern hillside overlooking the vlei near Windhoek. Indications are that caves occur on many different levels, possibly determined by previous water tables. Where the limestone is impermeable it is possible for a number of separate water tables to occur. Groundwater tends to concentrate on the limestone-shale and limestone-sandstone contacts, forming underground streams (Blacquiere, 1962). It has been suggested by geologists that these underground streams unite and have a single subsurface outlet to the sea (M. Swart, pers. comm.). Various theories have been propounded but, although reference is made to a survey undertaken in 1958 (Cape Department of Nature Conservation, 1958), no detailed geological survey has been published.

The quality of groundwater varies according to borehole location and depth. Streams on bedrock of the Table Mountain series yield water of good quantity and quality. Water pumped from within the limestone is very high in calcium carbonate. A borehole at Koppie Alleen, some 100 m from the sea, yields good quality drinking water, but a sinkhole at the end of Cloete's sloop, some 2 km inland, has water of low utility.

Besides water from the Sout River, De Hoop Vlei receives input from many springs in the surrounding limestone. Most of these issue from the limestone contact with the Table Mountain series. In the Windhoek region this is above the

vlei surface, and streams are formed, whilst nearer De Hoop the springs issue on the vlei bed. When the bed of the vlei is exposed these springs show as localised muddy patches. It is possible that drainage from the eastern parts of the "duine" is subterranean - possibly unconnected to De Hoop Vlei. On the Melkkamer side of the vlei, however, borehole water levels fluctuate with that of De Hoop Vlei, indicating that there is a continuous water table in this area (M.Swart, pers. comm.).

3.1.2.2. Soils

Alongside topographic and climatic factors, soil type is an important factor in land use planning, particularly in a rural environment. Successful crop production is especially dependent on the maintenance of healthy and fertile soil.

One of South Africa's major environmental problems is the loss of topsoil by erosion. This was emphasised by Sir H. Bennett, an American authority on soil conservation, as early as 1944 when he visited the Union at government request (Bennett, 1944). His brief investigations showed the wheatlands of the western and southern Cape to be in particular need of proper soil conservation measures. The soils of the Rûens are shallow and rocky, and therefore need to be protected from erosion if soil structure and fertility are not to deteriorate.

Although contour ploughing is now practised in the Rûens, this area is in need of further erosion control by means of constructed terraces, since the slope of much of the

cultivated land is in excess of 4%. Farmers are reluctant to apply this form of control as terraces would present difficulties to the large harvesting machines (D. Cronje, pers. comm.). There is some evidence of progress with the construction of terraces at the present time in the vicinity of Proteem and Kathoek.

The soils of the entire catchment are classified as shallow soils on rock, and have an orthic A horizon - as do the majority of South African soils (MacVicar et al, 1977). As an aid to agricultural planning and management, the soils of the Bredasdorp agricultural ward have been classified according to the binomial system developed by MacVicar et al (1977) and the region accordingly divided into reasonably homogeneous farming areas (Smit and Goldswain, 1980). A summary of this work as it applies to the study area appears in Table 3-4 and Figure 8.

In brief, there are two main soil forms present in the entire catchment, namely Mispah and Glenrosa forms. These forms are closely related. The Mispah form has no B horizon - the orthic A horizon directly overlies hard rock - whereas the Glenrosa form has a lithocutanic B horizon (i.e. rock-derived). The lithocutanic B horizon is formed in this case from tilted and weathered shales. Soil material accumulates between bedding planes. Where shales are flat-lying the soil is classified as of Mispah form (MacVicar et al, 1977 p. 27). In the study area shales are often tilted and fissured, with bedding planes almost vertical.

The Kanonkop and Southfield series of the Glenrosa form have

6 - 15% clay mixed with fine sand in the A horizon; the Williamson series has 15 - 35% clay. These soils fall into the B/C category as regards runoff potential which is the midpoint of a 7-point ordinal scale (Schulze and Arnold, 1979). With the exception of the Hutton form, which is not encountered frequently, all other soils of the entire catchment have moderately high to high runoff potential, according to the grouping by Schulze and Arnold (1979) - see Table 3-6. Seen in conjunction with the hilly nature of the landscape, these soils definitely require protection against erosion.

Tables 3-4, 3-5 and 3-6 which follow summarise the information available on the soils of the region and their characteristics as defined for purposes of classification.

Table 3-4. DOMINANT SOIL TYPES FOR EACH REGION

(after Smit and Goldswain 1980; MacVicar et al 1973,1977)

A Littoral/Near Littoral Sands with Lithosols (De Hoop region)			B Weakly Developed Soils on Rock (Catchment)		
1 Dune Veld			1 Golden Triangle		
***Mispah	Muden	Ms20	**Mispah	Mispah	Ms10
	Kalkbank	Ms22	**Glenrosa	Kanonkop	Gs13
(Valsrivier)	Valsrivier	Va40	Swartland	Swartland	Sw31
(Estcourt)	Elim	Es31	Shortlands	Shortlands	Sd22
2 Mid-Dunes			2 Mid-Rûens		
***Mispah	Mispah	Ms10	**Mispah	Mispah	Ms10
	Kalkbank	Ms22	**Glenrosa	Kanonkop	Gs13
(Glenrosa)	Southfield	Gs23	Swartland	Swartland	Sw31
			3 Red Rûens		
			*Mispah	Mispah	Ms10
			*Shortlands	Glendale	Sd21
				Shortlands	Sd22
			*Glenrosa	Kanonkop	Gs13
			Swartland	Swartland	Sw31
				Hogsback	Sw32
			Hutton	Shorrocks	Hu36
Key to percentage representation:			4 Kraaiheuwels		
***	90% of region		**Glenrosa	Kanonkop	Gs13
**	30-40%			Williamson	Gs16
*	20-29%		**Mispah	Mispah	Ms10
()	less than 5%		Swartland	Swartland	Sw31
				Hogsback	Sw32

Table 3-5. DIAGNOSTIC HORIZONS OF CATCHMENT SOILS

(after MacVicar et al, 1977)

A Soil Forms:

Mispah	Orthic A;	overlies hard rock
Glenrosa	Orthic A;	lithocutanic B
Hutton	Orthic A;	Red apedal B) red colour) distinguishes
Shortlands	Orthic A;	Red structured B) these from) Mispah form
Swartland	Orthic A;	Pedocutanic B; overlies saprolite
Valsrivier	Orthic A;	Pedocutanic B; unconsolidated base
Estcourt	Orthic A;	E; Prismacutanic B

B Soil Series:

Mispah form:

Msl0	Mispah	non-calcareous A; base hard rock
Ms20	Muden	calcareous A; base hard rock
Ms22	Kalkbank	calcareous A; base hard rock

Glenrosa form:

Gsl3	Kanonkop	fine sand, 6-15% clay (A); non-calcareous B downwards
Gsl6	Williamson	fine sand, 15-35% clay (A); non-calcareous B downwards
Gs23	Southfield	fine sand, 6-15% clay (A); calcareous B downwards

Hutton and Shortlands forms:

Hu36	Shorrocks	B21 horizon has undifferentiated sand, 15-35% clay, and is eutrophic; non-calcareous B
Sd21	Glendale	35-55% clay, eutrophic (B21); non-calcareous B
Sd22	Shortlands	55% clay, eutrophic (B21); non-calcareous B

Swartland, Valsrivier and Estcourt forms:

Sw31	Swartland	B non-red; 35-55% clay (B); non-calcareous (B and C)
Sw32	Hogsback	B non-red; 55% clay (B); non-calcareous (B and C)
Va40	Valsrivier	B non-red; 15-35% clay (B); calcareous (B or C)
Es31	Elim	B lacks continuous black cutans; 25% clay (B); medium grade sand and 0-6% clay (E)

Table 3-6. RUNOFF POTENTIAL OF CATCHMENT SOILS

(after Schulze and Arnold, 1979)

*Group	Soil Series
A/B	Hu36
B/C	Gs13, Gs16, Gs23
C	Ms10, Ms20, Ms22, Sd22
C/D	Sw31, Va40
D	Sw32, Es31

*The hydrological groups are defined as follows:

- A: low runoff potential - infiltration rate high, permeability rapid.
- B: moderately low runoff potential - moderate infiltration rates, permeability slightly restricted.
- C: moderately high runoff potential - infiltration rate slow, permeability restricted, soil shallow.
- D: high runoff potential - very slow infiltration rate, permeability severely restricted. Includes very shallow soils and those of high swell-shrink potential.

The groupings A to D above were devised by the United States Soil Conservation Service. This classification system was expanded by Schulze and Arnold (1979 p. 11) with the inclusion of the intermediate categories A/B, B/C and C/D to form a 7-point scale for South African soils.

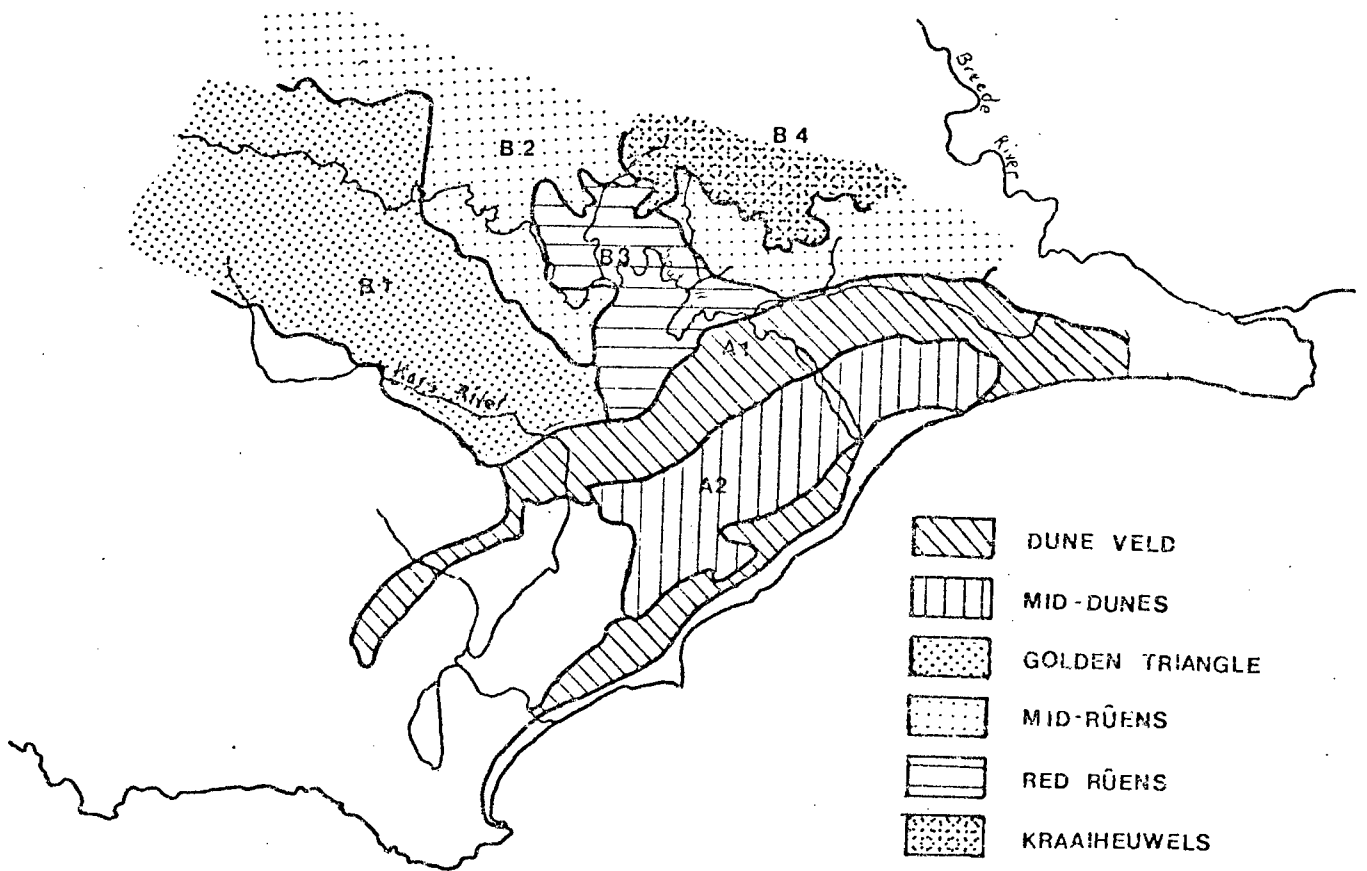


Figure 8: Reasonably homogeneous farming areas after Smit and Goldswain (1980)

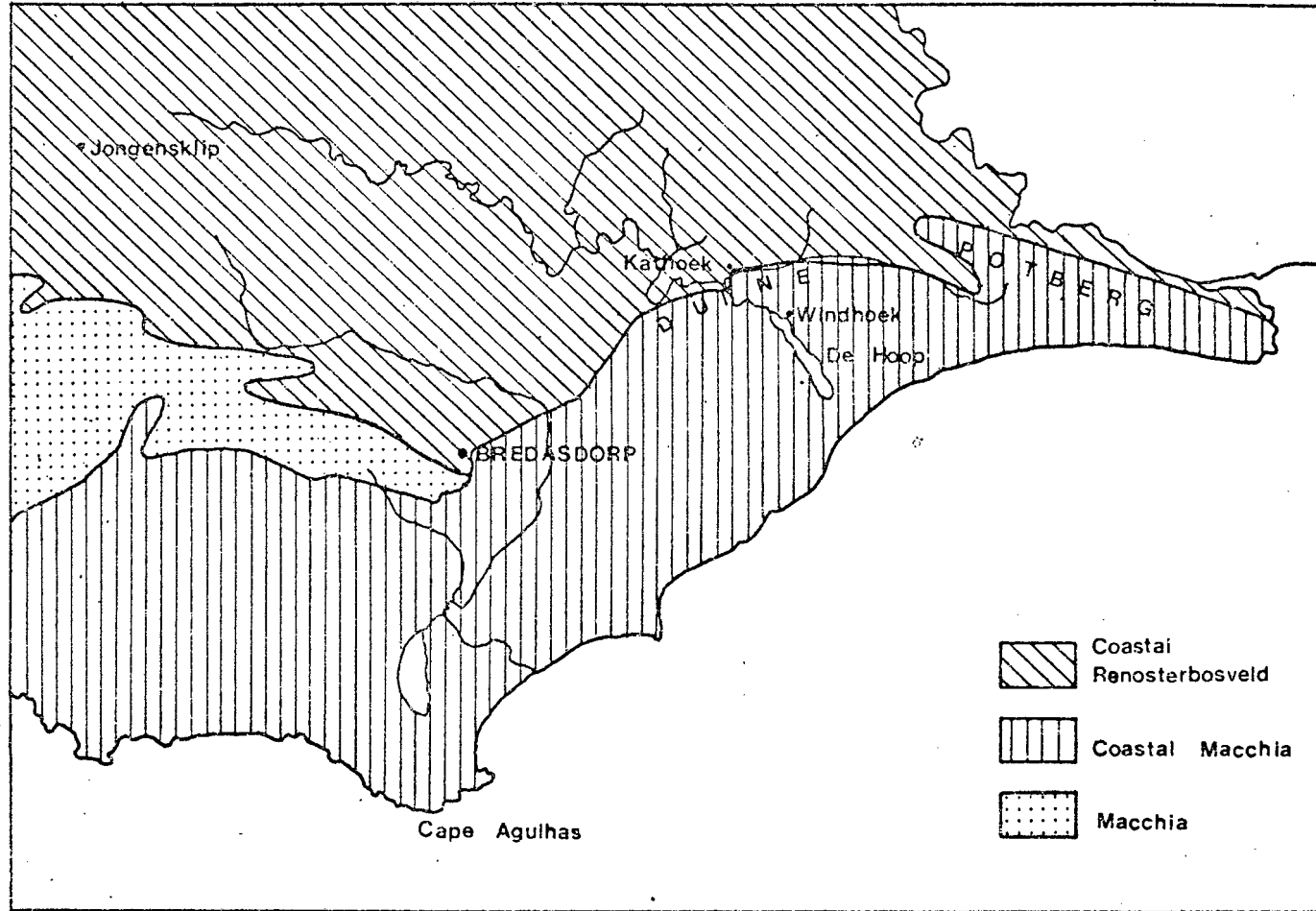


Figure 9: Main vegetation types in the study area after Acocks (1947)

3.1.2.3. Vegetation

According to the work done by Acocks (1975) the study area includes two main natural vegetation types, namely Coastal Rhenosterbosveld - in the catchment - and Coastal Macchia in the De Hoop region. Both of these fall under the broader heading of temperate and transitional scrub types.

The most obvious human impact on the catchment must be the almost complete replacement of the natural vegetation with agricultural crops and planted pasture. Apart from what little scrub remains in the kloofs, there is no natural vegetation to be seen. It is interesting to note that the shrub after which this veld type is named - Elytropappus rhinocerotis, the Rhenosterbos - was in the 1930's considered to be a weed which, although indigenous to the western Cape, had spread along the main wagon routes due to its use as a packing material (Du Toit and Du Toit, 1938). It is considered worthless in terms of pasturage and suppression of its growth by means of regular controlled burning has long been advocated in farming circles (Du Toit and Du Toit, 1938; Jordaan, 1946; Bateman, 1961). Jordaan (1946) does concede that, because of its rapid rate of growth, the rhenosterbos could assist in the fight against soil erosion.

The Rhenosterbos vegetation type is thus regarded as an apparent climax community which is maintained by regular disturbance (Jordaan, 1946). The potential natural climax community can only be estimated from the vegetation in undisturbed kloofs. This would seem to be dominated by

scrub forest vegetation such as milkwood (Sideroxylon inerme) and taaibos (Rhus spp.), with some grasses, notably Themeda triandra (Acocks, 1975 p. 86; Jordaan, 1946). In the lower Sout River valley on the farms Kathoek, Van der Stelskraal and Windhoek the vegetation includes some succulents such as Aloe ferox and resembles the valley scrub of the south-eastern Cape (Acocks, 1975 p. 86).

The Coastal Macchia of the De Hoop region has not been extensively ploughed due to the shallow, oligotrophic soils and the hardness of the limestone. This vegetation type includes representatives of the typical fynbos families - namely Proteaceae, Ericaceae and Restionaceae - as well as some 20 grass species. Shrubs and trees such as Euclea spp., Sideroxylon inerme, Rhus spp. and Olea spp. are also present (Acocks, 1975 p. 87).

The Coastal Macchia of the limestone area differs in composition from that of other regions and warrants classification as a distinct veld type from that of the western and southern coastal areas when future, more detailed botanical work is undertaken (Acocks, 1975 p. 87). It is estimated that the potential climax stage of this transitional scrub type as well as the Coastal Rhenosterbosveld would be an open scrub with grass.

It is probable that the entire study area has been overgrazed in the past, thereby reducing the grass component. This is confirmed in the view expressed by both Mr Mike Swart (pers. comm.) and Bateman (1961, p. 90), that the proportion of grasses, especially Themeda triandra, to bushy vegetation has decreased substantially from what it

was a century ago. The De Hoop region differs from the Swellendam-Mossel Bay area referred to by Bateman (1961) as regards both soil type and climate, hence the original vegetation may have differed in composition from that of the latter region as regards the extent of Themeda cover. Acocks (1962) has suggested that Ehrharta spp. may have been of greater importance in binding the fine peaty soil of the limestone area. Although it is not possible to quantify these changes, there is reason to believe that changes in vegetal cover have occurred during the past century and that these are at least partly due to agricultural activities, in this case overgrazing and unwise use of fire.

The problem of invasive alien plants is encountered throughout the fynbos region. This is also the case in the De Hoop region. The mobile sand dunes along the southern Cape coast were considered to be a major agricultural problem in the 1930's and their reclamation was tackled with determination by the government Department of Agriculture and Forestry. It was estimated that the Bredasdorp district was losing some 300 acres of agricultural land per annum, the annual landward advance of the sand dunes being of the order of 20 yards (Dreyer, 1938 p. 86). The recommended stabilisation procedure for large dunes was bushing, i.e. covering the affected area with cut Acacia cyclops and A. saligna. These always carry their own plentiful supply of seed, therefore need little further attention (Walsh, 1968 p.52 - 54). Although the use of these alien plants was restricted to cases of supposed necessity, A. cyclops in particular has become a problem in the De Hoop region, especially on the farm Dronkvlei and to the west of De Hoop

Vlei where there are some dense thickets.

Although the average farm in the catchment has its own plantation of Eucalyptus trees for use as timber, this region is remarkably clear of invasive alien plants. The same cannot be said of the Kars River valley or Riviersonderend whose catchments are adjacent to the study area. This is probably due to the fact that in the study area some 90% of the land is under cultivation.

The nature and extent of the vegetative cover is an important factor in the water balance of a region since evapotranspiration accounts directly for the loss of anything from 60 to 100 percent of the precipitation in an area. It also influences most components of the water balance to a greater or lesser extent - infiltration, passage of soil water and water-holding capacity of the soil are examples (Hall, 1971 p. 6). Yet, predictably, the influence of the change in vegetative cover from natural bush to grain, upon the quantity of runoff produced in any one storm becomes less significant with increasing amounts of rainfall and with decreasing soil quality. The influence of land use category (i.e. vegetative cover) upon quantity of runoff is highest within this catchment for soils of hydrological group B/C (i.e. Glenrosa form) and storm rainfall of 24 mm and less - in which case there is an almost six-fold increase in the amount of runoff produced where natural vegetation is replaced by grain. (These computations - details of which appear in Appendix D - are based upon the United States Soil Conservation Service (SCS) Technique as adapted for South African conditions by Schulze

and Arnold (1979).) In all cases investigated, the quantity of runoff from the best soil (B/C) under grain cultivation exceeded that from the worst soil (D) with natural vegetation cover. A further point to be borne in mind is that natural vegetation provides an almost constant amount of cover, whereas marked seasonal differences in cover occur in the case of agricultural crops.

3.1.3. Hydraulic characteristics

Besides the factors of climate, vegetation, geology and soils already discussed, the way in which a catchment responds to rainfall input and the quantity of runoff generated is also strongly dependent upon its physical configuration and geomorphology.

3.1.3.1. Catchment Size

In modelling runoff from rainfall one of the primary inputs required is the catchment area. The most obvious use of this figure is to convert depths of rainfall or runoff to volumes. Catchment size is also of primary importance in the selection of a method for determining water yield, since area features as a variable in most formulae (Rossouw, 1980).

The surface area of the De Hoop catchment as shown in Figure 2 is 1 198 sq. km. This figure was determined by planimetry from the 1:250 000 topographic maps 3319 (Worcester) and 3420 (Riversdale). As such, the De Hoop catchment is

considered medium in size.

This classification of catchments by size does serve as an initial guide in the selection of a methodology, but is not the only criterion. As Raudkivi (1979 p. 172) points out, catchments of similar size do not necessarily show similar hydrological behaviour and it is often more useful to categorise catchments according to their hydrological response to rainfall. Those catchments in which the response is slow and storage effects dominate are considered "hydrologically large", whereas catchments characterised by a rapid response to rainfall with minimal storage are "hydrologically small". A small, swampy catchment would thus be classified as hydrologically large and modelling methods suited to catchments of large surface area would apply (Raudkivi, 1979). As will become apparent in the further discussion of hydraulic characteristics, the De Hoop catchment must be classified as hydrologically large.

3.1.3.2. Catchment shape

The Sout River catchment does not conform to the more typical pear or fan shapes, but is elongated and narrows toward the source zone. It is positioned between the large pear-shaped catchment of the Breede River and the almost circular Kars River catchment - as depicted by Midgley and Pitman (1969, pp. 119 - 120).

3.1.3.3. Catchment slope

Average surface slope for the catchment area was calculated to be 8,798%. This figure was determined hypsometrically from 1:50 000 topographical maps of the area. A grid was placed over the region and 100 points selected at random. At each point the vertical rise or fall over a 500 m horizontal distance at right angles to the contour lines was recorded. The steepest slopes are in the vicinity of Potberg and the "Kraaiheuwels" where an average of 12% slope was obtained for the catchments of the Potberg and Brakkuil tributaries.

The hillside slope is of importance in the consideration of sediment production since runoff velocity is partially controlled by this parameter. All slopes of over 4% warrant the construction of terraces to inhibit soil loss by erosion (D. Cronje, pers. comm.). Slope also exerts some influence on the form of the hydrograph, especially in hydrologically small catchments. This aspect is of lesser importance in the Sout River catchment, which displays a slow overall response to rainfall.

3.1.3.4. Channel length and gradient

The length of the main channel of the Sout River from its source on the farm Alexanderskloof to the outfall at the causeway on the farm Van der Stelskraal is 141 km (measured on the 1:50 000 topographic maps listed in Appendix A). This figure is considerably higher than the 90 km suggested

by the Hack relationship $L = 1274 A^{0.6}$ (metric form of that quoted by Dunne and Leopold, 1978 p. 500) which describes landscape form in many regions of the world, and somewhat higher than the 122 km given by the South African version $L = 1738 A^{0.6}$ (Schulze and Arnold, 1979 p. 56).

This discrepancy is largely accounted for by the combination of channel gradient and topography of the area. The river follows a tortuous, winding course through hilly terrain and has a channel gradient of only 0,001 365 (H/L in Figure 11). Consequently the velocity of streamflow is generally minimal and flow is almost always laminar. With the exception of the source zone, the channel gradient is virtually uniform, and few regions of accelerated flow are found. The additional volume of water entering the main stream from the tributaries is accommodated by the widening of the channel at the respective entry points in the cases of major tributaries.

The very sluggish catchment response to rainfall is thus largely attributable to the abovementioned aspects of landform - in particular the large channel storage capacity which exerts a buffering effect on streamflow by accommodating increased water yield without causing a corresponding increase in discharge at De Hoop.

3.1.3.5. Major tributaries

The system of stream ordering described by Strahler (1954) was applied to the study area, using all watercourses indicated on the relevant 1:50 000 topographic maps. This

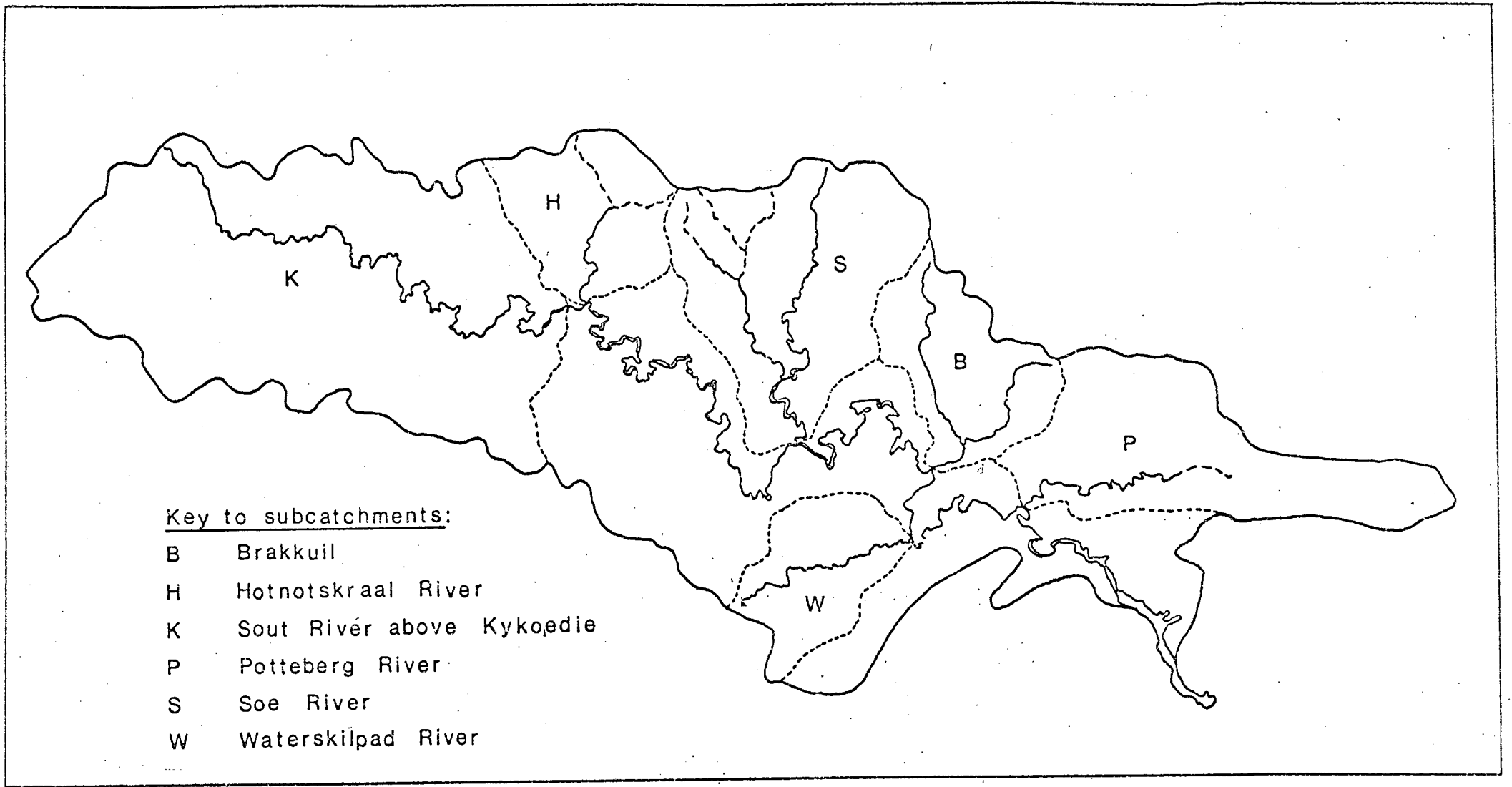


Figure 10: Subcatchments of the Sout River catchment

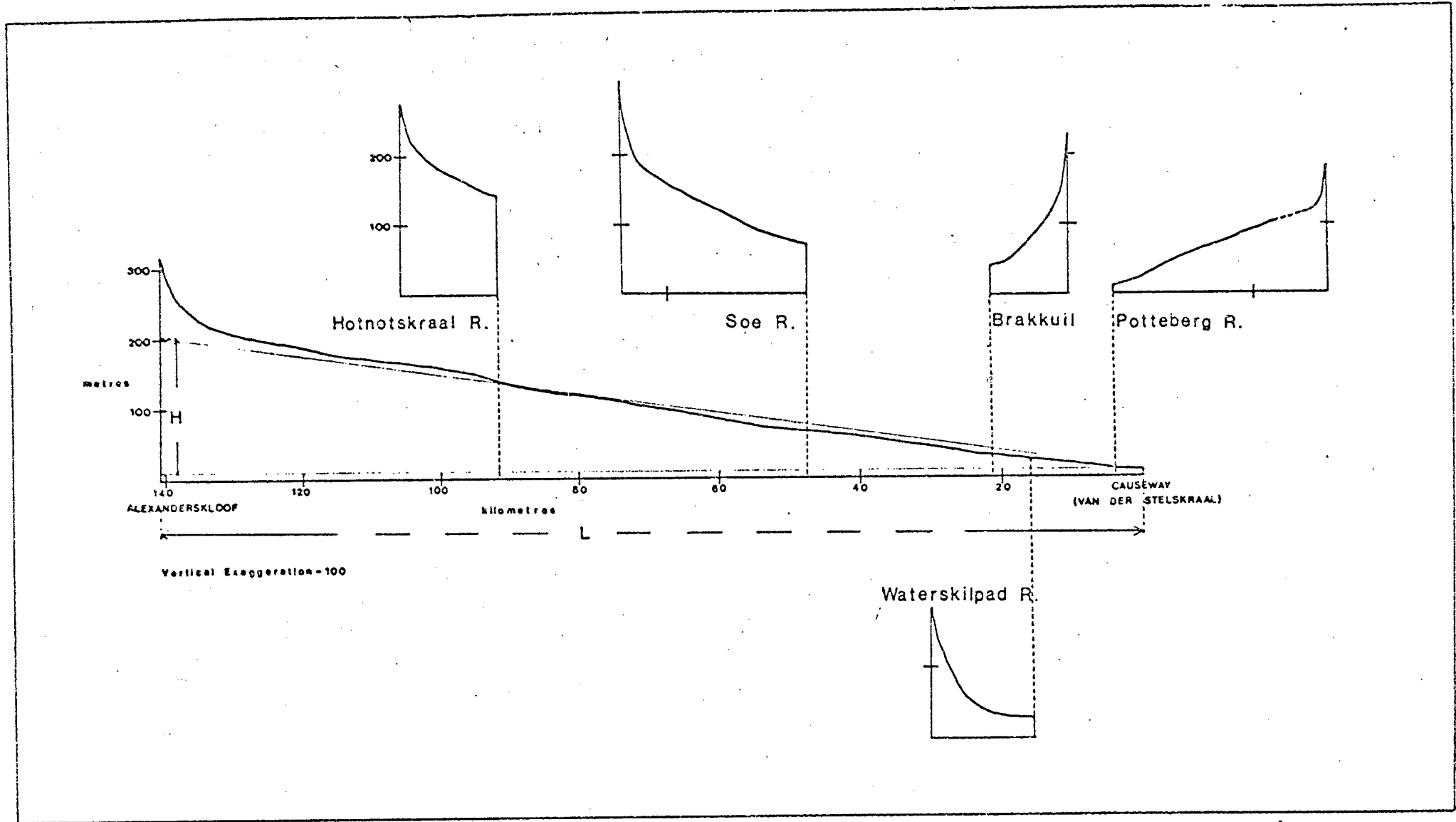


Figure 11: Channel profiles of the Sout River and its tributaries

yielded a catchment of the seventh order. Many of the streams of order 3 and less are ephemeral, only carrying water immediately after a storm. Figure 10 depicts the main subcatchments, i.e. those of orders 5 and 6. These are discussed briefly below, proceeding in a downstream direction.

1. The Sout River above Kykoedie

The Department of Water Affairs maintains a streamflow gauge (G5M08) approximately 20 m upstream of the point where the Bredasdorp-Stormsvlei tarred road crosses the Sout River near Kykoedie. It is in order to utilise these streamflow data that this subcatchment is demarcated as a separate unit.

A number of unnamed watercourses are indicated as originating in the hills in the neighbourhood of the farms Grootkloof, Hooggeleë and Skildskloof near Jongensklip. Examination of these in the field reveals evidence of subsurface springs in the region. However, these do not yield sufficient water to cause streamflow, but are discernible merely as damp, swampy areas. The "watercourse" at Hooggeleë, as marked on the maps, is vegetated and in places grain is sown across this slight hollow. The tributary rising at Skildskloof has a stronger flow of water which has recently been dammed up just west of the Rietpoel railway station - this tributary thus makes little contribution to the Sout River under normal circumstances. Nevertheless these streams unite to form a fourth order tributary to the Sout River.

The Sout River rises to the north-east of Hooggeleë on the farm Alexanderskloof and develops into a fourth order stream prior to its junction with the aforementioned eastern tributary. Thus the Sout River above Kykoedie is a fifth order stream. Several streams of lesser order enter from both the north and south as the Sout River follows an approximately east-south-easterly course towards Kykoedie, draining an area of 382 sq. km.

2. Hotnotskraal River

This stream, of order 5, enters the Sout River from the north approximately 8 km downstream of the gauge at Kykoedie. It is a lesser known stream which drains an area of approximately 76 sq. km. to the west and north-west of Proteem. The Bredasdorp-Stormsvlei main road bisects this subcatchment, closely following the main watercourse.

3. Soe River

This major fifth order tributary of the Sout River drains an area of 146,5 sq. km. to the east and south-east of Proteem. The western tributary of this river is known as the Klein Soe River. In the region between the farms Remhoogte and Hasiesdrift the Soe River runs approximately parallel to the Sout River which is 3 - 4 km to the west and also flowing in a southerly direction. For this reason the Soe and Sout Rivers are often confused locally.

The Soe River resembles the Sout in that it also widens in its lower reaches, particularly downstream of its junction with the Klein Soe. This indicates the presence of larger

volumes of water and a more reliable flow than occur in the other tributaries discussed, as well as the capacity for channel storage of this runoff.

4. Brakkuil

This lesser known tributary drains an area of 80 sq. km. to the east of the main Bredasdorp-Swellendam road. Its overall drainage pattern is southerly although its actual entry into the Sout River is from an easterly direction.

5. Waterskilpad River

This is the only fifth order stream situated to the south of the Sout River. It runs from west to east some 5 - 7 km inland of the limestone "duine" and drains an area of approximately 63 sq. km. which is situated roughly east of the Bredasdorp-Swellendam tarred road and north of the gravel road to Malgas and Infanta.

6. Potberg River

Although the Potberg River drains a relatively large area of 147 sq. km. in the east of the study area, its effective catchment size may well be less. The river rises in a kloof behind the Potberg main farmhouse and flows towards the border depression region between the limestone "duine" and the shales of the northern part of the catchment, where the river becomes discontinuous. Macpherson (1960b) made the following observation on drainage in this region:

The Potberg river is "in actual fact . . . made up of separate water-catchment valleys running both east and west and usually ending in a sponge or soak. We counted nine such entities and not one continuous river. Water in this area flows in both directions in the space of a few hundred yards."

Drainage from the next kloof to the east of Potberg farm, the kloof which has become known as the breeding site for a colony of Cape vultures, appears to follow a westerly direction, yet shows no surface connection to the Potberg stream. To the east of this kloof, drainage appears to be in an easterly direction.

Because this watercourse is not clearly defined it is not uncommon, even on present-day maps, to find the Potberg River incorrectly drawn as being connected to the seaward-draining Klipdriftsfonteinspruit. The data given by Midgley and Pitman (1969 pp. 98 and 119) regarding catchment size and mean annual runoff are incorrect for this reason.

3.1.3.6. Hydrological response to rainfall

Catchments in the sclerophyllous bush vegetation zone of the southern and south-western Cape Province are characterised by a relatively slow response to rainfall - which has been attributed to various physiographic factors, notably soil type and groundwater behaviour (Pullen, 1969 pp. B.6 - B.9).

The clayey nature of most soils in the study area (excepting those of the Mispah form) results in the absorption of relatively large quantities of water by infiltration - which is stored as soil moisture. As a result of the relatively

high proportion of rainfall absorbed via infiltration, as opposed to direct overland runoff, the hydrograph of streamflow shows a slow initial rise. The sand and clay mixtures in the upper horizons of these soils are soon saturated since the rate of infiltration exceeds the rate of further downward percolation. The soils are relatively shallow and overlie less permeable rock. The interflow component of runoff therefore shows an abnormally rapid response. This causes a prolonged rise of the hydrograph - the nett result of this process being interpreted as a particularly long time to peak, or increased basin lag (Pullen, 1969 p. B.6).

A further factor to consider is that the demarcation of the boundary of a watershed is primarily a surface characteristic and whilst the area so defined may be employed to draw conclusions regarding overland flow and interflow from soil moisture, this boundary does not necessarily bear any relevance to the passage of groundwater at deeper levels. The bed of the Sout River is some 30 - 50 m higher in altitude than either the Breede or Kars rivers if north-south cross-sections of the area are considered, which means that drainage from groundwater reservoirs could well be away from or below the level of the Sout River. This would explain the absence of a sustained base flow in this particular river.

Personal observation of streamflow to De Hoop and inspection of the rainfall and streamflow records for Kykoedie indicate that:

1. Streamflow is strongly dependent on the spatial distribution and intensity of rainfall. Unless the rainfall exceeds approximately 80 mm (which must be distributed over not more than 3 - 4 consecutive days) and is centred over the Jongensklip region, no streamflow occurs at De Hoop. (This observation applies particularly to the case where the antecedent flow is low or nil.)
2. Average observed response time (time to peak) is of the order of 3 - 4 days at Kykoedie and 4 - 5 days at De Hoop. This greatly exceeds the response time of most other catchments, which is generally less than 48 hours.
3. Deep pools occur at several points in the river course. Their capacity for channel storage, the uncertainty regarding the groundwater behaviour, the minimal channel gradient and consequent slow catchment response to rainfall lead to the conclusion that this catchment must be classified as hydrologically large.

3.2. LAND USE

3.2.1. Early settlement and land use

By the turn of the 18th century, employees of the Dutch East India Company were making frequent trips across the Hottentots Holland to the region known as the Overberg to obtain timber and to barter with the Hottentots for cattle (Mossop, 1927; Burrows, 1952). Having severely decimated whatever supplies of these commodities were available in the immediate surrounds of the Cape settlement, the early settlers found in this area both a plentiful supply of timber and wealthy Hottentot communities from whom they were able to obtain large numbers of cattle in exchange for liquor and other products of their Western culture.

As time progressed, company cattle posts were established in the Overberg region. These are regarded by the Marais Commission (1970) as the reason for the slow initial colonisation of the Caledon area by free burghers under the quitrent system:

"During the first years of the 18th century the stock-farmers trekked northwards At that stage they could not trek eastwards because the Governor had monopolised land in that direction. His cattle-posts were spread over the present district of Caledon and barred the way for the colonists over the Hottentots-Holland gorge. After the recall of Willem Adriaan van der Stel the Trek to the East started."

(Marais Commission, 1970 p. 11)

Direct reference to the study area is lacking in the records of the early travellers. The hot mineral spring in the

Swartberg near Caledon was an important tourist site and was visited by most travellers in the region. Thereafter the eastward highway followed a route similar to that followed by the present Caledon-Riviersonderend-Swellendam road which skirts the study area to the north.

Some remarks made by Sparrman, the Swedish physician-cum-botanist, provide a vague indication of agricultural progress in the Caledon district in the latter years of the 18th century. Whilst at the Caledon Warm Baths in July 1775, Sparrman noted some of the wild animals that frequented the area. He mentions the spotted hyena (Crocuta crocuta) which was a particular threat to saddle-horses and oxen by night; the African hunting dog (Lycaon pictus), described as wild dogs which "herd together in companies"; the African wild cat (Felis libyca); lynx (Felis caracal); serval (Felis serval); birds of shrub- and grassland habitat and "extensive serpents". Although a lion was reported to have been troublesome some 11 miles from the Bath at the time, Sparrman remarked that "the lion . . . is now almost extirpated from this part of the country". At the present time this could be said of all large predators within the study area.

Sparrman found the area through which he travelled to Swellendam inhabited by both colonial farmers and Hottentot communities. Farming was mixed. There were some wheat fields in the district at the time, but agricultural development was hampered by the scarcity of implements, e.g. iron ploughshares were in short supply and very expensive at the Cape (Sparrman, 1785 Vol. 2). Livestock consisted

mainly of cattle and "considerable droves of draught oxen" (Sparrman, 1785 Vol. 1). Lichtenstein visited the area some 25 years later. He remarked that the "cornfields" did not extend much beyond Swellendam due to the high cost of transporting the grain to the Cape. It would seem likely that most farms were situated close to the main wagon route. The southern part of the study area was more desolate -

the country from Swellendam "southwards towards Cape Agulhas is very deficient in water, and scantily inhabited, but affords at the moist times of the year the means of feeding a few cattle."

(Lichtenstein, 1928 Vol. 1 p. 198)

Michiel van Breda - who acquired the farm Zoetendalsvallei in 1812, and after whom the town Bredasdorp is named - is generally accredited with having pioneered merino farming in the Bredasdorp district. Sheep farming has gradually outstripped other stock and by 1965 livestock and grain crops were of approximately equal economic importance to the agriculture of the district, sheep and cattle contributing to the income of the average farm in the ratio 9:2 (Agricultural Economic map 1965).

Immediately prior to European settlement at the Cape, it would seem that the study area was inhabited largely by Hottentot tribes. One of the larger and more powerful communities was known as the Hessequa tribe. It is not unlikely that the large number of current inhabitants of the region who bear the surname "Hess" are descended from this tribe.

Another section of the local populace is still regarded as being distinctly of bushman descent. These are very much in

the minority, but there are some local rumours of caves bearing bushman paintings in the Potberg mountain. These have yet to be scientifically documented, but the possibility exists that bushmen may have inhabited this southern region at at some earlier date.

3.2.2. Recent agricultural developments

The current system of agriculture in the study region is based upon an average crop rotation of 10 - 12 years. This is constituted as follows: 1 year wheat, 6 - 8 years planted pasture (mainly lucerne), 1 year wheat, 1 year barley or oats and 1 year fallow (Smit and Goldswain, 1980). This implies that in any one year 60 - 67% of the land is utilised as grazing for sheep and other livestock. Leguminous pasture crops such as lucerne and clover help to improve soil quality as well as providing for the nutritional needs of livestock.

"Sheep numbers have considerably increased since the application of crop rotation systems incorporating dryland lucerne, clover and winter oats pastures. As the nutritional level is relatively high most of the time, an exceptionally good type of Merino has for quite a number of decades been farmed in the Rûens region with a wool production per sheep that is at present the highest in the country."

(Marais commission, 1970 p. 120)

Possible future developments foreseen by the Marais commission include a possible doubling of wool production through the use of supplementary feeding schemes, and the use of presently excessive spring grazing to fatten slaughter stock from the Eastern Cape. It is felt by the

Commission that grain farming has reached its maximum extent in this region, but that yields may be further improved as the major problems of rust and infestation by insect pests are overcome with more resistant wheat cultivars.

This currently favourable farming pattern has been made possible by two major twentieth century industrial advances, namely automotive machinery and chemical aids in the form of fertilisers and pesticides.

3.2.2.1. Machinery

A random sample of the earliest available aerial photographs of the catchment (photography in December 1939/January 1940) show the area to be fully utilised for agricultural production and stripped of natural vegetation. In respect of the areal extent of crop production, the present level was thus reached at least 40 years ago.

The first mechanical tractors appeared in the 1920's and began to replace the traditional animal-drawn implements. The Marais Commission (1970 p. 153) reports a sudden upswing in tractor sales in the post-war years of 1946 to 1948 - an increase from 2 000 to 8 000 new tractors sold per annum. Simultaneous with the growth in mechanisation has been the growth of the steel industry and the ready availability of higher quality ploughshares and other implements. This has resulted in increased efficiency and a less labour-intensive agricultural pattern. Further magnification of this trend has occurred in recent years with the advent of large combine harvesters.

3.2.2.2. Chemical aids

One of the main substances used to enhance soil fertility in the Rûens is lime - which is readily available from the Bredasdorp lime works, situated along the inland extremity of the "duine". Nitrogenous fertilisers are also applied. During the war years these were in short supply and a local farmer earned some £10 000 through the sale of bat guano from the well-known bat cave on the farm Windhoek. This was of low general nutrient value and the venture was a short-lived economic success (Green, 1962 p.203).

The use of pesticides has increased markedly since the 1940's. Some powerful herbicides are used to combat rust, which is a regular problem in the study region. Another major use of herbicides is to control weeds in both grain and pasture lands. Two recent arrivals on the market that are used for this purpose and which can have long-lasting effects are sold under the trade names Kerb and Glean (D. Cronje, pers. comm.). The use of these chemicals is expected to increase substantially in the near future.

In the last decade aerial crop-spraying has become the norm. This method of pesticide application, whilst of obvious convenience to the farmer, is potentially more harmful to wildlife than manual application of pesticides. The volume of poison being dispensed at any one time is larger than by the manual method, and aerial application achieves wider coverage of the land. Direct contamination of waterways due to wind drift is almost inevitable when poisons are aeri-ally applied.

3.2.2.3. Environmental effects

There have been few, if any, attempts to control the abovementioned developments as regards their impact on the environment. The use of machinery and pesticides is governed entirely by expediency and the economic situation of the land-owner. This is particularly regrettable in the case of pesticides where it has been stated that a farmer is free to apply these in whatever quantities he can afford, the only "control" measure imposed being the recommendations found on the label (D. Cronje, pers. comm.). This control measure is merely a control imposed upon the manufacturer, and applies in order to register a chemical for sale to the public. The consumer is free to disregard the prescribed dosages and precautionary measures if he so chooses.

In most cases farmers do appreciate nature and are aware of the value of wildlife, and would not wilfully misuse pesticides. Yet knowledge of the possible long-term consequences of pesticides in the environment is still very deficient and mistakes have been made in the past. It would be of great benefit to have the application of pesticides better documented and controlled.

(a) Wildlife

Agricultural progress has undoubtedly had severe effects on the wildlife of the study area. This occurred initially through loss of habitat as land was cleared, and then as a result of competition with man's agricultural goals. There has been both the deliberate extermination of large

predators as well as the unintentional loss of plant and animal species through reduction of habitat and accidental poisoning.

An incident worthy of further investigation involves De Hoop Vlei in the years 1981 - 1982. In July 1982, when De Hoop Vlei had held water for some 17 months, the open water was strangely devoid of Potamogeton pectinatum (vlotgras) which usually covers the waterbody rapidly. This aquatic plant was only growing in isolated patches close to springs. This happened to coincide with a similar observation on the absence of Myriophyllum spp. from Verlorenvlei - which drains part of the Swartland grain region (J. Grindley, pers. comm.).

After a dry period in 1980, flow was resumed in the Sout River following the heavy rains which caused the Laingsburg flood disaster in January 1981. During the growing season (May - July) of that year a serious plague of the Russian wheat louse was experienced. Unfortunately, heavy rains were experienced in June within days of the fields having been sprayed with Folimat and Metasystox, and some farmers were obliged to repeat the application of these systemic poisons, at great cost, in order to save their crops. Some of these chemicals could therefore have found their way into De Hoop Vlei. In addition the usage of the herbicides Kerb and Glean which were introduced in 1979 and 1982 respectively, is predicted to increase greatly in future years. These offer long-lasting protection against weeds in pastures and, if present in runoff from agricultural lands, could cause damage to aquatic plant life (D. Cronje, pers. comm.).

Although the growth rate of Potamogeton appeared to be normal at De Hoop during spring 1982 (C. Heyl, pers. comm.), the situation needs to be monitored as there is a possibility that its absence might have been due to contamination of the water by herbicides.

Both Brand (1961, p. 19) and Mr M. Swart (pers. comm.) have commented on the large numbers of water turtles (Pelomedusa subrufa) that were present in the vlei until the 1960's. At the present time these are a rarity, only one specimen having been sighted during a six-year stay at De Hoop (1975 - 1980) (A. Butcher, pers. comm.). Interviewed in July 1982, Mr M. Swart (pers. comm.) could not recall when he had last seen a turtle at Melkkamer.

Given the extremely low rainfall of the years 1968 - 1970, a climatic condition which is unprecedented in the 100-year rainfall record, it is not impossible that this decline in turtle numbers might represent a natural catastrophic decrease in the population size of this and possibly other components of the ecosystem. On the other hand, the possibility of progressive pollution of the vlei via contaminated runoff from agricultural lands can likewise not be excluded without further investigation.

(b) Water regime

The increase in Hortonian overland flow on farmlands due to vegetational changes has been discussed in Section 3.1 under the heading vegetation. These computations refer only to runoff changes associated with the observed change in surface cover. In effecting these surface changes there

are, however, also secondary impacts upon the water regime of the area.

The early aerial photographs of the region show prolific tracks across the lands, most of them running with the slopes. At that stage farmers were largely unaware of the potential hazard of soil erosion, and the need for careful planning of access routes and patterns of working the lands was not realised. Through experience of increased runoff and soil erosion, awareness and understanding of the processes involved was cultivated. Access routes have since been minimised and all movement of machinery on the lands is planned to follow contour lines or watershed boundaries as far as possible. As mentioned earlier in this chapter in the section on soils, the space required to manoeuvre large machinery is often quoted as the main hindrance to applying further erosion control measures. The optimal terracing distances for the various soils and slopes of the Rûens, to minimise runoff velocities and thereby reduce soil loss, have yet to be established and form the subject of a current research programme at the University of Stellenbosch (B. Schloms, pers. comm.).

However well-planned the use of machinery may be, its mere use inflicts some environmental impact in the form of compaction of the deeper soil layers. This reduces the porosity of the soil and can thereby increase both overland flow and the interflow components of runoff. Compaction of the soil surface also occurs through trampling by livestock.

Many small impoundments afford some compensation in the regional water budget for the increased runoff mentioned

above. Krige (1973) estimated that there were some 2 000 small earth dams in the Rûens area. At the present time the South African Transport Services are constructing a service road alongside the railway line through the district. Gravel for this purpose is obtained from the nearest convenient spot, on the understanding that all gravel pits thus created are bulldozed to form small dams before they are abandoned. This practice has increased the number of small farm dams, although these have a very meager capacity. The only impoundment of any size is to be found near Rietpoel station, as mentioned in Section 3.1.3. Several minor roads dissect the catchment, crossing the Sout River many times by means of concrete causeways. These often have deep pools on the upstream side, which are possibly man-made in order to reduce flow velocities at these points.

Although none of these human impacts upon the study area has been quantitatively studied, the agricultural development of the region has obviously caused some severe, and many lesser, impacts upon both biological and physical aspects of the catchment that supplies water to De Hoop Vlei.

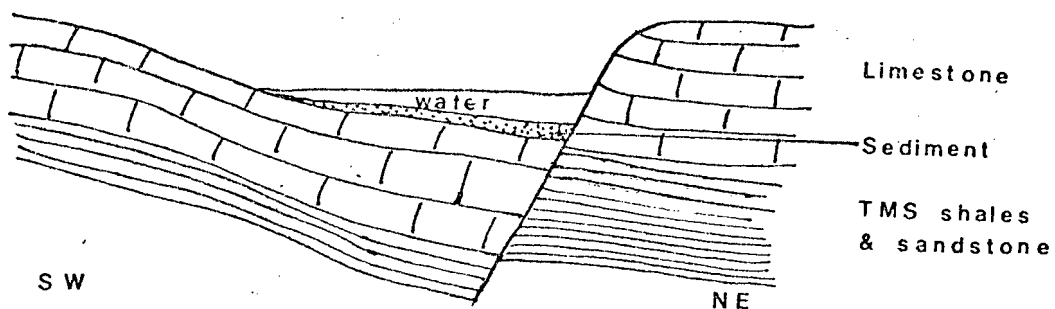
Problems related to runoff and soil erosion may have reached a peak in the early years of mechanised agriculture and it is possible that these are close to being under control at present. Further improvements in agricultural practice are likely to reduce runoff and soil loss. One of the problems that does require further research is the question of pesticide misuse. If De Hoop Vlei is becoming polluted this could have serious long-term effects on its value as a wetland.

4. PHYSICAL CHARACTERISTICS OF DE HOOP VLEI

4.1. GEOMORPHOLOGY

As a karst feature, De Hoop Vlei might be classified as a polje i.e. a large enclosed depression. Its situation within a limestone environment and its dimensions in terms of area and length fulfill the primary requirements of the definition. The north-eastern bank consists of approximately 15 m high limestone cliffs at the De Hoop farm site grading to limestone rubble towards Die Mond, whilst the south-western bank on the farm Melkkamer is graded more gently. This would suggest tectonic influence in the formation of the vlei. A probable cross-section of this polje is shown in the following figure:

Figure 12 : Cross-section of De Hoop Vlei



This is not entirely a solution feature and does not conform exactly to any of the typical polje types referred to by Russell (1981 p.14) but may nevertheless be a permissible

variation.

If the legend of the sinkhole is assumed correct, this would suggest that the base of the vlei, at least in the lower reaches near Die Mond, must also be limestone. In the region of Die Mond the vlei resembles a large solution doline rather than a tectonically generated depression. If this is so it is possible that a sinkhole in this region would have drained into an underground waterway as do those on the north-eastern bank (Blacquiere, pers. comm.).

The northern section of the vlei is an old river valley incised into the limestone. It seems likely that the Sout River originally continued its course in a channel close to the cliffs until it reached the doline at Die Mond. In the wetter seasons the water may have covered a wider area and in time the three features of river valley, channel close to the fault line and solution doline united to form the present-day landform which resembles a polje. The surveyor's sketch of the waterbody in 1850, which accompanies deed 95 of 1850 in the office of the Surveyor General in Cape Town, would seem to support this view since the vlei is depicted as two portions - the northern vlei ending at De Hoop, and a southern portion in the Die Mond area - linked by a stream alongside the limestone cliffs.

At one stage of its geomorphological history the vlei probably formed a transitory lagoon prior to being blocked from the sea by sand dunes. In reports from the field corner of the Potteberg district in the 1860's the beach in this region is referred to as "die mond van Soutriviers Strand" and in 1880 as "the mouth of Salt River Vley"

(letters filed at the Cape Archives: Swellendam - Incoming letters from Field Cornets 1865 - 1904). These names are no longer in use, probably due to the development of a settlement at Skipskop and the attempted housing development at Skihaven. The oral tradition linking this beach with De Hoop Vlei has thus been lost, although the verbal connection may only have been for want of any other landmark as a reference point and may therefore not have held any further geographical significance.

The limestone hills of the "duine" serve as a vast groundwater reservoir, supplying water to the many springs that enter the vlei. These issue mainly at the limestone-shale interface which in places is at or below the bed of the vlei. Occasional surface streams are formed. Even during the prolonged spell during which the Sout River was dry the springs continued to yield well, but this input to the vlei was lost almost entirely via evaporation and seepage.

In earlier years the vlei used to leave a chain of pools when input from the Sout River ceased and the water receded. These pools were fed by the springs. However, due to the high rate of sedimentation these pools are considerably shallower than they were even 50 years ago, and when the vlei was dry during the period 1968 - 1976 there were only isolated shallow pools in the major kloofs. Lesser springs which issue directly into the main body of the vlei were evident only as localised muddy patches and did not cause any significant deepening of the vlei or form pools at those points. Despite the obvious reduction in depth, sufficient

water was retained in the kloofs and other upstream pools to facilitate the survival of several species of fish and other aquatic life-forms. As evidence of this a pair of pied kingfishers was observed regularly on the causeway to the farm Windhoek within three days of the resumption of flow in the Sout River in June 1976. These pools thus play an important role in the ecology of the vlei and promote resilience of the ecosystem to disruption by drought.

4.2. CAPACITY

At the time that it was decided to attempt to estimate the basin capacity of De Hoop Vlei it was unfortunately no longer dry. Nevertheless a survey was undertaken in July 1981 - when the water level registered by the gauge at De Hoop was 3,4 m.

4.2.1. Approach

In order to estimate the volume of water in the vlei for any particular water level, the following approach was adopted:

* Transects were drawn parallel to each other across the main body of the vlei. The direction 50 degrees was a suitable choice since this aligned well with the shape of the Die Mond section as well as the northern parts of the vlei. The positioning of these transects was planned on the 1:50 000 map of the vlei to meet two conditions :

- Firstly, it had to be possible to locate the transect positions with reasonable accuracy in the field. This limited the number of transects that could be plotted

since there is only one trigonometrical beacon in the immediate vicinity of the vlei, and from much of the vlei this beacon is not visible. A more useful landmark is the tower on the "island" at De Hoop. This was employed as a reference point in the survey.

- Secondly, the transect lines were positioned in such a way that the area enclosed by joining the endpoints of two adjacent transect lines closely equalled the actual surface area of the vlei in that region.

* The volume of water in the main body of the vlei was estimated "trapezoidally" as $0,5 \sum_i d_i (A_i + A_{i+1})$, where d_i = perpendicular surface distance between transects i and $i+1$, and

A_i = area of cross-section of transect i for a particular water level

* Of the kloofs only the major ones, viz. Fransfontein and Voëlhoek, were surveyed. One transect across each was plotted and the area of the cross-section so obtained was employed to determine an average depth for that kloof.

* The volume of water in the kloofs was estimated roughly by determining an average depth $d = A/D$, where

A = area of cross-section for a particular water level, and

D = distance across the water surface.

Volume was estimated as the product of surface area and average depth d . It was not possible to determine a corresponding surface area for each water level. The volume of water in the kloofs has therefore been overestimated by adopting a constant surface area for each kloof - this constant being the maximum surface area.

* The total volume of water in the vlei was computed as the sum of the volumes obtained for the main vlei and the major kloofs. The calculation of volume was repeated for descending 20 cm intervals of depth by determining the respective cross-sectional areas from the graphical representation of the transects.

A basic assumption underlying this approach to the determination of basin capacity is that the base of the vlei is essentially flat and that all changes in depth occur gradually rather than abruptly. This is in agreement with the observed state of the bed of the vlei when it was exposed in 1975 - 76.

A second assumption is that the water surface was at a constant height above the mean sea level throughout the vlei at the time of survey. This has not been tested, but would seem to be a fair approximation since there is seldom any discernible current in the vlei due to both the flatness of the bed of the vlei as well as the minimal gradient of the Sout River channel. The 10 m contour line shown on the 1:10 000 orthophotos of the vlei corresponds fairly closely to the recorded flood levels in 1957 (estimated at approximately 11 m above MSL) and would seem to indicate that the water surface is virtually horizontal throughout the vlei.

4.2.2. Method

The survey was carried out on 14 and 15 July 1981. It had rained on the previous two days and for the duration of the

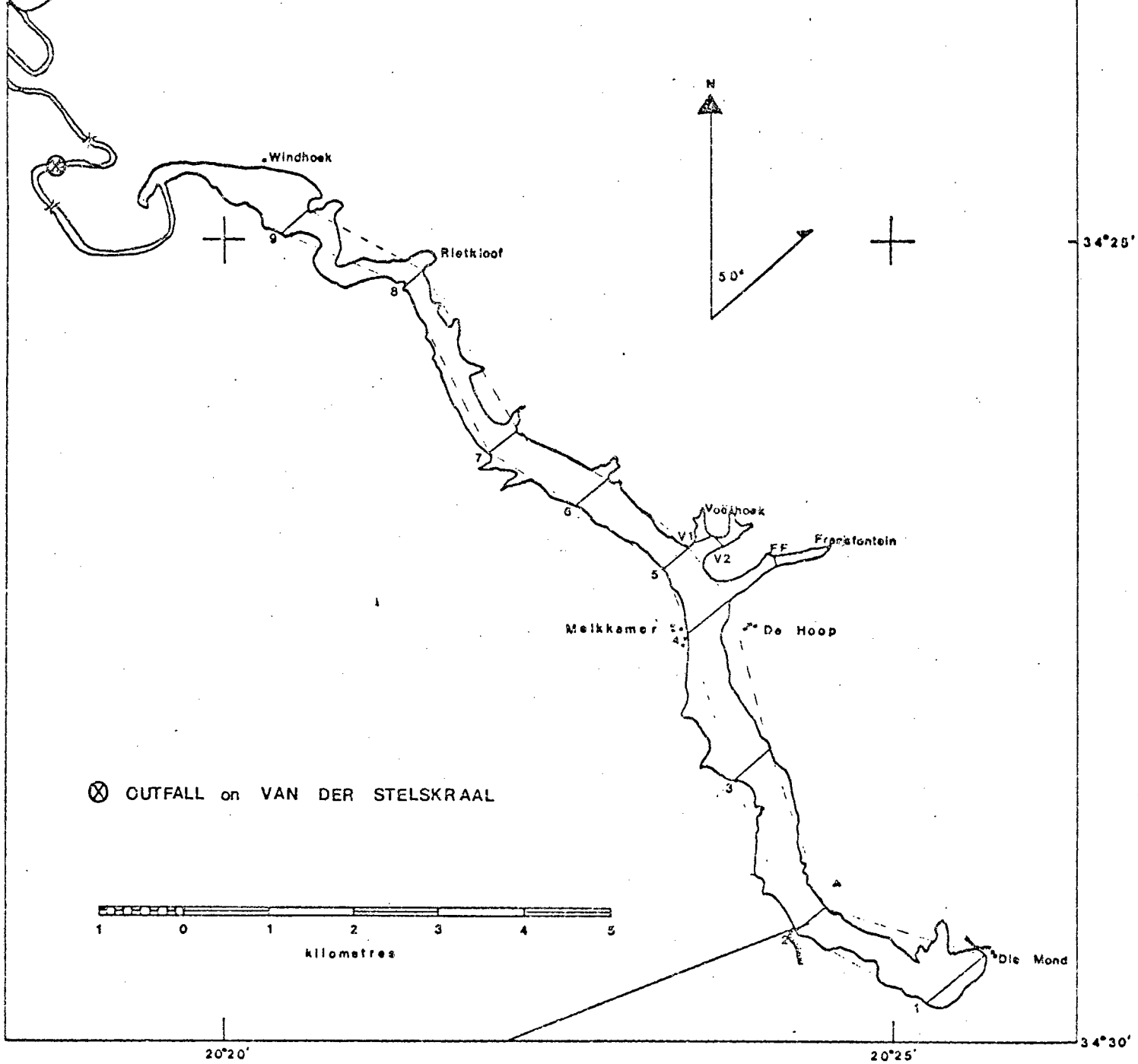


Figure 13: De Hoop Vlei, showing transect positions

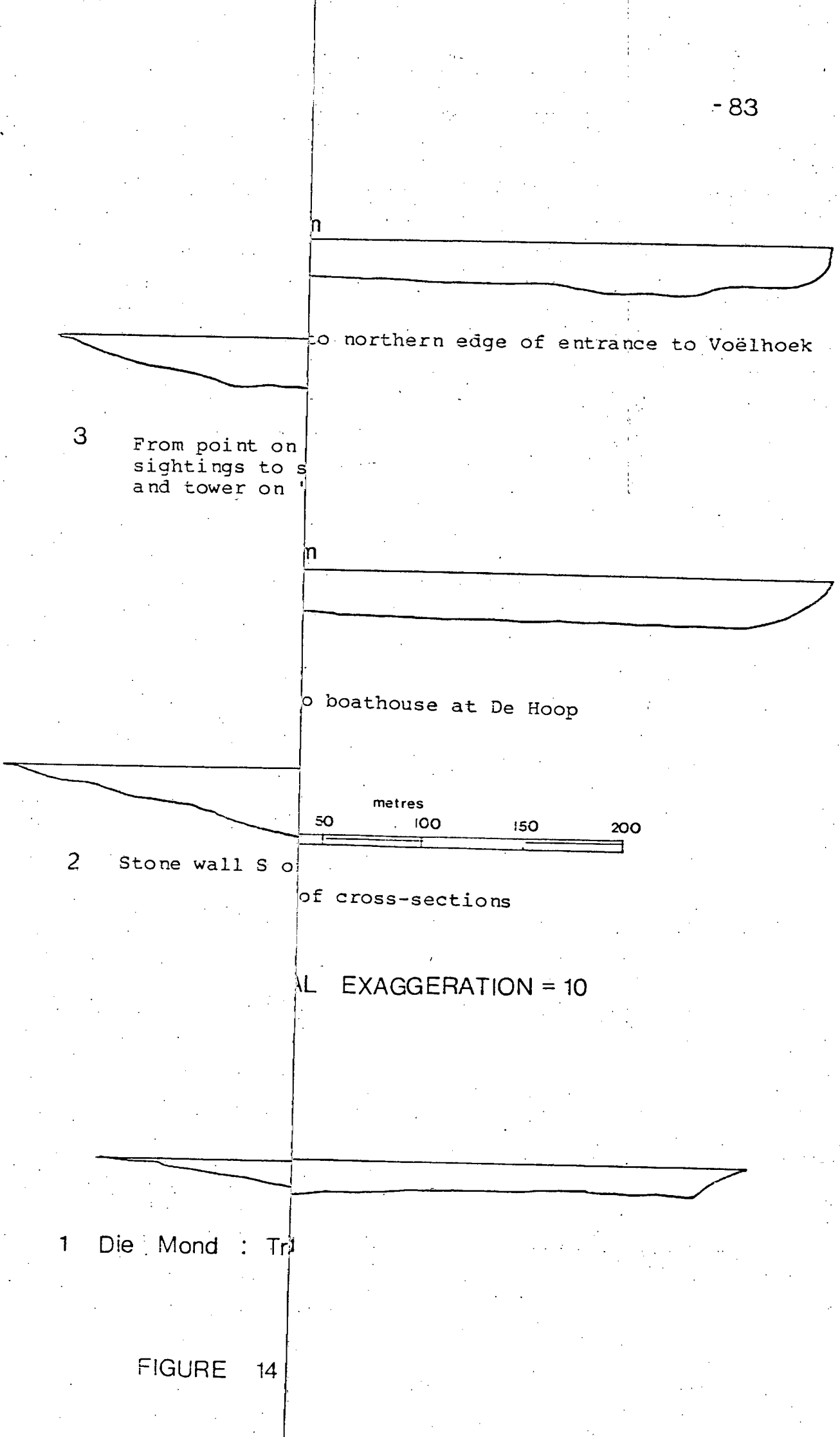
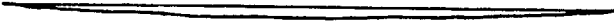


FIGURE 14

d = 200 m



- 9 To southernmost point of Die Eiland (Windhoek)

d = 300m



- 8 To southern side of Rietkloof

d = 395 m



- 7 Upper entrance to Droëkloof to lower entrance to
William's kloof

d = 465 m



- 6 From marsh area to southernmost edge of entrance to Tierhoek

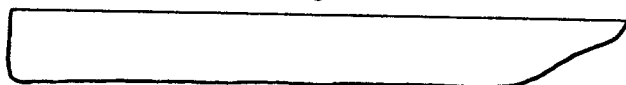
Voëlhoek

d = 190 m



V1 Southern entrance to Voëlhoek kloof 1, direction 66°

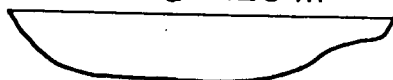
d = 200 m



V2 NW to SE across Voëlhoek kloof 2, from endpoint of V1
direction 136°

Franfontein

d = 125 m



FF Across Fransfontein beneath waterpipe, direction 346°

survey the weather was particularly calm, and only a slight north-westerly breeze was experienced in the early morning near Die Mond.

Nine parallel transects were plotted in the main vlei between "Die Eiland" near Windhoek and Die Mond. The positions of these transects and the graphical representation of the cross-sections are shown in Figures 13 and 14 respectively.

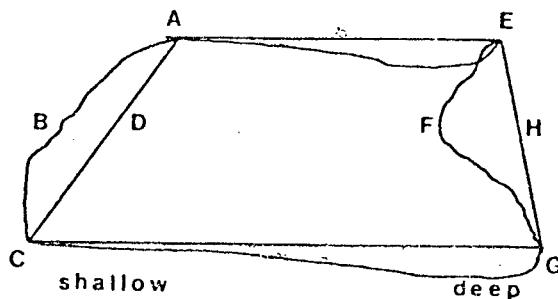
Transects were traversed from SW to NE the line having been positioned from compass bearings and marked with two ranging poles 5 - 10 m apart on the shore. A third pole was positioned in the vlei in line with the first two at a suitable distance so that a navigable depth was reached. Depth and distance from the water's edge were measured with a ranging pole and measuring tape respectively. The profile of the vlei was then mapped by motoring at a steady slow speed (approximately 2,5 m/s) in the set direction recording the fathometer reading every 15 seconds from the time the third pole was passed until the rocky cliff of the NE bank was reached. The remaining unnavigable distance was in all cases small enough to be measured with a 2,5 m ranging pole. The distance covered per 15 second time interval was determined from total map distance for that transect, minus starting and finishing unnavigable distances.

4.2.3. Accuracy

Errors resulting solely from measuring techniques yield an error factor of approximately 15% (see Appendix E). The

accuracy of this approach to determining capacity is also dependent on the distance between the transects and the number of trapezoidal volumes calculated. Another factor which affects the accuracy of the results relates to the equal area criterion applied in the selection of transect positions.

Figure 15 : Areal substitution



In this figure the area ABCD equals the area EFGH but the substitution of area ACEG (trapezium) for the actual surface ABCGFE would lead to an overestimate of volume due to the fact that the area EFGH falls within a deeper zone than does ABCD. This error of areal substitution has been avoided as far as possible. In the case of transects 1, 2 and 3 in the lower reaches of the vlei it was not possible to avoid this. There may well be compensation for this apparent overestimate, however, in that the vlei deepens slightly towards Die Mond. The deepest part of the vlei is situated between transects 1 and 2. It was not possible to subdivide this particular region due to a lack of survey points.

4.2.4. Results

From these calculations it would appear that volume increases with depth at a rate of approximately 0,5 million cubic metres per 20 cm as the main channel fills for gauged depths of up to 2 m, and at a rate of 0,8 to 0,9 million cubic metres per 20 cm as the flatland in the central and southern region is inundated. These results are tabulated in Appendix E, and represented graphically in Figure 16 overleaf.

Since the vlei overflows its southwestern bank at a gauged depth of 7,7 m, the graph in Figure 16 was extrapolated to this value on the horizontal axis in order to determine a probable maximum capacity of the vlei. In the case of a vlei such as De Hoop the increment in volume increases with each fixed increment in depth and the second derivative must be non-zero and positive. The graph of volume versus depth must therefore of necessity be concave upward and may not have any points of inflection. The maximum surface area, which corresponds to the gauged depth of 7,7 m, is 6,2 sq. km. At this point the first derivative must assume the value of 6,2 million cubic metres per metre - or 1,2 million cubic metres per 20 cm. This maximum gradient has been applied from the depth of 3,4 m onward to determine an upper bound of the capacity of the vlei. A lower bound of this capacity was determined by projecting the straight line which joins the last two measured points on the graph (X and Y in Figure 16). According to these projections the total capacity of De Hoop Vlei is within the range of 31,6 to 36,7 million cubic metres. If the average error of 15% in the

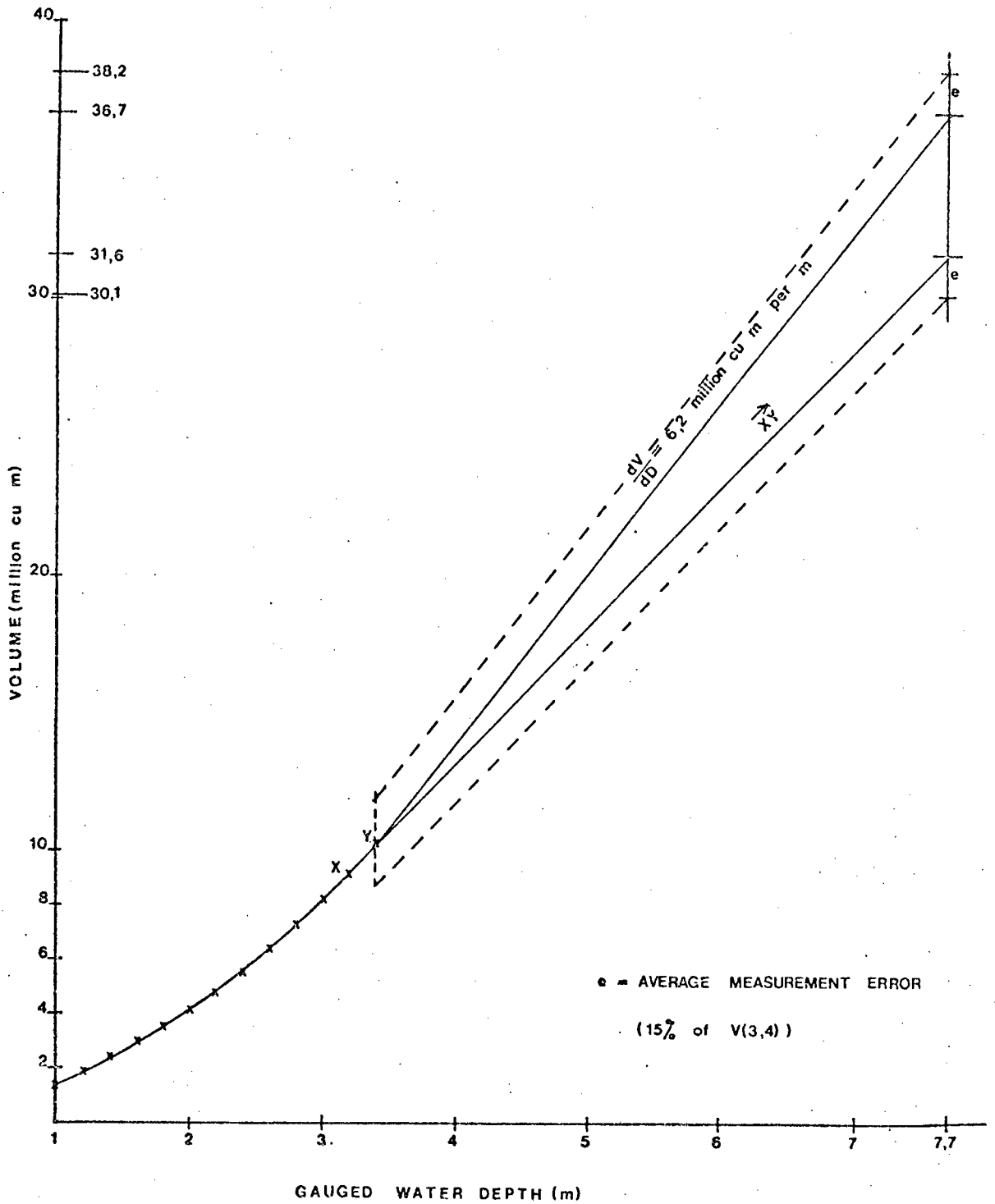


Figure 16: Relationship of water volume to gauged depth at De Hoop

initial calculations is taken into account, the estimated capacity of the vlei is within the wider range of 30,1 to 38,2 million cubic metres.

4.3. SEDIMENTATION

Three main processes contribute to the accumulation of sediment in De Hoop Vlei. These are the mechanical disintegration of shales - which occur in the catchment and which underlie the limestone surrounding De Hoop Vlei; aeolian processes, particularly in the Die Mond region; and decomposition of organic detritus.

4.3.1. Particle size distribution

A research project was carried out by Barker and Chunnnett (1981) to assess the distribution of soil particle sizes in sediments of De Hoop Vlei. A core of 5 cm diameter and maximum depth of 30 cm was taken close to the waters edge at each of 10 sites. The sand fraction was separated from the silt/clay by washing through a 63 micron sieve. The particle size distribution of the sand fraction was then determined using a settling column.

The results of this brief survey indicate that the silt/clay fraction is significantly higher in the northern section of the vlei than towards the mouth, where the sediment consists almost entirely of fine wind-blown sand (see Figure 17).

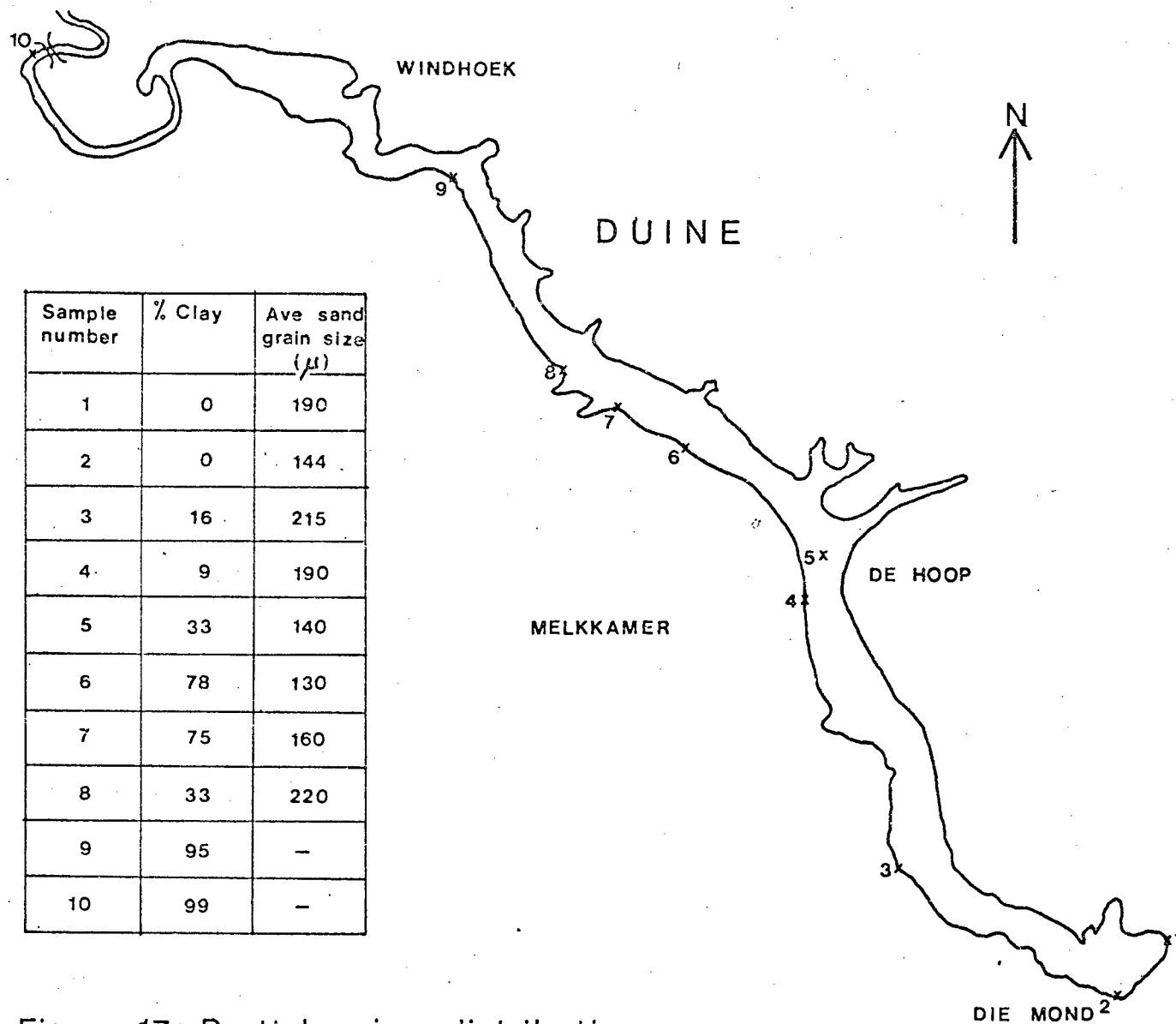


Figure 17: Particle size distribution
after Barker and Chunnnett (1981)

Clay percentages are as follows:

Die Mond region	0%
Melkkamer	9 - 16%
Central to northern vlei	33 - 78%
Windhoek region	95 - 99%

With the exception of one sample at Die Mond, all samples were taken on the south-western bank of the vlei. It is probable that a higher proportion of clay would be found in the main bed of the vlei which is unvegetated and more often submerged. The clay fraction in the sample taken on the "island" between De Hoop and Melkkamer was 33% as opposed to 9% at a nearby point on the Melkkamer bank. The island is more often exposed than the surrounding parts of the vlei, which should therefore have an even higher percentage of silt/clay.

Sediment particle size in a fluvial environment normally decreases in the downstream direction, as heavier particles are deposited first. The reversal of this trend at De Hoop may be due in the first place to the lack of any significant current in the main waterbody. Secondly, the sediment is strongly influenced by local geomorphological characteristics. Wind-blown fine sand from the coastal dunes is the major source of sediment at Die Mond. Sediments in the central and northern region, which is flanked by the "duine", contain some larger rock-derived particles. The clay fraction is strongly dependent on the situation of the particular sample site in relation to vegetation and rock debris. The samples from the Windhoek region are probably derived largely from the soils of the

catchment region.

4.3.2. Rate of sedimentation

With the abovementioned variation in origin and type of sediment, it will be recognised that the rate of sedimentation is likely to vary in different parts of the vlei. An estimate of sediment yield, based on regional averages and catchment area, is within the range 0,29 to 0,75 million cubic metres per annum (Schwarz and Pullen, 1966 p. 344). If this were distributed uniformly over the 6,2 sq. km. area of the vlei, it would represent a reduction in depth of between 49 and 125 mm per annum. In the case of the Sout River, where flow is unreliable, this would seem to be an overestimate of the average annual sediment yield.

A short-term indication of sedimentation at De Hoop can be inferred from remarks regarding the gauge for measuring lake level which was installed by the Department of Water Affairs in 1978. This autographic recorder was erected at De Hoop in March 1978 with the 1 m mark on the measuring staff at the bed of the vlei (M. de V. Jordaan, pers. comm.). When the bed was again exposed in April 1980, the gauged "depth" was given as 1,13 m, i.e. 130 mm of silt had accumulated in approximately 26 months - a sedimentation rate of approximately 60 mm per annum. This is within the range suggested by Schwarz and Pullen, but applies specifically to the inundated region at De Hoop where the rate at which sediment accumulates should be relatively high. (This level of 1,13 m should not be confused with sediment accumulation

caused by the gauge itself. The comment "teogeslik op 1,35 meter" appears on the record for February 1980, indicating the height to which the inside of the flotation column was silted at the time. Flow in the vicinity of the gauge is negligible and the measuring staff is not large enough to form a significant obstruction to the movement of sedimentary materials.)

The only longer-term indication of the actual rate of sedimentation is to be found in occasional remarks related to water depth in the main channel. It is known at De Hoop that the "island" between De Hoop and Melkkamer becomes submerged when the gauged water depth at the boathouse is 2,4m (8 feet) (A. Butcher, M. de V. Jordaan, pers. comm.). The 1:10 000 orthophoto of De Hoop records a spot height on this island of 7 m above MSL. The bed of the vlei is therefore currently approximately 4,6 m above MSL at De Hoop. The deepest point measured near Die Mond during the July 1981 survey of the vlei was 0,9 m deeper than at De Hoop. This would indicate that the lowest point of the bed of the vlei is presently some 3,7 m above MSL (Figure 18).

These observations differ markedly from those of Harrison (1957), who stated that

". . . the normal level of the lake is only about 30 feet above sea and soundings in the main bed go down to a similar depth . . ."
(Harrison, 1957 p. 58)

In the same article, Harrison described the main bed of the vlei as being "deeply scoured". Survey notes made in May 1947 were quoted:

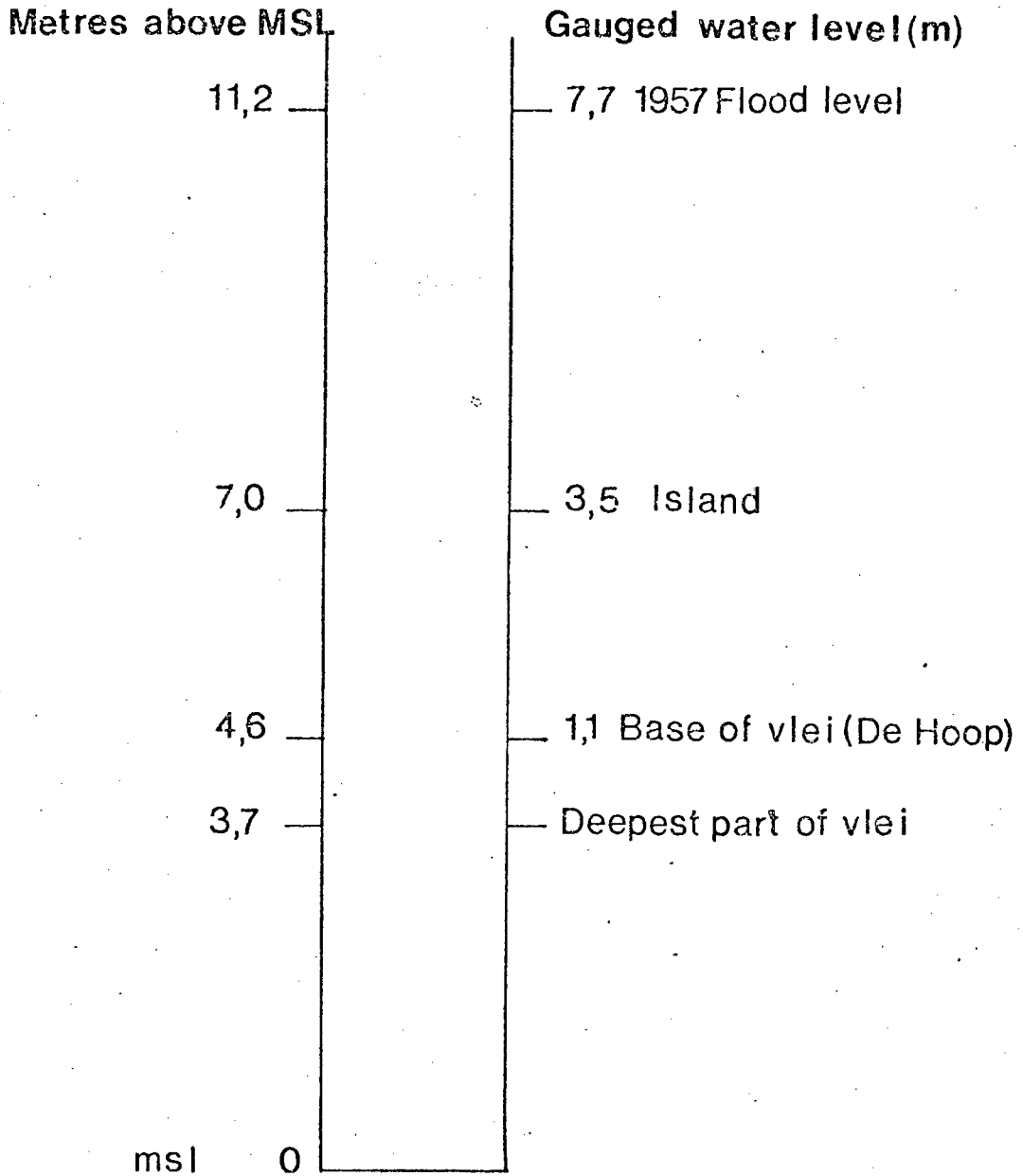


Figure 18: Relationship of gauged water levels to MSL

" . . . the lake was deep without shallows, except at the ends of a few creeks. Bottom materials: stones, sand, debris and rock ledges."

(Harrison, 1957 p. 59)

This description does still apply if the vlei is viewed from the eastern cliffs when full, but the bottom materials described are found only in the immediate vicinity of the cliffs. Two to three metres away the bed of the vlei is virtually flat and the dominant bottom material is clay/silt.

If it were assumed that the bed of the vlei was at sea level in the 1950's, it would appear that up to 3,7 m of sediment may have accumulated in the past 20 - 25 years. This is a maximum accumulation and would refer to the filling of the deepest point rather than to a uniform distribution. Considering the geomorphology of De Hoop Vlei, it is doubtful whether the bed of the vlei could have been below MSL in this century. Farming practices were probably at their worst in the pre-1950 period and the rate of sedimentation at De Hoop due to soil erosion in the catchment would have been maximum at this time. The bed of the vlei might therefore have been somewhat above MSL in the 1950's.

Figure 18 shows the approximate relationship of gauged water levels to MSL. (This is approximate since the water depth at which the "island" is submerged is based on hearsay rather than accurate measurement.) A field survey showed the floor level of Mr Mike Swart's house on the farm Melkkamer to correspond to a gauge level of 7,7 m. The 1957 flood reached this level, which currently corresponds to an

actual water depth of 6,6 m at De Hoop. The article which was written by Harrison (1957) before the 1957 flood mentions a water depth of 9 m (30 ft) as being normal. Uys and MacLeod (1967) quote a similar figure, whilst Brand (1961) measured a depth of 8 m (26,6 ft) at the De Hoop boathouse two years after the 1957 flood. It is clear that water depths of these magnitudes would cause significant flooding of surrounding farmlands at the present time.

It is possible that the figure of 9 m was based upon 1947 survey notes, as were other observations quoted in the article by Harrison (1957). The vlei is described by local residents as having been full in the late 1940's. In 1959 Brand (1961) measured a water depth of 8 m at a time when the water level was receding after a flood. At the present time a water depth of 6 m would be just below flood level. These estimates point to an average rate of sedimentation of slightly less than 1 m per decade, or 100 mm per annum, at De Hoop over the past 3 decades. As the main channel becomes shallower with time, sediment is deposited over a wider area, and it is to be expected that the annual reduction in depth at the gauging point might decrease with the passage of time. It is clear that the recent estimate of 60 mm per annum is in keeping with this trend.

From this partial and fragmentary information, it is not possible to make any inference regarding the influence of human activities upon sedimentation rates. However, the question of sedimentation at De Hoop is of great importance to the problem of managing this water resource. If an average sedimentation rate of 100 mm per annum were assumed

to apply in the inundated region of the vlei, and if it were arbitrarily assumed that on average about 50% of the total vlei area were regularly inundated during the period 1950 - 1980, the average annual sediment accumulation would be of the order of 0,3 million cubic metres, which is in agreement with the lower estimate of Schwarz and Pullen. This estimate suggests that the water-holding capacity of the vlei is likely to have diminished by approximately 6 million cubic metres since the 1957 flood (if allowance is made for the fact that the vlei was dry for 5 years of this 25-year period).

4.4. RECORDED EXTREME EVENTS

During the past century De Hoop Vlei is known to have overflowed its southwestern banks and flooded surrounding farmlands on two occasions, namely in December 1906 and August 1957. At the opposite extreme in its water regime most of the vlei was dry, except for the pools formed by some springs, in the years 1903, 1945, 1975 and 1980. These occurrences are referred to as floods and droughts respectively and are discussed further in this section. Published information on these events is limited to a list of the years of their occurrence (Harrison, 1957) and a brief description of the 1957 flood (Uys and MacLeod, 1967). From the average rainfall record for the catchment the years of excessive or deficient rainfall have been extracted and ranked in Table 4-1. In the ensuing discussion the verbal accounts of these events are compared with the information contained in this table and the monthly rainfall record.

4.4.1. Floods

The water level associated with flooding of the surrounding farmlands has never been directly measured. Although the department of Nature Conservation has a record of water levels at De Hoop which covers the period April 1958 to August 1968, it is incomplete and has several inconsistencies, since the gauge was moved or replaced three times during this period. An autographic recorder has been in operation since 1978, during which period water levels have been relatively low. Crucial periods such as the flood

of 1957 and the refilling of the vlei after drought in the years 1977 and 1981 are either not covered, or are omitted from this record. It is therefore not possible to utilise these data to determine the dynamics of the De Hoop hydrological system and its response to excessive rainfall.

Table 4-1. RAINFALL EXTREMES, 1882 - 1980

A. Rainfall in excess of 127% M.A.P. ($\bar{x} + 1.s$)

Rank	%M.A.P.	Hydrol. year
1	275	1909
2	150	1907
3	144	1902
4	143	1957
5	140	1977
6	138	1951
7	134	1904
8	(131	1888
	(131	1890
	(131	1921

B. Rainfall less than 76% M.A.P. ($\bar{x} - 1.s$)

Rank	%M.A.P.	Hydrol. year
1	58	1973
2	60	1928
3	66	1970
4	67	1969
5	(72	1968
	(72	1899
	(72	1906
8	73	1950
9	75	1903

In the absence of any definite measurement of flood levels, the house of Mr Mike Swart has been used as a reference point to determine the peak water levels reached by the major floods of 1906 and 1957. This house is situated in close proximity to the vlei on the farm Melkkamer and was flooded to windowsill height in 1906, and floor level in 1957. By field survey these levels were determined as 11,8 and 11,2 m above MSL respectively.

The first verifiable flood occurred at De Hoop in December 1906. Although the rainfall for the hydrological year ended September 1906 had been very low - a mere 72% of M.A.P., this was distributed in the form of showers at times favourable to the farming pattern of the time, viz. April and June. The Van Breda family diary bears an entry for 30 June 1906 which describes the lambing season as "most prosperous" and the June showers as well timed for the completion of sowing. A cold spell during August resulted in the only known snowfall recorded for this district (see Section 3.1.1). The antecedent moisture conditions were thus unusual, but by no means excessively wet when "a record SE rain ... flooding the local rivers" fell on 15 December 1906 (Van Breda diary). The entry continues: "Reports received of damage in different parts of the district as also in other districts"; and on 16 December: "River impassable". (This refers to the Kars River.)

The catchment rainfall for December 1906 was 188 mm - the highest December rainfall in the 100-year record. This is almost 9 times the average December rainfall and more than double the second highest December figure for the period of

record. According to the daily rainfall record for Cape Agulhas (M. van Breda, pers. comm.), 71,6% of this rain fell in the form of heavy showers to steady rain during the 24-hour period ended at 8:30 a.m. on 15 December, and 81,4% during the period 11 - 15 December.

The floodwaters reached a peak level of 11,8 m and must have caused considerable flooding of surrounding farmlands. Judging from the length of time taken for floodwaters to recede after the 1957 flood, and from rainfall records for the period 1906 - 1909, the vlei must have continued to overflow to the southwest for at least three years after the December 1906 flood. Although rainfall was only slightly above average in the hydrological year 1908, the year 1909 was characterised by particularly heavy rainfall. With the exception of April (in which 52,8 mm was recorded), the months March to September were extremely wet, monthly rainfall ranging from 74,4 mm in June to 206,5 mm in September. (All of these monthly amounts exceed $\bar{x} + 1.s$ where monthly means and standard deviations are as in Table 3-2.) It will also be seen from Table 3-2 that the three-month period July to September 1909 is the wettest on record. Yet the year 1909 is not specifically mentioned in connection with flooding at Melkkamer. It is most likely that the period from December 1906 through to 1909 is merged in the memories of local people and remembered as a single event, referred to as 'the 1906 flood'.

It is maintained that this 1906 flood was the first since European occupation of the area, and could therefore possibly be the first ever. A milkwood tree, which

according to oral tradition was well over 100 years old and the trunk of which had a diameter equal to that of a large wagon wheel, died shortly after the flood due to waterlogging of the root zone. This tree had stood beside the farmhouse (M. Swart, pers. comm.). The age of this tree could be verified if pieces could be traced - since it is claimed that parts of the trunk were made into furniture.

It was over 50 years before a second major flood occurred at De Hoop. The winter of 1957 was exceptionally wet in several parts of the Cape Province, including the southwestern districts. The Cape newspapers carried reports of severe floods in both the northern Cape and the Cape Peninsula. The rainfall on the catchment of De Hoop during the months of May to July was above average and had resulted in abnormally high water levels at De Hoop. Heavy rains in mid-August cause the water level to rise suddenly and on the weekend of 17 - 18 August water flowed through Mr Mike Swart's house necessitating that the house be evacuated. This was front-page news in Die Burger on Monday 19 August, where it was estimated that 6 688 ha (8 000 morgen) of land to the south and south-west of De Hoop was flooded and that some farm roads in the vicinity were under as much as 8 ft of water. These figures are probably exaggerated, as Mr. C. Burgers (pers. comm.) has estimated the actual flooded area, excluding 'islands' at only 2 980 ha. This latter estimate is based upon a study of the vegetation from aerial photography in 1962.

This water had not markedly receded when a heavy thunderstorm broke over the district on the afternoon of 1

October. The entire southwestern Cape experienced continuous heavy rain and hailstorms for the following two days. Road and rail washaways temporarily isolated the entire Bredasdorp district, where the farmlands were completely under water. Heavy crop losses were sustained and significant amounts of topsoil were lost. It was reported after these rains that soil was up to 30 cm deep in places on the Caledon-Napier road. In the Cape Argus of 2 October the Sout River is described as having been in spate and at its highest level for that year. The peak water level associated with this flood is estimated at approximately 11 m above MSL at De Hoop.

Even though rainfall was close to average in the following two years, it took 2 - 3 years for the floodwaters to visibly recede at Melkkamer (Uys and MacLeod, 1967 p. 235). This could be attributed to the fact that inflow from the Sout River would have compensated for water loss through evaporation and seepage in the downstream regions; and secondly, that waterlogging often occurs on Melkkamer because the limestone is close to the surface and seepage is thus slow.

This temporarily enlarged waterbody attracted large numbers of birds to the area. Although most of the vegetation was submerged, there were several thickets of Acacia cyclops on higher ground which became excellent heronries. Smith (1959) estimated that literally thousands of birds flocked to the area after the 1957 flood. Of particular note is the fact that the greater flamingo (Phoenicopterus ruber) bred at De Hoop during that period. Although the greater

flamingo is regularly observed at De Hoop, the main breeding ground for this species is further north, namely in South West Africa and Botswana. The flamingoes were attracted to the many shallow, nutrient-rich pans which were left as the floodwaters receded, and their population size peaked at between four and five thousand individuals in the summer of 1960/1961. An estimated 800 nests with eggs were observed in the Reimerskraal area in that year (Uys and MacLeod, 1967). This is the only large-scale breeding record for the greater flamingo in South Africa (C. Heyl, pers. comm.).

Besides these major floods there have been instances in which lesser flooding has occurred at Melkkamer. There are two regions on the southwestern bank of the vlei where some spillover used to occur when the vlei was 'full'. There is no specific information regarding these events except that spillover is said to have occurred in the 1920's and in the late 1940's. This flooding was of short duration and did not extend beyond the immediate vicinity of the vlei on these occasions. After the 1957 flood the bank of the vlei was built up to form dykes in these and other low-lying regions, which had been eroded by the floodwaters.

If the dates of the major floods are compared with the rainfall extremes listed in Table 4-1, it will be seen that the hydrological year 1902, which is ranked one place above 1957 as regards excessive annual rainfall, is not accounted for in the verbal account of floods at De Hoop. In 1902 rainfall in excess of 70 mm fell in the months February, August and September, but that for April, May and July was well below average. A similar situation is recorded in 1977

(ranked fifth according to annual rainfall) where the months February, April and May were relatively wet, but the intervening month of March was drier than average. Although the total annual precipitation was similar in the years 1902, 1957 and 1977, the year 1957 differs in that there was a five-month sequence of above average rainfall, in two consecutive months of which over 80 mm of rain was recorded.

It is apparent from this discussion that both major floods occurred in years in which the annual rainfall exceeded 500 mm. Secondly, this excess of almost 150 mm above the mean occurred as a single storm event in 1906, and in consecutive months in 1957. In other years of equally high annual rainfall the excess above the mean was not concentrated over consecutive months and no major flooding occurred at De Hoop.

A third factor which influences flooding is the spatial distribution of storm rainfall. Heavy rainfall over the Bredasdorp district in August 1978 caused local flooding and damage to roads in the Kars River catchment, but, although the Sout River flowed strongly for two to three days afterward, this input was not large enough to cause a significant increase in the water level at De Hoop. It appears that the storm rainfall associated with both of the major floods was widespread, affecting the entire catchment area as well as causing waterlogging in the surrounds of De Hoop Vlei.

4.4.2. Droughts

The absence of water in De Hoop Vlei is less noteworthy than the presence of excessive amounts, and droughts are therefore more difficult to pinpoint than floods in the history of the vlei.

The Marais Commission (1968) distinguishes three types of drought to which South Africa is subject. These are

(a) seasonal droughts, which occur annually; (b) droughts of shorter or longer duration (periodic droughts); and

(c) critical droughts, of three or more years duration.

Periodic droughts are a regular occurrence in South Africa, and on average 20 of every 60 years are dry. Critical droughts are less frequent and in the study area these are predicted to occur once in 18 years (Marais Commission, 1968).

In order to clarify the term 'drought' for De Hoop, the known periods (the 'verbal account') of low water levels are compared with the average catchment rainfall record. Harrison (1957) mentions that in the years 1903 and 1945 'the greater part' of the lake bed was exposed, but there is no indication of the actual extent of this exposure. In 1975 and 1980 the entire bed of the vlei was exposed, only the springs being excepted. In the discussion which follows the rainfall record for the periods surrounding the years 1903, 1945 and 1975 is examined and compared with that for the years of low rainfall listed in Table 4-1(B).

Six consecutive years of subnormal rainfall in 1895 - 1900 were followed by good rains in 1901 and 1902. The total

rainfall for the year October 1902 to September 1903 was only 275 mm, largely due to deficient winter rains. It could be that the year 1903 is remembered as the lowest water level prior to the 1906 inundation, and was not necessarily a year of critical drought.

The year 1945 is less noteworthy as regards annual rainfall. This year, for which the total rainfall was 364 mm, marked the beginning of a 4-year sequence of sub-average rainfall, but apart from a drier than average summer and wetter than average winter, the rainfall for this year was in no way remarkable.

The average catchment rainfall record shows two other sequences of deficient rainfall to have occurred, namely the five-year dry sequences of 1926 - 1930 and 1933 - 1937. Neither of these is remembered in the verbal account of low water levels at De Hoop.

The most recent dry spell which caused exposure of the entire bed of the vlei, occurred during the period 1968 to 1973. In each of the three consecutive years (1968 - 1970) the annual rainfall was below 76% M.A.P. (\bar{x} - 1.s). If annual rainfall is ranked from lowest to highest, these years rank 5th, 4th and 3rd respectively (see Table 4-1(B)). After a slight recovery in the years 1971 and 1972, the rainfall of 1973 was the lowest on record, namely 214 mm (58% M.A.P.). As a result of this sequence of deficient rainfall the Sout River dried completely, and streamflow was zero at Kykoedie for almost seven years between December 1967 and May 1976. (Some flow was recorded for the periods July 1971 - November 1972 and September - October 1974.)

There was thus virtually no input to De Hoop Vlei from its catchment during this time and the vlei became progressively emptier and more saline until the entire bed of the vlei was exposed in 1975. Until June 1976 the vlei was completely dry and was used as a direct route for nature conservation vehicles travelling between De Hoop and Windhoek.

After rainfall in April and June 1976 the Sout River began to flow again at De Hoop in late June. Good winter rains in 1977 raised the water level still further, but as the inflow from the Sout River declined during 1978 - 1980, the vlei dried rapidly and, apart from a shallow pool near Die Mond, the bed of the vlei was again exposed from the summer of 1979/80 until February 1981.

On the basis of the rainfall record and the length of time for which the vlei was dry, it seems likely that the 1968 - 1973 drought was the most severe in the 100-year period of recorded rainfall. (As the Sout River has only been gauged since 1965, there is no record of the effects on streamflow of previous dry periods.) This recent drought is the only known dry period at De Hoop that is clearly identifiable from the rainfall record.

The dominant aquatic primary producer in De Hoop Vlei is Potamogeton pectinatum (vlotgras). This plant is unable to tolerate salinities in excess of 15 ppt for long periods (C. Heyl, pers. comm.), and consequently dies off rapidly during a prolonged drought. The salinity of De Hoop Vlei is generally between 5 and 11 ppt, but is known to have reached 50 ppt during the dry period in January 1981 (D. Coetzee, pers. comm.). Since P. pectinatum is the major determinant

of the carrying capacity of the vlei for primary consumers such as waterfowl and coot (C. Heÿl, pers. comm.), its absence has obvious repercussions on the ecosystem. It is not known how long it will take for the ecosystem to recover from the extreme depletion of water reserves and the persistence of highly saline conditions which have occurred in the past decade.

It would seem from this comparison of the observed dry periods at De Hoop with the ranked list of years of deficient rainfall, that, besides regular seasonal (summer) droughts, there have been at least six droughts of longer duration and only one verifiable critical drought at De Hoop during the past century.

4.4.3. Conclusion

This discussion has shown that the major floods and the recent drought correspond to years of extremely excessive or deficient rainfall respectively. It is therefore not possible to determine whether the agricultural development of the catchment or the rumoured blockage of the sinkhole have significantly affected the degree of flooding or dessication which has occurred during this century. There are no recorded extreme rainfall events in the pre-1903 period, and it is therefore not possible to ascertain whether similar rainfall input as caused the floods of 1906 and 1957 might have caused less extensive flooding in earlier times. The observed rate of sedimentation would suggest that this might have been the case, irrespective of the alleged impacts of human activities. The relation of

rainfall input to basin capacity is therefore of prime importance in flood prediction. Other factors which determine the quantity of rainfall that becomes runoff, i.e. intermediate processes which can be modified by man, are of lesser significance than excessive rainfall in causing floods. The effect of these parameters is explored by means of an hydrological model in the following chapter.

5. HYDROLOGICAL MODELS AND THE DE HOOP CATCHMENT

In the previous chapter the recorded extremes in the water regime of De Hoop Vlei have been shown to be reflected in the rainfall record. High annual rainfall is not, however, the only criterion in deciding whether or not water levels were high at De Hoop in a particular year, although climatic factors exert a major influence on these extreme events.

The extent to which human activities have affected the water regime of the vlei is not readily quantifiable, yet the agricultural development of the study area over the past century must have affected the water balance of the region. In defining runoff zones for South African catchments Midgley and Pitman (1969 p. 30) state that "of all the catchment features associated with runoff, vegetal cover seemed to have by far the strongest influence". For practical purposes Midgley and Pitman have found the description of vegetation in terms of Acocks veld types to be an adequate basis (alongside soils, geology and relief) for the classification of runoff zones, and actual vegetal cover is not considered. The importance of the actual vegetation in the water budget of a region is, however, mentioned by other writers (e.g. Monke, 1971) who stress that changes in cover from naturally occurring vegetation to either agricultural crops or forest can have vast effects on the hydrology of a region. The processes within the hydrological cycle that are most affected by changes in vegetation are interception, infiltration and evapotranspiration.

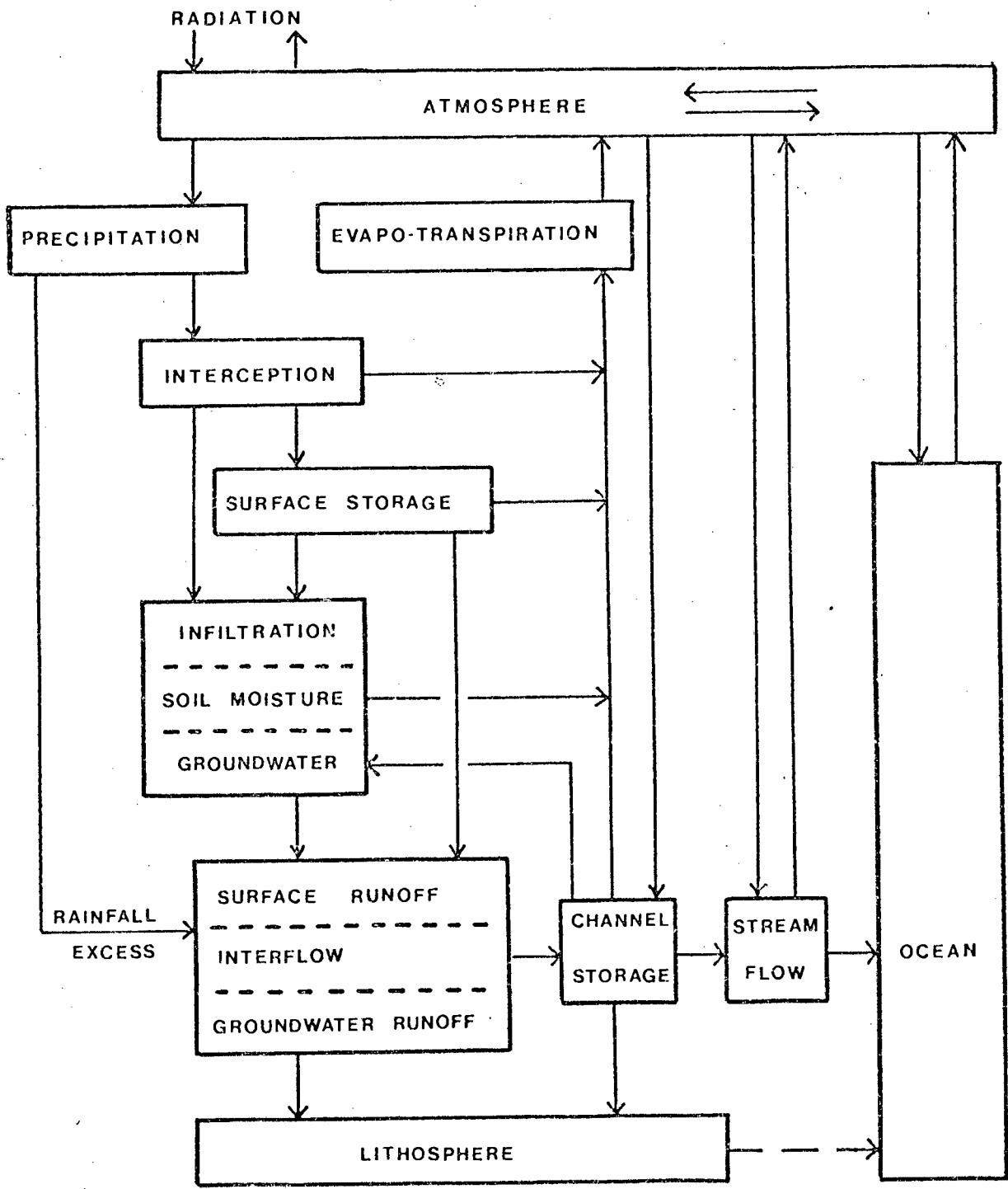


Figure 19: Systems diagram of the hydrological cycle after Raudkivi (1979)

Whilst it is recognised that vegetal changes have some effect on the hydrology of any catchment, it is only practical to quantify these effects for small catchments. In large catchments, the increase in runoff due to deterioration in the vegetal cover is often offset by channel storage effects. It is important, therefore, to distinguish between the processes of runoff and streamflow. As is shown in Figure 19, the process of runoff is more directly linked to factors connected with vegetal cover, whereas streamflow forms part of a more complex system and is further removed from the processes of interception, infiltration and evapotranspiration. In general, it is true that the larger the catchment, the greater the relative importance of intervening hydrological processes, notably channel storage, become.

In considering the possible impact of human activities on the hydrology of De Hoop, two hydrological techniques which are in common use for modelling the water yield of South African catchments have been applied to the study area. Firstly, the rational method as employed in the United States Soil Conservation Service (SCS) technique for estimating runoff from rainfall was used to provide an indication of the extent to which the process of runoff is affected by land use changes in the study area. Secondly, a computer programme which simulates hydrographs of streamflow from rainfall for both gauged and ungauged catchments in South Africa was applied to the study area in an attempt to determine the volumes of water which have reached De Hoop over the period of rainfall record. These modelling methods and the results are discussed in more detail in the sections

which follow. The actual data, tables used and output can be found in Appendices C and D.

5.1. RUNOFF

The SCS technique for estimating storm runoff from rainfall is based upon the rational method of runoff computation and is only applicable to small catchments in which slopes do not exceed 30%. It is used here purely for the purpose of gaining understanding of the probable effects of changes in land use upon runoff, and is not applied quantitatively to the entire study area.

The basic assumption which underlies the SCS runoff equation as described by Schulze and Arnold (1979, pp. 4 - 7) is that at any given time T during a storm, the ratio of accumulated runoff (Q) to potential runoff, i.e. effective storm rainfall, (Pe), is equal to the ratio of accumulated infiltration from the commencement of runoff until T (F) to potential maximum retention of the soil (S) -

$$\text{i.e. } Q/P_e = F/S \quad \dots(1)$$

where Q, Pe, F and S are expressed in the same units (in this case mm).

By making the further substitutions

$$F = P_e - Q ;$$

$P_e = P - I_a$, where P is the accumulated storm rainfall and I_a represents the initial abstraction - this includes all storm rainfall occurring prior to the commencement of surface runoff;

and $I_a = cS \dots(2)$, where c is an empirically determined coefficient of initial abstraction,

equation (1) becomes

$$Q = \frac{(P - cS)^2}{P + (1 - c)S}$$

To implement this method of determining runoff Q for given storm rainfall P , values must be assigned to the parameters c and S . The coefficient of initial abstraction, c , is determined from a table according to the total 5-day antecedent rainfall and season (growing or dormant). This coefficient is therefore related primarily to the antecedent moisture budget. The parameter S is related to the particular soil type and cover conditions prevailing in the study catchment, and for practical reasons has been transformed to a runoff curve number, CN , which is within the interval $[0 ; 100]$. An initial value of CN is determined according to land use and treatment classes, and soil type (see Appendix D, Table D-1); this value for CN is adjusted according to the antecedent moisture conditions and S is calculated according to the formula

$$S = (25400 / CN) - 254$$

[The relevant tables and calculations relating to storm rainfall occurring in April and June of 1976 (the June rainfall which caused renewed inflow to De Hoop after the

prolonged drought of 1972 - 1976) are given in Appendix D. The hydrological soil groupings and vegetation have already been described in Chapter 3, Section 3.1.2 under the headings soils and vegetation respectively.]

This method of predicting runoff has several limitations. Firstly, point rainfall is assumed to be evenly distributed over the catchment area. Daily rainfall figures are used, and storm intensity thus does not influence the calculation of runoff quantities. The description of the catchment hydrology is likewise oversimplified, since this is reduced to a mere two parameters, both of which relate to the soil moisture state. These are determined by two- and four-dimensional nominal classification procedures - for C and S respectively. (See Tables D-1 and D-2 in Appendix D.)

It is for these reasons that the SCS method is restricted in its application to areas which are smaller than 8 sq. km. and in which slopes do not exceed 30%. In these cases the advantage of using the technique is that the effects of changes in land use upon runoff can easily be estimated, since few input data are needed.

Extrapolation of this technique to catchments of larger area is inhibited partly by problems relating to the spatial and temporal distribution of rainfall. Variation in other factors such as soil type or land use can readily be accommodated by subdividing the catchment into homogeneous runoff units, and applying areal weighting when the individual estimates are summed. A major drawback of the SCS method which must be stressed is that this model estimates surface runoff only. Unless the intervening

transfers of water to channel storage can be adequately described in mathematical terms, it is impossible to draw any conclusions regarding streamflow from these calculations - as would be required for larger catchments.

Although even the smallest subcatchment in the study area is considerably larger than the maximum size to which the SCS technique may be applied, the method has attributes which are conceptually of interest in this study. Schulze and Arnold (1979) have adapted the method to South African catchments by assigning hydrological categories to all soil forms and series (using the nomenclature developed by MacVicar et al (1977)). The SCS coverage of land use and treatment classes was likewise adapted to South African conditions. This type of detail is not used in modelling techniques suited to larger areas, but is an important consideration with respect to the primary aim of this study, namely to investigate whether land use changes have markedly increased the amount of runoff from the De Hoop catchment during this century.

The SCS technique has therefore been used here to demonstrate the effect upon runoff of a major change in land use from the scrub of the winter rainfall region to contoured small grain farming. This has been applied to all soil series represented in the study area, i.e. the hydrological soil groups B/C, C, C/D and D. Results of these calculations for the dominant hydrological soil groups (B/C and C), i.e. soils of the Mispah and Glenrosa forms, are summarised in Table 5-1. (Results for all the hydrological soil groups represented in the study area are

tabulated in detail in Appendix D.)

Since this technique has not been applied to any particular part of the study area, but is considered in more general terms, the runoff depths have not been converted to volumes. The runoff depths have instead been expressed as a percentage of storm precipitation.

Antecedent rainfall and evapotranspiration figures, which have been omitted from Table 5-1, account for the irregularity in the values of N and G for increasing precipitation.

Table 5-1. INFLUENCE OF LAND USE UPON RUNOFF

Runoff as % Rainfall				

Soil form	Rainfall (mm)	Scrub Vegetation	Small grain	G/N
		(N)	(G)	

Glenrosa (B/C)	24	3,30	18,78	5,7
	29	0,73	3,39	4,6
	36,7	1,91	5,65	3,0
	38,1	1,06	3,27	3,1
	71,6	5,92	10,42	1,8
	72	8,49	15,59	1,8
Mispah (C)	24	6,30	23,09	3,7
	29	1,43	3,84	2,7
	36,7	2,97	6,23	2,1
	38,1	1,71	3,60	2,1
	71,6	7,37	11,02	1,5
	72	10,70	16,59	1,6

These calculations would seem to indicate that for the dominant soils of the study area, land use has a marked effect upon runoff. Although this effect as reflected in the figure G/N tends to decline for increasing amounts of precipitation, it is for these larger amounts of rainfall

that streamflow occurs. An increase of 50% or more in the runoff generated in such a storm is therefore significant. On the other hand, a six-fold increase in runoff from precipitation of only 24 mm is barely sufficient to produce streamflow. If the figures for Glenrosa and Mispah soils are compared, it will be seen that for the hydrologically poorer soil (Mispah) the actual quantities of runoff are higher than for soils of the Glenrosa form, under either natural vegetation or grain cover. Therefore the effect of a change in vegetal cover, whilst apparently smaller, could be more significant than in the case of the hydrologically better soil.

5.2. STREAMFLOW

In attempting to obtain some indication of the total water yield of a catchment such as that of De Hoop, it must firstly be recognised that to extrapolate from the runoff figures derived by means of SCS technique is meaningless due to the partial description of the hydrological cycle incorporated in that model.

A more complete description of a catchment as an hydrological system is employed in the mathematical model devised by Pitman (1973). This computer model has been widely applied in South African water resource studies since provision is made for its application to both gauged and ungauged catchments. No restriction is placed on the size of catchment to which the model may be applied. The response of any catchment to rainfall is mathematically described by 12 parameters - suggested regional values of

which are provided. The model is of the lumped parameter type and does not permit spatial variation in the values assigned to the parameters. The model does make provision for channel storage - which is expressed as a function relating to lag and attenuation of runoff.

The description of the runoff process is, however, too general to allow for spatial variation in catchment characteristics, such as soil type or vegetal cover. The Pitman model has therefore been applied to the study catchment with the purpose of obtaining (a) estimates of the water yield of the De Hoop catchment over time, and, in particular, (b) an indication of the magnitude of the storm runoff which caused the known major floods.

5.2.1. Rainfall Data

Monthly rainfall figures for various weather stations within and close to the study area were extracted from records held by the data bank for the Fynbos Biome project. This data base was expanded to include recent records from the offices of the Department of Agricultural Technical Services at Bien Donne, rainfall records kept by the nature conservation officer at De Hoop Nature Reserve, and private records of Mr P.A.J. de Wet of the farm Bosfontein. The records from a total of 14 weather stations were thus obtained. These are of varied lengths and a maximum of 11 were used in any one year. Details of the individual weather stations are in Appendix B of this report. Missing data were estimated from the records of surrounding rainfall stations according to

the formula

$$P_a = N_a/3 \cdot (P_b/N_b + P_c/N_c + P_d/N_d)$$

where P_x = monthly precipitation at rainfall station x

N_x = monthly long-term normal precipitation at x

(cf. Dunne and Leopold, 1978 p. 41)

The rainfall record for each station was therefore complete prior to being amalgamated with other records to determine the average catchment precipitation, since the AVRAIN programme does not make provision for handling missing data.

Various methods exist by which an average catchment precipitation may be determined from the individual rainfall records. The Thiessen polygon method was considered whereby adjacent rainfall measuring points are joined and the perpendicular bisectors of these lines are constructed so as to define a polygon about each rainfall station. The proportion of the catchment area within each polygon is used as a weighting factor, to determine an areally weighted average rainfall figure. This method of amalgamating individual rainfall records is often applied in catchments which have a non-uniform distribution of gauges. Thiessen polygons can, however, only be used successfully where the rainfall records are co-terminous, as the amount of work involved becomes prohibitive if records of greatly varied lengths are to be used.

The accuracy of the rainfall record, especially in the early years, is questionable since, from being vastly different before 1965, the annual figures suddenly show remarkable similarity in the post-1965 period. This is probably due to

to Weather Bureau attempts to standardise measuring techniques at that time.

It was therefore both expedient and appropriate to utilise the computer programme AVRAIN (Pitman, 1973) which reduces individual monthly precipitation figures to percent M.A.P. for each particular station and subsequently computes the arithmetic average of these figures to derive the average catchment monthly rainfall, expressed as % M.A.P. This method enables all available records to be utilised and applies smoothing to these individual records. (The programme AVRAIN is described by Pitman (1973) and output from this programme appears in Appendix B of this report.)

In order to comply with the format requirements for input to the AVRAIN programme, the rainfall data were arranged into hydrological rather than calendar years - an hydrological year being defined as the 12-month period ending on 30 September. Whilst this arrangement of data is not crucial to the functioning of the AVRAIN programme, it is important to the streamflow simulation programme MORSIM, where seasonal adjustments to evaporation data are made.

In order to convert the output from AVRAIN to depths of rainfall, it was necessary to provide a figure for the mean annual precipitation on the catchment. An amount of 369 mm was employed, which is the Thiessen weighted average of the mean annual precipitation at those stations with a minimum record length of 50 years.

5.2.2. Simulation of monthly streamflow

The computer programme MORSIM utilises monthly or daily rainfall data and average monthly evaporation figures in order to simulate hydrographs of streamflow. The output is in the form of monthly streamflow volumes expressed in million cubic metres. The form of the hydrograph is governed by the values of 12 catchment parameters, suggested regional values of which are provided by Pitman (1973, pp. 4.1 - 4.17). In the case of gauged catchments, the model can be calibrated to fit actual data by systematic adjustments to these parameters. The model can thereafter be used to extend the streamflow record to cover the entire period for which rainfall data are available.

In the upper portion of the De Hoop catchment, the subcatchment referred to in Section 3.1.3 as the Sout River above Kykoedie, streamflow is gauged by the Department of Water Affairs using a rectangular weir and autographic recorder (gauge G5M08). Monthly flow volumes for this gauge were obtained and employed as a basis against which to calibrate the Pitman model. The record begins in 1965 and data are available in processed form (unlike the lake level record G5L01 for De Hoop, which is unprocessed and of poor quality). Once the regional parameters have been adjusted so that the simulated streamflow record matches the actual record with an acceptable degree of accuracy, the model can be used to extrapolate this record both temporally - to cover the entire period of the rainfall record, and spatially - to cover the entire De Hoop catchment.

The actual record against which calibration of the model was attempted, spanned the period of extreme drought from 1968 to 1973 which resulted in the prolonged absence of flow in the Sout River. The measured mean annual runoff (M.A.R.) of 4,79 million cubic metres and standard deviation (s) of 1,62 in the logarithms of annual runoff, which are used as the basic goodness-of-fit parameters, proved impossible to match using the suggested calibration procedures. Suggested regional parameters yielded an estimate of 4,38 million cubic metres for M.A.R. and standard deviation of 0,256 in the logarithms of annual runoff. The simulated record displayed too uniform and sustained a distribution of flow, and it was not possible to raise s sufficiently whilst maintaining an acceptable value for M.A.R. (Details of the parameter adjustments attempted and the resulting performance of the model are given in Appendix C.)

Reasons for the failure to match simulated and recorded streamflow must be sought both in the data which was utilised and in the model itself. Although a 15-year record of streamflow is considered adequate for the purposes of calibrating the model, the Kykoedie record includes seven dry years, three of which are consecutive. This reduces the effective useful period of record. Had this record spanned a less extreme period, a more reliable indication of the catchment response to rainfall may have emerged. Other difficulties relate to the general structure of the model. For example, the spatial distribution of excessive rainfall is known to be an important determinant of streamflow in the study area. Storm rainfall centred over the Jongensklip area is the most effective stimulant to streamflow. A

further factor which must be considered is the temporal distribution of monthly rainfall. In the model an S-shaped cumulative frequency curve is applied to the monthly precipitation figures, so that rainfall is distributed equally between the first and latter halves of each month. This smoothing process is not necessarily in agreement with the observed streamflow-producing conditions in the catchment, which seem to indicate that single severe storms are the major contributors to streamflow at De Hoop.

In the light of the difficulties experienced with calibration, it was decided to apply the model to the entire De Hoop catchment as if it were ungauged, i.e. utilising the suggested regional parameters. For the period 1882 to 1980 this yielded a simulated M.A.R. of 18,89 million cubic metres and s (log) of 0,31. Whilst the reliability of this figure is not able to be tested, it would seem to be more realistic than the figure of 63,7 million cubic metres (25 000 morgen-feet) quoted by Midgley and Pitman (1969), which, although inadequate due to an incorrect delineation of the catchment as stated in Section 3.1.3.5., would seem to be the only published estimate of M.A.R. for De Hoop.

5.2.3. Conclusion

From the performance of the model for the gauged Kykoedie subcatchment, it would appear that the simulated streamflow record for De Hoop might represent a slight underestimate of the mean annual runoff (M.A.R.) and a gross underestimate of the variability of flow (since simulated streamflow is

always overestimated in dry years, and peak flows underestimated when the recommended regional parameters are employed). The long-term M.A.R. at De Hoop is of the order of 20 million cu.m., which is just over half the present total capacity of the vlei. (The total input to De Hoop includes input from the springs in the limestone area. Input from this source has not been estimated.)

Since the modelled runoff is based primarily on rainfall data, but also takes other environmental factors into account - e.g. evaporation, soil moisture condition and catchment physiography, it is to be expected that the simulated runoff record might provide a more powerful tool for predicting floods at De Hoop than does the rainfall record. To demonstrate that this is indeed the case, the years of high annual runoff are ranked in Table 5-2, alongside an abbreviated form of Table 4-1(A).

The five years of either high water levels or floods appear in the ranked listing of simulated annual runoff, although not in the expected order. The hydrological years 1909, 1907 and 1957 correspond to times of major flooding, and the years 1949 and 1921 to probable periods of spillover, as mentioned in Section 4.4. Inspection of the record of water levels which is kept at De Hoop shows that the water receded to below the base of the measuring pole at De Hoop during the summer of 1962, but that the sluice gate at "Cloete's sloot" was opened when the water level suddenly rose from 1ft 4in to 9ft 3in during the last week of August 1962. The water continued to overflow into Cloete's sloot until 15 October of that year, when it is recorded that the sluice

gate was closed. It is due to the antecedent dry situation, and the fact that by this time dykes had been constructed at the low places on the south-western bank, that water did not spill over onto Melkkamer at this time.

Table 5-2. RUNOFF AND RAINFALL RANKINGS

Annual Runoff in Excess of 30 million cu.m.			Excessive Rainfall	
Rank	Year	Annual Runoff (10 ⁶ cu.m.)	Rank	Year
1	1909	405	1	1909
2	1907	85	2	1907
3	1949	58	3	1902
4	1962)	33	4	1957
	1921)	33	5	1977
6	1957	32	6	1951
7	1890)	30	7	1904
	1902)	30	8	1888)
				1890)
				1921)

The relatively low position of the year 1957 in the ranked list of years of high runoff could be attributable to the cumulative frequency distribution which is applied to the monthly rainfall figures in the model. Heavy rainfall, which caused overflow at Melkkamer, is known to have been concentrated in mid-August and early October. The model has not accurately portrayed the effect of these storms.

Although little importance can be attached to the simulated runoff volumes, the runoff rankings in Table 5-2 provide a better indication of the number and timing of occurrences of high water levels at De Hoop than do the rainfall rankings. All years in which the simulated runoff exceeds 30 million

cubic metres are years in which water levels are known to have been high. There fewer anomalies in this ranking than in the rainfall ranking.

6. SUMMARY OF CONCLUSIONS

The primary aim of this study was to investigate the degree to which agricultural development of the Rûens area has contributed to the recent flooding of farmlands surrounding De Hoop. In the course of this investigation it was necessary to document some of the characteristics of the catchment area, about which little had previously been written.

Climatic factors are of obvious prime importance in the water regime of De Hoop Vlei, and it has been shown in this study that both the severe drought in the 1970's and the major floods of 1906 and 1957 can be traced directly to extremes in local annual rainfall. Other periods of high water levels are reflected more clearly in the record of streamflow, which was simulated for De Hoop using a computer model developed by Pitman (1973). Although this model is based primarily on rainfall data, evaporation figures and a 12-parameter description of the catchment hydrology are also used to simulate hydrographs of streamflow.

An important factor governing the water regime of De Hoop is the hydrologically large nature of its catchment. The Sout River is part of a seventh order drainage network, has a minimal channel gradient and a relatively large capacity for channel storage of runoff. The catchment therefore displays a sluggish overall response to rainfall. This tends to offset changes in runoff so that, although man has modified the environment considerably by replacing the natural ecosystem with an agricultural system, the effects of human

intervention in the hydrology of the region are localised and it is not possible to determine the exact extent to which streamflow at De Hoop has been changed.

At the local scale, the agricultural development of the catchment has significantly altered the water budget. The soils of the Rûens are hydrologically poor, as they are shallow and rocky, and have been severely eroded through mismanagement. Using the SCS technique for the computation of runoff, it has been demonstrated for the soils of the study area that overland runoff is increased up to six-fold for storm rainfall below 24 mm, but by 50% or less for storm rainfall in excess of 70 mm, if the natural vegetation is replaced by grain crops. Under saturated conditions most rainfall becomes runoff, regardless of land use.

It has not been possible to model streamflow to De Hoop with any accuracy. This can mainly be ascribed to the extremely dry conditions which have existed in recent times and which therefore reduce the effective length of the streamflow record for the purposes of calibrating the model. The present total capacity of the vlei has been estimated at between 30 and 38 million cubic metres. The simulated mean annual runoff from the catchment alone (excluding the limestone surrounds of the vlei) is of the order of 20 million cubic metres. In the light of the measured capacity, this would seem to be a reasonable estimate of the average water yield of the De Hoop catchment. All years in which the capacity of the vlei is known to have been exceeded are shown by the computer model to have had an annual streamflow in excess of 30 million cubic metres.

No documentary evidence has been found to either support or refute the legend of a blocked sinkhole being responsible for flooding at De Hoop. The tenacity with which many local residents support this rumour at least indicates that it cannot be lightly dismissed. Nevertheless, the magnitude of the modelled streamflow for the hydrological years 1907 and 1909 is such that extensive flooding would have occurred regardless of whether or not such a sinkhole had existed. In 1957 it is possible that, had a means of drainage existed, this might have helped to reduce the extent of the October flood, as the excessive rainfall was distributed over several previous months. It is, however, unlikely that the flood would have been prevented entirely. Hydrological modelling therefore lends no support to the notion that flooding at De Hoop could have resulted from the fact that drainage via a sinkhole had been blocked. Instead the water regime of the vlei has been shown to be closely related to rainfall and annual streamflow.

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1. Maps Consulted

1. Topographic

Scale 1:250 000

3319 WORCESTER

3420 RIVERSDALE

Scale 1:50 000

3419BA GREYTON

3419BB RIVIERSONDEREND

3419BC JONGENSKLIP

3419BD NAPIER

3420AA STORMSVLEI

3420AB SWELLENDAM

3420AC PROTEM

3420AD WYDGELEË

3420BC MALGAS

2. Other

Rainfall : 1:250 000 Isohyetal Map of South Africa
(Schulze, 1964)

Soils : 1:2 500 000 Soil Map of the Republic of
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Vegetation : Acocks, J.P.H. 1947 : Veld types of
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Agricultural Economics : 1:2 000 000 Agricultural
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2. Rainfall Records

NOTE : 'ZONE' REFERS TO WEATHER BUREAU CLIMATIC ZONE

2.1. Weather Bureau

	WB REF	ZONE	PERIOD	M.A.P. (1/10 MM)
BREDASDORP	32	3	1882 - 1971	4748
CALEDON	733	6	1882 - 1971	5420
DUNGHYE PARK	50	7	1914 - 1971	4084
KLIPDALE	828	7	1926 - 1971	3519
MIERKRAAL	595	7	1933 - 1971	3309
PROTEM	136	8	1925 - 1971	3972
SWELLENDAM	782	8	1889 - 1971	8024
WINDHEUWEL	311	7	1933 - 1971	3722

2.2. Agricultural Technical Services

	ATS REF	ZONE	PERIOD	M.A.P. (1/10 MM)
DUNGHYE PARK	111	7	1978 - 1980	4454
HOOGGELEË	32	7	1971 - 1976	4103
PROTEM	70	8	1972 - 1980	4082
WYDGELEË	80	8	1973 - 1980	3278

2.3. Mr P.A.J. De Wet

	ZONE	PERIOD	M.A.P. (1/10 MM)
BOSFONTEIN	8	1927 - 1977	3278

MONTHLY RAINFALL (1/10 MM) :

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1927	790	0	0	0	401	0	264	221	150	48	444	10
1928	188	155	94	135	33	409	0	28	69	41	218	196
1929	81	1001	302	0	381	239	132	178	109	671	216	102
1930	292	13	231	109	389	277	69	259	145	163	282	188
1931	373	175	61	102	81	259	823	18	30	986	175	132
1932	785	152	538	284	427	71	188	213	208	371	63	1194
1933	145	429	53	25	163	292	239	343	140	150	462	25
1934	63	196	112	447	193	239	10	84	104	467	587	287
1935	310	178	0	102	325	30	414	566	282	127	127	338
1936	91	391	183	66	10	48	89	312	137	549	122	386
1937	249	998	409	0	15	236	117	28	112	279	0	257
1938	152	173	437	104	0	427	328	213	226	361	185	213
1939	371	246	155	99	508	643	244	63	41	406	643	132
1940	76	178	89	0	610	175	373	279	208	102	0	94
1941	112	508	0	292	0	150	668	330	312	279	259	140
1942	457	145	206	208	25	168	70	462	279	13	201	86
1943	104	81	671	795	86	241	249	79	259	376	236	572
1944	165	846	79	71	74	216	333	516	544	102	455	749
1945	427	43	79	0	61	25	203	622	500	259	541	178
1946	1133	429	13	109	170	742	124	122	216	160	99	127
1947	277	58	0	38	114	869	231	231	155	538	107	338
1948	274	310	112	51	163	577	325	122	231	564	112	353
1949	1440	279	132	211	63	79	762	267	81	254	264	168

1950	15	1275	46	33	30	61	305	246	41	373	147	188
1951	320	551	150	610	0	399	330	239	452	462	305	630
1952	325	0	150	104	394	168	155	221	274	213	902	1372
1953	343	973	178	104	33	0	345	190	460	648	198	635
1954	612	419	0	0	0	117	0	1349	246	622	1189	0
1955	0	307	0	439	648	0	107	94	533	536	0	495
1956	490	86	0	0	76	330	130	554	305	498	876	178
1957	381	89	140	0	241	671	147	630	1008	363	777	244
1958	462	0	0	0	41	330	152	998	135	0	498	51
1959	160	122	277	345	361	155	955	538	41	988	780	165
1960	935	203	41	826	0	257	0	335	358	257	0	317
1961	97	0	373	696	185	94	257	734	196	292	264	292
1962	127	0	0	396	127	965	284	178	406	168	1648	0
1963	1105	71	97	206	208	201	373	208	145	394	216	58
1964	391	317	305	102	559	1179	366	104	696	170	373	305
1965	259	417	0	0	295	262	180	493	63	777	117	0
1966	724	566	127	69	0	132	163	358	23	97	836	488
1967	56	211	38	0	297	478	1473	597	391	302	198	376
1968	168	267	46	0	127	381	117	267	384	0	351	51
1969	231	284	0	51	150	51	340	33	673	76	112	155
1970	94	25	0	264	356	0	0	147	188	305	378	112
1971	218	10	102	38	363	655	582	361	411	1026	648	30
1972	145	709	63	102	178	71	500	302	196	259	404	541
1973	0	152	0	79	43	63	190	282	389	157	264	157
1974	38	130	76	213	493	145	0	495	102	86	947	236
1975	249	0	0	135	229	63	38	279	178	254	351	541
1976	140	33	0	23	135	587	1062	173	772	414	231	152
1977	442	165	0	0	587	183	597	770	434	373	211	394

2.4. Cape Department of Nature Conservation

	ZONE	PERIOD	M.A.P. (1/10 MM)
DE HOOP	8	1958 - 1980	3680

MONTHLY RAINFALL (1/10 MM) :

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1958	538	0	0	0	56	259	333	1044	117	0	513	206
1959	284	127	135	1077	417	353	1049	630	61	721	465	201
1960	511	190	64	284	71	505	53	683	363	328	198	432
1961	90	140	490	240	110	360	310	545	120	365	245	350
1962	170	0	230	415	295	585	255	205	325	140	1230	40
1963	825	410	100	490	250	600	320	180	195	520	250	35
1964	580	245	420	130	580	1125	200	105	870	360	460	270
1965	235	615	0	145	225	440	170	520	110	690	120	85
1966	480	440	245	250	30	135	185	300	85	380	990	500
1967	60	60	95	35	130	520	1480	460	620	210	255	245
1968	90	405	85	0	0	320	560	130	760	0	700	110
1969	275	260	0	80	50	60	460	95	615	160	175	90
1970	60	0	0	25	310	0	35	130	250	380	410	150
1971	275	0	0	0	365	455	540	435	330	1125	690	540
1972	250	615	90	0	240	160	400	500	110	285	475	535
1973	0	55	35	95	0	80	125	335	385	240	175	185
1974	50	215	295	345	465	155	25	595	100	65	995	495
1975	695	0	40	540	210	40	155	465	260	365	695	350
1976	100	0	100	0	220	715	650	160	920	510	300	185
1977	455	380	140	0	860	325	720	630	455	545	335	220
1978	90	445	0	0	468	195	235	203	225	640	335	118
1979	375	140	0	400	1190	0	0	515	340	480	295	120
1980	450	40	340	360	225	55	170	235	545	115	220	350

AVERAGE RAINFALL ON CATCHMENT OF DE HOOPVLEI
AS DETERMINED BY PROGRAMME AVRAIN (HRU 2/73)

DETAILS OF RAINFALL STATIONS USED

STATION	NUMBER	PERIOD OF RECORD
SWD8	782	1889 TO 1971
BRD3	322	1882 TO 1971
CLD6	733	1882 TO 1971
DND7	50	1914 TO 1971
MRK7	595	1933 TO 1971
PRT8	136	1925 TO 1971
KLP7	828	1926 TO 1971
BSH8	518	1927 TO 1977
WHW7	311	1933 TO 1971
DHP8	802	1958 TO 1980
WDG8	80	1973 TO 1980
HGG7	32	1971 TO 1976
CHP7	111	1979 TO 1980
PTM8	70	1972 TO 1980

NO.	GAUGES	RAINFALL INPUT AS PERCENT M.A.P.												
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YEAR
18882	2	3.95	3.42	1.41	1.82	5.08	8.65	15.19	9.24	4.52	15.75	6.73	3.77	79.53
18883	2	8.23	7.47	12.85	6.92	1.73	4.91	11.94	8.64	8.45	10.70	16.20	4.51	102.53
18884	2	9.55	1.03	2.55	11.27	8.14	5.77	4.90	7.24	25.37	9.94	2.93	12.41	101.10
18885	13	13.03	5.43	2.58	1.64	10.73	3.87	10.05	12.26	10.74	6.10	10.82	9.92	95.77
18886	2	6.27	3.74	1.29	3.68	8.15	5.66	6.69	12.21	8.28	10.14	13.61	9.46	94.20
18887	2	16	3.39	5.53	4.34	.44	3.33	12.32	8.65	4.02	10.35	11.69	1.50	94.19
18888	9	9.39	6.57	3.79	6.18	.70	5.65	13.37	19.68	17.70	18.92	17.09	12.43	131.47
18889	9	9.52	4.57	3.71	5.23	.93	4.28	5.65	4.10	7.44	6.85	14.73	5.42	77.43
18890	6	6.07	7.94	2.28	3.44	.40	7.37	9.81	31.49	3.72	14.91	12.11	3.03	130.57
18891	11	8.30	1.76	9.48	2.90	.28	3.19	7.15	8.52	20.22	9.46	9.91	7.84	103.00
18892	4	4.00	5.54	3.94	1.85	.83	14.98	16.87	10.54	18.68	16.21	10.07	15.55	120.08
18893	8	4.48	4.19	3.93	3.55	.96	4.51	4.25	8.54	10.23	6.29	8.77	14.61	83.32
18894	12	4.2	1.71	2.45	10.34	.00	2.39	8.74	11.56	9.90	9.17	6.93	5.22	118.75
18895	6	6.04	8.54	2.08	15.44	.86	1.91	10.74	10.21	10.52	2.93	6.53	9.28	87.09
18896	5	5.73	3.20	5.61	2.35	.07	8.93	8.46	9.11	10.59	4.79	15.61	4.25	83.70
18897	3	3.71	11.01	3.53	3.96	.14	5.31	5.27	15.16	4.57	8.62	5.10	7.74	78.11
18898	10	10.09	3.57	1.69	13.81	.69	4.47	14.82	8.22	5.44	13.59	3.85	4.12	89.36
18899	7	7.09	4.97	4.00	3.12	.43	3.21	9.81	12.33	4.61	4.44	10.24	4.80	72.06
19000	7	7.39	2.23	5.37	8.98	.98	6.79	14.52	7.85	3.70	7.98	16.43	2.26	91.47
19001	11	11.40	5.67	1.85	10.76	.81	2.35	3.16	19.77	4.57	9.89	4.84	19.41	126.49
19002	6	6.13	11.85	8.87	3.74	.00	16.48	3.10	7.90	14.47	9.75	20.01	23.31	144.59
19003	11	11.32	3.59	5.93	4.02	.56	4.07	5.21	4.47	16.27	5.20	7.07	5.89	74.58
19004	29	29.64	2.25	1.93	5.05	.39	5.01	8.41	6.53	7.12	8.83	17.19	9.04	134.35
19005	12	12.83	1.39	4.88	.44	.30	6.89	8.16	9.04	15.10	8.15	16.58	16.92	112.28
19006	14	14.10	1.27	2.29	.56	.02	6.66	11.85	8.24	3.95	5.93	9.96	7.63	72.46
19007	25	25.37	3.11	5.95	6.92	.02	12.69	11.03	15.50	4.79	3.71	4.24	11.66	150.98
19008	10	10.51	3.63	7.46	3.81	.77	4.51	20.90	2.44	23.43	12.82	11.40	6.50	110.38
19009	15	15.48	6.13	6.39	6.80	.13	40.35	14.32	27.03	20.17	34.93	55.95	40.41	275.10
19010	14	14.36	3.59	13.24	5.13	.73	16.23	4.33	10.13	9.90	4.61	6.19	7.62	110.05
19111	9	9.50	4.17	3.63	8.41	.66	3.56	2.66	30.26	9.97	16.78	6.03	10.74	111.09
19112	5	5.94	4.79	2.36	11.15	.30	7.87	6.27	15.72	8.08	4.53	9.63	13.80	93.44
19113	9	8.80	9.93	1.58	4.27	.27	2.02	4.72	8.31	6.37	14.43	12.98	19.78	89.08
19114	4	3.04	4.83	11.10	3.79	.79	2.03	5.34	20.08	18.47	12.82	13.91	8.93	106.78
19115	4	4.92	13.91	3.96	4.61	.30	5.87	5.54	6.72	12.96	13.00	7.18	8.12	89.68
19116	4	4.95	7.20	1.10	4.91	.38	11.13	13.67	13.30	12.97	6.65	15.14	7.44	101.84
19117	4	4.69	5.59	5.98	5.92	.22	8.70	12.20	11.75	10.92	22.50	8.83	10.77	105.21
19118	4	8.16	5.35	1.27	2.40	.63	12.15	3.24	18.36	14.10	25.74	.88	14.08	109.36

3. Simulation of Monthly Streamflow

3.1. Recorded streamflow

The Department of Water Affairs has maintained a streamflow gauge G5M08 at Kykoedie since 1965. Data from this gauge is arranged below in similar format to the output generated by the programme MORSIM. This table forms the basis against which to calibrate the computer model, and is subsequently referred to as 'observed streamflow'.

Table C-1 Observed Streamflow at Kykoedie

MEASURED RUNOFF AT GAUGE G5M08 CATCHMENT AREA = 382 SQ.KM M.A.P. = 372.MM													

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1965	.052	.225	.014	.000	.000	.000	.000	.000	.000	.000	.078	.937	.409
1966	.025	.001	.000	.000	.000	.000	.000	.000	.000	.000	.094	.637	.757
1967	.037	.001	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
1968	.138	.026	.000	.000	.000	.000	.661	.807	5.500	1.320	1.280	.261	9.867
1969	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.164
1970	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
1971	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
1972	.060	.005	.000	.000	.000	.000	.000	.000	.000	.261	5.500	.822	6.583
1973	.120	.000	.000	.000	.000	.000	.000	.381	1.090	.395	2.850	.749	5.440
1974	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.120
1975	.240	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	1.150	1.150
1976	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.240
1977	8.890	.242	.016	.000	.000	.003	1.660	.915	2.450	9.192	2.730	.460	26.558
1978	.128	.011	1.180	1.940	.000	.000	.000	.000	.000	.072	.193	1.140	4.664
1979	.093	.002	.000	.000	.000	.009	.000	.000	.000	.366	.366	.668	1.504
1980	.095	.005	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.100
% TOTAL	12.90	.68	1.58	2.53	.00	.02	3.03	3.10	23.87	23.07	20.96	8.27	100.00

MEAN(LOG) = -.354762 STD. DEV. = 1.619615 MEAN ANNUAL RUNOFF = 4.79 MILLION CUBIC METRES

FT - runoff from soil moisture at full capacity. This parameter is of prime importance in the study area, since it governs the balance between runoff and evaporation for a given soil moisture state. This is particularly important in determining dry-season runoff. Pitman acknowledges difficulty in providing regional values for this parameter, however, and although the recommended value is 4 mm, it may be appropriate to reduce this amount in order to increase the variability of the simulated runoff to better match the actual record (p 4.3 - 4.6).

GW - maximum groundwater runoff

GL - lag of groundwater runoff

Pitman found these parameters to be of significance in very few catchments, mostly situated in dolomitic areas. Recommended value of both parameters is 0 for the study region (p 4.10).

AI - impervious proportion of catchment. This parameter is standard and set to 0 except in the mountainous areas of the S.W. Cape or where urban development has taken place within the catchment (p 4.10).

ZMIN - minimum catchment absorption rate

ZMAX - maximum catchment absorption rate

Recommended values of 18 and 400 mm for these parameters respectively are used to determine the distribution of absorptive ability within the catchment. (A symmetrical triangular function is employed to describe this distribution.) These parameters influence the flow volumes but not reliability of flow (p 4.11 - 4.13).

PI - interception storage. All water held in interception storage is assumed to evaporate, and therefore plays no further role in runoff calculations. A standard value of 1,5 mm for this parameter was found to suffice in all but densely forested regions (p 4.13 - 4.16).

TL - lag of runoff other than that from soil moisture below groundwater capacity (GW). This parameter is within the range 0 - 0,5 months countrywide and affects the seasonal distribution of flow. As the study catchment does not exhibit as rapid a response to rainfall as the other S.W. Cape mountain catchments and is neither steep nor small, the recommended regional value of 0 is probably incorrect, and a more realistic estimate of TL is likely to be within the average range of 0,2 - 0,3 months (p 4.16).

R - parameter determining evaporation - soil moisture relationship. This parameter determines the rate at which evaporation decreases with diminishing soil moisture. The recommended regional value of 0 has been adopted (p 4.16).

3. Monthly average catchment evaporation in mm. The Symons pan data for Bredasdorp have been utilised. These are in close agreement with the mean Symons pan evaporation diagrams given by Pitman (1973, p A.1 - A.12).

4. First and last years of the simulation period.

The format requirements for these lines of data are described by Pitman (1973 Appendix C), or can be inferred from the listing of input to the programme MORSIM which appears in Table C-7.

The equations in which these parameters are utilised within the model are in most cases generalised best-fit relationships based upon data from many catchments throughout South Africa. Parameters which, from the description of the catchment in Chapter 3, would appear to require adjustment are FT (runoff from soil moisture at full capacity), ZMIN (minimum catchment absorption rate), TL (lag of runoff related to, i.a., physiography) and possibly ZMAX.

SYNTHESIZED RUNOFF AT GAUGE G5M08 CATCHMENT AREA= 382.SQ.KM M.A.P.= 372.MM

POW= 2.0 SL= 0.MM ST= 200.MM FT= 4.0 MM/MONTH GW= .0 MM/MONTH AI= .0 %
 ZMIN= 18.MM/MONTH ZMAX= 400.MM/MONTH PI= 1.5 MM GL= .00 MONTHS TL= .00 MONTHS NIT= 4/MONTH

P.EVAP.	94.4	181.0	206.0	215.0	170.0	150.0	99.0	68.0	48.0	41.6	54.4	72.8 MM	- R= .0
YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1965	.11	.95	.06	.01	.05	.16	.07	.47	.18	.43	.31	.22	3.01
1966	.27	.27	.07	.02	.01	.00	.02	.04	.04	.08	3.13	.48	4.43
1967	.29	.10	.02	.00	.00	.01	6.10	.44	1.51	.75	.86	.68	10.76
1968	.47	.27	.06	.01	.00	.00	.01	.10	.68	.22	.40	.28	2.52
1969	.22	.14	.03	.01	.02	.01	.53	.07	.30	.18	.19	.15	1.84
1970	.12	.05	.01	.00	.13	.01	.00	.01	.25	.32	.90	.37	2.18
1971	.28	.11	.02	.01	.01	.02	.10	.19	.26	2.29	2.24	.77	6.30
1972	.43	.25	.08	.02	.03	.02	.66	.30	.34	.39	1.07	.56	4.14
1973	.31	.12	.03	.01	.00	.00	.02	.04	.08	.18	.19	.30	1.28
1974	.16	.09	.03	.01	.11	.05	.02	1.77	.23	.20	3.98	.81	7.46
1975	.58	.21	.04	.05	.01	.01	.01	.23	.08	.36	1.00	.41	2.98
1976	.29	.13	.03	.01	.00	.31	.72	.46	1.56	.54	.43	.32	4.80
1977	.52	.47	.09	.02	.61	.06	1.75	1.42	.55	.78	.81	.61	7.69
1978	.34	.25	.10	.02	.01	.01	.15	.06	.07	.45	1.16	.50	3.12
1979	.36	.14	.03	.04	2.06	.07	.02	.63	.32	.69	.62	.51	5.49
1980	.44	.15	.03	.04	.01	.00	.02	.05	.70	.19	.23	.21	2.08
% TOTAL	7.43	5.29	1.05	.39	4.37	1.08	14.54	8.94	10.18	11.49	25.01	10.24	100.00

MEAN(LOG)= .572030 STD. DEV.= .255932 MEAN ANNUAL RUNOFF = 4.38 MILLION CUBIC METRES

Table C-3 MORSIM Output for Gauge G5M08

3.3. Calibration Procedure

The first stage in the calibration of the model consists in matching the basic 'goodness-of-fit' parameters of the simulated record to those of the observed streamflow record. The performance of the model using the recommended regional values of the various parameters is shown in Table C-4, where the acceptable limits for matching the simulated to observed flow are the following :

M.A.R.	+/- 8%
Mean (log)	+/- 0,032 units
Std deviation	+/- 12%

In simulation tests on approximately 50 catchments throughout the country, Pitman achieved a closer correlation than the above, with an average error of about half of the above-mentioned limits (Pitman, 1973 p 5.8). This smaller range is given below as the 'preferred interval'.

Table C-4 Initial Performance of MORSIM Programme

	M.A.R. (x10 ⁶ cu.m.)	Mean (log)	Standard deviation (log)
Observed record	4,79	-0,354769	1,619615

Outer limits acceptable	[4,41;5,17]	[-0,387;-0,323]	[1,425;1,814]

Preferred interval	[4,60;4,98]	[-0,371;-0,339]	[1,522;1,717]

Regional parameters (semi-arid)	4,38	0,572	0,256

Arid zone parameters	0,48	-1,072	1,10

The initial attempt to simulate streamflow for Kykoedie using the suggested semi-arid parameters, yielded a figure for the mean annual runoff that was fairly close to the desired range. The distribution of runoff was, however, too uniform - as is reflected in the excessively high value for the mean (log) and very low estimate of standard deviation. Peak flows were grossly underestimated and deficient flows overestimated (see Tables C-1 and C-4).

Since the criteria adopted by Pitman in order to classify catchments as humid, semi-arid or arid are not stated, and since the mean annual precipitation recorded in the study area is less than 400 mm, the model was re-run selecting the arid zone parameter values wherever possible. This did have the desired effect of increasing the variability of flow in the simulated record, but all flows were much below the required amounts, and M.A.R. much too low (Table C-4).

In Table C-5 the values which were assigned to the various parameters for these two runs are listed - with Pitman's comments on the effects of increasing those considered relevant in this case (Pitman, 1973 p 5.6).

From the information listed in Tables C-4 to C-6 it is apparent that the primary aim of parameter adjustment should be to seek that parameter or combination of parameters which exerts the strongest influence on the standard deviation. The following parameter adjustments are possibilities :

- (1) FT decrease
- (2) ZMIN increase
- (3) ZMAX decrease

Since these adjustments failed to achieve the desired result, model sensitivity to changes in the following parameters was sought :

- (4) POW
- (5) TL

The results of these experiments are listed in the section on sensitivity tests which follows.

Table C-5 Values of Model Parameters

	Semi-arid	Arid	Effects of INCREASING this parameter
POW *	2	0	M.A.R. decreased Std dev. increased
SL *	0	0	
ST "	200	200	
FT	4	0	M.A.R. increased Std dev. decreased
GW "	0	0	
GL "	0	0	
AI *	0	0	
ZMIN	18	18	M.A.R. decreased Std dev. increased
ZMAX	400	400	M.A.R. decreased
PI *	1,5	1,5	
TL "	0	0,25	distribution more even overall lag of runoff
R	0	0	M.A.R. increased Std dev. decreased

* Parameters regarded by Pitman as 'standard', i.e. should only be adjusted if satisfactory correlation between simulated and observed record cannot be attained by changing the remaining parameters.

" These parameters affect seasonal distribution of flow only and have NO effect on either M.A.R. or standard deviation.

Table C-6 Suggested scheme for parameter adjustment
(from Pitman, 1973 p 5.7)

Simulated record compared

with Observed values

Zone

MAR, Mean(log)	Standard deviation	Humid/Semi-arid	Semi-arid/Arid
too high	too high	increase ST	increase ZMAX
too high	too low	decrease FT	increase ZMIN
too high	acceptable	increase ST	increase ZMAX
too low	too high	increase FT	decrease ZMIN
too low	too low	decrease ST	decrease ZMAX
too low	acceptable	decrease ST	decrease ZMAX
acceptable	too high	increase FT & ST	decrease ZMIN & increase ZMAX
acceptable	too low	decrease FT & ST	increase ZMIN & decrease ZMAX

3.4. Model sensitivity to parameter adjustments

The tables which follow demonstrate that for the Kykoedie subcatchment there is no single parameter which exerts sufficient influence on the variability of streamflow in order to match the simulated to the observed streamflow record. M.A.R. generally exhibited a much greater sensitivity to parameter adjustments than did s. The suggested regional parameters yielded an initial estimate for M.A.R. that was slightly outside of the acceptable interval, but at no time was it possible to achieve an acceptable estimate for s without reducing M.A.R. substantially.

Several combinations of parameter adjustments were attempted with similar results, and for the sake of brevity and clarity the tables which follow deal with adjustments to individual parameters, all others retaining the suggested regional values except where otherwise stated.

(1) Effects of decreasing FT

FT	M.A.R. ($\times 10^6$ cu.m.)	M.A.R. (log)	s
4	4,38	0,572	0,256
3	3,90	0,513	0,272
2	3,41	0,443	0,294
1	2,92	0,335	0,330
0	2,41	0,232	0,401

* POW = 3, ST = 200

4	3,37	0,420	0,326
3	3,14	0,382	0,337
2	2,90	0,340	0,352
1	2,66	0,290	0,371
0	2,41	0,232	0,401

* POW = 2, ST = 150

4	4,78	0,612	0,253
3	4,23	0,550	0,269
2	3,67	0,475	0,293
1	3,10	0,379	0,332
0	2,51	0,242	0,412

(2) Effects of increasing ZMIN

ZMIN	M.A.R. ($\times 10^6$ cu.m.)	M.A.R. (log)	s
18	4,38	0,572	0,256
20	4,27	0,560	0,257
22	4,16	0,548	0,257
24	4,05	0,536	0,257
25	4,00	0,531	0,257
26	3,95	0,526	0,258
28	3,86	0,515	0,257
30	3,76	0,504	0,257
40	3,37	0,457	0,254
50	3,06	0,418	0,247

(3) Effects of decreasing ZMAX

ZMAX	M.A.R. ($\times 10^6$ cu.m.)	M.A.R. (log)	s
400	4,38	0,572	0,256
360	4,95	0,619	0,268
320	5,75	0,677	0,281
300	6,28	0,711	0,288
200	6,92	0,750	0,295

* ZMIN and ZMAX changed simultaneously

	ZMAX	M.A.R. ($\times 10^6$ cu.m.)	M.A.R. (log)	s
ZMIN 24	300	5,71	0,666	0,294
	280	6,28	0,703	0,303
	260	6,99	0,745	0,311
ZMIN 26	300	5,54	0,652	0,296
	280	6,09	0,688	0,304
	260	6,76	0,729	0,314
ZMIN 28	300	5,38	0,638	0,297
	280	5,90	0,673	0,306
	260	6,55	0,713	0,316

(4) Changes to POW

POW	M.A.R. ($\times 10^6$ cu.m.)	M.A.R. (log)	s
0	20,70	1,314	0,039
0,5	11,09	1,034	0,100
1,0	7,28	0,834	0,158
1,5	5,41	0,685	0,210
2,0	4,38	0,572	0,256
2,5	3,76	0,486	0,295
3,0	3,37	0,420	0,326
3,5	3,11	0,371	0,350
4,0	2,93	0,335	0,368

(5) Changes to TL

TL	M.A.R. ($\times 10^6$ cu.m.)	M.A.R. (log)	s
0	4,38	0,572	0,256
0,05	4,38	0,573	0,255
0,1	4,38	0,573	0,253
0,15	4,38	0,574	0,252
0,2	4,38	0,574	0,251
0,25	4,38	0,575	0,250

Table C-7 Input to MORSIM for De Hoop

	1198	369.	4		0	18	400	15	0	0			
	20	0	200	40									
	118	181	206	215	170	150	99	68	48	52	68	91	
	1882	1980											
DEHOOP82	3.95	3.42	1.41	1.82	5.08	8.65	15.19	9.24	4.52	15.75	6.73	3.77	
DEHOOP83	8.23	7.47	12.85	6.92	1.73	4.91	11.94	8.64	8.45	10.70	16.20	4.51	
DEHOOP84	9.55	1.03	2.55	11.27	8.14	5.77	4.90	7.24	25.37	9.94	2.93	12.41	
DEHOOP85	13.03	5.43	1.38	1.64	10.73	3.87	10.05	12.26	10.74	6.10	10.62	9.92	
DEHOOP86	6.27	8.74	1.29	3.68	8.15	5.66	6.69	12.21	8.28	10.14	13.61	9.46	
DEHOOP87	22.16	3.85	6.53	4.34	.44	8.33	12.32	8.65	4.02	10.35	11.69	1.50	
DEHOOP88	9.39	6.57	3.79	6.18	.70	5.65	13.37	19.68	17.70	18.92	17.09	12.43	
DEHOOP89	9.52	4.57	3.71	5.23	5.93	4.28	5.65	4.10	7.44	6.85	14.73	5.42	
DEHOOP90	6.07	7.94	21.28	3.44	9.40	7.37	9.81	31.49	3.72	14.91	12.11	3.03	
DEHOOP91	8.30	11.76	9.48	2.90	4.28	3.19	7.15	8.52	20.22	9.46	9.91	7.84	
DEHOOP92	4.00	5.54	3.94	1.85	1.83	14.98	16.87	10.54	18.68	16.21	10.07	15.55	
DEHOOP93	8.48	4.19	6.93	3.55	2.96	4.51	4.25	8.54	10.23	6.29	8.77	14.61	
DEHOOP94	12.42	16.31	2.46	10.34	4.30	21.39	8.74	11.56	9.90	9.17	6.93	5.22	
DEHOOP95	6.04	8.54	.38	15.44	2.86	1.91	10.74	10.21	10.52	2.93	6.53	9.28	
DEHOOP96	5.73	3.20	5.61	2.35	5.07	8.93	8.46	9.11	10.59	4.79	15.61	4.25	
DEHOOP97	3.71	11.01	3.53	3.96	4.14	5.31	5.27	15.16	4.57	8.62	5.10	7.74	
DEHOOP98	10.09	3.57	1.69	13.81	5.69	4.47	14.82	8.22	5.44	13.59	3.85	4.12	
DEHOOP99	7.09	4.97	4.00	3.12	3.43	3.21	9.81	12.33	4.61	4.44	10.24	4.80	
DEHOOP 0	7.39	2.23	5.37	8.98	7.98	6.79	14.52	7.85	3.70	7.98	16.43	2.26	
DEHOOP 1	11.40	5.67	17.85	10.76	16.81	2.35	3.16	19.77	4.57	9.89	4.84	19.41	
DEHOOP 2	6.13	11.85	.87	3.74	27.00	16.48	3.10	7.90	14.47	9.75	20.01	23.31	
DEHOOP 3	11.32	3.59	5.93	4.02	1.56	4.07	5.21	4.47	16.27	5.20	7.07	5.89	
DEHOOP 4	29.64	25.25	1.88	5.05	10.39	5.01	8.41	6.53	7.12	8.83	17.19	9.04	
DEHOOP 5	12.83	1.99	4.88	.44	11.30	6.89	8.16	9.04	15.10	8.15	16.58	16.92	
DEHOOP 6	14.10	1.27	.29	.56	2.02	6.66	11.85	8.24	3.95	5.93	9.96	7.63	
DEHOOP 7	25.37	3.11	50.95	6.92	1.02	12.69	11.03	15.50	4.79	3.71	4.24	11.66	
DEHOOP 8	10.51	3.63	7.46	3.81	2.97	4.51	20.90	2.44	23.43	12.82	11.40	6.50	
DEHOOP 9	15.48	6.13	6.39	6.80	7.13	40.35	14.32	27.03	20.17	34.93	55.95	40.41	
DEHOOP10	14.36	3.59	13.24	5.13	14.73	16.23	4.33	10.13	9.90	4.61	6.19	7.62	
DEHOOP11	9.50	4.17	3.63	8.41	5.36	3.56	2.66	30.26	9.97	16.78	6.03	10.74	
DEHOOP12	5.94	4.79	2.36	11.15	3.30	7.87	6.27	15.72	8.08	4.53	9.63	13.80	
DEHOOP13	.80	9.93	3.88	1.58	4.27	2.02	4.72	8.31	6.37	14.43	12.98	19.78	
DEHOOP14	3.04	4.83	2.37	11.18	3.79	2.03	5.34	20.08	18.47	12.82	13.91	8.93	
DEHOOP15	4.92	13.91	3.96	4.61	2.90	5.87	5.54	6.72	12.96	13.00	7.18	8.12	
DEHOOP16	4.95	7.20	3.10	4.91	1.38	11.13	13.67	13.30	12.97	6.65	15.14	7.44	
DEHOOP17	4.69	.59	5.98	5.92	2.36	8.70	12.20	11.75	10.92	22.50	8.83	10.77	
DEHOOP18	8.16	5.35	1.27	2.40	3.63	12.15	3.24	18.36	14.10	25.74	.88	14.08	
DEHOOP19	8.02	5.00	2.63	6.36	8.44	3.93	7.26	7.87	7.56	11.25	10.35	8.53	
DEHOOP20	8.14	6.05	2.40	.30	3.67	4.24	1.84	20.55	28.08	17.22	9.69	7.76	
DEHOOP21	5.56	4.87	9.14	3.50	11.97	5.51	11.81	3.18	33.10	16.25	12.07	13.62	
DEHOOP22	3.83	1.91	6.78	12.47	6.39	17.80	5.29	5.87	16.61	4.89	12.82	2.98	
DEHOOP23	6.09	20.02	1.10	5.65	1.57	.84	13.76	20.39	15.25	11.25	10.55	4.09	
DEHOOP24	8.57	17.89	2.20	3.14	5.72	3.86	4.96	6.21	20.87	7.19	17.92	5.07	
DEHOOP25	5.98	10.49	1.93	5.15	1.80	10.67	7.95	3.15	24.67	9.70	7.77	10.15	
DEHOOP26	6.95	3.98	1.89	2.58	1.56	5.35	5.77	7.56	6.82	22.14	10.28	7.92	
DEHOOP27	21.74	7.32	.45	1.21	7.62	5.28	4.91	10.80	7.54	2.71	14.35	1.98	
DEHOOP28	3.06	5.14	3.32	3.92	1.84	10.28	.99	1.29	8.26	1.48	9.10	11.42	
DEHOOP29	1.57	15.77	6.81	1.08	6.89	8.16	5.64	5.97	7.92	16.85	8.31	4.79	
DEHOOP30	4.75	3.04	11.89	6.16	7.15	12.54	4.43	8.43	3.98	4.13	13.89	11.87	
DEHOOP31	11.42	7.30	2.44	7.29	3.79	8.62	23.50	3.54	4.13	21.87	14.19	6.86	
DEHOOP32	20.98	3.44	15.22	4.70	7.93	3.52	2.19	7.45	10.53	11.32	4.17	32.29	
DEHOOP33	4.71	8.25	3.37	.88	2.46	7.11	3.56	11.39	14.19	9.11	15.54	2.86	
DEHOOP34	2.08	7.44	3.86	7.52	5.93	4.87	1.09	5.08	4.95	16.21	19.70	11.15	
DEHOOP35	12.67	7.24	.44	1.46	2.63	3.49	12.00	16.97	10.15	7.36	4.73	8.18	
DEHOOP36	4.88	10.37	5.75	5.46	3.07	2.87	2.55	13.58	5.06	11.66	6.28	11.80	

DEHOOP37	7.26	21.98	10.24	1.70	1.16	7.61	3.68	2.07	10.98	15.95	1.73	10.64
DEHOOP38	4.54	5.37	9.71	4.31	1.51	13.08	9.88	10.54	6.80	9.21	10.04	15.76
DEHOOP39	10.72	4.78	3.55	2.41	16.47	11.88	7.49	4.12	2.99	11.27	18.49	3.73
DEHOOP40	4.79	4.28	4.11	1.56	24.28	5.70	12.60	3.35	11.95	5.37	1.14	6.31
DEHOOP41	4.37	16.63	.54	6.47	2.93	1.92	16.28	13.83	14.58	8.80	11.05	11.71
DEHOOP42	13.47	3.95	3.11	6.25	1.99	5.86	3.89	16.68	11.41	2.95	6.53	4.26
DEHOOP43	7.66	1.54	13.47	18.11	4.95	9.16	9.16	5.94	6.70	6.18	9.62	11.52
DEHOOP44	6.34	15.60	3.60	1.71	.92	4.93	4.96	14.92	19.38	3.51	16.61	21.09
DEHOOP45	7.18	1.38	2.44	.20	.88	2.15	7.77	25.95	17.84	13.56	16.00	3.39
DEHOOP46	27.74	3.26	1.23	1.81	3.70	17.79	3.23	4.40	6.56	7.54	4.53	8.49
DEHOOP47	6.44	.75	.68	1.04	4.12	17.20	10.60	7.19	7.66	15.32	4.53	7.16
DEHOOP48	10.04	8.24	1.41	1.90	2.91	13.54	7.13	3.06	6.98	11.50	1.47	9.04
DEHOOP49	45.85	2.34	3.22	3.45	.81	1.02	15.25	8.21	3.71	7.22	9.48	5.43
DEHOOP50	2.60	26.26	1.57	1.03	.44	.92	9.43	4.09	2.37	13.99	3.01	7.66
DEHOOP51	11.67	17.76	4.49	14.60	1.22	7.12	11.31	5.86	18.35	14.28	9.82	21.62
DEHOOP52	7.09	2.44	.89	2.74	6.97	3.49	4.56	6.97	7.73	9.59	16.69	19.67
DEHOOP53	7.24	26.61	3.52	2.79	2.10	1.05	14.44	6.16	8.01	14.45	11.41	7.55
DEHOOP54	8.17	13.11	.26	.45	2.33	5.89	7.59	26.03	10.32	17.85	22.14	2.94
DEHOOP55	3.28	7.34	2.41	5.73	23.47	1.99	4.55	3.85	12.44	20.33	19.71	7.38
DEHOOP56	12.96	2.75	1.60	.88	4.66	7.67	4.17	19.01	13.43	15.82	14.09	5.09
DEHOOP57	10.95	1.34	7.62	.35	9.19	13.51	5.13	22.05	25.31	14.82	20.21	12.55
DEHOOP58	20.92	.48	.19	.10	3.16	11.95	9.28	27.21	7.98	.46	18.54	3.06
DEHOOP59	6.92	3.20	3.98	9.12	7.96	6.29	24.19	14.70	2.55	15.20	18.80	6.36
DEHOOP60	15.84	2.08	1.79	6.70	2.29	7.24	3.37	10.51	12.45	9.42	3.43	6.78
DEHOOP61	3.32	3.31	10.68	11.19	2.04	7.11	7.75	11.59	5.97	9.77	14.46	11.86
DEHOOP62	7.66	.41	1.70	9.46	7.15	15.05	8.59	4.80	16.48	6.16	35.12	2.82
DEHOOP63	22.58	11.06	.92	7.07	5.60	9.73	7.75	7.11	7.43	16.56	11.13	1.60
DEHOOP64	9.38	7.55	9.23	4.98	8.04	20.21	5.48	4.80	20.30	8.09	14.68	6.94
DEHOOP65	6.94	17.51	.53	1.49	7.69	10.02	6.45	13.38	3.98	13.81	5.48	1.58
DEHOOP66	12.69	11.48	5.94	4.44	1.19	3.90	5.94	6.68	2.59	6.75	24.98	10.24
DEHOOP67	2.98	2.29	1.59	.75	4.20	7.65	32.24	11.40	16.06	8.39	10.01	8.08
DEHOOP68	5.72	9.28	1.69	.68	2.05	5.28	5.26	8.20	14.57	3.14	11.23	4.85
DEHOOP69	6.26	7.46	.88	4.01	5.41	2.33	13.08	1.88	12.71	4.80	5.18	3.25
DEHOOP70	4.95	1.83	.21	2.80	9.74	.53	.42	4.82	10.06	11.28	14.31	5.30
DEHOOP71	7.22	.92	3.10	.92	6.53	8.28	10.89	10.82	10.24	22.80	18.65	5.15
DEHOOP72	5.21	14.19	4.24	1.82	6.46	4.61	15.00	11.52	7.57	8.66	14.77	12.05
DEHOOP73	.94	4.05	1.63	2.45	.60	2.43	5.58	7.42	9.71	7.74	7.99	7.55
DEHOOP74	1.97	5.85	3.73	6.78	13.95	5.76	1.29	19.85	4.73	2.41	28.60	11.52
DEHOOP75	11.77	1.63	.71	9.31	3.36	2.08	2.95	11.11	6.06	11.08	16.70	9.90
DEHOOP76	5.28	3.04	1.47	.57	4.37	17.40	22.46	9.51	22.75	10.17	6.52	5.48
DEHOOP77	13.85	10.09	3.54	.74	19.16	7.01	20.33	21.73	12.51	13.41	9.39	8.63
DEHOOP78	1.91	11.89	5.45	2.22	9.09	5.29	11.38	4.64	7.22	13.94	15.24	7.54
DEHOOP79	8.35	2.57	1.17	9.10	30.43	.06	.25	15.18	10.46	13.70	12.27	7.13
DEHOOP80	11.57	.70	7.13	8.39	4.76	1.05	6.17	7.28	17.15	1.95	7.95	8.72

SYNTHESIZED RUNOFF AT GAUGE DEHOOP CATCHMENT AREA = 1198.SQ.KM M.A.P.= 369.MM

POW= 2.0 SL= 0.MM ST= 200.MM FT= 4.0 MM/MONTH GW= .0 MM/MONTH AI= .0 %
 ZMIN= 18.MM/MONTH ZMAX= 400.MM/MONTH PI= 1.5 MM GL= . 0 MONTHS TL= .00 MONTHS NIT= 4/MONTH

P.EVAP.	94.4	181.0	206.0	215.0	170.0	150.0	99.0	68.0	48.0	41.6	54.4	72.8 MM	- R= .0
YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1882	.25	.12	.03	.01	.02	.17	1.40	.56	.46	2.14	1.09	.82	7.07
1883	.68	.40	.83	.17	.05	.04	.58	.37	.52	.96	2.66	1.16	8.43
1884	1.02	.37	.07	.44	.18	.10	.09	.19	8.15	1.56	1.22	1.63	15.02
1885	1.77	.60	.13	.02	.35	.07	.34	.82	.88	.77	1.18	1.21	8.14
1886	.81	.54	.12	.03	.13	.08	.12	.74	.53	.91	1.83	1.36	7.20
1887	6.09	.84	.24	.08	.02	.14	.68	.41	.35	.76	1.24	.71	11.55
1888	.68	.34	.11	.07	.02	.04	.86	3.60	3.33	4.85	4.85	3.49	22.23
1889	2.29	.87	.20	.07	.06	.05	.07	.09	.22	.33	1.65	.72	6.62
1890	.54	.37	4.36	.18	.27	.17	.37	16.43	1.26	2.56	2.38	1.50	30.40
1891	1.04	1.00	.44	.09	.04	.03	.10	.25	3.95	1.26	1.48	1.25	10.93
1892	.78	.34	.10	.03	.01	1.21	2.09	.86	3.63	3.44	2.48	3.52	18.50
1893	1.88	.72	.24	.07	.03	.03	.04	.22	.53	.48	.71	1.86	6.79
1894	1.52	2.30	.28	.36	.08	4.36	.50	.91	.95	1.13	1.09	.87	14.34
1895	.61	.44	.11	1.37	.09	.04	.39	.48	.74	.56	.57	.76	6.16
1896	.53	.23	.09	.03	.03	.20	.23	.39	.73	.59	2.19	.93	6.17
1897	.56	.66	.14	.04	.03	.04	.06	1.41	.40	.63	.60	.64	5.21
1898	.80	.30	.07	.91	.11	.07	1.26	.44	.43	1.46	.83	.61	7.28
1899	.50	.25	.08	.03	.02	.02	.28	.78	.38	.40	.78	.56	4.06
1900	.50	.21	.08	.20	.16	.12	1.22	.45	.39	.55	2.46	.89	7.23
1901	1.06	.41	2.43	.52	1.99	.19	.09	3.45	.58	.92	.78	3.97	16.39
1902	1.07	1.02	.18	.04	9.52	2.09	.37	.39	1.59	1.19	4.86	8.07	30.40
1903	2.71	.96	.25	.07	.02	.02	.05	.07	1.83	.56	.64	.58	7.77
1904	13.79	8.69	.51	.11	.36	.10	.22	.22	.33	.59	2.79	1.29	29.00
1905	1.67	.51	.13	.03	.43	.13	.22	.38	1.72	1.00	2.97	3.58	12.76
1906	2.68	.78	.13	.02	.01	.06	.57	.34	.31	.37	.73	.67	6.66
1907	8.50	.70	68.99	.55	.12	.71	.58	1.80	.70	.63	.56	1.04	84.89
1908	.97	.36	.18	.06	.03	.03	4.04	.36	6.46	2.18	2.25	1.62	18.53
1909	2.62	.76	.24	.13	.12	35.62	1.89	10.91	6.11	71.62	177.10	97.54	404.65
1910	4.36	1.41	1.12	.17	1.22	1.83	.30	.57	.76	.66	.67	.69	13.76
1911	.77	.32	.09	.16	.06	.04	.03	14.10	1.26	3.30	1.80	1.81	23.74
1912	1.12	.46	.11	.43	.06	.14	.12	1.65	.66	.64	.91	1.78	8.08
1913	.71	.54	.13	.03	.02	.02	.03	.19	.22	1.46	1.58	4.58	9.51
1914	1.22	.46	.11	.43	.07	.03	.05	3.59	3.40	2.23	2.88	2.05	16.51
1915	1.24	1.51	.25	.07	.03	.05	.07	.15	.97	1.39	1.01	.98	7.72
1916	.66	.37	.11	.04	.02	.41	1.01	1.19	1.50	1.12	2.55	1.47	10.43
1917	.92	.32	.10	.07	.03	.17	.67	.81	.97	6.36	2.10	2.05	14.56
1918	1.40	.59	.13	.03	.02	.57	.10	2.71	1.71	9.75	2.10	2.55	21.67
1919	1.44	.59	.14	.08	.17	.06	.13	.24	.35	.90	1.08	1.00	6.18
1920	.83	.40	.11	.02	.01	.02	.02	3.81	11.78	4.29	2.88	2.20	26.36
1921	1.34	.54	.34	.08	.56	.12	.62	.22	19.35	3.63	3.00	3.19	32.99
1922	1.62	.54	.18	.67	.13	2.36	.28	.27	2.21	.84	1.62	.92	11.65
1923	.60	3.79	.24	.07	.03	.01	.90	3.97	2.31	1.95	2.06	1.42	17.34
1924	1.05	2.87	.28	.06	.05	.04	.05	.11	4.25	.94	3.51	1.37	14.57
1925	.88	.74	.15	.05	.02	.35	.21	.15	7.38	1.41	1.36	1.45	14.16

Table C-8 MORSIM Output for De Hoop

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1926	.98	.41	.09	.02	.01	.03	.06	.17	.25	5.40	1.56	1.30	10.29
1927	5.75	.95	.20	.03	.10	.06	.07	.47	.39	.37	1.53	.61	10.52
1928	.34	.17	.06	.03	.01	.30	.06	.04	.19	.14	.37	.80	2.50
1929	.36	1.65	.23	.05	.07	.16	.11	.16	.32	2.39	1.10	.86	7.45
1930	.56	.23	.59	.11	.12	.70	.16	.31	.27	.29	1.36	1.27	5.97
1931	1.25	.55	.14	.11	.04	.18	6.11	.54	.44	5.41	2.61	1.63	19.01
1932	5.42	.87	1.53	.16	.16	.07	.04	.14	.52	.91	.65	18.31	28.78
1933	1.46	.71	.18	.04	.01	.08	.05	.53	1.38	.96	2.51	1.14	9.04
1934	.60	.33	.10	.12	.07	.06	.04	.05	.10	1.88	4.14	1.78	9.26
1935	1.88	.74	.16	.03	.01	.01	.56	2.18	.99	.99	.90	.87	9.31
1936	.59	.60	.17	.07	.03	.02	.02	.91	.28	.90	.69	1.20	5.49
1937	.76	5.19	.66	.12	.02	.10	.06	.05	.48	1.98	.69	.93	11.04
1938	.54	.26	.33	.07	.02	.75	.40	.62	.52	.82	1.11	2.53	7.98
1939	1.48	.57	.14	.04	1.72	.68	.31	.24	.22	.74	3.36	1.01	10.50
1940	.62	.27	.08	.02	6.62	.25	.85	.31	.91	.63	.52	.43	11.50
1941	.32	1.98	.15	.07	.03	.02	1.67	1.26	1.88	1.36	1.75	1.90	12.39
1942	2.11	.67	.15	.08	.03	.05	.05	1.91	.97	.68	.66	.55	7.91
1943	.50	.20	.88	2.50	.17	.28	.34	.26	.35	.44	.76	1.16	7.84
1944	.70	1.80	.22	.05	.01	.02	.04	1.31	3.65	1.04	2.94	5.89	17.66
1945	1.78	.63	.12	.02	.00	.00	.11	8.52	3.40	2.70	3.90	2.04	23.22
1946	12.14	1.16	.00	.04	.02	2.27	.19	.16	.24	.41	.42	.55	17.79
1947	.44	.18	.00	.01	.01	2.00	.56	.40	.52	2.06	1.03	.88	8.14
1948	.95	.53	.13	.02	.01	.85	.21	.16	.25	.84	.50	.60	5.05
1949	52.59	1.04	.20	.05	.02	.01	1.30	.35	.31	.43	.73	.59	57.62
1950	.37	8.91	.28	.04	.01	.00	.21	.09	.10	1.15	.43	.47	12.08
1951	.91	2.64	.26	1.18	.09	.10	.52	.25	2.97	2.18	1.77	6.25	19.13
1952	1.79	.65	.12	.03	.07	.04	.05	.13	.27	.59	2.53	4.54	10.81
1953	1.43	9.89	.48	.09	.03	.01	1.08	.24	.41	1.66	1.47	1.14	17.92
1954	.92	1.21	.19	.03	.01	.04	.13	8.67	1.31	3.81	7.37	2.43	26.11
1955	1.24	.56	.14	.06	5.94	.21	.11	.11	.81	4.33	4.92	1.97	20.41
1956	2.11	.68	.13	.02	.02	.11	.07	3.01	1.52	2.77	2.84	1.70	14.98
1957	1.52	.52	.21	.04	.20	.90	.19	5.11	9.00	3.70	6.77	3.95	32.10
1958	6.76	1.33	.20	.03	.01	.53	.32	10.22	1.30	1.02	3.71	1.24	26.65
1959	.81	.33	.09	.21	.16	.11	6.73	1.91	.90	2.30	4.48	1.89	19.91
1960	2.90	.73	.14	.08	.03	.09	.06	.41	.95	.88	.73	.64	7.64
1961	.42	.17	.40	.48	.07	.10	.17	.66	.41	.77	1.94	1.67	7.27
1962	1.08	.39	.07	.23	.12	1.31	.38	.28	2.16	.88	24.37	2.16	33.42
1963	6.82	1.55	.30	.12	.07	.29	.22	.26	.38	2.36	1.53	.95	14.87
1964	.82	.45	.33	.09	.15	3.62	.33	.27	4.08	1.21	2.49	1.47	15.29
1965	1.01	2.68	.25	.04	.10	.32	.16	1.03	.43	1.50	.88	.61	9.00
1966	1.12	.84	.21	.07	.02	.02	.06	.13	.13	.23	7.85	1.48	12.16
1967	.84	.29	.06	.01	.01	.10	17.38	1.37	2.86	1.86	2.01	1.64	28.44
1968	1.05	.67	.15	.03	.01	.03	.05	.20	1.39	.55	1.03	.69	5.85
1969	.52	.34	.08	.02	.04	.02	.77	.16	.89	.48	.49	.39	4.21
1970	.29	.13	.02	.01	.24	.04	.01	.03	.35	.74	1.72	.86	4.44
1971	.67	.26	.06	.01	.05	.15	.47	.63	.81	6.47	4.88	2.16	16.63
1972	1.25	1.59	.26	.06	.06	.05	1.30	.81	.64	.87	2.18	1.85	10.92
1973	.91	.31	.07	.02	.01	.01	.04	.14	.42	.49	.65	.67	3.73
1974	.41	.20	.07	.08	.97	.15	.08	3.46	.54	.48	12.39	2.13	20.96
1975	1.89	.63	.11	.22	.05	.02	.02	.45	.25	.78	2.61	1.40	8.44
1976	.88	.34	.07	.01	.01	2.09	5.43	1.00	6.58	2.39	2.03	1.47	22.31
1977	2.01	.96	.22	.04	2.92	.23	3.85	5.42	2.20	2.83	2.41	1.98	25.08
1978	1.10	.97	.22	.06	.20	.08	.52	.22	.33	1.45	2.32	1.28	8.74
1979	1.02	.40	.08	.20	14.27	.30	.08	1.39	.77	1.71	1.86	1.32	23.38
1980	1.45	.46	.17	.18	.06	.03	.06	.15	2.27	.61	.67	.77	6.89
% TOTAL	11.69	5.53	5.16	.85	2.79	3.86	4.15	8.04	9.24	12.41	21.62	14.67	100.00

MEAN(LOG)= 1.101272 STD. DEV.= .310124 MEAN ANNUAL RUNOFF = 18.89 MILLION CUBIC METRES

4. Calculation of Runoff

4.1. Standard Procedure

In order to estimate runoff volumes from rainfall, the standard SCS procedure as adapted to small catchments in South Africa is described by Schulze and Arnold (1979, pp 46 - 54) as follows :

1. Determine daily rainfall amount for the particular storm. (Either a single gauge within or close to the catchment may be used, or suitably aggregated records from several gauges.)
2. Using a soils map of the catchment, in which the binomial classification system of MacVicar et al (1977) is employed, determine the hydrological soil group for each soil unit from the table produced by Schulze and Arnold (1979 pp A-1 to A-8).
3. Determine land use and treatment classes from aerial photographs, maps or field observation. Superimpose the soils and land use maps to subdivide the catchment into homogeneous hydrological response units. To each such unit a runoff curve number CN1 is assigned from table D-1.
4. The curve number CN1 must then be adjusted according to the prevailing antecedent moisture conditions. Three possible methods are described by Schulze and Arnold (1979) of which the Hawkins method was selected in this

case.

The Hawkins method employs the formula

$$CN2 = 1\ 200 / (1\ 200/CN1 + ET - (P - Q))$$

where ET = antecedent evapotranspiration

P = antecedent precipitation

Q = antecedent runoff (assumed 0 for most South African conditions)

5. A value is assigned to c (coefficient of initial abstraction) from Table D-2.
6. Runoff volume is calculated for each hydrological response unit either by calculation or nomogram. In this case the solution by calculation was preferred :

$$Q = (P - cS)^2 / (P + (1 - c)S)$$

where $S = (25\ 400/CN2) - 254$

The results are areally weighted and summed in the case of a catchment which was subdivided in step 3.

4.2. Procedure adopted in this study

Although the soils of the study catchment have been classified according to the binomial system, because of the size of the catchment this information is not available in cartographic form. It was therefore not possible to carry out the requirement 3 above. Even if this information had been available the size of the catchment precludes the application of the SCS technique as outlined in the previous section.

Steps 2 and 3 above were therefore modified to suit the aims of this study as follows :

2. Hydrological soil groups represented in the study area were listed but not mapped.
3. For each hydrological soil group, a runoff curve number CN1 was assigned for each of the following land use and treatment classes as described in Table D-1 :

Scrub : Brush - winter rainfall region

and

Small grain : Contoured - winter rainfall region

Runoff volumes for two rainfall events, using readings from three raingauges within the De Hoop catchment, were calculated for the different land use categories and soil types and the results compared.

Table D-1 Runoff Curve Numbers
from Schulze (1979 p A-10)

LAND USE	TREATMENT/PRACTICE/DESCRIPTION	HYDROLOGICAL CONDITION	HYDROLOGICAL SOIL GROUP							
			A	A/B	B	B/C	C	C/D	D	
Fallow	Straight row	-	77	82	86	89	91	93	94	
Row Crops	Straight row	Poor	72	77	81	85	88	90	91	
	Straight row	Good	67	73	78	82	85	87	89	
	Contoured	Poor	70	75	79	82	84	86	88	
	Contoured	Good	65	70	75	79	82	84	86	
	Contoured and terraced	Poor	66	70	74	77	80	81	82	
	Contoured and terraced	Good	62	67	71	75	78	80	81	
Garden crops	-	-	45	56	66	72	77	80	83	
Truck crops	Straight row	Good	68	71	75	79	81	83	84	
Small grain	Straight row	Poor	65	71	76	80	84	86	88	
	Straight row	Good	63	69	75	79	83	85	87	
	Contoured	Poor	63	69	74	79	82	84	85	
	Contoured	Good	61	67	73	78	81	83	84	
	Contoured - winter rainfall region	Good	63	66	70	75	78	80	81	
	Contoured and terraced	Poor	61	67	72	76	79	81	82	
	Contoured and terraced	Good	59	65	70	75	78	80	81	
Close seeded legumes or Rotation meadow	Straight row	Poor	66	72	77	81	85	87	89	
	Straight row	Good	58	65	72	75	81	84	85	
	Contoured	Poor	64	70	75	80	83	84	85	
	Contoured	Good	55	63	69	74	78	81	83	
	Contoured and terraced	Poor	63	68	73	77	80	82	83	
	Contoured and terraced	Good	51	60	67	72	76	78	80	
Sugarcane	Straight row; trash burnt	-	43	55	65	72	77	80	82	
	Straight row; trash mulch	-	45	56	66	72	77	80	83	
	Straight row; limited cover	-	67	73	78	82	85	87	89	
	Straight row; partial cover	-	49	60	69	75	79	82	84	
	Straight row; complete cover	-	39	50	61	68	74	78	80	
	Contoured; limited cover	-	65	70	75	79	82	84	86	
	Contoured; partial cover	-	25	46	59	67	75	80	83	
	Contoured; complete cover	-	6	14	35	59	70	75	79	
	Pasture or veld (range)	-	68	74	79	83	86	88	89	
	-	-	49	61	69	75	79	82	84	
-	-	39	51	61	68	74	78	80		
-	Contoured	Poor	47	57	67	75	81	85	88	
-	Contoured	Fair	25	46	59	67	75	80	83	
-	Contoured	Good	6	14	35	59	70	75	79	
Irrigated pasture	-	Good	35	41	48	57	65	68	70	
Meadow	-	Good	30	45	58	65	71	75	81	
Woods	-	Poor	45	56	66	72	77	80	83	
	-	Fair	36	49	60	68	73	77	79	
	-	Poor	25	47	55	64	70	74	77	
Scrub	Brush - winter rainfall region	-	28	34	44	53	60	64	66	
Orchards	Winter region, understory of crop cover	Good	39	44	53	61	66	69	71	
Coffee	No ground cover	-	48	59	68	74	79	82	83	
	Ground cover; terraces	-	22	38	52	61	68	72	75	
Forests/Plantations	Humus depth 25 mm; Compactness :	compact	52	62	72	77	82	85	87	
		moderate	48	58	68	75	78	82	85	
		loose/friable	37	49	60	66	71	74	77	
	Humus depth 50 mm; Compactness :	compact	48	58	68	73	78	82	85	
		moderate	42	54	65	70	75	78	81	
		loose/friable	32	45	57	62	67	71	74	
	Humus depth 100 mm; Compactness :	compact	41	53	64	69	74	77	80	
		moderate	34	47	59	64	69	72	75	
		loose/friable	23	37	50	56	61	64	67	
	Humus depth 150 mm; Compactness :	compact	37	49	60	66	71	74	77	
		moderate	30	43	56	61	66	69	72	
		loose/friable	18	33	47	52	57	61	65	
Urban/Suburban Land Uses	Open spaces, parks, cemeteries	Good (75%+grass cover)	39	51	61	68	74	78	80	
		Fair (50-75% grass cover)	49	61	69	75	79	82	84	
	Commercial/business areas	85% impervious	89	91	92	93	94	95	95	
		72% impervious	81	85	88	90	91	92	93	
	Residential: lot size 500 m ²	65% impervious	77	81	85	88	90	91	92	
		1000 m ²	61	69	75	80	83	85	87	
	1350 m ²	38% impervious	57	65	72	77	81	84	86	
		30% impervious	54	63	70	76	80	83	85	
	2000 m ²	25% impervious	51	61	68	75	78	82	84	
		20% impervious	48	58	65	71	75	78	81	
	Paved parking lots, roofs, etc.	-	98	98	98	98	98	98	98	
	Streets/Roads: tarred, with storm sewers, curbs	gravel	76	81	85	88	89	90	91	
		dirt	74	77	82	85	87	88	89	
		dirt-hard surface	74	79	84	88	90	91	92	
		-	74	79	84	88	90	91	92	

Table D-2 Coefficient of Initial Abstraction
 from Schulze (1979 p A-9)

AMC Group	Dormant Season		Growing Season	
	Total 5-day rainfall (mm)	Coefficient of initial abstraction C	Total 5-day rainfall (mm)	Coefficient of initial abstraction C
I	Less than 12	0,05	Less than 36	0,05
II	12 to 28	0,15	36 to 53	0,08
III	over 28	0,25	over 53	0,15
Generally		0,125		0,08

4.3. Results

DIFFERENCES IN RUNOFF DUE TO CHANGES IN VEGETATION
AS DETERMINED USING THE SCS TECHNIQUE

LAND USE	HYDROL SOIL GP	CN1	CN2	S	Q
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IN ALL THE CASES BELOW, C = 0.05

1. HOOGGELEË

A. 29 APRIL 1976

PPT = 24.0 5-DAY ANTECEDENT PPT = 17.1 5-DAY ANTECEDENT ET = 16.5

SCRUB VEG	B/C	53.0	54.4	212.5	.79
SCRUB VEG	C	60.0	61.9	156.6	1.51
SCRUB VEG	C/D	64.0	66.1	130.2	2.07
SCRUB VEG	D	66.0	68.3	118.1	2.40
SML GRAIN	B/C	75.0	77.9	72.0	4.51
SML GRAIN	C	78.0	81.2	58.9	5.54
SML GRAIN	C/D	80.0	83.3	50.8	6.37
SML GRAIN	D	81.0	84.4	46.9	6.84

B. 18 JUNE 1976

PPT = 72.0 5-DAY ANTECEDENT PPT = .0 5-DAY ANTECEDENT ET = 8.0

SCRUB VEG	B/C	53.0	39.2	394.6	6.11
SCRUB VEG	C	60.0	42.9	338.7	7.70
SCRUB VEG	C/D	64.0	44.9	312.2	8.63
SCRUB VEG	D	66.0	45.8	300.2	9.09
SML GRAIN	B/C	75.0	50.0	254.0	11.22
SML GRAIN	C	78.0	51.3	241.0	11.94
SML GRAIN	C/D	80.0	52.2	232.8	12.43
SML GRAIN	D	81.0	52.6	228.9	12.67

2. WYDGELEË

A. 29 APRIL 1976

PPT = 71.6 5-DAY ANTECEDENT PPT = 4.3 5-DAY ANTECEDENT ET = 16.5

SCRUB VEG	B/C	53.0	34.4	483.5	4.24
SCRUB VEG	C	60.0	37.3	427.6	5.28
SCRUB VEG	C/D	64.0	38.8	401.1	5.87
SCRUB VEG	D	66.0	39.5	389.1	6.16
SML GRAIN	B/C	75.0	42.6	342.9	7.46
SML GRAIN	C	78.0	43.5	329.9	7.89
SML GRAIN	C/D	80.0	44.1	321.7	8.17
SML GRAIN	D	81.0	44.4	317.8	8.31

B. 18 JUNE 1976

PPT = 29.0 5-DAY ANTECEDENT PPT = .0 5-DAY ANTECEDENT ET = 8.0

SCRUB VEG	B/C	53.0	39.2	394.6	.21
SCRUB VEG	C	60.0	42.9	338.7	.42
SCRUB VEG	C/D	64.0	44.9	312.2	.55
SCRUB VEG	D	66.0	45.8	300.2	.62
SML GRAIN	B/C	75.0	50.0	254.0	.98
SML GRAIN	C	78.0	51.3	241.0	1.11
SML GRAIN	C/D	80.0	52.2	232.8	1.20
SML GRAIN	D	81.0	52.6	228.9	1.25

3. PROTEM

A. 29 APRIL 1976

PPT = 38.1 5-DAY ANTECEDENT PPT = 4.5 5-DAY ANTECEDENT ET = 16.5

SCRUB VEG	B/C	53.0	34.6	479.2	.41
SCRUB VEG	C	60.0	37.5	423.3	.65
SCRUB VEG	C/D	64.0	39.0	396.9	.80
SCRUB VEG	D	66.0	39.8	384.8	.88
SML GRAIN	B/C	75.0	42.9	338.7	1.25
SML GRAIN	C	78.0	43.8	325.6	1.37
SML GRAIN	C/D	80.0	44.4	317.5	1.45
SML GRAIN	D	81.0	44.8	313.6	1.50

B. 18 JUNE 1976

PPT = 36.7 5-DAY ANTECEDENT PPT = .0 5-DAY ANTECEDENT ET = 8.0

SCRUB VEG	B/C	53.0	39.2	394.6	.70
SCRUB VEG	C	60.0	42.9	338.7	1.09
SCRUB VEG	C/D	64.0	44.9	312.2	1.33
SCRUB VEG	D	66.0	45.8	300.2	1.46
SML GRAIN	B/C	75.0	50.0	254.0	2.07
SML GRAIN	C	78.0	51.3	241.0	2.29
SML GRAIN	C/D	80.0	52.2	232.8	2.43
SML GRAIN	D	81.0	52.6	228.9	2.51

5. Calculation of Water Volumes

5.1. Input Data

As outlined briefly in section 4.2, nine parallel transects of the main body of the De Hoop vlei were surveyed with the object of calculating the intervening trapezoidal volumes for decreasing water levels. The cross-section of each transect was drawn with a vertical exaggeration of 100 and the areas measured. (This was done by counting squares, as this was more accurate than planimetry in this case.)

Input to the FORTRAN computer programme which was written to perform these calculations consisted of the following :

- (1) the perpendicular distances between transects;
- (2) volumes of water in the kloofs Voëlhoek and Fransfontein;
- (3) areas of cross-sections 1 to 9, each line of input corresponding to a particular water level.

5.2. Calculations

Having read the abovementioned input data the following calculations were carried out for each water level (line of data in (2) and (3)) :

- (1) Volumes for the kloofs were totalled and stored as
TOT(I)

- (2) Volume was calculated for each trapezoid as

$$0.5 * D(I) * (A(I,J) + A(I,J+1))$$

The 8 volumes thus calculated were summed and added to

5.4. Accuracy

A. Accuracy of linear measurements

w = distance across transect ; Scale 1:50 000

error +/- 25 m

d = water depth ; Fathometer registers in feet

error +/- 0,15 m

D = distance between cross-sections ; Scale 1:50 000

error +/- 25 m

B. Areas of cross-sections

$$(w \pm 25)(d \pm 0,15) = w \cdot d \pm \underbrace{(25d + 0,15w + 3,75)}_{\text{error}}$$

	w (m)	d (m)	error (m ²)	area	error (%)
A1	758	3.0	192,45	2287,5	8,4
A2	448	2,8	140,95	1269,375	11,1
A3	432	2,7	133,05	1156,25	11,5
A4	620	2,2	151,75	1344,375	11,3
A5	387	1,7	104,3	676,875	15,4
A6	465	0,9	93	421,125	22,1
A7	395	0,9	82,5	341,25	24,2
A8	300	0,8	65,75	250,875	26,2
A9	200 *	0,2 **	1,00	40,75	2,5

* Measured with tape ; error +/- 0,005 m

** Measured with ranging pole and tape ;

error +/- 0,005 m

$$\text{Error}(9) = 0,005(d + w + 0,005)$$

A_i = Area of cross-section drawn from transect i

(water level = 3,4 m)

AREALLY WEIGHTED AVERAGE ERROR = 12,38%

C. Volumes

$$\text{Volume of trapezoid}(i) = 0,5(A_i + A_{i+1}) \cdot D_i$$

D determined from 1:50 000 map ;

error +/- 25 m

$$\text{Volume} = 0,5(A_i + A_{i+1} \pm (e_i + e_{i+1})) \cdot (D_i \pm 25) \text{ cu.m.}$$

$$\text{Error} = 12,5(A_i + A_{i+1} + e_i + e_{i+1}) + D_i/2 (e_i + e_{i+1})$$

	A_i	A_{i+1}	e_i	e_{i+1}	D	Error(m ³)	V(m ³)	Error %
V1	2287,5	1269,375	192,45	140,95	1600	315348	2845500	11,08
V2	1269,375	1156,25	140,95	133,05	1715	268700	2079973	12,92
V3	1156,25	1344,375	133,05	151,75	1615	264793	2019255	13,11
V4	1344,375	676,875	151,75	104,3	775	127685	783234	16,30
V5	676,875	421,125	104,3	93	1200	134571	658800	20,43
V6	421,125	341,25	93	82,5	1125	110442	428836	25,75
V7	341,125	250,875	82,5	65,75	2125	166770	629133	26,51
V8	250,875	40,75	65,75	1,00	1350	49535	196847	25,16

V1 = Volume of trapezoid enclosed by A1 and A2 , etc.

VOLUMETRICALLY WEIGHTED AVERAGE ERROR = 14,91%