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DEPARTMENT OF FISHERIES AND WATER
REPUBLIC OF NAMIBIA

KARSTLAND PLANT ECOLOGY INVESTIGATION:

FINAL REPORT ON THE BASELINE AND

MONITORING ACTIVITIES

THE PERMANENT SECRETARY
DEPARTMENT OF FISHERIES AND WATER
Private Bag 13193
WINDHOEK
9000

Report by:
WATER QUALITY DIVISION
RESEARCH SECTION

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1. INTRODUCTION

The Karstland Borehole Scheme is a very important interim source of water for the Eastern National Water Carrier. The judicious abstraction of the groundwater in the Karst area is to be carried out by means of a large number of boreholes and a network of pipelines.

"Plants are a measure of the conditions under which they grow, and act as an index for soil and climate. The fact that changes in vegetation occur is visible proof of the dynamic nature of the environment. It is necessary to be able to record and follow vegetation changes in order to predict and determine and control any changes which would severely upset the desired balance". (Reference No. 11)

The Karstland Plant Ecology Investigation was thus launched with the aim being to determine any possible disturbances to the woody vegetation in the area resulting from large scale groundwater withdrawal.

A Steering Committee of experts, co-opted from other Institutions and interested parties from local Departments, was appointed to guide and co-ordinate the research activities.

The first task undertaken by the committee was to draw up a working programme for the initial phases of the investigation. The working programme outlined the baseline activities and the initial short-term monitoring tasks to be carried out prior to groundwater abstraction. This programme has been improved upon since the commencement of the investigation. The investigation has been concentrated mainly in Area I, as this area will be the first to be pumped. (Refer to Annexure 1)

2. OBJECTIVES

The objectives of the Karstland Plant Ecology Investigation are to detect any possible detrimental changes to the woody plant communities in the Karstland area which may have arisen as a result of the large scale abstraction of groundwater.

This report sets out the findings of the baseline study, as well as providing guidelines for future monitoring work. It is only against the detailed background and multi-disciplinary data base that forms the baseline study described in this document, that any possible detrimental changes can be observed explained and rectified.

It should however be noted that several of the baseline activities are also recommended as long-term monitoring activities.

The scope of this document is relatively wide, in that it describes the activities undertaken during the baseline study, outlines the results and offers limited explanations. It also describes the long-term activities and results thereof thus far.

3. WORKING PROGRAMME

3.1 BASELINE ACTIVITIES

3.1.1 Groundwater mapping

i) Map the present groundwater level contours relative to the soil surface, as a one-off task.

ii) Identify and map the sensitive zones according to groundwater levels less then 20 metres from the soil surface and indicate extraction points in these zones.

3.1.2 Vegetation/Soil mapping

i) Classify the woody plant communities and identify the dominant communities in the sensitive zones. Map accordingly using aerial photographs.

ii) Classify and map the soil types in the sensitivie zones.

iii) Correlate the woody plant communities with the soil types, and with the groundwater levels less than 20 metres from the soil surface. Map the result.

3.2 INITIAL MONITORING

3.2.1 Water level monitoring

i) Monitor the natural groundwater level fluctuations in the synclines and map the contours.

ii) Monitor the decline in groundwater level due to extraction of water for construction purposes at Uitkomst and Brandwag.

3.2.2 Rainfall monitoring

i) Monitor the areal rainfall pattern over the whole of the Karstland by mapping the contours as a one-off task.

ii) Monitor the point rainfall pattern by collecting daily rainfall data for selected rainfall stations.

3.2.3 Soil moisture monitoring

i) Monitor the moisture content of the classified soils in the shallow water table areas on a monthly basis.

3.2.4 Vegetation monitoring

i) Select and lay out permanent belt transects across contact zones near extraction points. Subdivide these transects into subplots.

ii) Manual ground surveys.

Monitor growth and vitality of woody tree species in the subplots on an annual basis, in the same sequence and at the same time of year.

iii) Infra-red aerial photography as an alternative for future ground surveys.

Investigate and evaluate the possibility of infra-red photography for the monitoring of transects sites.

If feasible, carry out annual infra-red aerial photographic surveys of all transects.

iv) Fixed point photography.

Carry out biannual fixed point photography along all transects and of individual tree species at/near recorders or production boreholes.

TRANSECT STRIP MAPS:-

After the first aerial survey in 1986, it was decided to prepare more detailed large scale vegetation maps for each of the transect strips. These strip maps would include the actual belt transect (1000 m x 5 metres) as well as the adjoining 250 metres of vegetation on either side, as flown and photographed during the aerial survey. It was important to obtain a broader view of the area on either side of the transect in order to monitor changes in vegetation patterns. The scale for these maps was the same as the photographs, 1: 1667.

The various woody plant communities as well as any man made amenities were delineated and outlined directly onto the photographs of the 1986 Aerial Survey. These were then traced onto transparencies for each transect area, and classified according to their areal affinities relative to the topography. The species composition within the various specified communities was listed and thereafter ground checked.

Although the vegetation maps showing the plant communities appear to take on a static character, these maps and the photographs both record the vegetation at a given moment.

A listing of species composition in the different plant community types of each transect in given in TABLE 4.2.

GENERAL WORKING MAPS:-

For this purpose, a one-off, large scale (1:50 000) general working vegetation map of the relevant areas was drawn up, using black and white aerial photographs. These are the most commonly used mapping aids. Such a general map is the most helpful way for recognising the spatial relations of the plant communities. The most recent photographs available were those taken in August/September 1973, but they nevertheless served as a useful tool for both subdividing the general vegetation cover into more homogeneous subunits, and also for identifying the entire contact zones of the different Areas.

The main variations in homogeneous communities and the more obvious patterns were outlined onto the aerial photographs, which had been prepared as a air photo mosaic of the whole area. A tracing of the farm boundaries and major landmarks taken from the topographic map, was prepared so that the vegetation type boundaries and other information could be transferred onto an overlay. Ground checks of the air-photo derived maps were carried out thereafter, and species composition and distribution noted.

It is always necessary for field work to accompany air-photo mapping in order to achieve a "calibration" of the field variation or pattern of plant communities with the patterns seen on the air photographs. This is referred to as ground truthing.

The spatial distribution of vegetation units along the contact zones were of particular importance, as these were the areas where monitoring and sampling would be concentrated.

This original 1:50 000 vegetation map was prepared for a specific purpose, as the stepping stone to the next mapping stage which followed after the first aerial survey was undertaken.

TABLE 4.1: DETAILS OF TRANSECTS IN KARSTLAND

TRANSECT NO	FARM NAME	TRANSECT LENGTH	TRANSECT DIRECTION	DEPTH OF 1984 WATER TABLE (m from soil surface)
1	Uitkomst/Brandwag	300 m	NNW - SSE	0 - 5 m
2 *	Urupupa	700 m	N - S	0 - 5 m
3 **	Urupupa	-	-	5 - 10 m
4	Buschbrunnen	1000 m	N - S	5 - 10 m
5	Kombat/Asis	1000 m	N - S	10 - 15 m
6	Okambongora	1000 m	NNW - SSE	10 - 15 m
7	Buschbrunnen	1000 m	N - S	15 - 20 m
8	Buschbrunnen	1000 m	N - S	15 - 20 m
9	Kombat mine	1000 m	N - S	30 - 50 m
10	Berg Aukas mine	750 m	N - S	25 - 30 m

* Transect 2 was originally 1000 m in length, but 300 metres have been "lost" due to changes in land-use.

** Transect 3 was disregarded for manual and aerial monitoring purposes as it was not suitable enough. It is however still used as a Fixed Point Photography monitoring site.

The latter two transects (No 9 and 10) were to serve as case studies, as groundwater had already been extracted from these areas for 20 - 30 years. These sites are of particular importance since they seem to confirm that no catastrophic effects need be anticipated. The mine areas were included in order to assess or predict the possible impact on the vegetation in the other areas of the Karstland, should the water table also be lowered to such an extent.

4.1.2 Vegetation mapping

At the outs[illegible] of this study, it was important to understand the geographic [illegible]ibution of [illegible] Karst area's vegetation, concentrating especially on [illegible] d p[illegible]ea II. Area I would be the first area to undergo large un[illegible]straction.

iii) the transects should be located near production boreholes and/or water level recorders.

iv) the transects should include different plant communities in order to obtain a good species variation.

It was decided that a maximum of ten (10) transects be laid out, to include one transect at each of the mines, namely, Kombat mine in Area I and Berg Aukas mine in Area II. These ten sites were initially decided upon, but after field checking all these potential sites, only nine were chosen, and of these nine, five were selected as representative samples for the purpose of manual ground monitoring.

These sites were then physically marked out using Y-section poles to indicate one side of the length of each transect. The poles followed a compass line direction, were 50 metres or 100 metres apart depending on the accessibility of the transect, and were painted orange.

The transects were laid out in a roughly N-S direction, crossing the E-W contact zone where possible. The transects were originally numbered from one to ten, two transects having been designated to each area with a different water table level within the sensitive zones of 0-20 metres.

The transects are not similar enough to enable them to be compared directly with each other, thus over time each transect can be compared only with itself. The details of each transect at the onset of this investigation are presented in TABLE 4.1.

The regular monitoring of the groundwater levels in the Karst area as well as the updating of the data and water level contour maps is the responsibility of the Geohydrology Division.

SITE SELECTION:-

At the outset of this study, the monitoring method proposed by the Steering Committee was that of the Transect Method. This method involves marking off a strip of selected, representative vegetation, within which various measurements of all the plants are carried out. Initially a vegetation monitoring method was sought in which all possible variations occurring in the area where extraction was to take place, could be checked and noted. It was not certain which plant species would be influenced by extraction but it was assumed that the woody species on the contact area would most likely be affected first. However the possibility could exist that those species further away from the contact might be more sensitive or may be unable to adapt to the new conditions, and thus these species may be affected more than those on the contact. It was decided that the belt transect method would thus be the most effective monitoring method in all aspects, although it is a very intensive sampling method.

It was imperative that the belt transects should be permanent so that the same monitoring action could be repeated on the same sites, with time. Initially only Area I would fall under investigation as extraction from the production boreholes would take place there first. However the mine area of Area II would also be included in the investigation.

The criteria for the choice of study sites were as follows:-
(Refer to Annexures 1 and 2).

i) The (belt) transects should be located within the sensitive zones as on the original groundwater contour map of 1984, namely the [illegible] the [illegible] table is between 0-20 metres from the soil's [illegible]

[illegible] transects should where possible cross over the contact zone, to [illegible] that contact vegetation transition should be present.

4. INITIAL MAPPING AND CLASSIFICATION

The baseline study involved both the mapping and classification of various components within the areas under investigation, as well as the monitoring of these elements and any factors relating to them.

4.1 METHODS

4.1.1 Groundwater mapping/site selection

GROUNDWATER MAPPING:-

At the outset of the Karstland Plant Ecology Investigation a contour map was drawn up of Area I (1:50 000) depicting the groundwater levels at that time. This was a one-off task to determine the localities of the sensitive zones with respect to vegetation, relative to the water table. This map was to serve as a point of departure.

The existing groundwater levels in metres from the soil surface, the proposed extraction points, the localities of the water level recorders, and the outline of the syncline in relation to the contact zone, were indicated on this contour map. The contact zone is a zone of higher permeability, which, because of a thick layer of porous calcrete absorbs a large amount of the surface water.

The sensitive zones within Area I were then identified from this map as being those areas where the water table was less than 20 metres from the soil's surface, and hence also where extraction points were situated. The majority [illegible] extra[illegible]n points are located along or near contact zones.

[illegible]s were chosen as the areas to be investigated for any [illegible] an[illegible]s[illegible]t of changes in water table levels. The 20 [illegible]miting depth, as it was decided that the [illegible]ed by anything deeper. Of the total Karst area [illegible] ology, only 13% was included in the sensitive [illegible]mmencement, and it was from within these zones [illegible]pling sites were selected. Annexures 1 and 2 [illegible] and II.

3.3 CASE STUDY

3.3.1 Berg Aukas/Kombat

i) Monitor the woody vegetation by transect/infra-red photographic methods on an annual basis at Berg Aukas and Kombat mines.

ii) Collect quantitative data on groundwater levels, groundwater extractions, and rainfall at both Berg Aukas and Kombat mines.

iii) Assess whether the woody vegetation has been affected by long-term groundwater extraction from these mines. From this, predict any possible similar effects in other areas of the Karstveld.

3.4 LONG-TERM MONITORING

3.4.1 Long-term monitoring of factors affecting the woody vegetation will be put into operation once the large scale withdrawal of groundwater commences.

3.5 PROGRESS REPORTING

3.5.1 Submit a quarterly progress report to the Department of Water Affairs.

3.5.2 Submit a biannual progress report to the Steering Committee.

3.5.3 Hand in final reports and maps etc. after completion of specific one-off tasks.

[illegible]ion of the working programme activities, the co-opted [illegible]l be [illegible]ired to present a final report with on[illegible] th[illegible]rawal of groundwater from the area, as [illegible] programme to be followed.

BLE 4.2: WOODY SPECIES OCCURING IN VEGETATION COMMUNITY TYPES ALONG TRANSECTS, DESCRIBED ACCORDING TO AREAL AFFINITIES RELATIVE T TOPOGRAPHY Page 1 of 2

SPECIES	Tr 1				Tr 2		Tr 4		Tr 5			Tr 6		Tr 7			Tr 8			Tr 9				Tr 10			
	1	3	4	5	1	2	1	2	1	2	5	1	2	3	4	5	1	2	3	1	2	4	5	1	2	4	5
Acacia karroo	X	X			X	X	X	X	X	X		X	X	X			X		X	X								
A. tortilis									X	X				X			X	X	X	X	X				X		
A. mellifera	X	X	X		X	X	X	X	X	X		X	X	X	X		X	X	X	X	X			X	X	X	
A. reficiens	X	X			X	X	X	X	X	X		X	X	X			X	X	X	X	X	X		X	X		
A. hereroensis					X	X	X	X	X	X			X	X	X		X	X	X	X	X	X					
A. hebeclada		X												X				X		X	X						
A. erubescens					X	X														X	X						
A. nilotica			X		X												X	X	X	X	X						
A. nebrownii									X	X										X	X						
A. fleckii						X							X							X	X						
A. ataxacantha									X	X										X	X	X					
Barchemia discolor																											X
[illegible]cia albitrunca		X			X	X							X				X		X								
Carissa edulis							X	X				X	X														
Cassine transvaalensis	X	X			X	X	X	X				X	X				X										
Cataphractes alexandri																			X								
Cyphostemma juttae				X							X		X			X						X	X				X
Combretum hereroense		X				X	X	X				X	X	X			X	X	X					X			
C. imberbe		X	X			X	X	X					X	X	X		X	X	X	X	X			X	X		
C. molle						X							X				X	X	X			X	X				
C. apiculatum		X	X	X		X					X	X	X			X	X		X				X		X	X	X
Commiphora africana		X		X		X					X	X	X			X	X	X	X			X	X	X	X	X	X
C. pyracanthoides	X	X	X	X		X		X			X	X	X	X	X	X	X	X	X			X	X	X	X	X	X
C. angolensis				X												X											X
C. glaucescens				X	X						X				X	X	X						X				X
[illegible] tenuipetiolata						X											X	X	X							X	X
Croton gratissimus	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X			X	X	X	X	X	X
Dichrostachys cinerea	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Diospyros lycioides	X	X				X	X	X				X	X				X										
Dombeya rotundifolia	X	X	X	X		X			X	X	X		X	X		X	X	X	X			X	X	X	X	X	X
Ehretia rigida		X			X	X	X	X				X	X	X			X		X					X	X		
Elephantorrhiza suffruticosa									X	X																X	
Erythrina decora																							X			X	X
Euclea undulata	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	
Euphorbia candalabra																											X
Ficus thonningii	X		X	X							X					X							X				X
F. cordata	X		X	X							X			X		X							X				X
F. sycomorus	X		X	X																							
Fockea multiflora																											X

(1.) Contact Community (2.) Plain Community (3.) Slope Community (4.) Mountain Base Community (5.) Mountain Community

Transects 1, 2, 4, 6, 8 have more accurate listing of species present due to actual manual monitoring having been carried o there.

Transects 5, 7, 9, 10 were examined by walking along transects. This table will be added to with time.

ABLE 4.2: WOODY SPECIES OCCURING IN VEGETATION COMMUNITY TYPES ALONG TRANSECTS, DESCRIBED ACCORDING TO AREAL AFFINITIES RELATIVE TOPOGRAPHY

SPECIES	Tr 1				Tr 2		Tr 4		Tr 5			Tr 6		Tr 7			Tr 8			Tr 9				Tr 10			
	1	3	4	5	1	2	1	2	1	2	5	1	2	3	4	5	1	2	3	1	2	4	5	1	2	4	5
Grewia flava	X	X	X		X	X	X	X	X	X		X	X	X	X		X	X	X	X				X	X	X	
G. flavescens	X	X	X		X	X	X	X	X	X	X	X	X				X			X	X	X	X	X	X	X	
G. bicolor					X	X		X									X		X		X			X	X		
G. retinervis	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X								
G. villosa	X				X	X																			X		
Gyrocarpus americanus																											X
Kirkia acuminata			X	X							X				X	X						X	X	X	X	X	X
Lannea discolor																							X				
Lonchocarpus nelsii						X			X	X													X				
Maytenus heterophylla	X	X		X	X	X	X	X	X	X	X	X	X	X		X	X						X	X	X	X	
M. senegalensis	X			X			X	X			X		X			X			X				X				
Mundulea sericea	X	X				X		X					X										X				
Obetia carruthersiana																							X				X
Olea europaea	X	X			X	X	X	X				X	X														
Ozoroa insignis						X							X					X	X				X				
O. paniculosa																	X		X								X
Pavetta zeyheri	X	X																									
Peltophorum africanum			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X				X
Rhus lancea	X	X			X	X	X	X	X	X		X	X	X			X	X	X								
R. marlothii	X	X			X	X	X	X	X	X		X	X	X			X	X	X		X						
R. pyroides	X	X	X			X	X	X	X	X			X					X	X								
Securingea virosa		X		X			X	X	X	X	X	X	X			X	X	X		X	X		X		X	X	
Sclerocarya birrea			X	X							X		X		X	X		X	X				X		X	X	
Spirostachys africanum																								X	X	X	
Tarchonanthus camphoratus		X			X	X	X	X	X	X		X	X	X			X	X	X								
Terminalia prunioides		X	X																					X	X	X	
Ximenia caffra	X	X		X	X	X	X	X			X	X	X			X	X		X								
X. americana							X	X																			
Ziziphus mucronata	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				

(1.) Contact Community (2.) Plain Community (3.) Slope Community (4.) Mountain Base Community (5.) Mountain Commun

Transects 1, 2, 4, 6, 8 have more accurate listing of species present due to actual manual monitoring having been carried there.

Transects 5, 7, 9, 10 were examined by walking along transects. This table will be added to with time.

These basic vegetation maps should prove to be useful in the long run as they present an "inventory" of the existing plant communities (as classified for this study), their localities and the extent and geographic distribution in the area at that time.

These maps will serve as documentation of the research sites. Maps at such large scale are of particular use in studies concerned with measuring vegetation changes, and record the actual vegetation, namely, the currently existing vegetation mosaic of an area. Hence, these maps will serve as standards of reference.

In addition, the vegetation maps can be utilized in conjunction with the other transect site maps (see geological and soil mapping below) prepared in the same manner as the vegetation maps, to analyse the environment and the relationships between the vegetation and the site it occurs on.

These types of maps are referred to as sliced maps, and over the long term, (5 - 10 years), can be repeated and then compared with the originals.

4.1.3 Soil mapping

As the characteristics of soils, directly or indirectly, affect plants, the edaphic factors were also examined. Here, the Agriculture Division, (Administration for Whites) was requested to classify the soil types present within and around the transect areas. The lengths of the transects were walked and where the soil types changed, the sites were marked. Thereafter 1 m x 1 m pits were dug at these sites so that soil profiles could be described and each soil type classified. All the classification details were tabled and a short report was written up by the Agriculture Division. (This report and the soil classification data are to be found in the Karstland Plant Ecology Box File).

The mapping of the soil types along each transect area was carried out with the aid of the 1986 aerial photographs in the field. The boundaries of the various classified soil types as noted in the field and on the photographs, were outlined directly onto the colour photographs and thereafter the delineations were traced onto transparencies to produce the soil maps.

4.1.4 Geological formations mapping

After the first aerial photographic survey, it was decided to also have geological maps drawn up for each transect strip, outlining the local geological features of those areas eg. faults, contact zones, rock formations etc.

The Geohydrology Division were asked to outline all the various features on the aerial colour photographs, after which they were traced onto transparencies, to be used as overlays. The size of each geological strip map was the same as that of the vegetation and soils maps.

These three map types will serve as the permanent records of each transect site and can be used in conjunction with the 1986 permanent records of aerial photographs.

4.2 RESULTS

4.2.1 Vegetation-soil-geology mapping

Each transect has a set of three sliced maps (scale 1:1667), consisting of a vegetation map, a pedological map and a geological map. These maps were drawn up with the aid of the 1986 aerial survey photographs. Each set of three maps has the contact indicated where present, the direction of the syncline denoted by arrows, and each map of a set of three has the same boundary lines, namely, the same area is covered on the ground.

The strips of land mapped do not only include the transect line of 5 metres, but cover an area as wide as 500 m and slightly longer than the transect lengths. The additional width has been added to give a more extensive view of the area, and allows more scope for interpretation.

The transect lines are indicated on the vegetation maps, which show the various plant community types as classified according to their areal affinities. The communities are delineated from each other by different hatchings, and within each, the tree cover densities are indicated too. This should ensure that any major changes can be detected over the long term. The woody species occuring in the various community types are listed in TABLE 4.2 and should be referred to frequently. Land uses have also been indicated so that any changes or additions can be detected over the long-term.

The various soil types and localities of the soil profile pits along the transects are indicated on the pedological maps.

The geological rock type formations, localities of water level recorders and production boreholes in the vicinity of each transect, are indicated on the geological maps. The direction of the dip or fold of the syncline's strata is also indicated by means of arrows on each map.

Transect 1 and 2 have been reproduced on a smaller scale as examples of these strip maps, and have been included in this report. The original sepias and copies of the sliced maps of all the transect are stored in the Karstland Plant Ecology Box File. Transect 1 is represented in Figures 4.1 to 4.3, and Transect 2 is represented in Figures 4.4 to 4.6. Transects 4 to 10 should be referred to using the original 1:1667 sepia maps.

A discussion of all the transects follows, and the tabulated list of mapping details are presented in TABLE 4.3. Refer to Annexures 1 and 2 for orientation.

i) TRANSECT 1

Transect 1 is situated on the Brandwag/Uitkomst farm. It is 300 m in length and 5 m wide and extends down the slope of the mountain. The sliced maps for this transect cover an area or strip of land longer than just 300 m, and approximately 500 m wide.

The transect crosses from the fringe of a mountain base community through a contact community, to a slope community. See TABLE 4.2 for species' lists. The contact community has a very dense tree cover and this is evident as a thick band of trees. The slope community has a slightly less dense tree cover, but from the map it is apparent that this slope community varies in tree cover density in places. (See smaller scale of Transect 1, Figure 4.1).

With regard to the soil types along this transect area, the soils map shows that the whole transect is located on a Mispah. Refer to Figure 4.2.Two soil profile pits were dug along this transect at approximately the 50 m marker pole and at the 250 m marker pole. The former pit was dug in the contact community. Here the Orthic A horizon is 20 cm deep, below which the B-horizon starts. The latter is a hard rock calcrete layer. Plant roots were found to occur to a depth of ±20 cm.

The second profile was dug in the slope community area. Here the Orthic A horizon is only 10 cm deep, below which lies the hard rock calcrete layer. Plant roots in this area were found to occur to 15 cm.

This soil type (Form: Mispah, Series: Kalkbank) is brown-black and dark red to grey in colour at the respective profiles. It has a very poor water holding capacity and poor drainage except where the calcrete layer is porous. Little or no leaching occurs due to the poor drainage. The A-horizon has a fair amount of organic material present. (More details are available in the soil survey report by the Agriculture Division, Administration for Whites in the Karstland Plant Ecology Box File).

With regard to the geological features of this area, the geological map shows that the transect starts on the fringe between dolomite and granite, but remains on the granite, covered by calcrete and soil, for the entire length. This transition where the two rock types meet is referred to as the contact zone, a more permeable and porous zone. The strata on the southern limb of the syncline dip steeply north as indicated by the straight arrows on the map. Both a water level recorder and a production borehole are in close proximity to this transect. Refer to Figure 4.3.

ii) TRANSECT 2

Transect 2 is situated on the Urupupa farm. It is 5 m wide and 700 m long and is parallel to the farm camp fence. Initially this transect was 1000 m long, but due to the extension of the cultivated lands, 300 m have been "lost". The transect area strips originally mapped were 500 m wide and approximately 1000 m long. Since the initiation of the study, a large area around this transect has been ploughed. This area, which no longer exists as natural vegetation has been indicated on the vegetation map. (See smaller scale of Transect 2, Figure 4.4).

The vegetation map shows that the transect begins in a plain community, crosses through the contact community and again continues into a plain community. The plain communities it crosses have various degrees of tree cover densities from very dense to moderately dense. The contact community has a very dense tree cover.

The soils map shows that originally three soil types were crossed. Refer to Figure 4.5. From the beginning of the transect (plain community) to the end of the contact community, the soil type is a Mispah. From there to 100 m from the end is a Hutton soil, and the last soil type is a Glenrosa. Two soil profile pits were dug within the Mispah soil type at approximately 50 m and 300 m along the transect, and one in each of the other soil types, at approximately the 700 m and 1000 m marker poles.

The first Mispah pit was dug in amongst the plain community. Here the Orthic A-horizon is 25 cm deep under which lies the hard rock calcrete layer. Plant roots were found to occur down to a depth of 25 cm. The colour of this top horizon is reddish-brown with the B-horizon consisting of white calcrete rocks.

The second Mispah pit was dug on the fringe of the contact and plain communities. The Orthic A-horizon is 30 cm in depth, below which lies the hard rock calcrete. Plant roots were found to occur to depth of 30 cm. The colour of the soil is a dull red colour.

This soil type (Form: Mispah, Series: Kalkbank) has a very poor water holding capacity and poor drainage due to the B-horizon. Little or no leaching occurs because of the poor drainage.

The third soil profile pit was dug in the Hutton soil type, inhabited by a plain community. The Orthic A-horizon is 15 cm deep under which lies the Red Apedal B layer. Plant roots were found to occur to a depth of 60 cm. The colour of this soil is red in both horizons. This soil type (Form: Hutton, Series: Malonga) has a very good water holding capacity due to the depth of the soil, and has good drainage, due to the low clay percentage. This soil is ideal for cultivation. Depending on the quantity of rain, moderate to good leaching will occur.

The fourth soil profile pit dug in a Glenrosa type soil is also inhabited by a plain community. This part of the transect has since been removed. The Orthic A-horizon is 20 cm deep, underlain by a Lithocutanic B-horizon. The A-horizon is red in colour but the B-horizon is interrupted with grey and yellow eroded rocks. Plant roots occur to a depth of 30 cm.

This soil type (Form: Glenrosa, Series: Lekfontein) has a poor water holding capacity. The drainage fluctuates and is linked to the rainfall. This is due to the shallowness of the soil. Little or no leaching occurs due to the poor drainage.

With regard to the geological features of this area, the geological map shows that the transect begins on phyllite and after the contact zone crosses onto dolomite. The former is coverd by calcrete and sandy soil. The direction of the arrows shows that the strata on the southern limb of the syncline are overfolded. A water level recorder is situated very close to this transect. Refer to Figure 4.6.

iii) TRANSECT 4

Transect 4 is situated on the Buschbrunnen farm It is 1000 m in length and 5 m in width. This transect begins in a plain community, crosses through a contact community and again continues in a plain community. The plain community on either side of the contact zone appears to have different degrees of tree cover densities according to the delineations present on the vegetation map. Refer to TABLE 4.2 for species' listing. The contact community is situated on a slightly raised terrain which later drops down to a lower level where the plain community begins. The former community has a very dense tree cover.

From the soils map it is evident that three soil types occur in this area, a Hutton, a Mispah and a Rensburg. The transect begins on the fringe of the Hutton and Mispah, but the tree cover is only moderately dense here as it appears as though some man-made disturbance could have taken place quite a while ago. The first soil profile pit was thus dug in the next soil type, the Mispah, in the contact community area. The whole of this community appears to be concentrated in this Mispah soil type (Form: Mispah, Series: Kalkbank). The top horizon, the Orthic A-horizon is 20 cm in depth, under which lies the hard rock calcrete layer. The A-horizon soil is a dark reddish-grey colour, while that of the B-horizon is an orange colour. This soil's water holding capacity is poor, as is the drainage in this soil, and little or no leaching takes place.

The second and third pits were dug in a Rensburg soil type inhabited by a plain community. Both pits were identical in profile descriptions. (Form: Rensburg, Series: Rensburg). The top horizon, Vertic A, is 25 cm deep. and the horizon below this is the Gley B-horison. Plant roots were found to occur to a depth of 30 cm. The A-horizon's colour is brown-grey while the B-horizon is light grey. This soil has a very good water holding capacity mainly because of the clay content but also because of the B-horizon. However, the drainage is very poor, often leading to drowning. Little leaching occurs because of the high clay content.

From the geological map, it is evident that both dolomite and phyllite are present. The dolomite begins at the contact zone and extends northwards, while the phyllite extends from the contact zone southwards. The transect begins on the dolomite but continues on phyllite for the entire length. The syncline strata are steeply overfolded as shown by the arrows. A water level recorder is in close proximity to the beginning of the transect.

The original sepia maps should be referred to for Transects 4 to 10.

iv) TRANSECT 5

Transect 5 is situated on the Kombat/Asis farm. It is 1000 m in length and 5 m wide and runs parallel to the gravel road which passes the mine's slimes dam.

The vegetation map shows that three plant community types are present within the mapped area, namely, contact, plain and mountain communities. The transect crosses from a plain, into a contact and again into a plain community. The former again has varying degrees of tree cover, from very dense to sparse. The contact community is evident as a very broad band of dense vegetation.

The soils map shows that three soil types are present within the mapped area. The transect begins on an Avalon, and then crosses into a Hutton and ends in an Avalon again. The mountain community through which the transect does not cross occurs on a Mispah. Two soil profile pits were dug, one in the Avalon and one in the Hutton soil types.

Both the plain and contact communities occur on the Avalon. This soil type (Form: Avalon, Series: Ruston) has an Orthic A-horizon to a depth of 20 cm, under which lies a yellow-brown Apedal B-horizon to a depth of 60 cm, under which lies a soft Plinthic. The colour of the soil is yellow-brown with black spots. Plant roots were found to a depth of 60 cm and also deeper to 120 cm. This soil has a good water holding capacity due to a low clay content in the top soil which encourages infiltration, and a higher clay content in the lower horizons which prevents the water from draining off too quickly.

Drainage is good in this soil however under heavy rainfall conditions, drowning could occur in the lower horizons, from 60 cm downwards. Little leaching occurs because of the clay content.

The second pit was dug in a Hutton soil type, inhabited by a plain community. This soil type (Form: Hutton, Series: Malonga) has an Orthic A-horizon to a depth of 25 cm and a Red Apedal B underlying this layer. Plant roots were found to occur to a depth of 120 cm and even deeper. The colour of this soil is red with a fair amount of black and white spots. This

soil's water holding capacity is good to moderate due to the fair amount of clay present. However, in dry years the soil could dry out easily. This soil has good drainage and thus leaching takes place easily, however it would not be critical due to the clay content in the lower horizon.

The geological map shows that the transect begins on phyllite which is covered by a layer of soil in places, and then crosses onto dolomite also covered by a layer of soil in places. The transition occurs at the contact zone, which is concealed. The northern strata of the syncline dip steeply south. A water level recorder is situated along the transect line on the contact zone.

v) TRANSECT 6

Transect 6 is situated on the Okambongora farm. It is 1000 m in length and 5 m in width, and runs parallel to a camp fence.

The vegetation map shows two plant community types, namely, contact and plain communities. The transect starts in the contact community, and crosses into the plain community at the contact zone. Both contact and plain communities have varying tree covers, from dense to moderately dense in the former community, and from dense to very sparse in the latter community. The contact community extends over a very broad area of land.

The soils map shows two soil types along the transect area. The transect begins on a Mispah and extends through a small patch of Milkwood at ±800 m and then continues onto a Mispah. Soil profile pits were dug in each of these soil types. Both contact and plain communities occur on the Mispah, and a plain community occurs on the patch of Milkwood.

The Mispah soil (Form: Mispah, Series: Kalkbank) has an Orthic A-horizon to a depth of 20 cm, under which lies a hard rock calcrete horizon. Plant roots were found to occur to a depth of 20 cm. The soil has a brownish-black colour. This soil has a poor water holding capacity, poor drainage and little leaching takes place due to the hard rock calcrete horizon.

The Milkwood soil (Form: Milkwood, Series: Sunday) has a Melanic A-horizon to a depth of 25 cm, under which lies a hard rock calcrete layer. Plant roots were found to occur to a depth of 30 cm. The colour of this soil is brownish-black in the A-horizon and brownish-grey in the B-horizon. The water holding capacity of this soil is poor due to the soil's shallowness, and little leaching occurs due to poor drainage.

The geological map shows that the transect begins on phyllite and then crosses onto dolomite from the contact zone northwards. The strata on the southern limb of the syncline dip steeply north as shown by the straight arrows.

vi) TRANSECT 7

Transect 7 is situated on the Buschbrunnen farm. It is 5 m wide and 1000 m long, runs parallel to a farm fence and a service road, and extends up a gradual slope towards the base of a mountain in the north.

The vegetation map shows three plant community types, namely, a slope community, mountain base community and a mountain community. The transect does not enter into the latter community. The transect begins in a slope community and crosses into the mountain base community. There is no contact zone or contact community present. The slope community has various tree cover densities, from very dense to moderately dense.

The soils map shows that four soil types occur, namely, Mispah, Glencoe, Clovelly and Hutton. The transect begins on a Clovelly, crosses onto a Glencoe, then onto the Mispah for the rest of the length with the exception of a small patch of Glencoe within the last 400 metres. Only the last part of the northern end of the transect has a mountain base community on Mispah, while the rest of the transect is slope community on Mispah, Glencoe and Clovelly. The transect does not enter the Hutton soil type.

The Clovelly soil (Form: Clovelly, Series: Dudfield) has a 35 cm deep Orthic A-horizon, underlain by a yellow-brown Apedal B-horizon to a depth greater than 120 cm. Both horizons are yellow in colour, and plant roots were found to a depth of 120 cm. This soil has a good water holding capacity as a result of its depth. Drainage is moderate due to the high percentage of clay, and leaching is not very prevalent, also because of the clay content.

The Glencoe soil (Form: Glencoe, Series: Klipstapel) has an Orthic A-horizon to a depth of 20 cm, underlain by a yellew-brown Apedal horizon to a depth of 70 cm, underlain by a hard Plinthic. Plant roots were found to occur throughout the profile into the hard Plinthic layer. This soil has a good water holding capacity, but poor drainage and little leaching takes place.

The Mispah soil (Form: Mispah, Series: Kalkbank) has a 30 cm deep Orthic A-horizon underlain by a hard rock calcrete horizon. Plant roots occur to a depth of 30 cm. The A-horizon's colour is yellow-brown to grey. This soil has a poor water holding capacity, poor drainage and little leaching occurs.

The geology map indicates that the transect begins on dolomite, passes over a narrow band of limestone and phyllite and continues on dolomite. The dolomite is inhabited by both slope and mountain base communities, while the band of limestone and phyllite is inhabited by a slope community. This band occurs at the crest of the slope. There is no contact zone present.

vii) TRANSECT 8

Transect 8 is situated on the Buschbrunnen farm. It is 1000 m (plus an extra 100 m long on the aerial photographs), and 5 m wide.

This transect begins in a contact community, passes through a patch of slope community, continues through a plain community into slope community again, then enters into contact community again. This transect thus crosses two contact zones, and runs parallel to a farm fence for most of its length. The two contact communities have varying tree covers, from very dense to very sparse. The slope communities both have moderately dense tree covers while the plain community has very sparse tree cover. This latter community occupies an area within a slight depression in the topography.

The soils map shows that there are three soil types present, namely, a Rensburg, a Mispah and a Katspruit. The transect begins on a Rensburg (contact community), passes onto a Mispah (slope and plain communities), crosses a patch of Katspruit (plain community) and ends on a Mispah (contact community) again. Three soils profile pits were dug, one in each soil type. The Rensburg soil (Form: Rensburg, Series: Rensburg) has a 30 cm deep Vertic A-horizon underlain by a Gley B-horizon. Plant roots were found in the first 30 cm. This soil is brownish grey in colour. This soil has a good water holding capacity as a result of the high clay content. Drainage is poor and drowning often occurs under very wet conditions. Little leaching takes place due to the clay content.

The Mispah soil (Form: Mispah, Series: Kalkbank) has a 25 cm deep Orthic A-horizon underlain by a hard rock calcrete horizon. Plant roots were found to a depth of 25 cm. This soil is red in colour. It has a poor water holding capacity, poor drainage and little leaching takes place.

The Katspruit soil (Form: Katspruit, Series: Killarney) has an Orthic A-horizon to a depth of 30 cm, under which lies a G-horizon. Plant roots were found to occur to a depth of 30 cm. The colour of this soil is a dull reddish-brown and the second horizon is a pale yellow colour. This soil has a moderate water holding capacity but the soil is mostly saturated. Drainage is poor and very little leaching occurs.

The geology map shows that the transect begins on phyllite until the first contact zone, where it continues on dolomite. It then continues on limestone and phyllite from the second contact zone onwards. A water level recorder is situated close to the transect on the first contact zone in the north. The strata at the northern contact dip steeply southwards, and the strata at the southern contact dip steeply northwards. A third contact zone lies to the south of the transect.

viii) TRANSECT 9

This transect is situated in the Kombat mine area. It is 1000 m long and 5 m wide. It begins close to the main tarred road, crosses over a railway line running adjacent to the Kombat mine, continues very close to a small inhabited area and ends in the mountains.

The vegetation map shows that four plant community types are present within the mapped area. The transect begins in a plain community, crosses into a contact community, continues into a mountain base community and ends in a mountain community. The contact community has a moderately dense tree cover and it is in this area that the small dwellings are located. A fair amount of disturbance is thus evident.

The soils map shows that four soil types are present within the mapped area, although the transect passes over only three of them. The transect begins on a Glencoe, in a plain community, passes onto a Clovelly in contact and mountain base communities, and continues onto a Mispah, in the mountain community. Soil profile pits were dug in the two former soil types. The Hutton soil type on the mountain was not examined.

The Glencoe soil type (Form: Glencoe, Series: Klipstapel) has an Orthic A-horizon to a depth of 20 cm under which lies a yellow-brown Apedal horizon to a depth of 70 cm, underlain by a hard Plinthic. Plant roots were found to occur throughout the profile. The colour of this soil is yelllow-brown. This soil has a good water holding capacity but poor drainage and very little leaching takes place.

The Clovelly soil type (Form: Clovelly, Series: Torquay) has an Orthic A-horizon to a depth of 50 cm, underlain by a yellow-brown Apedal horizon. Plant roots were found to occur throughout the profile. The colour of this soil is yellow-brown. This soil has a good water holding capacity due to the depth of the soil. It dries out quickly due to the low clay content and has good drainage. Leaching is moderately good especially in very wet years.

The Mispah soil type (Form: Mispah, Series: Kalkbank) has an Orthic A-horizon to a depth of approximately 30 cm, underlain by a hard rock calcrete horizon. Plant roots occurred to a depth of 30 cm. The A-horizon is yellow-brown to grey in colour. This soil has a poor water holding capacity, poor drainage and little leaching takes place. This is due to the shallowness of the soil and the second horizon.

The geological map shows that the transect begins on phyllite and at the contact zones crosses onto dolomite. Two boreholes are situated very close to the transect and contact zone. The strata of the syncline dip steeply to the north.

ix) TRANSECT 10

Transect 10 is situated in Area II on the Berg Aukas farm, very close to the Berg Aukas mine. It is 750 m in length and 5 m wide, and extends from the main gravel road past the mine almost parallel to the farm fence, and ends near the top of the mountain just above the farm house.

This transect begins in a plain community, crosses into a contact community which is a very broad band of very dense vegetation, continues into a plain community again, runs through a mountain base community and ends in a mountain community. The tree cover is very dense north of the contact zone and moderately dense south of the contact zone.

The soils map shows that two soil types occur here, namely, a Mispah and a Clovelly. A soil profile pit was dug in each of the soil types. The middle section of the transect extends over the Clovelly soil inhabited by a plain community, while the beginning and end extend over a Mispah, inhabited by plain, contact, mountain base and mountain communities.

The Mispah soil type (Form: Mispah, Series: Buden) has a 20 cm deep Orthic A-horizon, underlain by a hard rock calcrete horizon. Plant roots were found to occur to a depth of 20 cm and even into the calcrete layer. The soil is yellow-brown in colour. This soil has a very poor water holding capacity, its drainage is very poor and very little leaching takes place.

The Clovelly soil (Form: Clovelly, Series: Vaalbank) has an Orthic A-horizon to a depth of 30 cm, underlain by a yellow-brown Apedal B-horizon to a depth of 60 cm. Plant roots were found to a depth of 60 cm and deeper. The colour of this soil is mostly yellowish-brown with some white spots. This soil has a good water holding capacity, good drainage and leaching takes place easily.

The geological map shows that the transect begins in a granite formation and at a contact zone crosses onto dolomite. The strata on the northern limb of the syncline dip steeply towards the south.

TABLE 4.3: VEGETATION - SOIL - GEOLOGY MAPPING DETAILS OF EACH TRANSECT Page 1 of 3

	VEGETATION (PLANT COMMUNITY TYPES)	SOILS					GEOLOGY (ROCK FORMATION TYPES)
		FORM: HORIZONS/DEPTH cm	WATER HOLDING CAPACITY	DRAINAGE	LEACHING	PLANT ROOTS' DEPTH cm	
TRANSECT 1 UITKOMST/BRANDWAG 300 m	Moutain base/ Contact fringe	Mispah:	poor	poor	little/ none		Dolomite/Granite transition
	Contact community	Orthic A horizon 0 - 20 cm Hard rock calcrete horizon 20 - N*				20 cm	Granite - covered by calcrete and soil
	Slope community	Mispah: Orthic A horizon 0 - 10 cm Hard rock calcrete horizon 10 - N*	poor	poor	little/ none	15 cm	Granite - covered by calcrete and soil
TRANSECT 2 URUPUPA 1000 m - 300 m	Plain community	Mispah: Orthic A horizon 0 - 25 cm Hard rock calcrete horizon 25 - N*	poor	poor	little/ none	25 cm	Phyllite - covered by calcrete and soil
	Contact community	Mispah: Orthic A horizon 0 - 30 cm Hard rock calcrete horizon 30 - N*	poor	poor	little/ none	30 cm	Phyllite - covered by calcrete and soil
	Plain community	Hutton: Orthic A horizon 0 - 15 cm Red Apedal B horizon 15 - N*	very good	good	moderate/ good	60 cm	Dolomite - outcrops in place
	Plain community	Glenrosa: Orthic A horizon 0 - 20 cm Lithocutanic B horizon 20 - N*	poor	fluc-tuating	little/ none	30 cm	Dolomite - outcrops in places
TRANSECT 4 BUSCHBRUNNEN 1000 m	Plain community	Hutton/Mispah fringe					Dolomite
	Contact community	Mispah: Orthic A horizon 0 - 20 cm Hard rock calcrete horizon 20 - N*	poor	poor	little/ none	20 cm	Phyllite - covered by calcrete and soil
	Plain community	Rensburg: Vertic A horizon 0 - 25 cm Gley B horizon 25 - N*	very good	very poor	little	30 cm	Phyllite - covered by calcrete and soil

*N represents depth of next horizon deeper than the soil profile pit.

TABLE 4.3: VEGETATION - SOIL - GEOLOGY MAPPING DETAILS OF EACH TRANSECT Page 2 of 3

	VEGETATION (PLANT COMMUNITY TYPES)	SOILS					GEOLOGY (ROCK FORMATION TYPES)
		FORM: HORIZONS/DEPTH cm	WATER HOLDING CAPACITY	DRAINAGE	LEACHING	PLANT ROOTS' DEPTH cm	
TRANSECT 5 ASIS/KOMBAT 1000 m	Plain community	Avalon: Orthic A horizon 0 - 20 cm Yellow brown Apedal B horizon 20 - 60 cm Plinthic horizon 60 - N*	good	good	little	60 - 120 cm and deeper	Phyllite - covered by layer of soil in places
	Contact community						Phyllite - covered by layer of soil in places
	Plain community						Dolomite - partly covered by soil in places
	Plain community	Hutton: Orthic A horison 0 - 25 cm Red Apedal B horizon 25 - N*	good/ moderate	good	alot	120 cm and deeper	Dolomite - partly covered by soil in places
TRANSECT 6 OKAMBONGORA 1000 m	Contact community	Mispah: Orthic A horizon 0 - 20 cm Hard rock calcrete horizon 20 - N*	poor	poor	little	20 cm	Phyllite - covered by calcrete and loamy soil
	Plain community						Dolomite
	Plain community	Milkwood: Melanic A horizon 0 - 25 cm Hard rock calcrete horizon 25 - N*	poor	poor	little	30 cm	Dolomite
	Plain community	Mispah:	poor	poor	little	20 cm	Dolomite
TRANSECT 7 BUSCHBRUNNEN 1000 m	Slope community	Clovelly: Orthic A horizon 0 - 35 cm Yellow-brown Apedal B horizon 35 - 120 cm	good	moderate	little	120 cm	Dolomite
	Slope community	Glencoe: Orthic A horizon 0 - 20 cm Yellow-brown Apedal B horizon 20 - 70 cm Soft Plinthic horizon 70 - N*	good	poor	little	70 cm	Dolomite
	Slope community	Mispah: Orthic A horizon 0 - 30 cm Hard rock calcrete horizon 30 - N*	poor	poor	little	30 cm	Dolomite
	Slope community	Glencoe:	good	poor	little	70 cm	Dolomite
	Slope community	Mispah:	poor	poor	little	30 cm	Limestone and Phyllite
	Mountain base community	Mispah:	poor	poor	little	30 cm	Dolomite

TABLE 4.3: VEGETATION - SOIL - GEOLOGY MAPPING DETAILS OF EACH TRANSECT

	VEGETATION (PLANT COMMUNITY TYPES)	SOILS					GEOLOGY (ROCK FORMATION TYPES)
		FORM: HORIZONS/DEPTH cm	WATER HOLDING CAPACITY	DRAINAGE	LEACHING	PLANT ROOTS' DEPTH cm	
TRANSECT 8 BUSCHBRUNNEN 1000 m + 100 m	Contact community	Rensburg: Vertic A horizon 0 - 30 cm Gley B horizon 30 - N*	good	poor	little	30 cm	Phyllite - covered by loamy soil in places
	Slope community	Mispah: Orthic A horizon 0 - 25 cm Hard rock calcrete horizon 25 - N*	poor	poor	little	25 cm	Dolomite
	Plain community	Mispah:	poor	poor	little	25 cm	Dolomite
	Plain community	Katspruit: Orthic A horizon 0 - 30 cm G-horizon 30 - N*	moderate	poor	very little	30 cm	Dolomite
	Slope community	Mispah:	poor	poor	little	25 cm	Dolomite
	Slope community	Mispah:	poor	poor	little	25 cm	Limestone and Phyllite - covered by calcrete and soil
TRANSECT 9 KOMBAT MINE 1000 m	Plain community	Glencoe: Orthic A horizon 0 - 20 cm Yellow-brown Apedal horizon 20 - 70 cm Hard Plinthic horizon 70 - N*	good	poor	very little	throughout profile	Phyllite - covered by soil
	Contact community	Clovelly: Orthic A horizon 0 - 50 cm Yellow-brown Apedal horizon 50 - N*	good	good	moderately good	throughout profile	Phyllite - covered by soil
	Mountain base community	Clovelly:	good	good	moderately good	throughout	Dolomite - partly covered by soil in places
	Mountain community	Mispah: Ortic A horizon 0 - 30 cm Hard rock calcrete horizon 30 - N*	poor	poor	little	30 cm	Dolomite - partly covered by soil in places
TRANSECT 10 BERG AUKAS MINE 750 m	Plain community	Mispah: Orthic A horizon 0 - 20 cm Hard rock calcrete horizon 20 - N*	poor	poor	very little	20 cm and deeper	Granite - covered by calcrete and soil
	Contact community	Mispah:	poor	poor	very little	20 cm and deeper	Granite - covered by calcrete and soil
	Plain community	Clovelly: Orthic A horizon 0 - 30 cm Yellow-brown Apedal B horizon 30 - 60 cm	good	good	alot	60 cm and deeper	Dolomite
	Mountain base community	Mispah:	poor	poor	very little	20 cm and deeper	Dolomite
	Mountain community	Mispah:	poor	poor	very little	20 cm	Dolomite
	Mountain community	Mispah:	poor	poor	very little	20 cm and deeper	Dolomite

5. GROUNDWATER LEVEL MONITORING

5.1 INTRODUCTION

The target area for the groundwater extraction of 20 x 10^6 m^3/annum, to supply the central area of Namibia is located between Otavi, Grootfontein and Tsumeb. This area is referred to as the Karstveld, and covers an area of approximately 2000 km^2. The Karst Borehole Scheme will consist of some 60 production boreholes spread over the entire area, connected by a collector pipe network. This scheme should provide an additional assured supply of water as one of the major sources of the Eastern National Water Carrier system.

Topographically this area forms part of the Otavi Mountainland rising from 1500 m to more than 1800 m above sea level. The rock types of the Otavi Mountainland give rise to the Karst, and consist mainly of dolomite and limestone of the Otavi Group of the Damara Sequence. The strata of the Otavi Mountainland have been folded into a number of synclines and anticlines, generally striking East to West.

Geological investigations have shown that potential aquifers with large quantities of groundwater appear to be confined to the synclinal dolomitic structures.

On the basis of these geological structures, the target area is subdivided into four (4) areas:-

Area I : Otavi Valley Syncline
Area II : Grootfontein-Berg Aukas Syncline
Area III: Harasib-Olifantsfontein Syncline
Area IV : Southern portion of Tsumeb Synclinorium

The investigation of the eastern most part of Area I was given priority by Geohydrology. This included a general geohydrological investigation of the area, the selecting of drilling sites, exploratory drilling and pump testing potential production boreholes. Twenty (20) production boreholes were located in this area, namely, the Kombat-Uitkomst Area.

The plant ecological investigation was also confined to this eastern most part of Area I, as well as a small portion of Area II, namely, the Berg Aukas mine area.

This section of the report contains data on groundwater levels for selected boreholes in these two areas, collected from water level recorders read on a quarterly basis.

On initiation of this study (July 1984), a 1:50 000 map of groundwater level contours in metres from the soil surface, was drawn up by the Geohydrology Division for Area I. Various data were included on this map for the purpose of selecting the study sites for the monitoring of the vegetation. These were the actual groundwater level contours, the positions of the production boreholes, the positions of the water level recorders, and the outline of the contact zones.

The monitoring of water tables and other geohydrological work is being carried out by the Geohydrology Division, who are responsible for the writing of detailed reports on this area's investigation.

By monitoring the groundwater fluctuations within this area, it is hoped that some direct or indirect relation can be determined between rainfall, groundwater levels and recharge (infiltration), soil moisture and vegetation vitality.

GEOLOGICAL BACKGROUND:-

Karstification results from natural processes caused by solution and leaching of limestones and dolomites. The infiltrating surface and groundwater solution is a dominant process in landform development and underground structures.

Owing to Karstification, the area is characterized by a marked absence of well-defined surface drainage systems.

Karst features such as solution channels and sinkholes tend to develope along joints, fractures, faults, shears and contact zones rather than being restricted to certain strata.

The water-bearing dolomite and limestone in the Karst area are chiefly confined to the four major synclinal structures. A syncline can be described as a structural basin in which the rock beds dip towards the axis of the trough in contrast to an anticline, being an upfolded arch where the rocks dip outward from the crest of the fold.

The primary hydrological porosity and permeability of the carbonate rocks are low, however the permeability and storage capacity have been increased considerably due to chemical solution along secondary structures such as joints, fractures, shears, faults and contact zones.

The investigation programme was essentially directed towards such zones of higher permeability. The contact zone is characterized in the field by a prominent band of vivid green vegetation, and the majority of the production boreholes are located on the various contact zones.

TOPOGRAPHIC RELIEF:-

The geohydrological parameters within the various areas are largely controlled by the topographic relief of the dolomite synclines.

The elevated areas with poorly developed courses are better drained than the flat lying areas, but the flat areas experience better infiltration rates of precipitation, and chemical solution of carbonate rocks is more intense.

According to the gradient, the groundwater tends to flow from the central elevated archs outwards to the boundaries of the syncline, where the water is dammed up along the "rims", against semi-pervious and impervious phyllite and lava.

The groundwater overflows the contact in a number of springs located along the contact between the basal dolomite and older rocks, and below the calcrete generally fringing the contact zone.

AREA I AND AREA II:-

Of the four synclinal areas identified in the Karst area, two were examined for the purpose of monitoring the vegetation status, namely, Area I extensively, and Area II in the Berg Aukas area. Refer to Annexures 1 and 2.

Area I comprises the eastern half of the Otavi Valley-Uitkomst syncline. The axis strikes in a west-east direction with a local flexure at Kombat, over a distance of approximately 65 km.

On the western side of the syncline the axis plunges eastward, whereas at the eastern end at the Uitkomst area, the plunge is reversed. The syncline forms a closed structrue. From the western closure the syncline widens gradually eastward to Kombat where the maximum width is approximately 15 km.

Both flanks of the syncline are composed of massive and bedded dolomite, thin-bedded limestone and subordinate phyllite, which give rise to the prominent mountain ranges and hills. The synline is asymmetrical in profile, strata on the southern limb dip either steeply north or are overfolded, and the northern limb has a more moderate dip towards the south.

Area II is underlain by the Grootfontein-Berg Aukas syncline which extends over a distance exceeding 60 km. The width of the syncline is between 2 - 3 km in the eastern part and in the western part widens to approximately 10 km.

On the western side of the farm Gauss 46, the syncline emerges into the Otavi Valley-Uitkomst syncline through an anticlinal structure. West of Grootfontein the syncline is transected by a thrust fault which locally forms the northern boundary of Area II.

The western part of the syncline of Area II is characterized by considerable relief with large dolomite outcrops, while the eastern part is mainly covered by calcrete with a few isolated dolomitic hills in the Berg Aukas area.

It is in this latter area that the detailed investigation is being done with regard to vegetation status, rainfall and groundwater monitoring.

AQUIFERS:-

The carbonate rocks of the Karstland have almost no primary porosity or permeability, and groundwater is stored in structures such as joints, fractures, faults, contact zones and solution channels. The geological structures of the Karstland are considered as one of the most important factors controlling the characteristics of aquifers.

The majority of the production boreholes have been located on various contact zones. Because of shearing and fracturing within the contact zones, chemical solution by infiltrating surface water and groundwater tends to exploit these structures, thus enhancing the permeability and storage capacity of the aquifer.

SPRINGS AND SEEPAGE:-

There are some 20 springs and an undefined number of seepages in the Karstland. Most of the springs issue from the basal dolomite contact zone, between dolomite and less permeable granite, metalava and phyllite at the rim of the dolomite synclines. These springs have been described as descending springs because they drain aquifers with a shallow water table under unconfined groundwater conditions. Their origin is mainly due to the topographic relief being locally lower than the water table.

The "flows" of the Karstland springs tend to be subject to seasonal fluctuations of the water table, and may dry up entirely during prolonged droughts.

Groundwater seepage occurs at a number of localities in the Karstland, but mainly along the contact of basal dolomite and phyllite or granite-gneiss. Another line of seepage is found together with low yielding fountains in laminated dark grey to blackish limestone.

The seepages are of temporary nature. They dry up completely during prolonged droughts, and during periods of heavy rainfall small springs issue from the seepage sources. It is generally in drainage courses or vlei-like depressions where the surface intercepts the water table, that seepage or springs occur mainly along contact zones.

INFILTRATION/RECHARGE:-

Direct precipitation on the dolomite underlain areas is considered to be the major or only source of recharge in the Karst area, while downward percolation of surface runoff is thought to be negligible.

Recharge from rainfall is not merely dependent on the annual amount of precipitation, but also on the intensity, duration and seasonal distribution. Other factors controling recharge are topography, thickness of soil cover and depth of the water table.

The rate of recharge which invloves vertical leakage of water through superficial deposits and secondary structures of the underlying carbonate rocks to the aquifer may vary considerably from place to place.

The recharge rate of the Karst area is still unknown and will only be established once the pumping scheme has been put into operation, and large-scale abstraction has taken place for several years.

In certain flat lying areas there are indications that the infiltration rate probably exceeds 8% of the Mean Annual Precipitation (MAP), namely, along the Grootfontein-Berg Aukas syncline. It is assumed that the recharge is limited to that percentage of the annual precipitation that directly infiltrates the dolomite syncline and reaches the groundwater table, because the syncline lies topographically higher than the surrounding calcrete plain from where no inflow can take place.

5.2 METHODS

5.2.1 Data collection

The Geohydrology Division is responsible for the collecting of all groundwater data for the whole Karstland area, starting with the exploratory investigation stage through to the routine water level monitoring stage.

At the outset of the ecological investigation, a 1:50 000 map of Area I was drawn up, which had indicated on it all the production boreholes, water level recorders and the then present groundwater level contours in metres from the soil surface. The selection of ecological study sites was based on these criteria.

Some boreholes in Area I and a few in Area II close to the Berg Aukas mine, were chosen as data collection points. This would ensure that groundwater level fluctuations could be checked and related where possible to soil moisture régimes, vegetation vitality and rainfall patterns.

Area I and Area II 's borehole data are presented in TABLE 5.1 and TABLE 5.2 respectively. The tables list the borehole numbers and all the data collected every three months for each site since monitoring began in the area. The units used for the purpose of this study are "metres from the collar height of the borehole casing". The boreholes are listed in groups as they occur on the various farms.

Figures 5.1 to 5.12 show the observed water level fluctuations in conjunction with the rainfall of that area over time.

5.3 RESULTS

The interpretation of the groundwater level data for the whole Karst Area as well as for specific boreholes in Area I and Area II, was carried out with assistance from the Geohydrology Division.

5.3.1 Data evaluation

GENERAL TRENDS:-

The discussion that follows summarises the groundwater status for the whole of the Karst Area.

The present Karstland water table monitoring system, initiated in 1983/84, comprises some 460 boreholes which are monitored on a quarterly basis. In addition, some 20 water table recorders have been installed intermittently since 1977 at widespread strategic boreholes.

The most noticeable feature about the behaviour of the water table over the past five to six years of monitoring, is the general, continuous decline of water levels in most parts of the Karstland area, This decline is evident despite the fact that abstraction on a larger scale has taken place at only a few isolated boreholes, namely, Kombat Mine, Brandwag (intermittently), Grootfontein (Municipality) and Berg Aukas (Otjiituo State Water Scheme).

This drop in water table is attributed firstly to the rainfall pattern, which has generally been below average within the Karstland area during the past six years. Secondly, because of the elevated terrain of the Karstland, namely, along a major watershed which controls the surface drainage but also the groundwater flow, the outflow of groundwater from this region is not being compensated by an inflow due to the absence of a hinterland to provide the inflow. It is thus evident that under the present situation, the outflow largely exceeds the recharge.

However, the water table in the Berg Aukas area (easternmost part of Area II) appears to be an exception. The Berg Aukas Mine ceased production in 1978 and the extensive cone of depression was eliminated in March 1986. The water table in this area appears to have attained stability, as reflected by

the hydrograph of recorder borehole 28216, and shows a substantial rise in water level in excess of two metres since the last rainy season. A similar rise was also recorded at Grootfontein at the beginning of 1989.

The general decline in the water table within the Karstland for the period 1983/84 to the end of 1988 is summarised in the attached table.

TABLE 5.3: DECLINE IN THE WATER TABLE WITHIN THE GROOTFONTEIN KARSTLAND FOR THE PERIOD 1983/84 TO 1988

AREA	MAXIMUM DECLINE IN WATERLEVEL (m)	MINIMUM DECLINE (OR RISE) IN WATERLEVEL (m)	AVERAGE DELINE IN WATERLEVEL (m)
Area influenced by abstraction at Kombat Mine	23,0 (borehole 27002 on Asis Ost 526)	20,5 (borehole 26991 on Asis 656)	22 (3,6 m/annum)
I Area not influenced by pumpage at Kombat Mine	21,1 (borehole 25366 on Rietfontein)	0,6 (borehole 27470 on Buschbrunnen)	11 (2,2 m/annum)
II Berg Aukas syncline	12,0 (borehole GH/3 on Gute Hoffnung	+ 4,8 (rise) (borehole 28154 on Berg Aukas)	2 (0,4 m/annum)
III Olifantsfontein syncline	12,3 (borehole 16762 on Irvington)	0,1 (borehole 27215 on Jägersquell)	5 (1 m/annum)
IV Southeastern part of Abenab synclinorium	6,6 (borehole 27471 on IImenau)	+ 3,8 (rise) (borehole 27234 on Abenab)	5 (1 m/annum)
Area surrounding dolomite synclines	7,8 (borehole 539/22 on IImenau 539)	+ 0,4 (rise) (borehole 27668 on Khusib)	4 (0,8 m/annum)

SPECIFIC TRENDS:-

The discussion that follows summarises the groundwater status for relevant boreholes in specific areas of the Karstland, relative to the study sites (transects). The data are grouped and discussed according to the farms on which the boreholes and study sites occur.

Refer to Figures 5.1 to 5.12 for graphical representation of water level behaviours and rainfall trends in the various localized area.

Section 6, Figure 6.2 shows the distribution and localities of these rainfall stations.

Refer also to Annexures 1 and 2 for orientation.

i) BANDWAG/UITKOMST

This area has four production boreholes for which data are collected, and two water level recorders. Monitoring of water levels began towards the end of 1985 and has been continued on a three monthly basis. One of the study sites (Transect 1) is situated within this area. A rainfall station is also located here 1009 850 (Uitkomst). Figure 5.1 shows the trends in rainfall for this locality.

As shown from the time-drawdown graph Figure 5.2, there is a clear down trend in water levels in the Brandwag/Uitkomst area, caused by natural discharge.

The average rainfall rate of 589.3 mm during the 1985-1988 period was not sufficient to cause long-term recovery. Only small fluctuations are observable during abstraction and rainy seasons. The down trend behaviour of the water levels in the relevant boreholes is shown in TABLE 5.4.

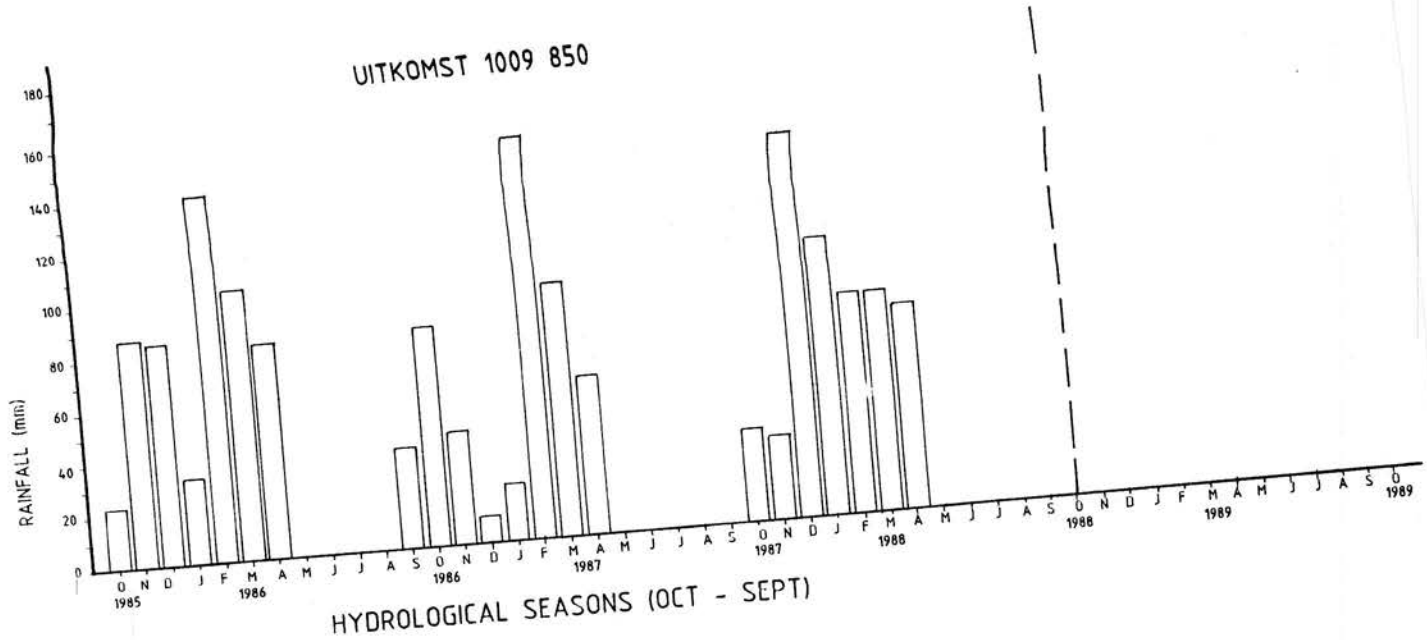


FIGURE 5.1 : RAINFALL IN AREA I - UITKOMST

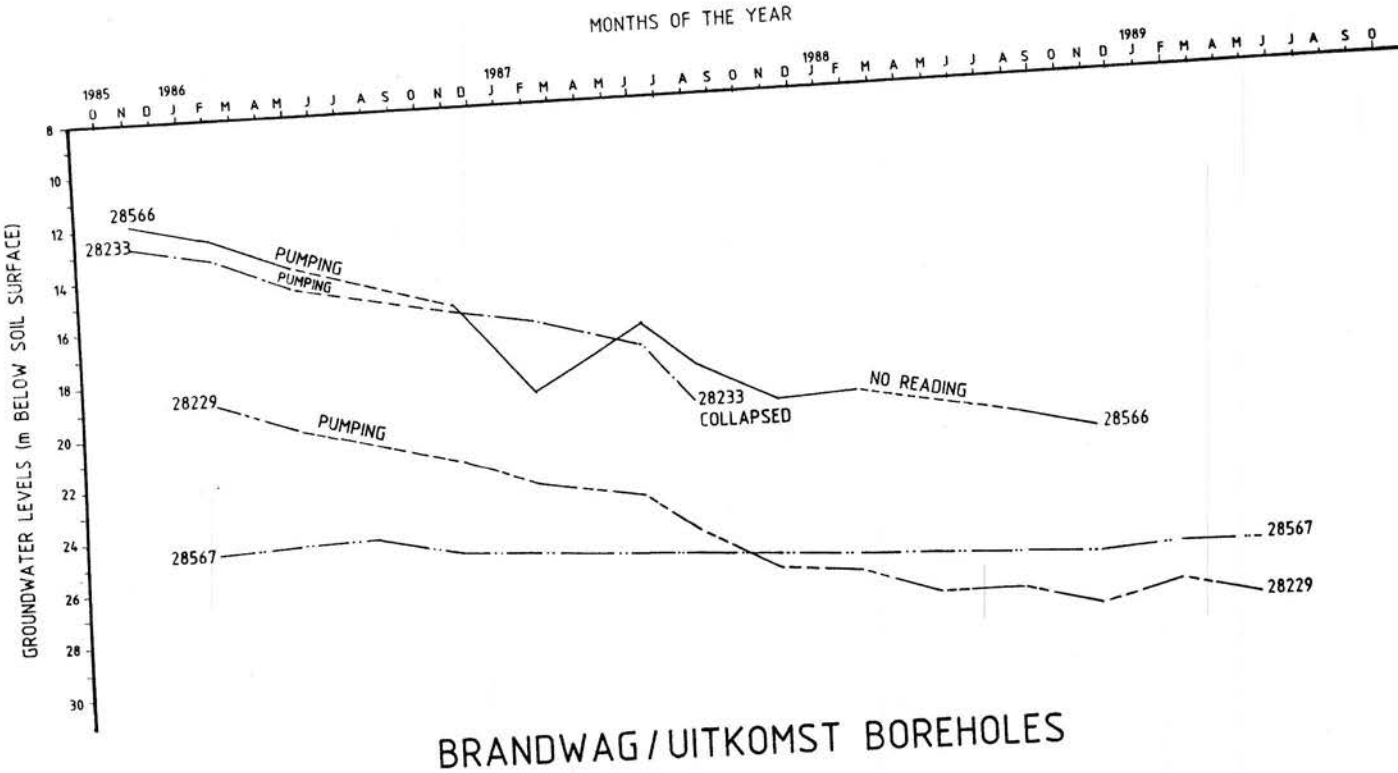


FIGURE 5.2 : WATER LEVEL FLUCTUATIONS IN AREA I - BRANDWAG/UITKOMST

TABLE 5.4: WATER LEVEL BEHAVIOUR IN BRANDWAG/UITKOMST AREA

BOREHOLE NO	TIME SPAN	RANGE IN WATER LEVEL CHANGE (m)	CHANGE IN WATER LEVEL DEPTH (m)
28566	11/85 - 11/88	11.88 - 21.11	-9.23
28233	11/85 - 08/87	12.75 - 19.51	-6.76
28229	02/86 - 05/89	18.84 - 27.46	-8.62
28567	02/86 - 05/89	24.55 - 25.46	-0.91

ii) OTJIRUKAKU

This area has three boreholes for which data are collected, and one recorder. Monitoring began towards the middle of 1983. The rainfall station in this area is that of 1009 852 (Otjirukaku). Figure 5.3 shows the rainfall trend in this area.

The behaviour of the water levels in the Otjirukaku area is shown in Figure 5.4 and TABLE 5.5. The long-term trend during 1983-1987 remains downward, but in the period between December 1988 and March 1989 an upward trend is observable. This is due to recharge from rainfall.

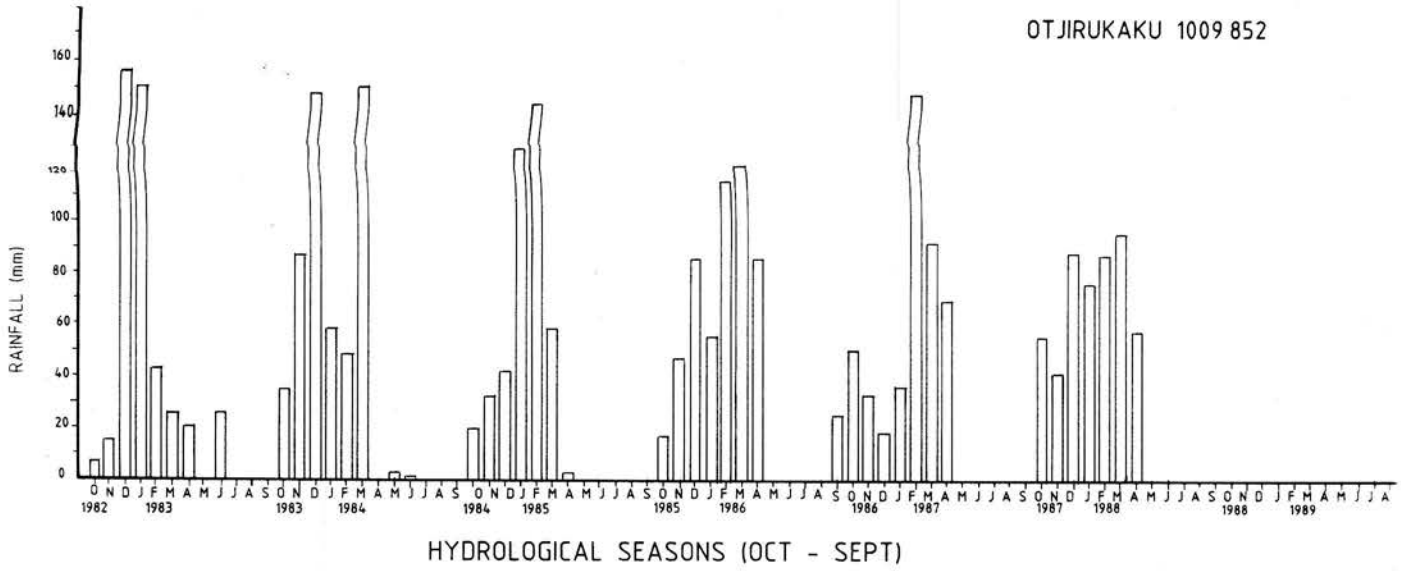


FIGURE 5.3 : RAINFALL IN AREA I - OTJIRUKAKU

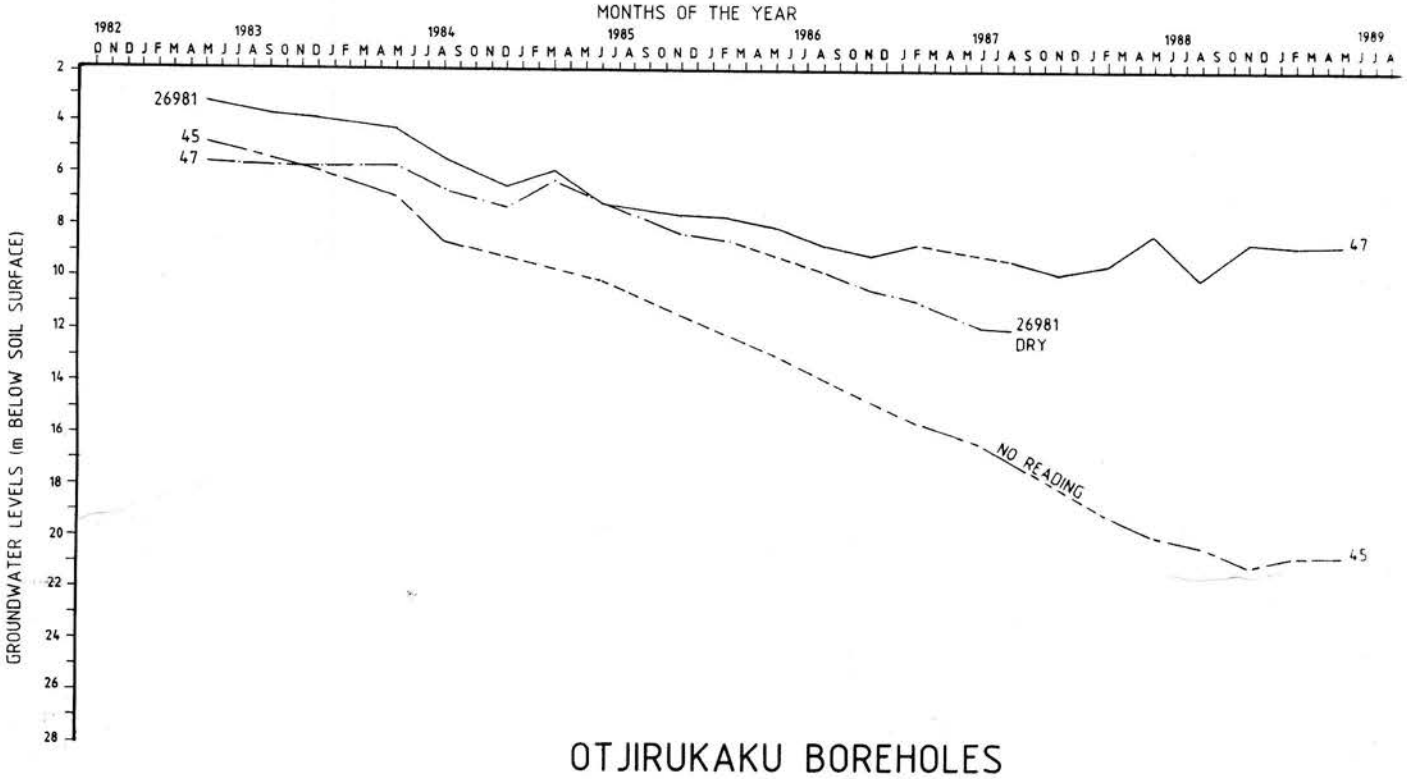


FIGURE 5.4 : WATER LEVEL FLUCTUATIONS IN AREA I - OTJIRUKAKU

TABLE 5.5: WATER LEVEL BEHAVIOUR IN OTJIRUKAKU AREA

BOREHOLE NO	TIME SPAN	RANGE IN WATER LEVEL CHANGE (m)	CHANGE IN WATER LEVEL DEPTH (m)
45	05/83 - 05/89	4.80 - 20.71	-15.91
47	05/83 - 05/89	5.60 - 8.70	- 3.10
26981	05/83 - 08/87	3.33 - 11.93	- 8.60

iii) OKAMBONGORA

There are four boreholes on this farm for which data are collected, one of which is located in a fairily shallow (high) water table area, and three are in slightly deeper water tables. Monitoring began towards the middle and end of 1983. The rainfall stations to be used as reference for this area are 1009 852 (Otjirukaku) and 1009 467 (Rietfontein). Figures 5.3 and 5.5 show the rainfall trends. One of the study sites (Transect 6) is located on this farm.

As shown in Figure 5.6 and TABLE 5.6 of the Okambongora area, a general drawdown trend is observed during the March 1983 to December 1988 period, from 1.8 m - 16.7 m. During the period of December 1988 to March 1989 water levels remained stable (probably only temporary), except in borehole 68, where a clear recovery is observable. This is due to rainfall.

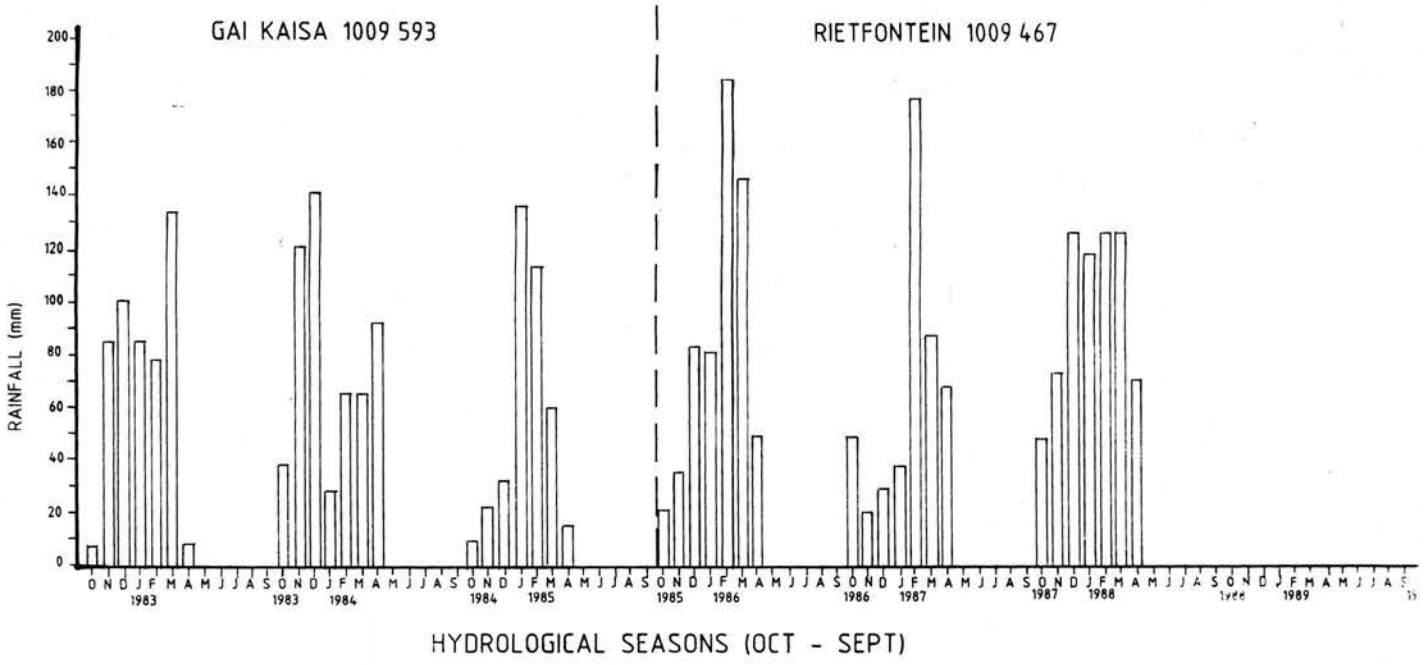


FIGURE 5.5 : RAINFALL IN AREA I - GAI KAISA AND RIETFONTEIN

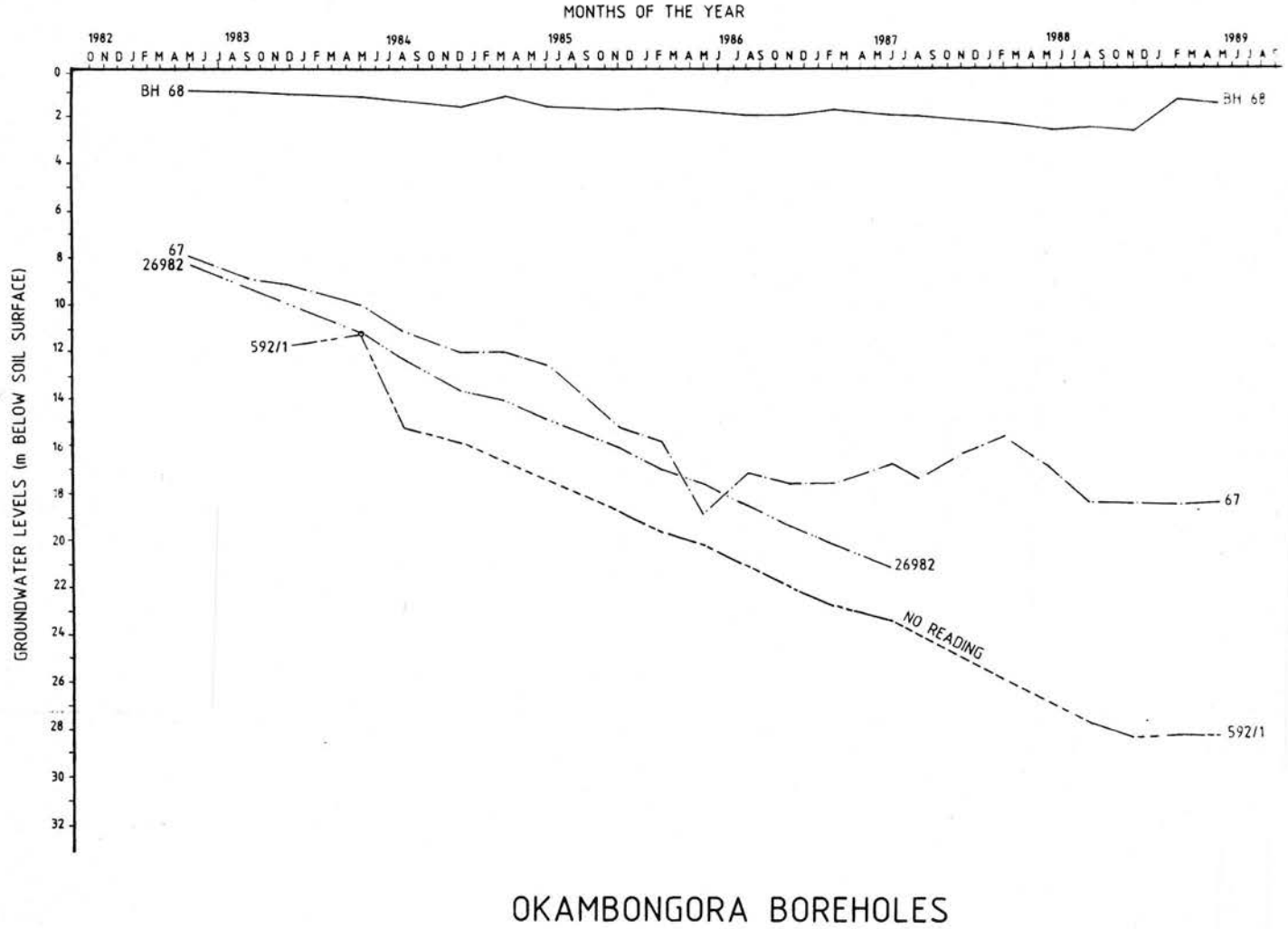


FIGURE 5.6 : WATER LEVEL FLUCTUATIONS IN AREA I - OKAMBONGORA

TABLE 5.6: WATER LEVEL BEHAVIOUR IN OKAMBONGORA AREA

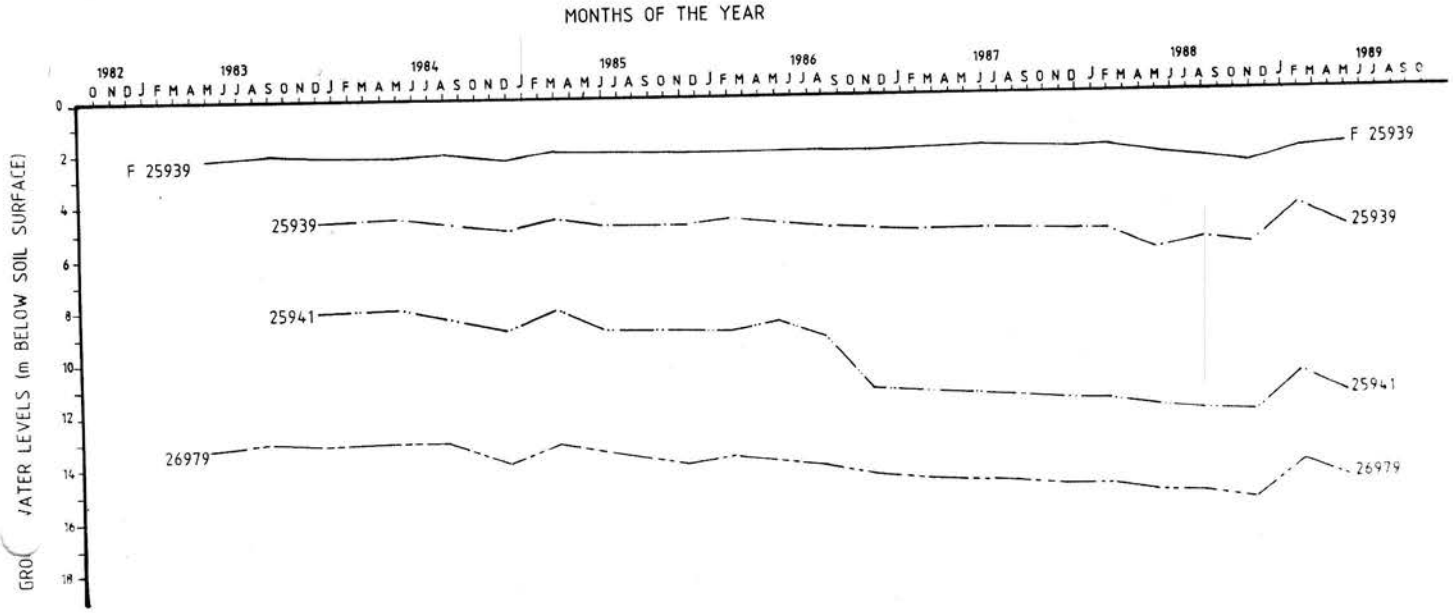
BOREHOLE NO	TIME SPAN	RANGE IN WATER LEVEL CHANGE (m)	CHANGE IN WATER LEVEL DEPTH (m)
67	05/83 - 05/89	7.96 - 18.46	-10.50
68	05/83 - 05/89	0.88 - 1.46	- 0.58
26982	05/83 - 08/87	8.27 - 21.22	-12.95
592/1	12/83 - 05/89	11.65 - 28.40	-16.75

iv) URUPUPA/RIETFONTEIN

Four boreholes and a fountain are being monitored in this area. A recorder is also situated here. Monitoring began towards the middle and end of 1983. The rainfall stations used as reference are those of 1009 593 (Gai Kaisa) and 1009 467 (Rietfontein). Figure 5.5 shows the rainfall trend. One of the study sites (Transect 2) is situated here.

Figure 5.7 and TABLE 5.7 show the water level trends for the Urupupa/Rietfontein area. Boreholes 25939 and fountain F 25939 appear to have been in a stable condition during the period May 1983 to May 1989, indicating a maintained balance between natural recharge from rainfall and underground inflow, and natural discharge. In boreholes 25941 and 26979, a long-term downward trend is observable.

In all cases small fluctuations are evident, caused by seasonal rainfall.



URUPUPA/RIETFONTEIN BOREHOLES

FIGURE 5.7 : WATER LEVEL FLUCTUATIONS IN AREA I - URUPUPA/RIETFONTEIN

TABLE 5.7: WATER LEVEL BEHAVIOUR IN URUPUPA/RIETFONTEIN AREA

BOREHOLE NO	TIME SPAN	RANGE IN WATER LEVEL CHANGE (m)	CHANGE IN WATER LEVEL DEPTH (m)
26979	12/83 - 05/89	13.35 - 14.80	-1.45
F 25939	12/83 - 05/89	2.20 - 2.08	0.12
25939	05/83 - 05/87	4.60 - 5.17	-0.57
25941	05/83 - 05/89	8.07 - 11.52	-3.45

v) BUSCHBRUNNEN

This farm has five boreholes for which data are collected, three in deep water tables and three in shallower water tables. There is one water level recorder on this farm. Monitoring started towards the middle and the end of 1983. The rainfall stations used as reference are those of 1009 467 (Rietfontein) and 1009 343 (Kombat). Figures 5.5 and 5.8 show the rainfall trends. Three study sites are situated on this farm, (Transects 4, 7 and 8).

In the Buschbrunnen area, Figure 5.9 and TABLE 5.8, water levels in boreholes 27004, 27048 and 26989 show a clear downward trend in the range from 2.6 m - 2.8 m a year. Only small fluctuations caused by rainfall are apparent. However, the long-term trend still remains downward.

In boreholes 27769 and 25353 except for small fluctuations, the water levels are stable, indicating a maintained balance between natural discharge and recharge.

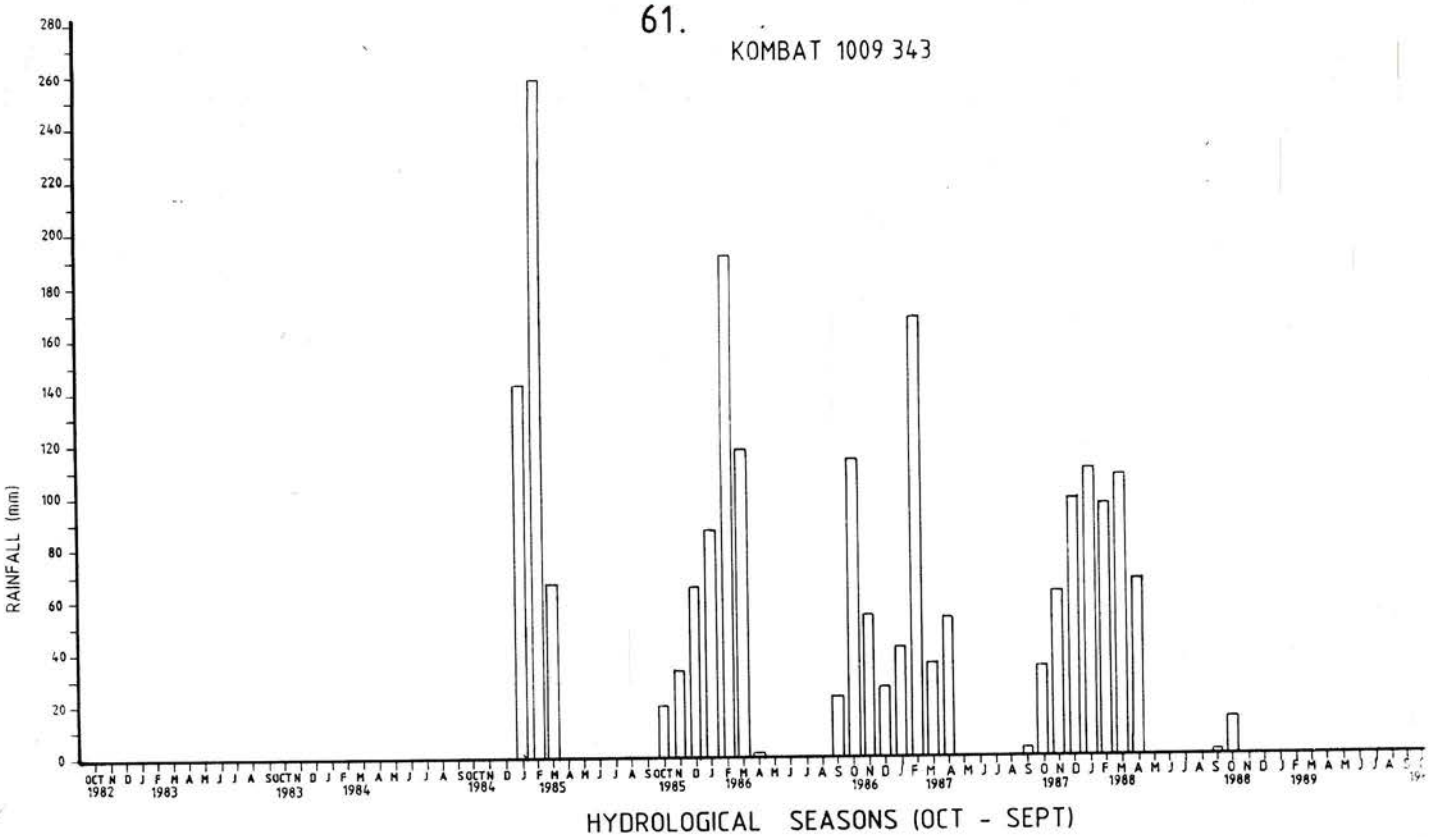


FIGURE 5.8 : RAINFALL IN AREA I - KOMBAT

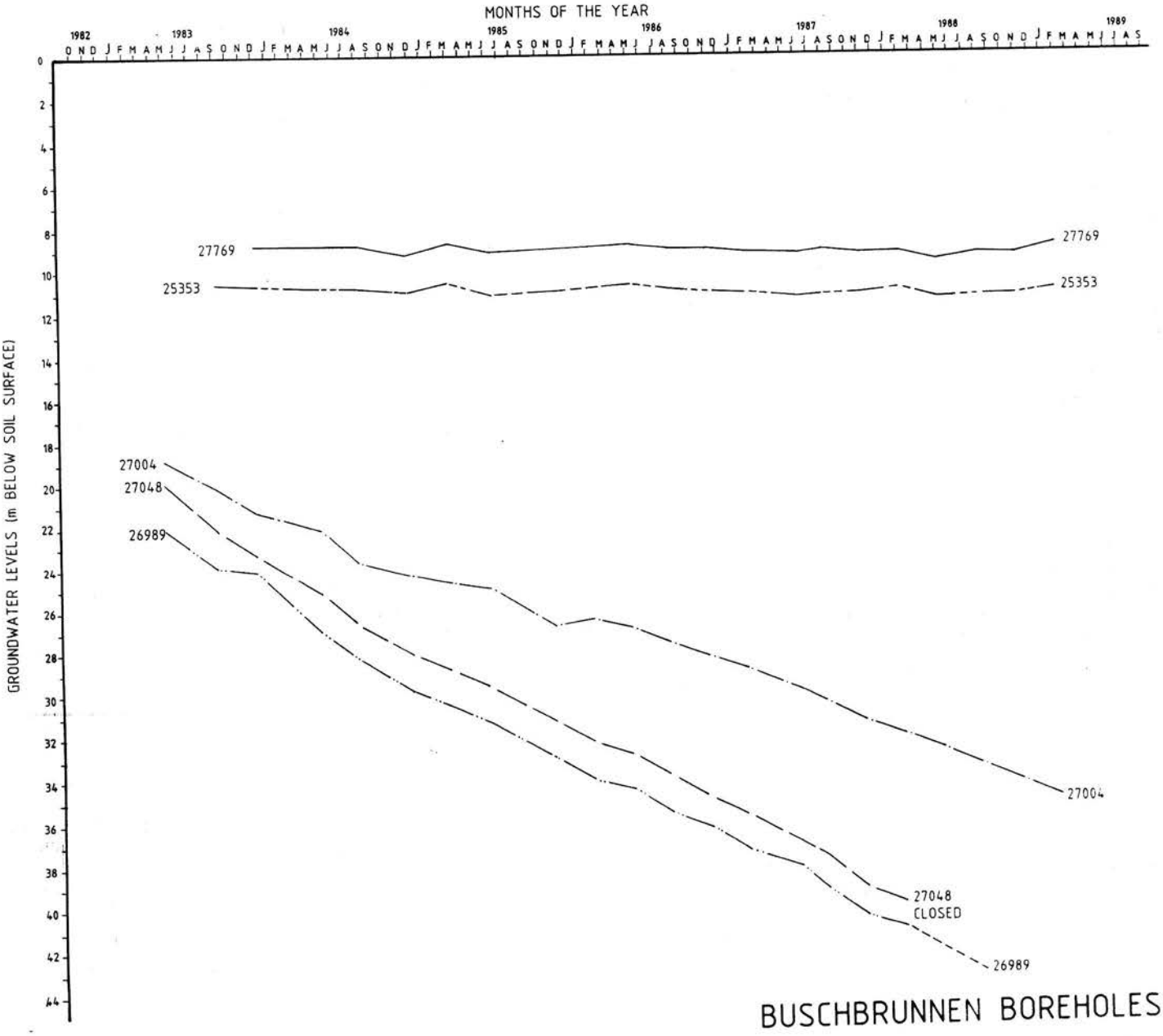


FIGURE 5.9 : WATER LEVEL FLUCTUATIONS IN AREA I - BUSCHBRUNNEN

TABLE 5.8: WATER LEVEL BEHAVIOUR IN BUSCHBRUNNEN AREA

BOREHOLE NO	TIME SPAN	RANGE IN WATER LEVEL CHANGE (m)	CHANGE IN WATER LEVEL DEPTH (m)
27048	05/83 - 02/88	19.88 - 39.95	-20.09
27004	05/83 - 02/89	18.86 - 35.05	-16.19
26989	05/83 - 08/88	22.08 - 43.10	-21.02
25353	09/83 - 02/89	10.59 - 11.05	- 0.46
27769	12/83 - 02/89	8.66 - 8.96	- 0.30

vi) **KOMBAT/ASIS**

There are five boreholes for which data are being collected, and three recorders located here. Monitoring was started in mid 1983. The Kombat rainfall station 1009 343, is used as reference. Figure 5.8 shows the rainfall trend. There are two study sites situated on this farm (Transects 5 and 9), one of which is very close to the mine.

In the Kombat/Asis area, Figure 5.10 and TABLE 5.9, a general downward trend in water level fluctuation is evident during the period May 1983 to December 1988. Some fluctuations occurred as a result of pumping in the main shaft at the Kombat Mine at the beginning of 1989.

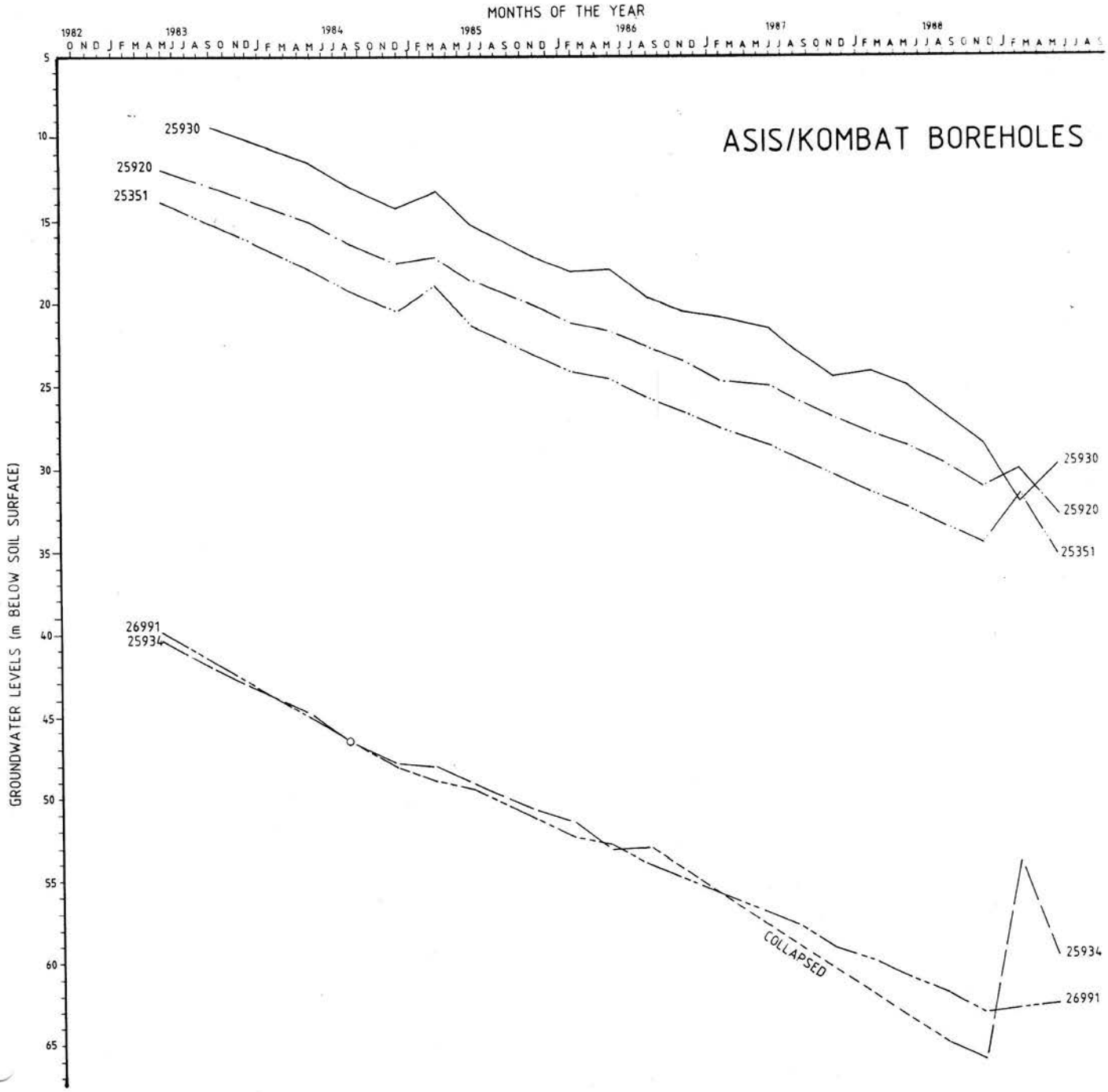


FIGURE 5.10 : WATER LEVEL FLUCTUATIONS IN AREA I - KOMBAT/ASIS

TABLE 5.9: WATER LEVEL BEHAVIOUR IN KOMBAT/ASIS AREA

BOREHOLE NO	TIME SPAN	RANGE IN WATER LEVEL CHANGE (m)	CHANGE IN WATER LEVEL DEPTH (m)
26991	05/83 - 05/88	39.93 - 62.92	-22.99
25934	05/83 - 05/89	40.40 - 59.90	-19.50
25920	05/83 - 05/89	11.92 - 32.74	-20.82
25351	05/83 - 05/89	13.89 - 35.32	-21.43
25930	09/83 - 05/89	9.31 - 29.96	-20.65

vii) **BERG AUKAS**

The Berg Aukas 593 area has six boreholes for which data are collected. Monitoring was started in mid 1984, late 1984 and late 1985. One study site (Transect 10) is situated in this area close to the mine. The rainfall station used as reference is that of 1010 422 (Berg Aukas). Figure 5.11 shows the rainfall trend.

From Figure 5.12 and TABLE 5.10, it is evident that the majority of boreholes around the Berg Aukas mine have been recovering during the period 1983 - 1989. This trend has occurred as a result of pumping having ceased in the mine saft. The water table has risen, filling the existing cone of depression. Only borehole 22656 shows a slight downward trend in water level reaction during the 1983 - 1989 period. In all cases small fluctuations are observed. These are caused by recharge from rainfall.

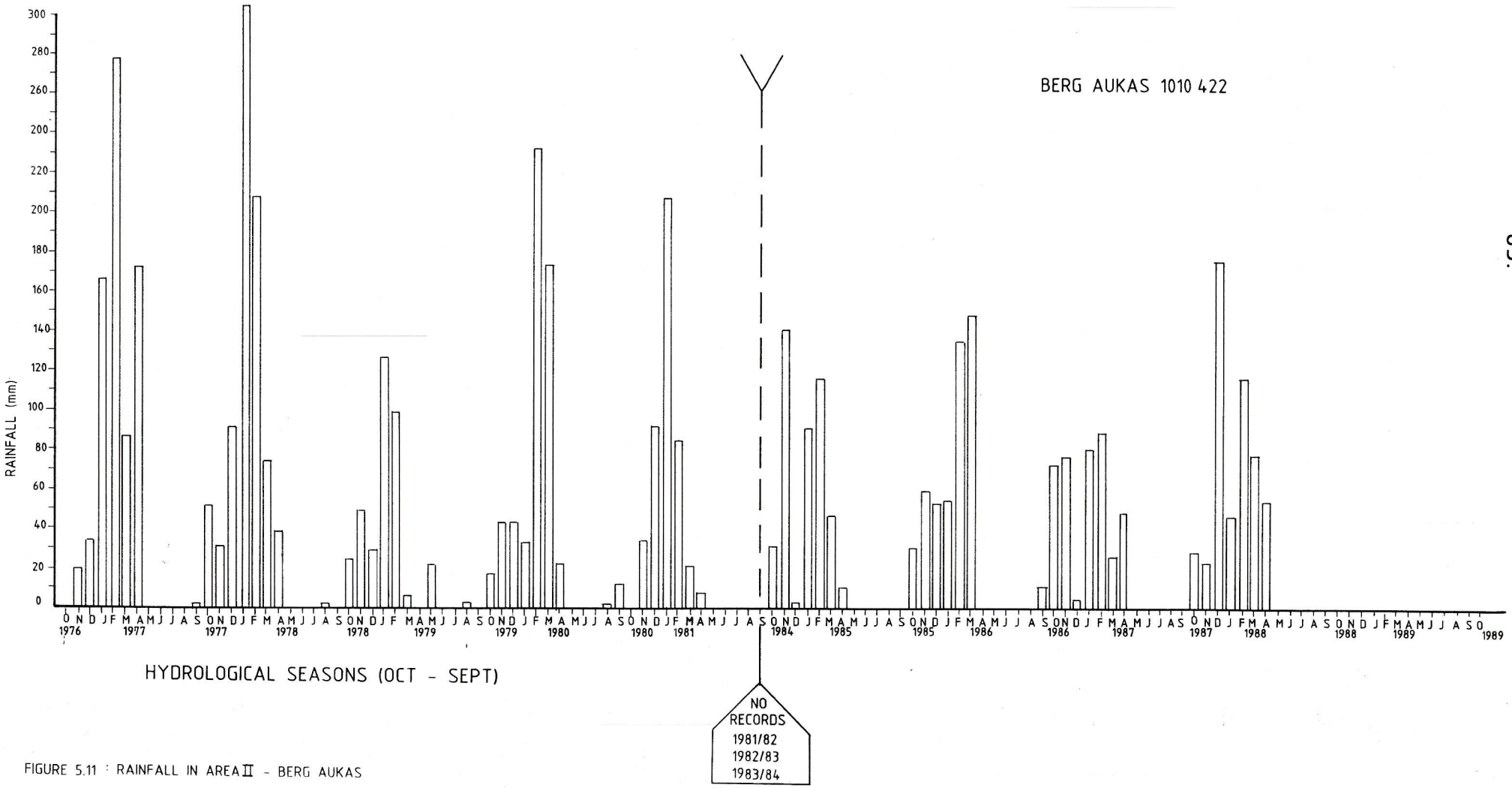


FIGURE 5.11 : RAINFALL IN AREA II - BERG AUKAS

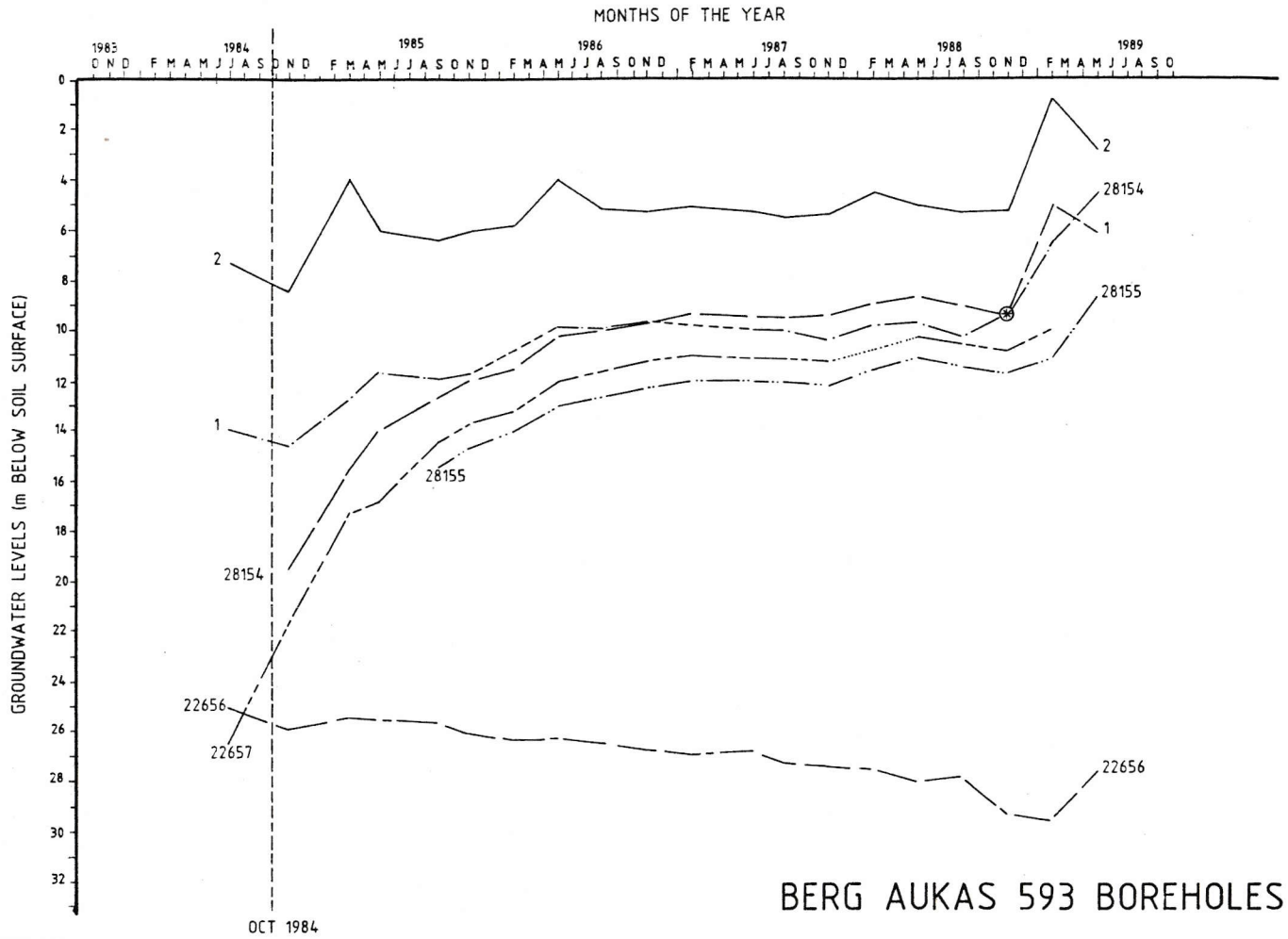


FIGURE 5.12 WATER LEVEL FLUCTUATIONS IN AREA II - BERG AUKAS

TABLE 5.10: WATER LEVEL BEHAVIOUR IN BERG AUKAS AREA

BOREHOLE NO	TIME SPAN	RANGE IN WATER LEVEL CHANGE (m)	CHANGE IN WATER LEVEL DEPTH (m)
1	07/84 - 05/88	13.99 - 6.10	7.89
2	07/84 - 05/89	7.33 - 2.85	4.48
22657	07/84 - 05/89	26.49 - 10.01	16.48
22656	07/84 - 05/89	25.08 - 27.60	- 2.52
28154	11/84 - 05/89	19.51 - 4.54	14.97
28155	09/85 - 05/89	15.47 - 8.70	6.77

6. RAINFALL MONITORING

6.1 INTRODUCTION

Rainfall in Namibia is strongly seasonal in character, and approximately 80% of the year's rain normally falls during the summer months, October through to March.

Rainfall is an important factor in the Karst area, since the majority of recharge to the underground reservoirs results from direct precipitation. The Karst area under investigation receives a rainfall of 500 - 600 mm per annum. The absence of well defined surface drainage systems indicates that little water is lost to surface run-off, which is thus favourable for infiltration. This situation is characteristic of an area undergoing constant karstification.

In this study, interest has been focused on the region between, in and around Otavi, Tsumeb and Grootfontein.

At the outset of this study, a map showing isohyets of long-term mean annual precipitation (M.A.P.) was drawn up for the whole Karst area. A global view of the rainfall pattern was thus obtained. Rainfall stations currently in operation were then selected for closer scrutiny. These stations provide the necessary data for the continuous monitoring of the Karstland rainfall pattern.

By monitoring the rainfall pattern within this investigation area, it may be possible to explain changes in the status of the vegetation vitality relative to the soil moisture régime and the groundwater table.

6.2 METHODS

6.2.1 Data collection

Records from 85 daily-read rain gauges covering a rectangular area of 215 km x 115 km were utilized in drawing up the isohyetal map of long term Mean Annual Precipitation (M.A.P.) for the whole Karstland area. The earliest records used for the drawing up of the isohyetal map date from 1897 (Outjo 0961 247) and the closing date of the data set assembled was 1984. The map was drawn up at a scale of 1:500 000. Refer to Figure 6.1.

Of these 85 rain gauges, 24 stations were selected for rainfall monitoring purposes on an annual basis. These are listed in TABLE 6.1.

These stations were chosen as representative data collection points covering the area which includes the four synclines and hence all the boreholes for the Karst Borehole Scheme. This area comprises eight rectangular sections corresponding to the two grid squares 1917 and 1918 in the Weather Bureau Scheme.

Sections are quarter-degree squares numbered according to the system adopted by the Weather Bureau, Pretoria. Rainfall station numbers comprise the section number and suffic number based on position among the 900 possible square minutes of arc within each section.

These particular rainfall stations were selected as they were the only stations still operational at the initiation of this study, and had fairly long records. Other stations in this vicinity had been closed either recently or a long time prior to the study, or had been opened too recently and had too few years of record.

It was decided at the outset not only to collect data from the date of the project's initiation, but also to look at records prior to that date. The 1979/80 hydrological season was chosen as the point of departure. A reason which prompted this choice was that the station Gaikos (1056 717) was the only "long standing" current station in that section. having been opened in 1979, and was thus an important data collection point.

Other important stations amongst those selected include Berg Aukas and Kombat, since these two mining areas came into existence in 1956 and 1961 respectively, (Berg Aukas closed down in 1978), and are considered important ecological impact case studies.

Information on anomalies in periods of record of the selected stations is included in Appendix 1.

TABLE 6.1: KEY RAINFALL STATIONS USED IN KARSTLAND ANALYSIS

STATION NAME	NO	CO-ORDINATES LATITUDE	CO-ORDINATES LONGITUDE	DATE WHEN STATION OPENED	MEAN ANNUAL PRECIPITATION M.A.P. (mm)
Grootfontein	1010 216	19°36'	18°08'	5-1968	576.9
Berg Aukas	1010 422	19°32'	18°15'	1-1962	527.3
Gabasis	1010 118	19°58'	18°04'	1-1940	439.9
Rietfontein 2.	1009 467	19°47'	17°46'	1-1940	570.5
Awagobibtal	1009 639	19°39'	17°52'	1-1940	594.0
Otjirukaku	1009 852	19°42'	17°59'	7-1926	564.1
Uitkomst	1009 850	19°42'	17°59'	3-1961	589.3
Gai Kaisa 1.	1009 593	19°53'	17°50'	1-1940	550.2
Kombat	1009 343	19°43'	17°42'	1-1985	543.3
Una	1008 660	20°00'	17°22'	4-1954	471.0
Otavi	1008 578	19°38'	17°20'	9-1913	528.2
Goabpforte	1008 302	19°32'	17°11'	12-1949	588.8
Huettenhof	1054 329	19°29'	17°11'	12-1951	582.1
Soavis	1054 231	19°21'	17°08'	1-1940	509.2
Sissekab	1055 350	19°20'	17°12'	1-1940	529.6
Tsumeb	1055 374	19°14'	17°43'	7-1911	527.3
Gaub	1055 447	19°27'	17°45'	1-1940	646.8
Toggenburg	1056 809	19°29'	17°57'	3-1952	592.4
Gaikos	1056 717	19°27'	18°24'	7-1979	507.8
Klein Huis	1057 204	19°24'	18°37'	8-1950	491.4
Abendruhe	1057 465	19°15'	18°46'	10-1962	476.0
Maroelaboom	1057 616	19°16'	18°51'	8-1931	434.1
Sonop	1057 723	19°03'	18°55'	1-1964	529.3
Otjituuo	1011 130	19°40'	18°35'	1-1940	430.1

1. Gai Kaisa station closed in September 1986.

2. Rietfontein station closed in December 1984 and re-opened in October 1985. This staion replaces Gai Kaisa.

6.2.2 Data processing

ANNUAL GRAPHICAL REPRESENTATION:-

A computer programme utilized by the Hydrology Division made it possible to extract the following for each station:

i) Mean monthly precipitation
ii) Mean annual precipitation
iii) Median annual precipitation
iv) Number of years of data

Histograms showing the monthly totals for each station as well as the monthly long term means have been drawn up on a seasonal basis (1 October - 30 September). Other information included on the histograms is; the total rainfall for that season, the mean seasonal rainfall and number of years used to calculate the latter. These histograms and the tabled monthly data are to be found in the Karstland Plant Ecology Box File. The information presented in this graphic format should be used for comparative referencing.

Figure 6.2 shows the distribution of these selected rainfall stations.

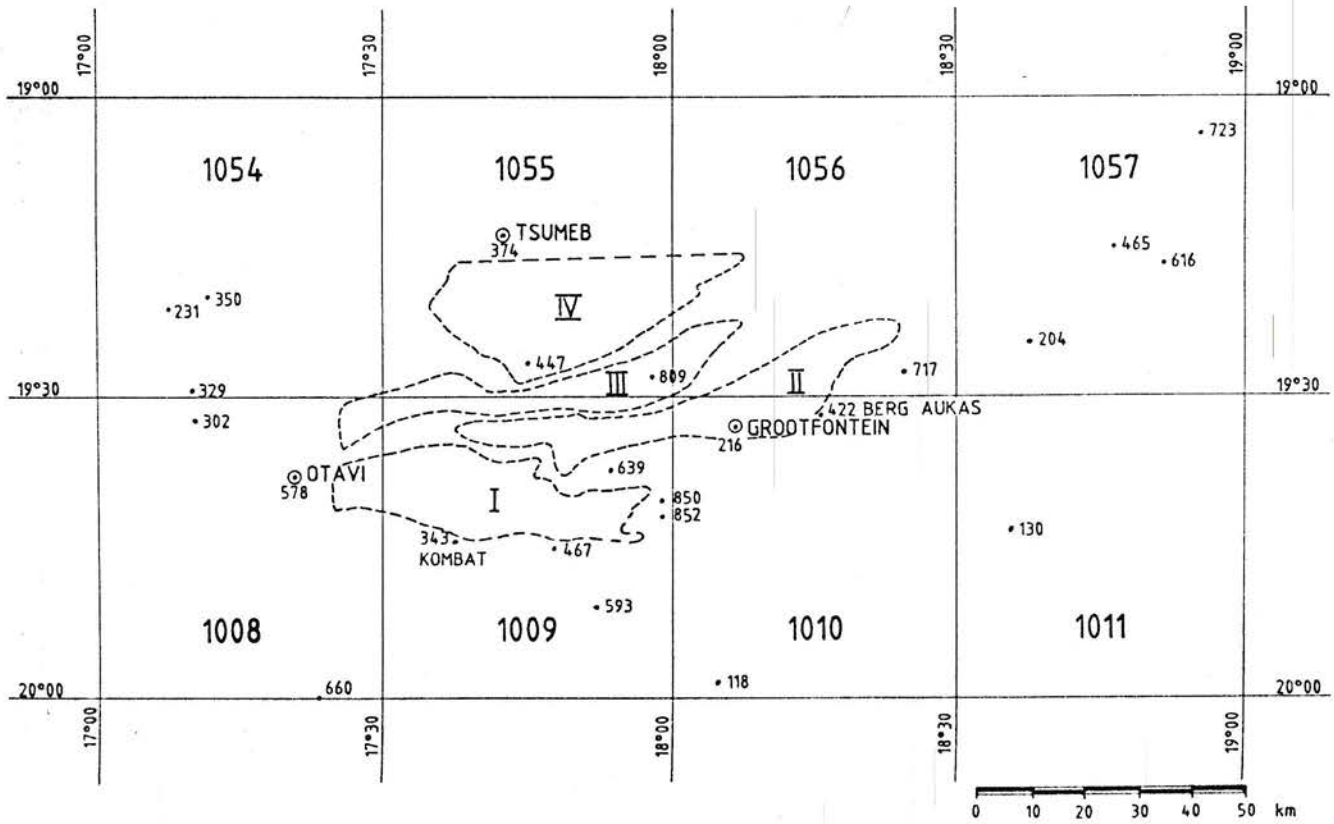


FIGURE 6.2 : KEY RAINFALL STATIONS IN EIGHT SECTIONS OF KARSTLAND

MULTIQUADRIC SURFACE FIT PROGRAMME (MQSF):-

After six months of taking monthly soil moisture measurements (explanation follows in Section 7) at sites on Brandwag/Uitkomst and Urupupa, it was suggested that more localized rainfall data should be collected at or near these sites, by installing additional rain gauges. As this suggestion would have been too expensive and impractical to impliment, an alternative was sought. The Multiquadric Surface Fit Programme used by the Hydrology Division was employed to calculate the mean monthly rainfall for both these areas, using the data from existing Met-Office rainfall stations located near the respective sites.

This programme fits a multiquadric surface to monthly rainfall data, whereby rainfall depths are integrated over a pre-determined grid system of rectangles.

Rainfall figures were computed for both the Brandwag/Uitkomst and Urupupa areas using the MQSF programme and the monthly data from four rainfall stations in the vicinity. As the monitoring of groundwater level fluctuations in Area I was started in 1983, the rainfall figures were computed as from the 1982/83 season onwards. The rainfall stations utilized in the MQSF programme are listed below:-

Gai Kaisa	1009 593
Awagobibtal	1009 639
Uitkomst	1009 850
Otjirukaku	1009 852
Rietfontein	1009 467

Due to the "temporary" closure of station 1009 593, the data from the re-opened station 1009 467 has been used for the 1986/87 season onwards.

The rainfall values computed for these two sites are given in TABLE 6.2, and represented graphically in Figures 6.3 and 6.4.

TABLE 6.2 : MULTIQUADRIC SURFACE FIT TO COMPUTE MONTHLY RAINFULL FOR BRANDWAG AND URUPUPA

		1982/83	1983/84	1984/85	1985/86	1986/897	1987/88	1988/89
BRANDWAG (TRANSECT 1)	OCT	7.02	26.97	43.97	20.60	67.46	44.97	
	NOV	42.11	79.62	27.51	67.04	38.31	36.60	
	DEC	109.60	151.80	53.58	85.14	14.76	116.01	
	JAN	120.15	45.19	97.10	45.05	28.77	91.14	
	FEB	34.31	63.13	159.99	127.86	149.28	85.78	
	MAR	27.22	67.03	73.10	113.57	94.04	89.56	
	APR	17.55	130.28	1.53	83.25	64.69	57.06	
	MAY	0.04	0.04	1.50	0.0	0.0	0.0	
	JUN	23.47	1.99	0.0	0.01	0.0	0.0	
	JUL	0.0	0.0	0.0	0.0	0.0	0.0	
	AUG	0.0	0.0	0.0	0.0	0.0	0.0	
	SEP	0.0	0.0	0.0	32.08	0.0	0.0	

		1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89
URUPUPA (TRANSECT 2)	OCT	6.71	29.60	10.64	17.30	50.29	48.09	
	NOV	27.72	86.50	27.31	40.77	26.20	59.40	
	DEC	134.07	139.20	36.31	76.50	26.92	110.39	
	JAN	103.31	46.45	118.76	58.60	38.45	103.56	
	FEB	58.87	56.83	114.18	107.24	160.93	109.47	
	MAR	51.27	43.18	53.51	127.40	84.44	115.27	
	APR	18.21	109.14	6.26	44.65	66.88	63.02	
	MAY	1.89	1.89	0.0	0.0	0.0	0.0	
	JUN	16.31	1.65	0.0	0.31	0.0	0.0	
	JUL	0.0	0.0	0.0	0.0	0.0	0.0	
	AUG	0.0	0.0	0.0	0.0	0.0	0.0	
	SEP	0.0	0.0	0.0	22.35	0.0	0.0	

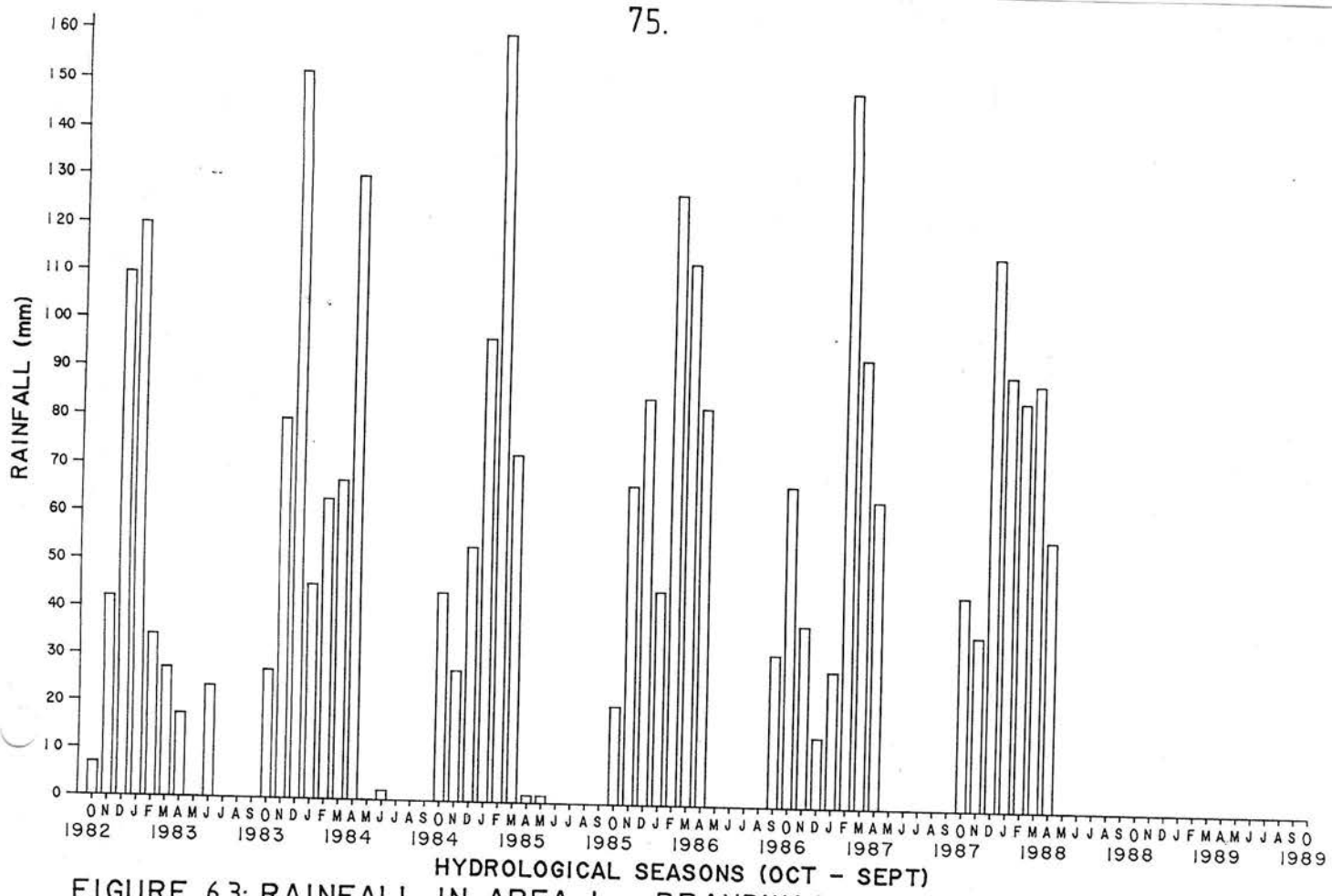


FIGURE 6.3: RAINFALL IN AREA I - BRANDWAG USING MQSF PROGRAMME

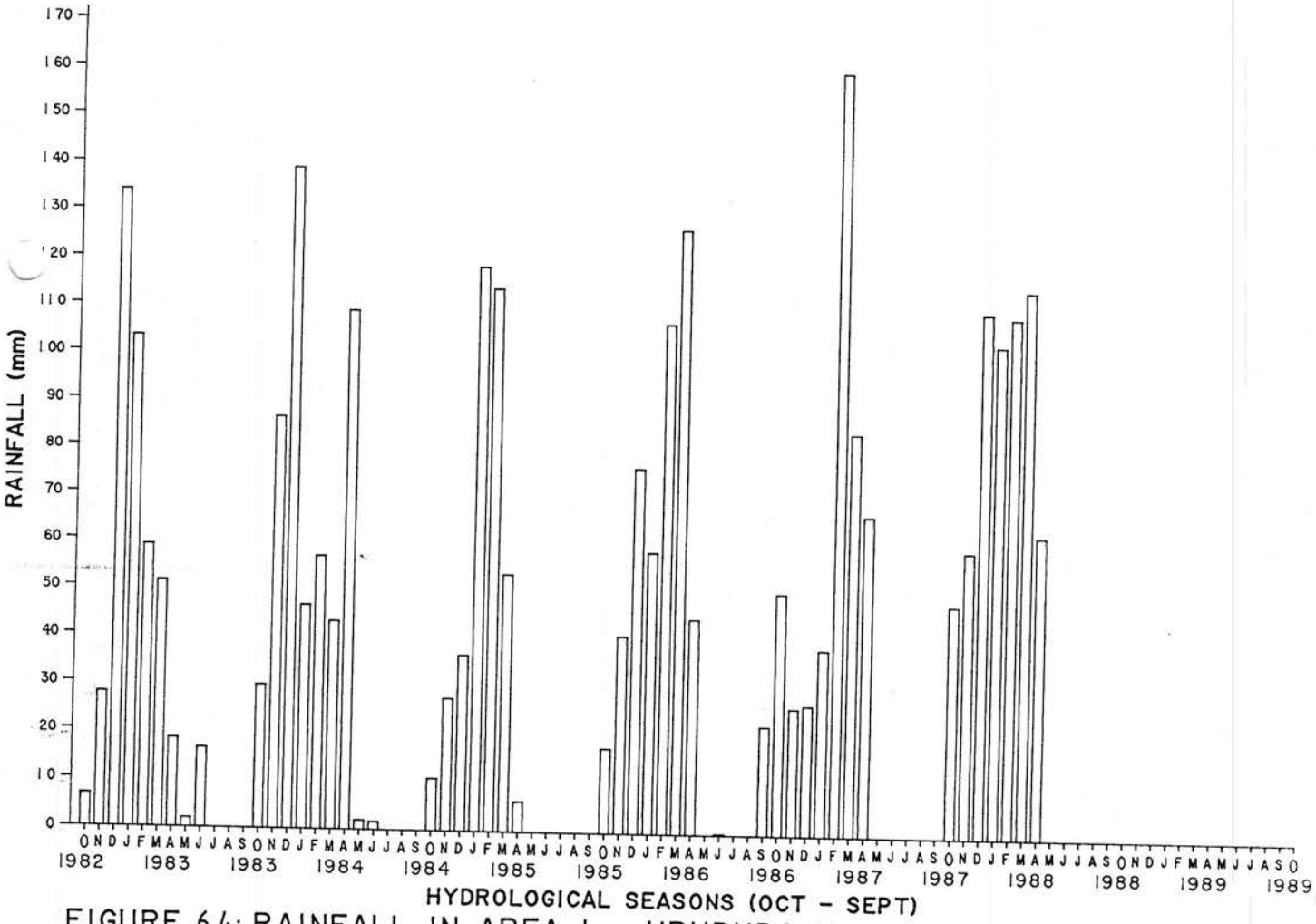


FIGURE 6.4: RAINFALL IN AREA I - URUPUPA USING MQSF PROGRAMME

POINT RAINFALL AND AREAL RAINFALL:-

TABLE 6.3 refers to the total annual precipitation, the mean annual precipitation and long term medians for each rainfall station for the seasons 1979/80 to 1987/88.

TABLE 6.4 shows the observed total seasonal rainfall as a percentage of the mean annual precipitation (M.A.P.) for the years since the initiation of the study, namely, 1985/86 to 1987/88. The 1988/89 season's available data were added to this table at the last moment, but have not been included in the discussion.

Contour maps (isohyets) were drawn up showing seasonal rainfall as a percentage of the long term mean (M.A.P.) for the two years of baseline study, 1986 and 1987, and the first year of long term monitoring thereafter 1988.

From these contour maps it is thus possible to obtain a global view of any particular year's rainfall pattern relative to the M.A.P. for this period. (See Figures 6.5, 6.6 and 6.7).

Included in TABLE 6.3 are the calculated long term medians for each station. The medians are used to give a more realistic view of the rainfall situation. The median is a positional value in contrast with the arithmetic character of the mean, and is less affected by extreme values within the group than the mean. This makes it a useful measure of the central tendency. The medians have been included since they have a more practical application in semi-arid climate areas as far as rainfall is concerned.

TABLE 6.3 : TOTAL SEASONAL PRECIPITATION (mm) FOR SELECTED RAINFALL STATIONS

STATION NAME/NO		1979/80	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	LONG TERM MEAN ANNUAL PRECIPITATION (MAP)	LONG TERM MEDIAN (UP TO 1987/88)
Grootfontein	1010/216	673.7	395.3	544.5	374.2	577.8	390.2	550.5	400.0	417.0	576.9	534.0
		1976/77	1977/78	1978/79	1979/80	1980/81						
*Berg Aukas	1010/422	748.6	802.6	359.5	578.5	448.7	439.6	493.4	400.0	523.5	527.3	468.4
Gabasis	1010/118	568.0	403.0	477.0	401.0	387.2	409.9	414.5	371.5	475.6	439.9	408.8
*Rietfontein	1009/467							601.5	469.6	692.0	570.5	504.3
Awagobibtal	1009/639	675.6	382.5	480.0	385.0	543.0	402.0	643.5	481.0	517.6	594.0	543.1
Otjirukaku	1009/852	939.4	404.0	470.4	447.2	533.0	427.5	550.5	445.0	498.0	564.1	509.3
Uitkomst	1009/850	811.5	376.3	529.0	313.5	550.0	484.1	593.1	464.8	536.5	589.3	541.5
Gai Kaisa	1009/593	656.0	409.0	477.0	503.0	550.0	389.0	412.3			550.2	503.0
*Kombat	1009/343							540.6	503.0	585.9	543.3	503.0
Una	1008/660	475.8	358.9	555.1	315.3	426.9	341.0	350.5	244.5	285.5	471.0	465.2
Otavi	1008/578	384.9	364.5	642.4	406.1	530.4	517.4	509.7	396.7	390.9	528.2	509.7
Goabpforte	1008/302	535.0	431.3	543.4	465.4	566.3	387.4	512.6	423.4	505.3	588.8	556.1
Huettenhof	1054/329	511.7	477.9	521.7	438.6	559.5	536.0	445.8	404.4	552.9	582.1	552.5
Scavis	1054/231	444.3	324.1	460.3	450.3	513.2	413.0	471.0	371.9	412.6	509.2	470.7
Sissekab	1054/350	533.8	343.4	505.8	373.4	574.5	385.7	498.9	322.2	392.6	529.6	514.5
*Tsumeb	1055/374	727.0	360.9	521.0	370.3	456.2	466.0	694.0		373.2	527.3	502.8
Gaub	1055/447	793.7	459.8	600.6	520.5	936.4	603.0	696.3	434.0	527.5	646.8	601.8
Toggenburg	1056/809	627.0	330.0	469.0	358.0	521.0	626.0	820.0	555.5	661.0	592.4	555.5
Gaikos	1056/717	759.0	440.0	379.7	464.1	542.4	436.3	630.2	462.1	488.1	507.8	464.1
Klein Huis	1057/204	483.9	409.3	329.0	370.4	551.4	423.0	442.5	306.8	271.4	491.4	446.4
Abendruhe	1057/465	646.0	442.5	294.0	336.0	628.5	559.0	506.5	313.5	517.5	476.0	493.8
Maroelaboom	1057/616	600.5	401.9	338.8	291.5	533.4	630.3	404.5	332.0	466.6	434.1	420.6
Sonop	1057/723	783.4	415.0	354.6	354.2	492.2	437.6	601.6	367.0	544.7	529.3	449.8
Otjituuo	1011/130	523.5	354.0	286.0	245.3	323.7	357.5	268.0	178.5	482.0	430.1	373.0
**Brandwag	1009/851				381.5	566.1	458.3	574.6	457.3	521.1		
**Urupupa	1009/674				418.4	514.4	367.0	495.1	454.1	609.2		

** Rainfall values calculated using Multiquadric Surface Fitting Programme. Actual stations do not exist.
* Stations temporarily closed.

TABLE 6.4: COMPARISON OF OBSERVED RAINFALL, PERCENTAGE OF M.A.P. AND LONG TERM MEAN SINCE INITIATION OF STUDY

STATION NAME/NO		MAP	1985/86		1986/87		1987/88		1988/89	
			% OF MAP	TOTAL	% OF MAP	TOTAL	% OF MAP	TOTAL	% OF MAP	TOTAL
Grootfontein	1010/216	576.9	95.4	550.5	69.3	400.0	72.3	417.0	82.6	476.6
Berg Aukas	1010/422	527.3	93.6	493.4	75.9	400.0	99.3	523.5	112.1	591.0
Gabasis	1010/118	439.9	94.2	414.5	84.5	371.5	108.1	475.6	93.3	410.5
Rietfontein	1009/467	570.5	105.4	601.5	82.3	469.6	121.3	692.0	153.8	877.5
Awagobibtal	1009/639	594.0	108.3	643.5	81.0	481.0	87.1	517.6	132.1	784.8
Otjirukaku	1009/852	564.1	97.6	550.5	78.9	445.0	88.3	498.0	128.7	726.0
Uitkomst	1009/850	589.3	100.6	593.1	78.9	464.8	91.0	536.5		
Gai Kaisa	1009/593	550.2	74.9	412.3						
Kombat	1009/343	543.3	99.5	540.6	92.6	503.0	107.8	585.9	105.0	570.5
Una	1008/660	471.0	74.4	350.5	51.9	244.5	60.6	285.5	131.0	617.0
[illegible]vi	1008/578	528.2	96.5	509.7	75.1	396.7	74.0	390.9	133.9	707.3
Goabpforte	1008/302	588.8	87.1	512.6	71.9	423.4	85.8	505.3	116.2	683.9
Huettenhof	1054/329	582.1	76.6	445.8	69.5	404.4	95.0	552.9	71.3	414.9
Soavis	1054/231	509.2	92.5	471.0	73.0	371.9	81.0	412.6	111.0	565.0
Sissekab	1054/350	529.6	94.2	498.9	60.8	322.2	74.1	392.6	97.1	514.3
Tsumeb	1055/374	527.3	131.6	694.0			70.8	373.2	81.0	427.0
Gaub	1055/447	646.8	107.7	696.3	67.1	434.0	81.6	527.5		
Toggeburg	1055/809	592.4	138.4	820.0	93.8	555.5	111.6	661.0	130.9	775.5
Gaikos	1056/717	507.8	124.1	630.2	91.0	462.1	96.1	488.1	125.0	634.7
Klein Huis	1057/204	491.4	90.0	442.5	62.4	306.8	55.2	271.4	97.7	479.9
Abendruhe	1057/465	476.0	106.4	560.5	65.9	313.5	108.7	517.5	128.6	612.0
Maroelaboom	1057/616	434.1	93.2	404.5	76.5	332.0	107.5	466.6	210.3	913.1
Sonop	1057/723	529.3	113.7	601.6	69.3	367.0	102.9	544.7	116.1	614.3
[illegible]tuuo	1011/130	430.1	62.3	268.0	41.5	178.5	112.1	482.0	121.8	524.0

6.3 RESULTS

Reference should be made to the contour maps included, Figures 6.5, 6.6 and 6.7. From these it is possible to consider total seasonal precipitation on an areal basis. The original sepia contours can be overlayed on one another to give a more dynamic impression of the rainfall pattern within the Karst area over the three hydrological years 1985/86 to 1987/88.