The Kuiseb environment: the development of a monitoring baseline

B J Huntley (Editor)

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Cover: Landsat image of the central Namib Desert, illustrating the strong contrast between the dune sea to the south and the gravel plains to the north of the Kuiseb River. The valley of the Kuiseb River passes westwards through the Namib-Naukluft Park to the Atlantic Ocean at Walvis Bay. The valley is occupied by tall *Acacia albida* and *A erioloba* woodlands, providing a linear oasis and migration route for both animals and plants through the desolate sand dune sea and gravel plains. The deep sands of the river bed provide a reservoir of water, the rapid exploitation of which could lead to major changes in the ecological, hydrological and geomorphological dynamics of this desert environment. This report describes the environmental factors which could be most seriously influenced by water extraction, and provides a data base for monitoring such changes, should extraction occur at an excessive rate. Cover acknowledgement: Hartebeesthoek Satellite Remote Sensing Centre, National Institute for Telecommunications Research, CSIR.

Editor's address
B J Huntley
Ecosystem Programmes
Foundation for Research Development
CSIR
P O Box 395
PRETORIA
0001

AIMS OF THE KUISEB ENVIRONMENT PROJECT

The Kuiseb Environmental Project is one of several large multi-disciplinary studies coordinated on behalf of participating organizations by the CSIR's Foundation for Research Development (previously Cooperative Scientific Programmes). Its specific aims are:

- To identify, assess and review potential environmental problems in the Kuiseb basin arising from water use, agricultural, mining, tourist and nature conservation developments.
- To identify and quantify key environmental features which, through regular monitoring, will provide baseline information on the types and rates of change within the system.
- To determine research needs on the processes influencing or influenced by such changes and to coordinate such research within a cooperative programme.
- To develop models of selected portions of the hydrological cycle and other environmental processes to assist in the assessment and prediction of the consequences of development.
- To provide responsible agencies with information and advice on means of reducing the undesirable effects of such changes.

PARTICIPATING ORGANIZATIONS

Council for Scientific and Industrial Research
Department of Agriculture and Nature Conservation, SWA/Namibia
Department of Environment Affairs
Department of Mineral and Energy Affairs
Department of Water Affairs, SWA/Namibia
Desert Ecological Research Unit (until 1974)
Municipality of Walvis Bay
State Museum, Windhoek
University of Durban-Westville
University of Natal
University of Pretoria
University of Stellenbosch
University of the Orange Free State
University of the Witwatersrand

ABSTRACT

The development of the world's largest open-cast uranium mine in the Namib Desert introduced rapidly increasing demands for water to the area in the early 1970's. In the absence of scientifically based information on the likely impact of water extraction from the fragile desert ecosystem, various government departments and universities established a cooperative research project to investigate the problem. This report outlines the nature of the regional environment, the types of changes expected to occur in the area as a consequence of water extraction from the Kuiseb River, and provides details of features of the geomorphology, hydrology and ecology that might be used as baselines against which to measure changes within the system.

SAMEVATTING

Die ontwikkeling van die grootste oopgroef-uraanmyn in die Namibwoestyn het 'n vinnig-stygende behoefte aan water in die gebied in die vroeë sewentigerjare tot gevolg gehad. In die afwesigheid van wetenskaplik-gefundeerde inligting oor die waarskynlike impak van wateronttrekking vanuit die sensitiewe woestynekosisteem het verskeie regeringsdepartemente en universiteite 'n koöperatiewe navorsingsprojek daargestel om die probleem te ondersoek. Hierdie verslag beskryf die aard van die omgewing in die gebied, die tipe veranderinge wat verwag word as gevolg van die onttrekking van water vanuit die Kuisebrivier, en dit verskaf besonderhede van aspekte van die geomorfologie, hidrologie en ekologie wat as 'n basis gebruik kan word om veranderinge in die sisteem te bepaal.

ACKNOWLEDGEMENTS

The execution of the multidisciplinary study described in this report would not have been possible without the enthusiastic leadership of the late Mr Bernabé de la Bat and Dr Wessel van Wyk (Chairman, Steering Committee) who played critical roles in guiding the project from initiation to completion.

Special thanks are also due to Mrs E Auret of the Foundation for Research Development, who acted as secretary to the Steering Committee throughout its term of office, and who organized and followed through the numerous discussion group meetings, workshops and general project administration. Her assistance in the preparation of the final report is also greatly appreciated.

EXECUTIVE SUMMARY

1. The development of the world's largest open-cast uranium mine at Rössing in the Central Namib Desert introduced rapidly increasing demands for water to the area in the early 1970's.

2. At the time it appeared that these demands would have to be met by water drawn from the Kuiseb River, either by abstraction from underground reservoirs in its lower reaches in the Namib-Naukluft Park, or through the construction of dams in its upper catchment in the Khomas Hochland and Escarpment.

3. The consequences of the increased use of the water resources of the Kuiseb basin were believed to cause a lowering of the water table which would result in: the death of the dense acacia woodland which forms a linear oasis across the desert; the unhindered northward advance of dunes from the main Namib Sand Sea; the termination of subsurface flow of freshwater from the Kuiseb to Sandvis Lagoon; the depletion of drought reserves for plains game and Topnaar Hottentot domestic stock through the loss of the acacia woodland and associated vegetation; and ultimately the siltation of Walvis Bay Lagoon.

4. In the absence of adequate factual information, an inconclusive debate between parties in favour or against the concept of increased water use from the Kuiseb River ensued. In 1973 however, the responsible authorities established a multidisciplinary cooperative research programme, the Kuiseb Environmental Project to, inter alia, identify and quantify key environmental features which, through regular monitoring, would provide baseline information of the types and rates of change within the system under an anticipated declining water table in order to provide decision makers with scientifically sound information on which to base management and conservation plans.

5. The limited availability of funds and manpower led to the use of a systems analytical approach in which the Kuiseb basin was divided into hydrological/ecological compartments within and between each of which the rates and directions of water transfers, and the factors influencing or influenced by these flows, could be studied.

6. The geological/geomorphological history of the Namib was studied and the results indicate that a desert environment has predominated uninterrupted for at least the last 65 million years. The present Kuiseb River valley developed approximately 16 million years ago, although the present incised course is probably 2-3 million years old. The Kuiseb River has been an effective barrier to the northerly advance of the main Namib Sand Sea for at least the last 1,8 million years.

7. Hydrological and geohydrological studies indicate that the Kuiseb catchment receives on average only 159 mm rainfall per annum and provides an extremely widely fluctuating water yield, ranging from ca 220 M m^3 to zero, with a mean of ca 40 M m^3 per annum at the base of the escarpment, with an as yet undetermined flow to the main abstraction area at Rooibank. During the last 146 years the river surface flow has reached the Atlantic on only 15 occasions.

8. Detailed monitoring of the sand dynamics on the Lower Kuiseb indicated that, in the absence of the flushing action of floods, the estimated time for dunes to cross the southern delta channel ranges from 25 to 100 years, approximately 1500 to 2000 years to cross the Rooibank to Swartbank area and from 100 to 800 years in the Swartbank to Natab sector.

9. The vegetation of the Lower Kuiseb was surveyed, classified and mapped and a detailed analysis of the structure and vitality of the woody species was measured in 17 belt transects and 39 permanent quadrats during July 1978 and July 1981. The study sites fell within three hydrological compartments, one of these being the main water abstraction area. Although fairly marked negative changes in the vitality of the woody species were recorded, the changes occurred in all sectors and appeared to be related to the below average rainfall experienced during the study period and not due to changes induced by water abstraction.

10. The use of aerial photographic techniques, especially that involving colour infra-red photographic emulsions, proved to be extremely efficient and accurate in monitoring changes in woody plant structure and vitality.

11. The availability and utilization of forage and water sources within the riverine woodland linear oasis was measured and indicated that they played a significant role in the ecology of oryx and Hartmann's zebra, particularly for the populations occupying the inland dune areas to the south of the Kuiseb. The domestic stock of the Topnaar Hottentot communities of the Lower Kuiseb were almost wholly dependent on these food and water resources.

12. Forage production on the gravel plains to the north of the Kuiseb varied considerably according to rainfall patterns and accounted for the massive fluctuations in the large herbivore population from an estimated maximum of 7212 animals in October 1979 to a minimum of 1039 in June 1981. The surviving animals became increasingly dependent on the food and water resources of the Kuiseb riverine woodland as the drought advanced.

13. The overriding conclusion which could be drawn from the studies conducted within the Kuiseb Environmental Project is that the entire ecosystem is extremely dynamic, undergoing unusually large fluctuations in all climatic, geomorphological, hydrological and ecological processes. Water is unquestionably the principal driving force in the Kuiseb environment and changes to the volume, rate and directions of flows within the system would have major consequences. As yet, man-induced changes to the hydrology of the Kuiseb basin have not been demonstrated to have influenced geomorphological or ecological processes within the area.

14. Water supplied from the nearby Omaruru River caused a considerable reduction in the rate of water abstraction from the Lower Kuiseb, following an initial three-fold increase from 1974 to 1977. This undoubtedly averted major changes being recorded during this study. The detailed baselines established during the project will provide an invaluable benchmark against which changes can be measured in the long term, whether or not increased water use from the Kuiseb becomes necessary in the future.

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1. INTRODUCTION

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The Namib Desert occupies 270 000 km^2 of the southwest African coast. It is a land of extreme environmental conditions, of thirst, heat, sandstorms and fog. It possesses unusually impressive landscapes and plants and animals which have evolved some of the most amazing adaphations for survival known to science. It is also a land about which people speak with emotion, their feelings of identity strengthened by such moving tales as those related in Henno Martin's "The Sheltering Desert" and Geoffrey Jenkin's "A Twist of Sand". It is thus not surprising that threats to the sanctity of this environment have aroused the passionate concern of biologists, conservationists and the lay public. The apparent conflict between mining and other industrial demands for water and the maintenance of the Namib ecosystem led to an emotive and often acrimonious debate in the early 1970's. It was due largely to the foresight of the late Bernabe de la Bat that the issue was brought before a properly qualified group of scientists and engineers for evaluation and monitoring.

The conflict originated with the proposal, in long-term water production plans, to pump the groundwaters of the Kuiseb basin to the limits of their yield (Anon 1971; Logan 1974). The water was needed for the rapidly increasing demands set by the Rössing open-cast uranium mine and for other industrial developments in the region. The consequences of such water abstraction, which would greatly exceed the then available estimates of inflow to the Lower Kuiseb, would have possibly included:

- the death of the linear oasis of riverine acacia woodland which provides a major food and shelter resource from the escarpment through the desert virtually to the sea at Walvis Bay;

- the decrease in water availability to desert populations of oryx, Hartmann's zebra and baboons which are largely dependent on the perennial water holes excavated in the bed of the Kuiseb Canyon;

- the reduction of the main forage source of the domestic stock of the Topnaar Hottentot communities, and of the water levels in their traditional wells;

- the movement of dunes across the Kuiseb River, ultimately to engulf Walvis Bay;

- the termination of the freshwater seepage from the Kuiseb under the dunes to Sandvis Lagoon, and the consequent extinction of those plants and animals dependent on this freshwater supply; and

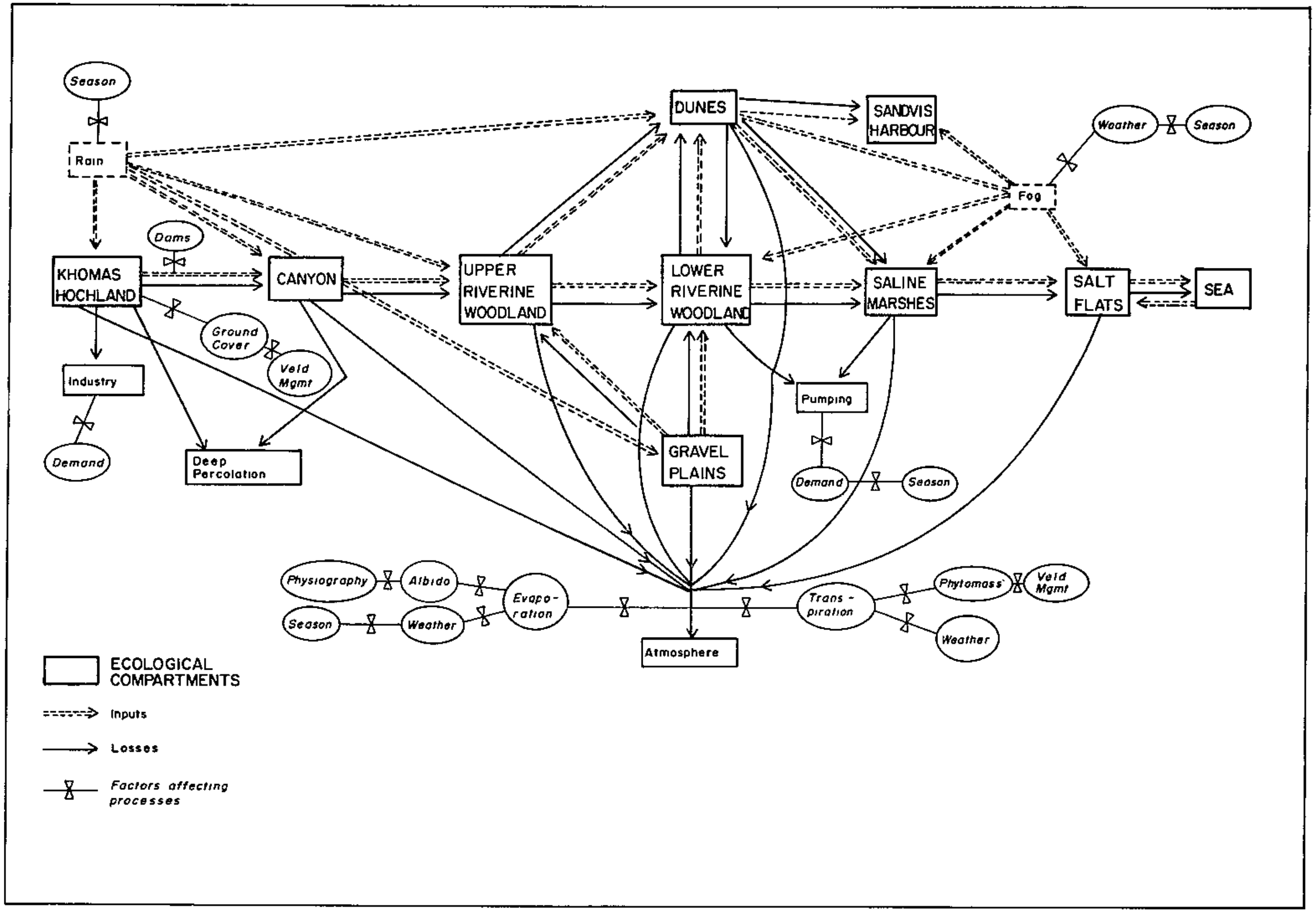

Figure 1. Preliminary descriptive model of Kuiseb basin hydrology.

- the siltation of Walvis Bay Lagoon.

Both parties involved in the conflict considered themselves to have valuable interests at stake - the development of the regional economy or the preservation of the natural environment. A further point in common was their singular lack of any incontrovertible evidence on which to base their diverging opinions on the influences of water extraction from the Lower Kuiseb.

On 16 March 1973 the late Mr de la Bat convened a meeting of interested parties to consider the need for a research programme into the ecology of the Kuiseb River system. The meeting led to the establishment of the Kuiseb Project Advisory Committee (Convener: Dr M K Seely) and to the approval on 9 January 1974 by the Executive Committee of the South West Africa Administration, of a memorandum which inter alia recommended the formal establishment of a coordinated cooperative study of the Kuiseb River environment. The original Advisory Committee was later succeeded by a Steering Committee (Chairman: Dr W L van Wyk) which, in addition to the strong support provided by South West African organizations, received substantial funds from the CSIR's National Programme for Environmental Sciences for research undertaken by scientists from universities and museums.

Thus within the course of a few years a major cooperative research venture of scientists and engineers from all persuasions had joined forces to examine the real nature of the structure and functioning of the Kuiseb environment. These studies would ultimately meet the project's principal objective, viz:

> "The determination of the optimal utilization of the natural resources of the entire catchment area and lower reaches of the Kuiseb River which will result in a minimum of damage to the environment".

From the outset it was clear that neither funds nor manpower would suffice to undertake a fully comprehensive study of all aspects of the Kuiseb environment. At an early stage a systems analytical approach was adopted, albeit in a rudimentary form (Anon 1976). A series of workshops were convened to identify current and future environmental problems arising from water use, mining, agriculture, tourism and nature conservation activities.

In particular an attempt was made to identify and quantify those environmental features which, through regular monitoring, would provide information on the types and rates of changes within the system. The monitoring programme would lead to the identification of major research needs, as would the review of available information which was undertaken by the original working groups established at the initiation of the project. One of the first workshops developed a crude descriptive model of the Kuiseb basin's hydrology (Figure 1) which helped to define the major ecological compartments, the inputs and losses of water to and from these and the factors affecting the directions and rates of these transfers. This model helped in defining the key questions which related to a core set of studies which were further developed by specialist working groups.

In the ten years that have passed since the cooperative project was conceived, a considerable volume of information has been assembled by participating researchers, in particular on the geomorphology, hydrology and ecology of the Kuiseb basin. Knowledge on the area's environment has furthermore been vastly extended by the detailed research activities undertaken by the Desert Ecological Research Unit at Gobabeb and by their workers in the Namib-Naukluft National Park.

The purpose of this report is not to review all the available literature on the Kuiseb basin. It is rather aimed at providing a brief synopsis of the first phase of the study, which aimed at establishing baselines for long-term monitoring of key environmental processes. Most of the information which has resulted from the project may be found in the published papers, and unpublished reports and theses which are referred to in the various chapters. Much of the information on water resources is contained in departmental records and is not readily available for quotation in the open literature. Sufficient information is however provided to allow a coherent discussion to be developed.

Several factors have contributed to making the Kuiseb Environmental Project a particularly interesting and challenging undertaking:

- The study area's distance from major research institutions and its inhospitable, mostly inaccessible terrain which made detailed studies using sophisticated techniques impractical.

- The prevailing rainfall pattern passed from exceedingly wet years (1974, 1976) to a very dry period (1980 to 1982). No flooding occurred during the latter period.

- The rate of water extraction, after rapidly increasing from 1975 to 1977, was reduced in 1980 to the estimated normal rate of replenishment.

- The fact that all extraction took place in one hydrologic compartment, without apparently influencing the hydrological state of those upstream, allowed for comparisons to be made of the response of vegetation to a wide range of water table changes.

- As a consequence of the marked fluctuation in rainfall patterns, forage and water availability, the large herbivore population fluctuated from over 7000 to nearly total depletion of forage reserves and a crash in the large herbivore population to less than 1100 animals.

The first phase of the Kuiseb Environmental Project was aimed, as noted above, at establishing a monitoring baseline. In many respects it did more than this, in providing a detailed description of important facets of the environment and in some cases providing important insights relating to ecosystem processes. The information gained has provided decision makers with a clearer understanding of many contentious issues, several of these being the "raison d'etre" for the Kuiseb Environmental Project.

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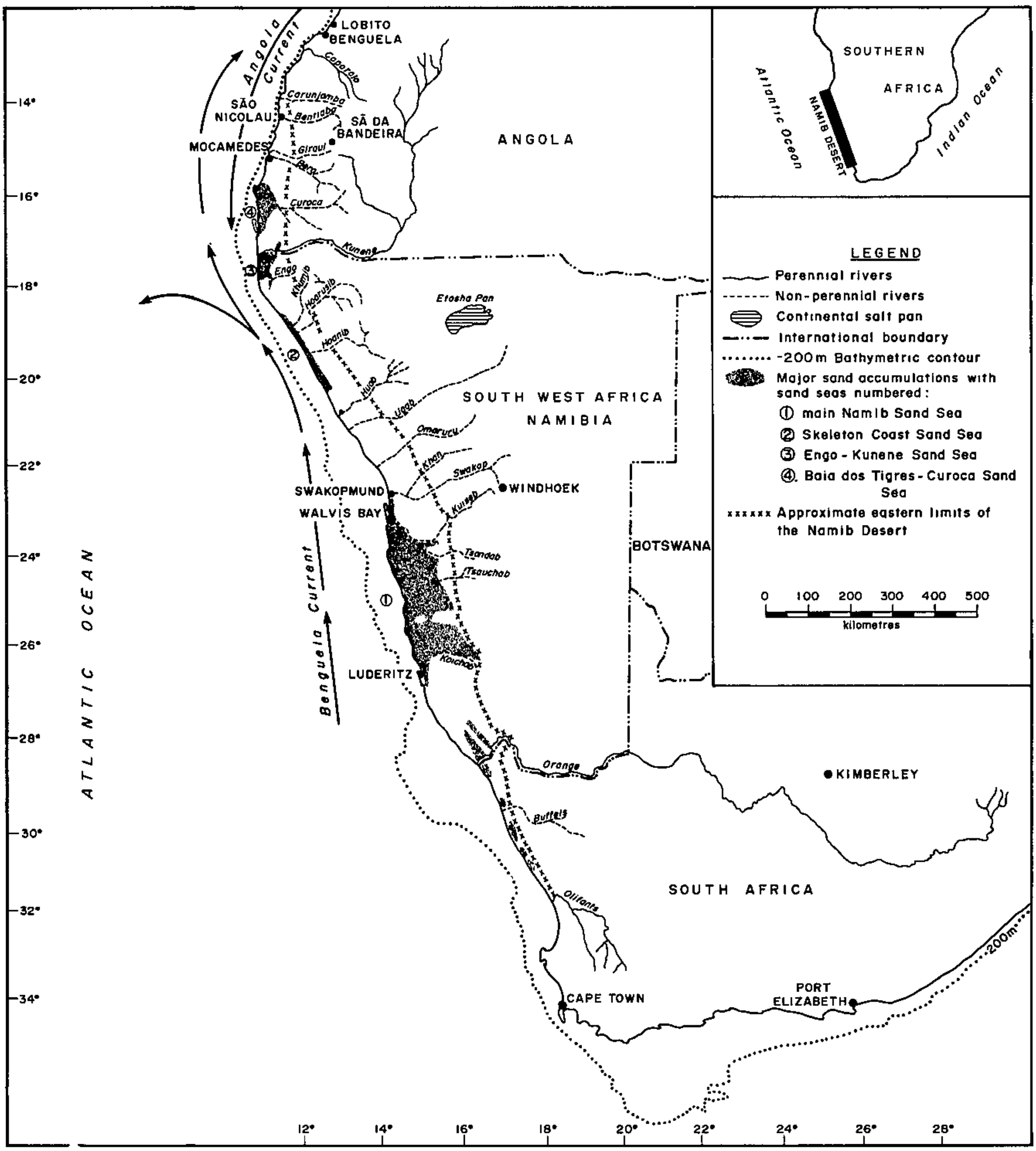

Figure 1. Map of the Namib Desert and environs.

2. THE KUISEB ENVIRONMENT

B J Huntley, CSIR

The Namib comprises the relatively narrow tract of land, some 2000 km long and mostly less than 200 km wide, lying west of the Great Escarpment between the Olifants River, Cape Province, South Africa and Sao Nicolau, Mocamedes District, Angola (Figure 1). The climate is mostly arid to extreme-arid, with the area north of the Kunene River receiving a summer rainfall maximum and the area south of the Orange River receiving a winter rainfall maximum. The desertic conditions are closely linked to the interacting, aridifying effects of the South Atlantic anticyclone, the cold northward-flowing Benguela Current, with associated upwelling and with the divergence of the South East Trades along the coast. Although the present desert can be considered a geologically youthful feature, the sedimentary history records the prevalence of desertic conditions during much of the Cenozoic (the last 65 million years) for this narrow tract of land. The geological history of the Central Namib is outlined by Ward (this volume, Chapter 3).

The Kuiseb River drains a catchment of approximately 14 700 km^2, rising in the Khomas Hochland and flowing 440 km through the Namib Desert to the Atlantic at Walvis Bay (Figure 2). Stengel (1964) provides a detailed account of the Kuiseb and its recent history, while Hattle (this volume, Chapter 4) details the catchment's surface water hydrology.

Long-term records of precipitation within the Kuiseb catchment range from 400 mm per annum in the upper catchment to less than 20 mm at the coast. Much of the moisture input in the Khomas Hochland is lost to the atmosphere by evapo-transpiration and by utilization in agriculture and mining, with a meagre 1 to 1,5 percent of the upland catchment water yield reaching the Lower Kuiseb, mainly by periodic flooding and a small amount of sub-surface flow. Very little surface water reaches the coast, being absorbed by the deep sands of the lower river bed, adjoining dunes and the delta area.

The regional vegetation of the Namib is outlined by Giess (1971) in his account of the vegetation of South West Africa. The Kuiseb catchment includes his vegetation types: 2 Central Namib, 3 Southern Namib, 4 Semi-desert and Escarpment Zone and 8 Highland Savanna. Aspects of these vegetation types are briefly described here-under and in Chapters 7, 8, 10, 11, 12 and 13.

The Kuiseb Environmental Project developed principally around the need to understand the role played by the water resources of the Kuiseb catchment in the region's ecological structure and dynamics. As noted in Chapter 1,

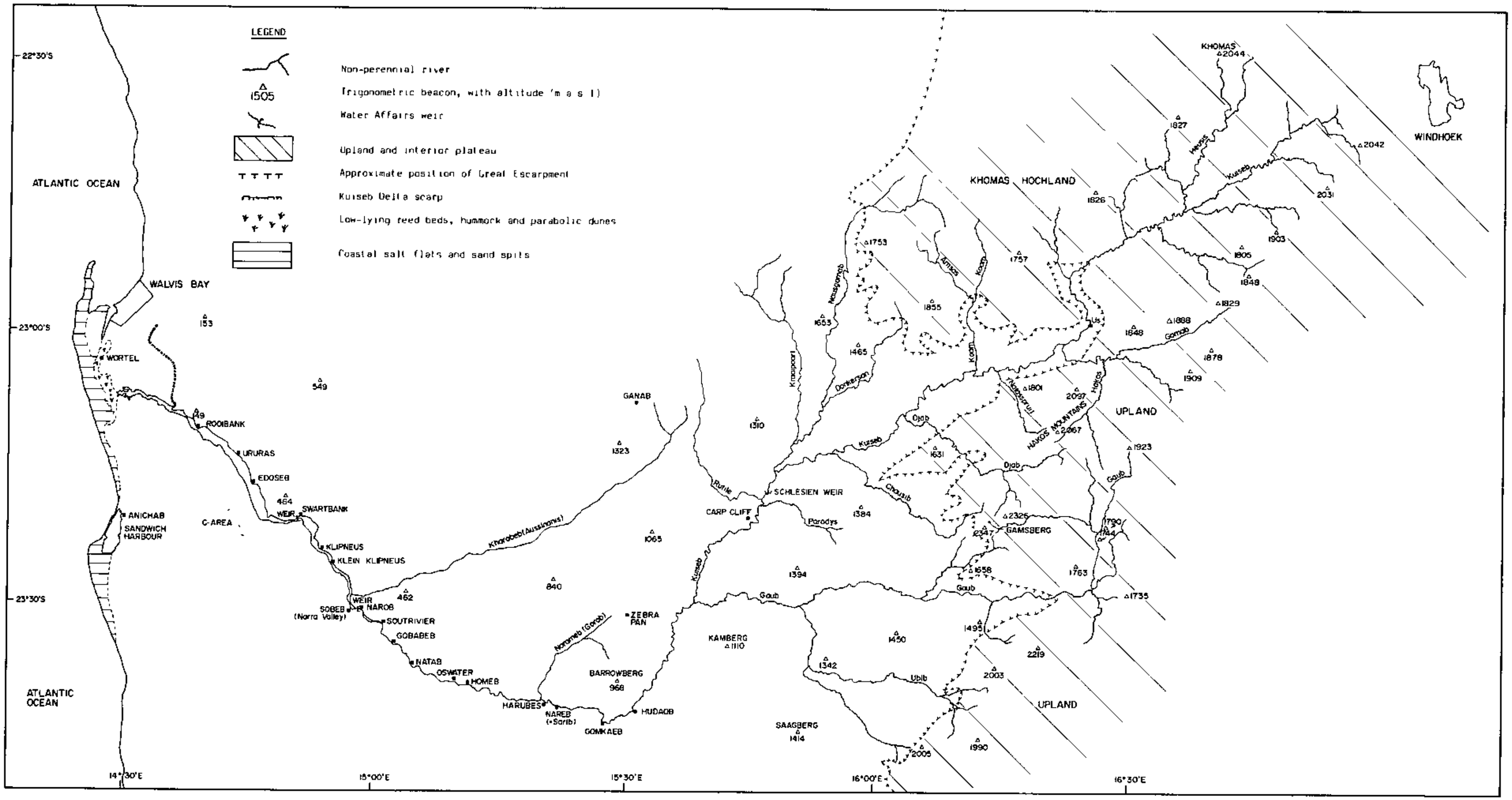

Figure 2. The Kuiseb River basin, indicating the major physiographic regions and study area sub-divisions. Prepared by J D Ward.

limited funds and manpower led to the adoption of a system analysis approach to the study and the definition of interrelated hydrological/ ecological compartments within the catchment. The first approximation model of the system (Chapter 1, Figure 1) identified 11 main compartments. A brief outline of some of their main characteristics is provided as a background to the more detailed accounts of some of the key topics studied in the project.

KHOMAS HOCHLAND AND ESCARPMENT ZONE

The sources of the Kuiseb River rise to the west of Windhoek on the Khomas Hochland. The Hochland is an extensive mica schist plateau of 800 to 2033 m (Figure 3), with well preserved remnants of the original planation surface. The area receives from 100 to 400 mm rainfall per annum, 70 percent of which falls in the months of January to March (see histograms, Chapter 4).

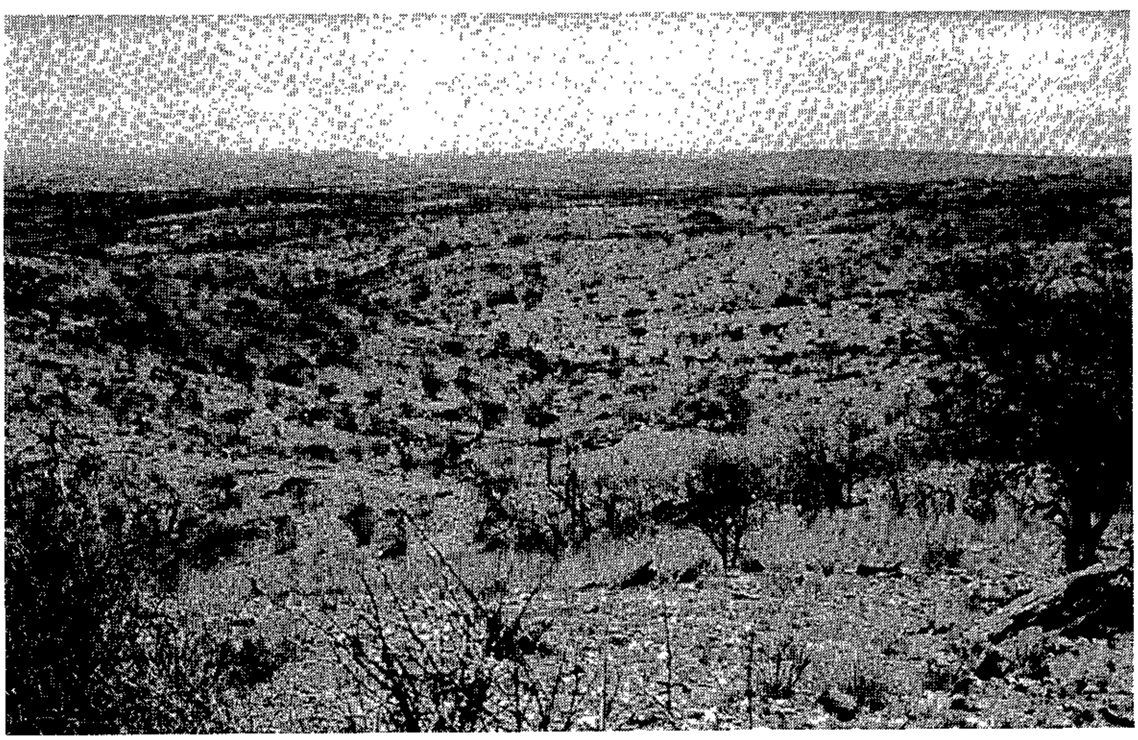

Figure 3. Rolling mica-schist hills of the Khomas Hochland (Photo: J D Ward).

The vegetation of the Hochland has been described in detail by Joubert (1973) and Giess (1971, 1974). The major area of the plateau is occupied by Highland Savanna (Giess 1971) which comprises an open low tree savanna dominated by 3 to 5 m tall _Acacia hereroensis_, _Combretum apiculatum_ and

Ziziphus mucronata. The herb stratum includes the perennial grasses Aristida meridionalis, Eragrostis nindensis, Anthephora pubescens and Brachiaria nigropedata and the annuals Aristida adscensionis, Pogonarthria squarrosa, etc. The escarpment zone falls within the Semi-desert and Savanna transition of Giess (1971). The terrain is extremely rugged, soils are shallow and precipitation generally much lower (50 to 150 mm) than on the more gently undulating plateau. With the exception of A hereroensis, all the species already mentioned occur on the escarpment slopes, with a wide variety of Acacia spp and in particular Commiphora spp. Succulent Euphorbia spp and other arid savanna/desert transition types such as Sterculia africana, Parkinsonia africana, Maerua spp, Boscia spp, etc make their appearance.

The unpredictable and widely fluctuating rainfall received in the Khomas Hochland and the escarpment, the shallow stony soils and scarcity of perennial surface waters account for the low agricultural productivity of the region. The upper Kuiseb catchment is occupied by 109 farms (of an average area of 7618 ha) which were estimated to carry a total of 35 567 cattle, 71 075 sheep and 3025 goats in the mid 1970's (Huyser 1979). A more recent estimate, based on the carrying capacity of the area (which ranges from 8 to 30 ha per large stock unit), indicates that the area's potential stock carrying capacity would be in the order of 76 230 cattle and 102 224 small stock - sheep and goats (Loubser pers comm 1983). The game population was estimated at 3000 kudu, 3200 oryx, 2000 Hartmann's zebra and 1200 springbok.

The water resources of the Kuiseb catchment were surveyed in detail by the National Institute for Water Research as a contribution to the Kuiseb Environmental Project (Huyser 1979). Of 591 sub-surface water sources examined, 90 percent comprised boreholes, 8 percent wells and 2 percent natural springs. The median depth of boreholes was 75,2 m, with the water table lying at a median of 18,9 m delivering an average of 1,6 m^3 hr^{-1}. Open water supplies (from dams and standing pools in riverbeds) accounted for 34 percent of the total water use (2694 m^3 d^{-1}) in the catchment. A survey of farm dams of the Khomas Hochland (Anon 1974) indicated that 407 dams occurred in the area, of which about half were built in the last twenty years. Their total potential storage capacity approximates 19,9 million m^3, which has been reduced to approximately 15,8 million m^3, due to siltation. Average dam capacity (excluding two large dams of 1,7 and 6,9 million m^3) was 27 600 m^3. The average annual runoff from the Khomas Hochland and Escarpment of ca 39,8 million m^3 has been reduced by ca 21 percent by the construction of farm dams.

An evaluation of the viability of the farms of the Kuiseb basin was undertaken early in the project (Joubert et al 1976). The farms were classified according to their current or potential economic viability: 72 were found to be viable, 11 were currently inappropriately managed but could be brought to viability, 12 (on the lower margin of the escarpment/desert transition) were considered totally unsuited to any farming practices, while the remainder suffered from a range of problems preventing their rapid attainment of viability. Logan (1977) provided guidelines for the possible reorganization of some of these latter farms.

Industrial developments in the Khomas Hochland catchment of the Kuiseb are extremely limited. A single copper mine (Matchless, owned by the Tsumeb Corporation) annually produces approximately 20 000 tonne of copper and pyrite concentrates from a reserve of 900 000 tonne ore of 2,37 percent copper and 15,01 percent silver.

KUISEB CANYON

From the foot of the escarpment (Figure 4) to the Nausgomab confluence the Kuiseb is moderately incised whereafter it flows through a deep (ca 100 to 200 m) canyon (Figure 5) to Natab. The canyon unit normally receives very little rainfall and little runoff from the surrounding plains and hills: it acts mainly as a passageway for the runoff from the Khomas Hochland to the Lower Kuiseb. The upper canyon floor is almost entirely rocky, with a few isolated pools which persist late into the dry season, and scattered patches of sparse vegetation on local sandbanks.

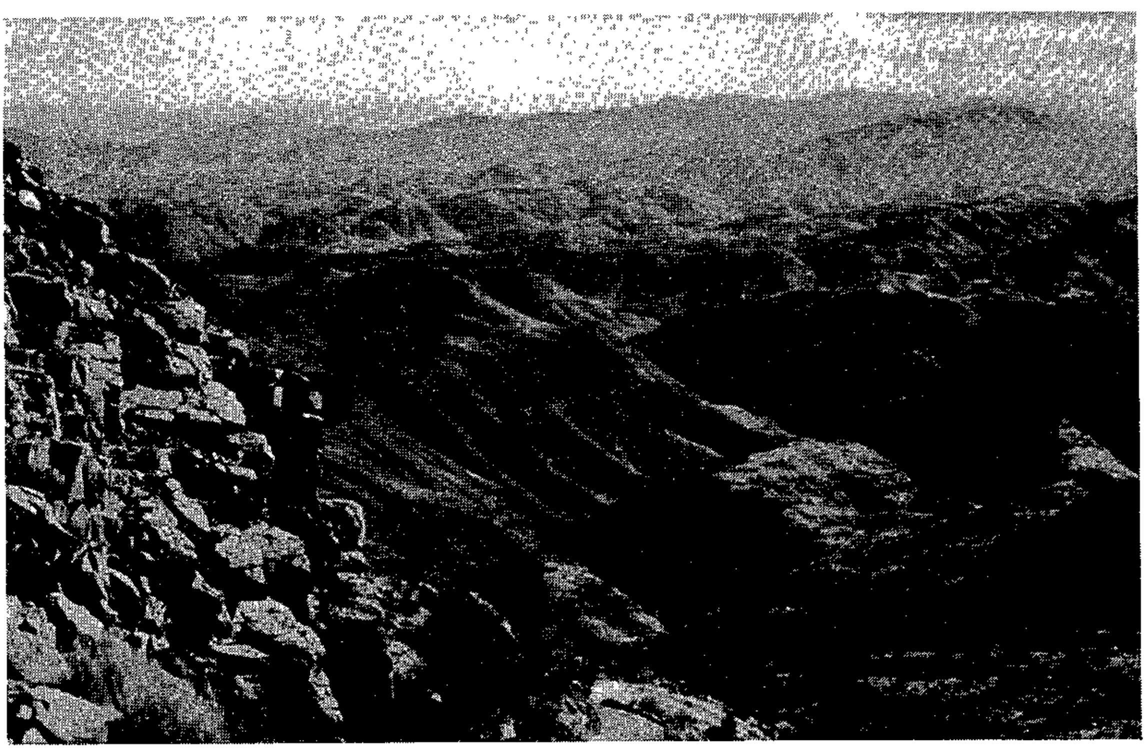

Figure 4. The deeply dissected Khomas Hochland escarpment zone (Photo: J D Ward).

UPPER RIVERINE WOODLAND (HARUBES TO THE GAUGING WEIR AT GOBABEB)

A key feature of the Central Namib environment is the linear oasis which crosses it from the base of the escarpment to the coast at Walvis Bay. This oasis is formed by a dense woodland which is supported by the periodic flood recharge of underground water supplies along the course of the

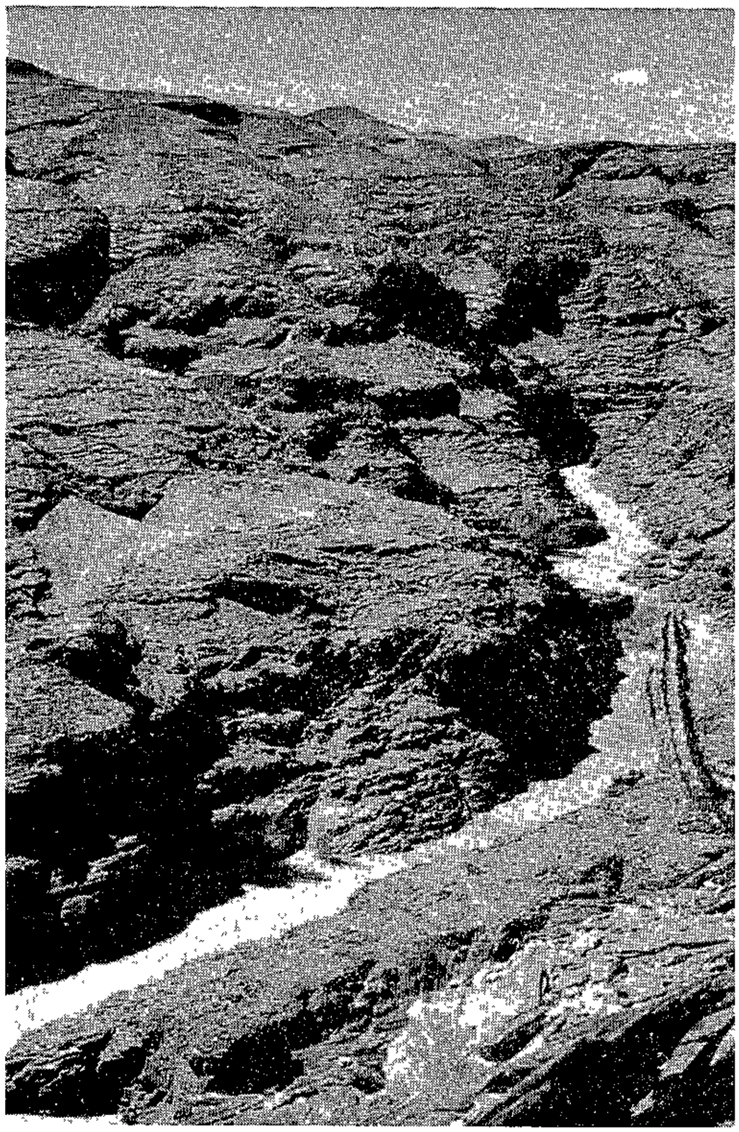

Figure 5. The deep canyon of the Kuiseb River near Hudaob (Photo: J D Ward).

Kuiseb. Over a distance of approximately 150 km, from Harubes to Rooibank, the groundwater supplies and soil conditions permit the maintenance of dense tall woodlands of Acacia albida, A erioloba, Tamarix usneoides and Euclea pseudebenus. These woodlands are of great importance to the downstream migration of both animals and plants, and provide food and shelter to plains game during critical periods. The plant communities of this oasis are described by Theron et al (1980), (and in Chapters 7 and 8, this volume) while valuable details of the river's flooding periodicity and the structure and general ecology of the woodlands are provided by Seely et al (1981). The latter paper draws attention to the constant fluctuations in the woodland structure brought about by variations in the frequency, intensity and duration of floods. (See also Ward, Chapter 9, this volume). For the purpose of the Kuiseb Environmental Project, the riverine

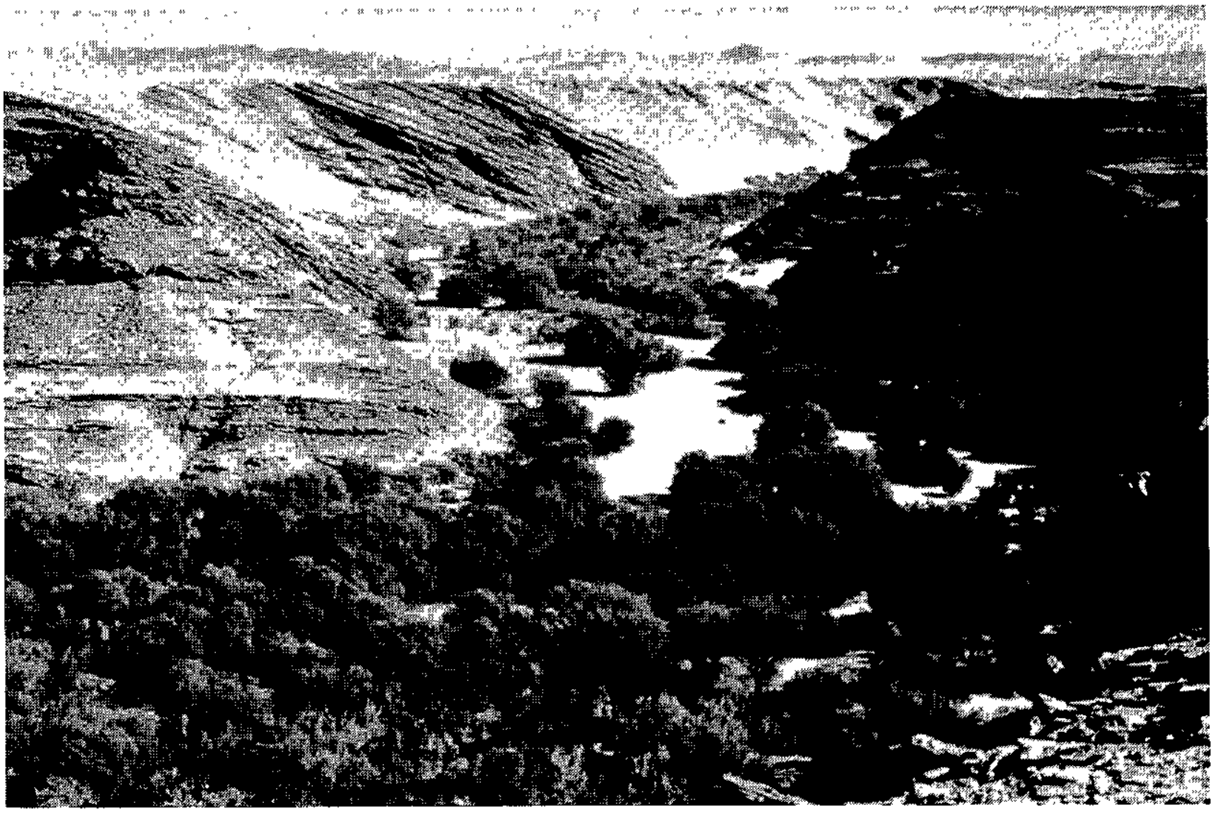

Figure 6. Upper Riverine Woodland (Photo: J D Ward).

woodlands were divided into three sectors in terms of their main hydrological and ecological characteristics.

The Upper Riverine Woodland sector extends downstream from Harubes, where the Kuiseb aggrades and has a wide sandy floor with low stream terraces occurring occasionally along the main channel. The river course continues to flow within the steeply sided walls of the Canyon (Figure 6) until Natab, whereafter the height and slope of the river margins is less severe.

In common with the Canyon area and all areas downstream, the Upper Riverine Woodland division receives very little water input either from rain or lateral runoff, the only meaningful supply being the input from floods rising in the Khomas Hochland and from sub-surface flow.

MIDDLE RIVERINE WOODLAND (GOBABEB TO SWARTBANK)

The lower sandy river bed of the Kuiseb is divided into several compartments by bedrock barriers which traverse the bed from the gravel plains in the northeast to the Sand Sea in the southwest. These barriers occur at Narob (gauging weir), Swartbank, Rooibank and at Mile 16. Each compartment comprises an elongated basin filled with sand and alluvium deposited by the river during floods. The compartments are bounded on the northern side by impervious bedrock. On the southern side they are bound by the Sand Sea which is underlain by pervious sediments into which considerable leakage of underground water from the sandy river beds may take place. The sand basins support Acacia spp woodlands which differ in

Figure 7. Middle Riverine Woodland at Gobabeb (Photo: J D Ward).

their structure from those of the Upper Riverine Woodland (see Theron et al, this volume, Chapters 7 and 8) (Figure 7). The Middle Riverine Woodland occurs in a reach of the river characterized by rock outcrops and generally thin (2 to 3 metres) alluvium in contrast to the Lower Riverine Woodland. No abstraction occurs within this section.

LOWER RIVERINE WOODLAND (SWARTBANK TO ROOIBANK)

This section is characterized by the absence of rock outcrops in the river bed along the left bank and by deeper alluvium. Water abstraction has occurred from the upper reaches of this compartment since 1976 and from the lower reaches since 1925.

KUISEB DELTA

Five km below Rooibank, at the rock barrier at Mile 16, the Kuiseb bed widens rapidly to form an extensive delta. The northern arm of the delta used to open into the sea at Walvis Bay, but is now diverted to the south by a flood protection wall. The indistinct southern arm comprises a mosaic of the previous river surface interspersed with the northern ends of several linear dunes, as well as mobile crescentic dunes and partly-vegetated hummock and parabolic dunes. Sub-surface flow of water from the Rooibank compartment is limited by the solid rock barrier at Mile 16, which crosses the river and extends more than a kilometre into the dunes. The groundwater level lies at 35 to 40 metres below the surface. Woody plants are represented by shrub forms of <u>Acacia erioloba</u>, less frequently <u>A albida</u>

Figure 8. Kuiseb Delta, at the edge of reed beds and saline marshes (Photo: J D Ward).

and in silty depressions *Tamarix usneoides* (Figure 8). The vegetation of the delta floodplain includes many ephemerals and short-lived perennials. The saline marshes within the delta are dominated by *Phragmites australis*, *Salsola* spp, *Lycium* spp and *Tamarix usneoides*.

SALT FLATS

Largely vegetationless salt flats lie between the saline marsh/dune hummock section and the sea. Sub-surface recharge to the inland portion of these flats is through groundwater flow from the Kuiseb. Surface flow is of rare occurrence, averaging once every eight years. The last floodwaters to penetrate to the sea occurred in 1934 and 1963. The influence of the development of a large salt works on the hydrology and ecology of the salt flats has not yet been monitored.

GRAVEL PLAINS

The Namib Platform, an extensive, relatively smooth planation surface, is exposed to the northeast of the Lower Kuiseb. This granite and mica schist platform is patchily covered by thin gravels, gypsum and calcrete. Most of these plains receive less than 50 mm rainfall per annum and support a very sparse grassland and dwarf succulent shrubland on which small nomadic populations of gemsbok, springbok, zebra, ostrich, etc subsist (Figure 9). These populations depend to a large measure on the availability of forage and water along the Kuiseb Canyon and Riverine Woodland sectors. Drainage lines and dry riverbeds, which occupy about three percent of the gravel

Figure 9. The gravel plains near Gobabeb (Photo: J D Ward).

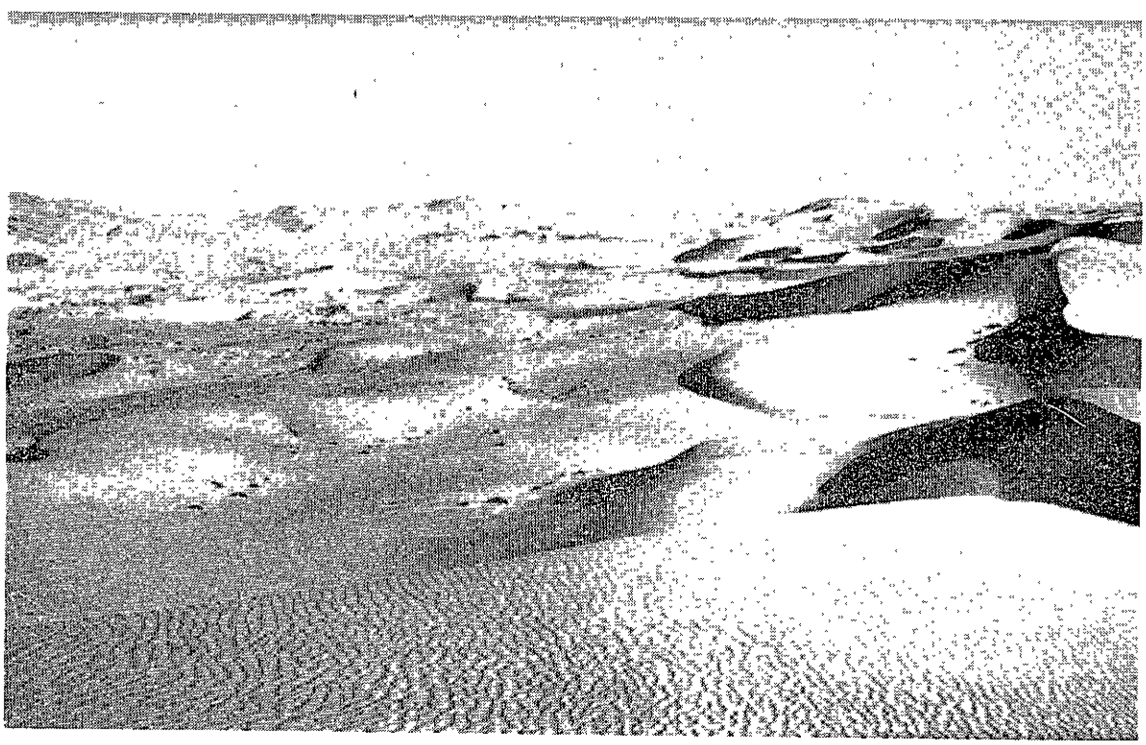

Figure 10. Dunes and interdune valley near Rooibank (Photo: J D Ward).

plains surface area, contribute substantially to the forage production of the plains. The main woody species include Acacia erioloba, A reficiens, Ziziphus mucronata and Euclea pseudebenus, while important herbs include Stipagrostis ciliata, S uniplumis, S hochstetteriana and various legumes. The plant communities of these plains are described in detail by Robinson (1976) and are outlined by Nel (this volume, Chapter 12). Two minor copper deposits, at Hope and Gorob, have been mined sporadically over the last century. Neither is currently operational, nor is either likely to become active in the immediate future.

DUNES

The Namib Platform slopes gently to the southwest, passing under the high mobile dunes of the main Namib Sand Sea south of the Kuiseb River.

Groundwater from the Middle and Lower Riverine Woodlands flows under the dunes and some of this is thought to emerge at Sandvis Lagoon. The local wind patterns result in the dunes moving very slowly in the northeasterly direction, the periodic scouring action of floods retarding this movement across the Kuiseb (see Ward, this volume Chapter 6, and Seely et al 1981).

The dunes are very sparsely vegetated, but arid grasslands cover the inter-dune plains and support small nomadic groups of large mammals (Figure 10), besides their diverse lower vertebrate and invertebrate faunas. A detailed account of the vegetation of the dunes is provided by Robinson (1976) while the structure and dynamics of the dune ecosystems is described by Seely and Louw (1980).

SANDVIS LAGOON

Sandvis Lagoon is a large, generally shallow lagoon lying at the foot of very high dunes on the Atlantic coast approximately 50 km south of Walvis Bay. Also known as Sandwich Harbour, the lagoon is a wetland of international importance as an overwintering stop-over area for palaeoarctic waders. Berry and Berry (1976) record 90 species of birds from Sandvis, including 18 palaeoarctic waders, 20 seabirds, 34 waterbirds and 18 landbirds. Up to 250 000 Cape cormorants use it as a roosting area, while thousands of terns and flamingoes feed in the lagoon.

The lagoon is considered of significance to the Kuiseb Environmental Project due to the belief that the freshwater seepage along its inland margin is derived from the Kuiseb. Geophysical studies suggest that two channels run from approximately Klipneus on the Kuiseb to the northern end of Sandvis Lagoon (Van Zijl and Huyssen 1967). Apparent changes in the water quality along the seepage line of Sandvis Lagoon were interpreted as a consequence of increased water extraction from the Lower Kuiseb (Hellwig 1974). Subsequent studies have not observed the predicted changes in the lagoon fauna and flora (Penrith 1979). Indeed Penrith suggests that the freshwater seepage has only a very limited area of influence in an otherwise marine lagoon. Reedbeds of Phragmites australis (Figure 11), thought to be dying out in the early 1970's, expanded considerably in the mid and late 1970's. Robinson (1976) describes the vegetation of Sandvis Lagoon, which includes Typha latifolia, Arthrocnemum affine, Sporobolus virginicus and Odyssea paucinervis communities.

Figure 11. Sandvis Lagoon, viewed from the northern end (Photo: J D Ward).

WALVIS BAY LAGOON

The Walvis Bay Lagoon comprises some 600 - 1000 ha of tidal flats. Tidal scouring has been greatly diminished as a result of road construction and salt works on the south bank and the lagoon is currently threatened by wind-blown sand from the surrounding dunes depositing along its southeastern shores.

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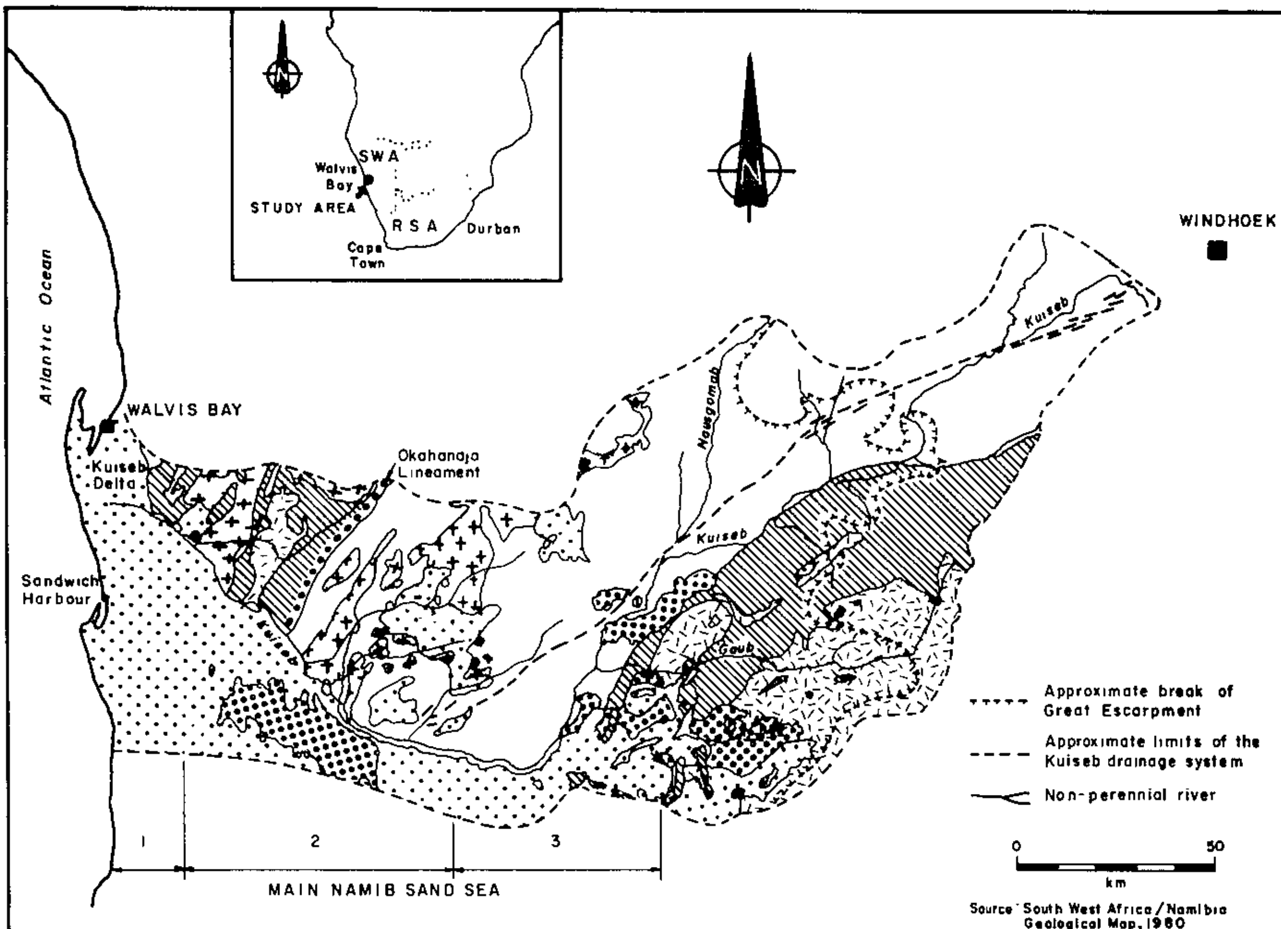

LEGEND

QUATERNARY sediments, including alluvium, river terraces, calcrete and MAIN NAMIB SAND SEA.
1 Coastal salt flats, compound transverse and barchanoid dunes
2 Complex linear dunes
3 Star dunes and 'multicyclic' dunes

TERTIARY sediments - calcrete conglomerate terraces along Kuiseb and Gaub Valleys
- red, partially consolidated dune deposits of the Namib Desert

JURASSIC - ETJO FORMATION of KAROO SEQUENCE - Dolerite dykes in western region

NAMIBIAN

syn-to post-tectonic granites, mostly SALEM and DONKERHUK

KUISEB FORMATION, with Matchless Member — — KHOMAS SUBGROUP — SWAKOP GROUP — DAMARA SEQUENCE

PRE-KUISEB FORMATION DAMARAN ROCK TYPES: KARIBIB, AUAS, CHUOS FORMATIONS (KHOMAS SUBGROUP); KUDIS SUBGROUP; NOSIB GROUP

MOKOLIAN

comprises: SINCLAIR SEQUENCE, REHOBOTH SEQUENCE — Middle to upper Mokolian

ELIM, ABBABIS, MOOIRIVIER FORMATIONS - Lower Mokolian

Figure 1. Simplified geological map of the Kuiseb drainage system (modified from the Geological map of SWA/Namibia, 1980).

3. GEOLOGICAL HISTORY OF THE KUISEB VALLEY WEST OF THE ESCARPMENT

J D Ward and V von Brunn, University of Natal, Pietermaritzburg

An evaluation of man-induced changes to the hydrological regime of the Kuiseb basin and the disposition of mobile dune bodies and of the biota which the environment supports needs to be made within the context of long-term changes in the Central Namib. These major environmental changes are summarized in the following outline and illustrated in the stratigraphy and regional geology illustrated in Figures 1 and 2.

The Central Namib desert tract developed in response to the formation of the Great Escarpment, mainly by headward erosion enhanced by continental uplift, following the break-up of West Gondwana in the Early Cretaceous, ca 130 - 135 Ma ago* (summarized in Tankard et al 1982). This narrow pediplain was formed across dominantly Damara Sequence rocks, which were graded down to the base level provided by the developing South Atlantic Ocean (Martin 1973a, b, c). Fully marine conditions were established in the South Atlantic by ca 80 Ma (summarized in Simpson 1977), and an extensive, relatively level surface was formed by the End Cretaceous, 65 - 70 Ma, similar to that in the Southern Namib (Beetz 1926; Gevers 1936; Martin 1973a; Selby 1976; Ollier 1977; Stocken 1978). This well-planed surface subsequently acted as a platform for the accumulation of Cenozoic sediments.

The Early to Middle Cenozoic sedimentary record in the Central Namib is dominated by arenaceous sediments of the Tsondab Sandstone Formation (Martin 1950; Ollier 1977; Besler and Marker 1979; SACS 1980). These deposits are characterized by widespread palaeo-dunes, which were deposited by a southerly wind regime, similar to the present-day situation (Martin 1950, 1961; Barnard 1973; Besler and Marker 1979). Furthermore, these sediments are indicative of arid/desertic conditions which probably prevailed for most of the Early to Middle Tertiary, some 60 Ma to 20 Ma ago (Martin 1950, 1961, pers comm 1981). As yet, no conclusive field evidence has been found of a well-developed Kuiseb fluvial system during that time.

The first manifestation of a well-developed, integrated Kuiseb-Gaub River system is recorded in the high-level terrace conglomerates, which mostly overlie the Tsondab Sandstone Formation in a broad, relatively non-incised

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*Ma = mega-anno, refers to units of time x 10^6 years, before present.

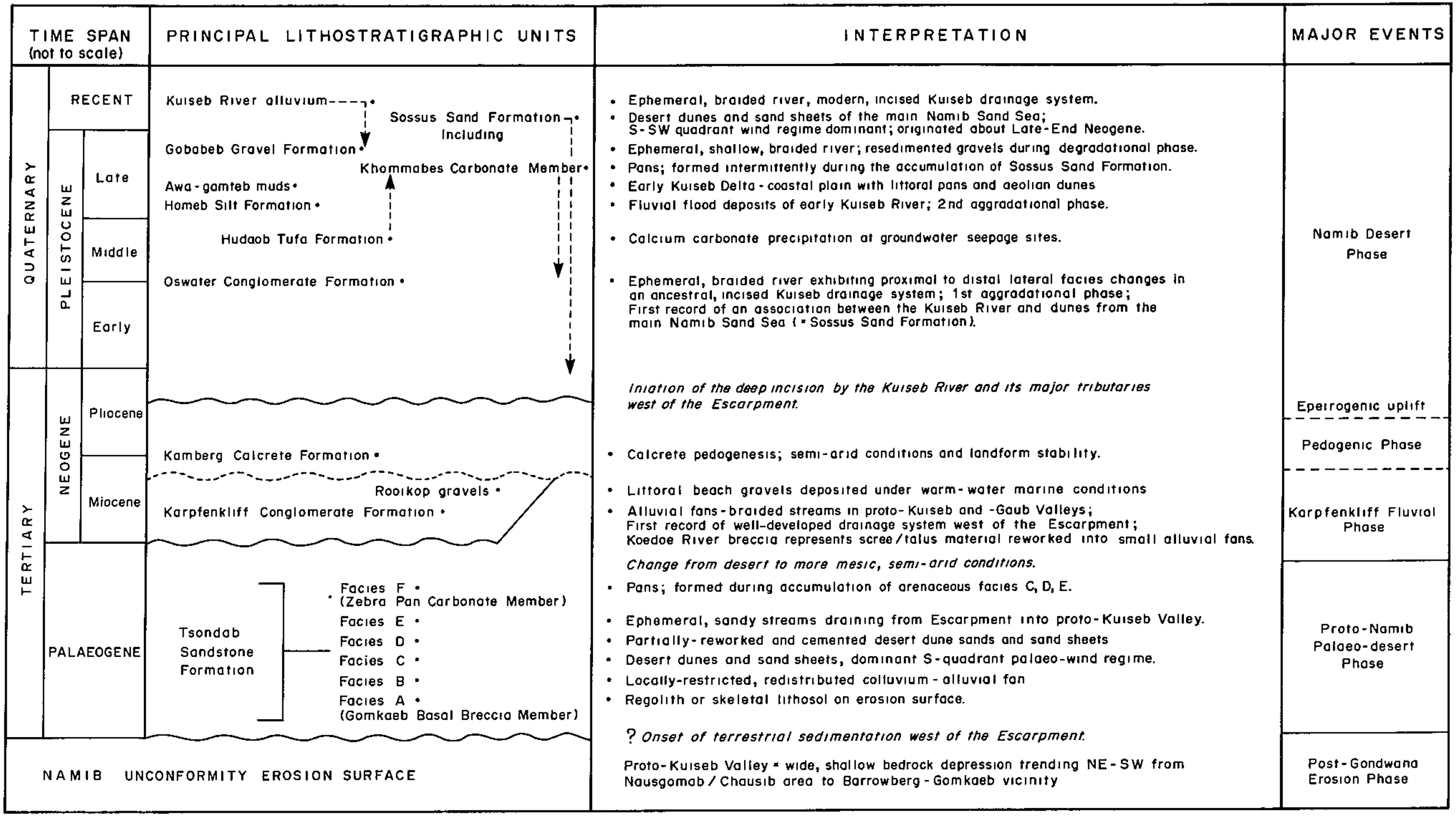

Figure 2. Summary of the inferred palaeo-environments and processes involved in the accumulation of the Cenozoic succession in the Kuiseb valley west of the escarpment.

valley (Martin 1950; Scholz 1968; Marker 1977; Ollier 1977; Besler 1980). These rudaceous sediments, from 60 m of well-cemented conglomerate in the east to lag gravels only in the west, have been named the Karpfenkliff Conglomerate Formation. They are considered to be probable Middle Miocene, ca 15 - 17 Ma, deposits (Martin pers comm 1981) related to the Post-African erosion cycle.

The End Miocene calcrete, ca 5 - 7 Ma (Stocken 1978; SACS 1980) is developed on both the Karpfenkliff Conglomerate, marking the end of the Middle Tertiary fluvial phase, and adjacent Tsondab Sandstone Formation arenites (Martin 1950). Yaalon and Ward (1982) have interpreted this surface limestone as a pedogenic calcrete, developed under semi-arid conditions and landform stability of ca 500 000 years, prior to the deep incision of the river courses traversing the Namib. This calcrete has been assigned the rank of Kamberg Calcrete Formation.

Widespread End Tertiary-Pleistocene (ca 2 - 4 Ma) continental uplift initiated river incision in the Namib strip (Korn and Martin 1955). In the Kuiseb, canyon formation was probably enhanced during that period by the resistant calcrete caprock of the Early-Middle Tertiary sediments lying on less competent Kuiseb Formation schists (Damara Sequence) as well as the breaching of the Great Escarpment, with resultant stream capture on the inland plateau. The subsequent End Tertiary-Quaternary (last 2 - 3 Ma) history of the Kuiseb Valley is one related to aggradational/erosional events (Korn and Martin 1955; Marker 1977; Ollier 1977).

The earliest aggradational phase is recorded by the rudaceous sediments identified as the Oswater Conglomerate Formation (Scholz 1968; Sawyer 1976; Marker 1977; Ollier 1977; Ward 1982). This phase is tentatively assigned to the Early-Middle Pleistocene, ca 1 to 0,5 Ma (Korn and Martin 1955). At that stage, large linear-type dunes were present along the left bank between Homeb and Gobabeb (Ward 1982) and the Kuiseb River was already flowing in a general northwesterly direction from Natab.

Subsequent re-incision was effected to a base level below the Oswater Conglomerate in the escarpment-canyon sector. The Homeb Silts, floodplain overbank deposits from an aggrading Kuiseb River (Ollier 1977) mark the next major sedimentary build-up in the Late Pleistocene, 19 000 - 23 000 BP (dated by Vogel 1982). However, other interpretations have been given to these fine-grained dominantly micaceous sediments, which occur between Gomkaeb in the Kuiseb Canyon, downstream to at least Sout River, including dune dam deposits (Scholz 1972; Goudie 1972; Rust and Wieneke 1974) and river end point sediments (Marker and Müller 1978; Vogel 1982). However, the Homeb Silts probably represent aggradational fluvial deposits testifying to the importance of the Kuiseb River as a barrier to the general northerly migration of the main Namib Sand Sea throughout the Pleistocene (ca 1 800 000 - 10 000 years BP).

Re-excavation of the Kuiseb Valley probably followed in the Early Holocene (tentative date of 9300 BP by Vogel, 1982, on the Gobabeb Gravels). For the remainder of the Holocene, and at least the last 6000 years (Brain and Brain 1977) the Kuiseb has maintained itself as an effective northern

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*BP = before present

boundary to the encroachment of the main Namib Sand Sea, except along the immediate coastal tract where the high-energy, south-southwesterly winds have transported sands across the Kuiseb delta to form the narrow coastal dune belt between Walvis Bay and Swakopmund.

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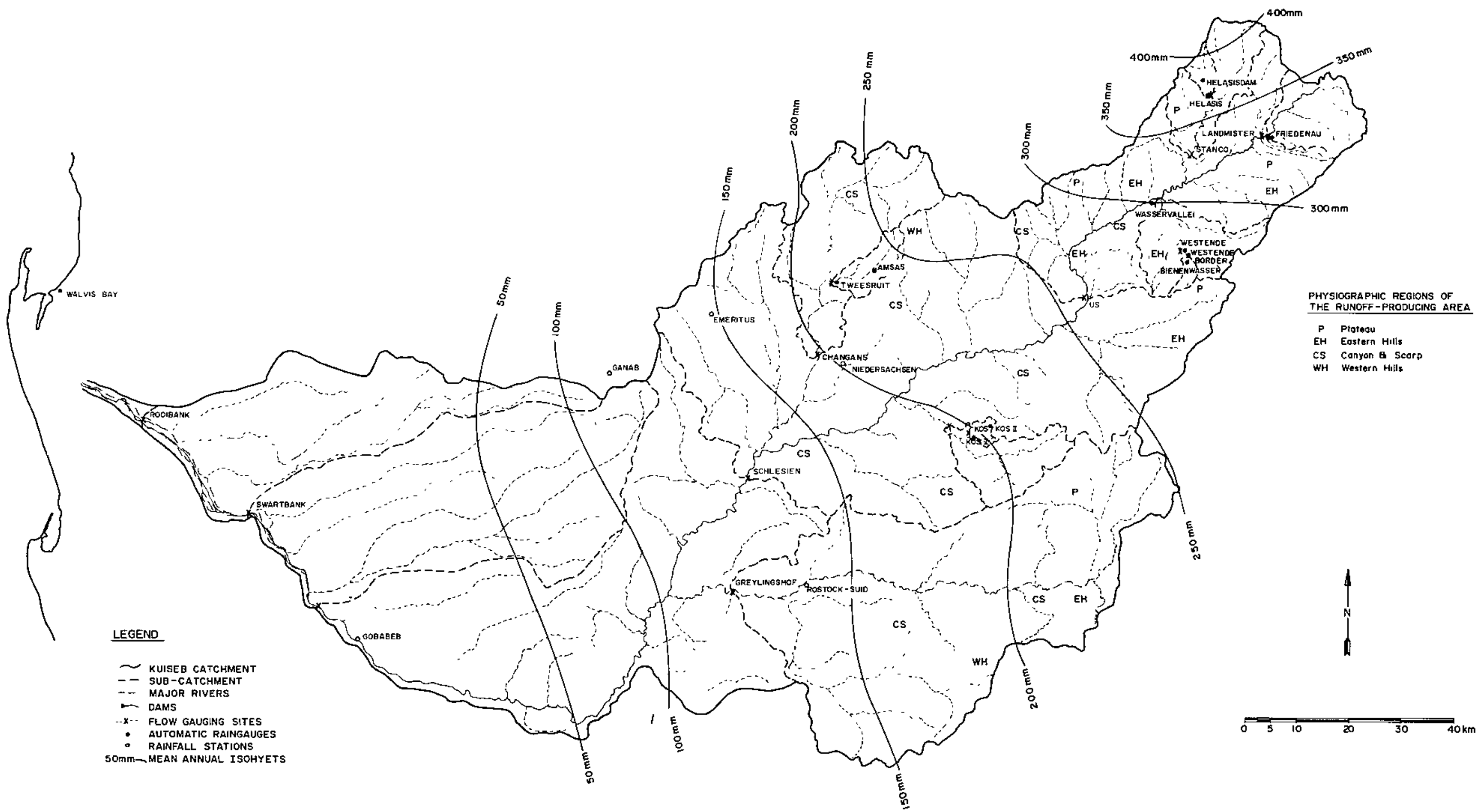

Figure 1. Rainfall and runoff over the catchment area of the Kuiseb River.

4. SURFACE WATER HYDROLOGY OF THE KUISEB

A Hattle, Department of Water Affairs, SWA/Namibia

THE KUISEB BASIN

Catchment size

The total catchment area of the Kuiseb upstream of Rooibank is 14 700 km^2. Of this, only the area upstream of the flow gauging weir of Schlesien (see Figure 1) on the main river, and upstream of the flow gauging station of Greylingshof on the Gaub River should be considered as runoff-producing. These catchments are 6 520 km^2 and 2 490 km^2 in size respectively. The remaining 5 690 km^2 is largely desert plain yielding runoff to the main river only in exceptionally wet years.

Hydrologic zones of the runoff-producing area

Hydrological investigations have been geared to study firstly the flow down the main channel, and secondly the variations in runoff originating from four different geomorphic zones of the Khomas Hochland and Escarpment. These zones and the monitoring points are indicated on Figure 1.

RAINFALL

Gauging network

By October 1982, the Hydrology Division of the Department of Water Affairs, SWA/Namibia had installed eleven automatic rain gauges within the catchment. The positions of these are shown on Figure 1. At all but one of these, six-minute intensities can be determined. One rain gauge was installed in 1973, but the others have only been in operation since dates ranging from October 1977 to April 1981.

In addition data from daily-read gauges are available from the Weather Bureau. This network varies, a few stations having been opened over the past few years, but a number having closed recently.

Average rainfall

Mean annual isohyets based on long-term records up until December 1976 were plotted by Richardson and Midgley and are re-produced for the Kuiseb area in Figure 1. The long-term average rainfall over the whole of each sub-catchment is summarized in Table 1. Rainfall data for various stations in the catchment are presented in Figure 2.

Table 1. Mean annual rainfall for sub-catchments.

Catchment outlet (Flow gauging site)	Catchment area (km^2)	Long-term rainfall over catchment (mm/a)
Rooibank	14 700	159
Swartbank	13 600	170
Gobabeb	11 700	190
Schlesien	6 520	239
Us	1 900	316
Landmister	231	334
Friedenau	210	335
Greylingshof	2 490	181
Changans	690	230
Tweespruit	81,6	243
Kos Tower	231	212
Kos Weir	20,1	205
Stanco	276	380
Heusis	38,4	394
Wasservallei	266	280
Westende	17,3	275

The mean annual rainfall for the 5 690 km^2 downstream of Schlesien and Greylingshof is only 58 mm. The mean annual rainfall over the runoff-producing area upstream of Schlesien is 239 mm and upstream of Greylingshof is 181 mm. Over these two runoff-producing areas therefore, some 2 000 million cubic metres of rain falls annually on average.

Rainfall during the project

Throughout this report, reference is made to the drought conditions of recent years. Since intensive monitoring began, the rainfall over the catchment dropped to very low levels (Figure 2 and Table 2).

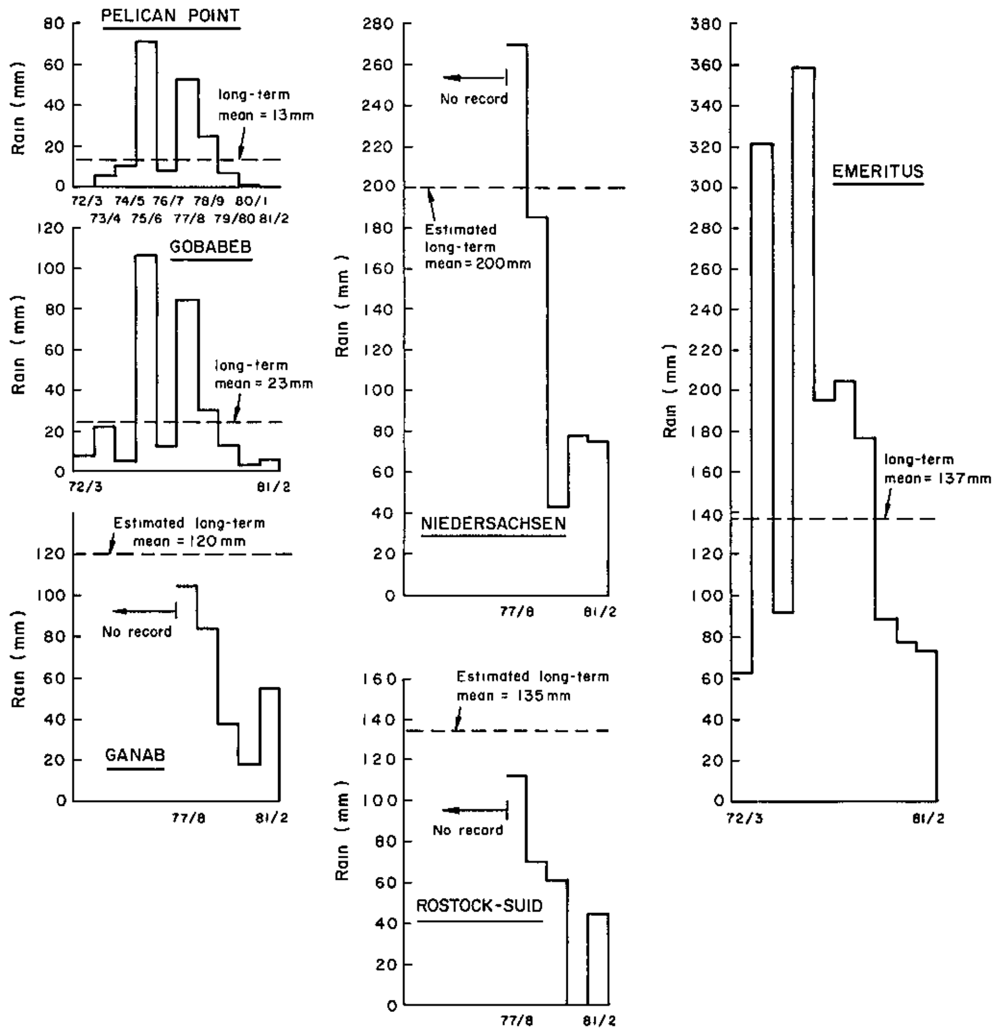

Figure 2. Rainfall data for various stations in the Kuiseb catchment.

Table 2. Seasonal rainfall as percentage of long-term mean.

Site	Mean annual rainfall (mm)	Rainfall as percentage of mean 1977/78	1978/79	1979/80	1980/81	1981/82
Heusis	350	141	91	73	41	43
Westende	280	134	113	105	38	44
Tweespruit	220	148	68	73	32	47
Kos I	200	182	100	60	23	34

It should be pertinently noted that runoff during the "wet" 1977/78 season was also low, presumably on account of the good vegetative cover which had built up over the previous few good rainfall years.

SURFACE FLOW

Total runoff from the upper catchment

The surface water input to the Lower Kuiseb system is the river flow in the Kuiseb passing Schlesien, and the river flow of the Gaub passing Greylingshof.

Kuiseb River

Gauging began at Schlesien in 1960/61 and the gauging efficiency of the weir under heavy sedimentation has only recently been closely examined by an hydraulics engineer. Preliminary results indicate that the mean annual runoff at the site is in the vicinity of 20 million cubic metres. The mean, of course, is influenced by rare very high flows, and the median annual flow is about half the mean (10 million cubic metres). The coefficient of variation of the annual flows is high, with a maximum of 106 million cubic metres and a minimum of 0,007 million cubic metres over the 21 years of satisfactory record.

The last season in which flow reached the Salt Flats was 1973/74, during which the flow past Schlesien was 60 million cubic metres. The last recorded flow into the sea was in 1962/63 when the Schlesien flow was approximately 106 million cubic metres. Indications are that the flow during 1933/34 could have been twice this amount.

Gaub River

Flow measurements at Greylingshof have not yet been critically examined, but indications are that the flow contribution from the Gaub River would be of the order of 20 percent of that of the Kuiseb.

Dissipation of flow downstream

The development of a model to predict the extent of recharge in the Lower Kuiseb, given the input at Schlesien and from the Gaub is currently receiving attention. There have been insufficient carefully monitored flows to calibrate the model as yet. This is an on-going long-term study.

Some information on flow dissipation is provided in Table 3.

Sediment yield

Monitoring has begun to determine the sediment carried in the Kuiseb to establish

- the long-term inflow of sediment to the Lower Kuiseb and

Table 3. Downstream limit of flows in the Lower Kuiseb.

Season	Flow ($10^6 m^3$) at Schlesien	Flow ($10^6 m^3$) at Greylingshof	Farthest point reached by flow downstream
1962/63	106	?	Sea
1973/74	60	?	Salt marsh
1975/76	37	?	Salt marsh
1977/78	7	minimal	Well point 01*
1978/79	4	minimal	Well point 01*
1979/80	0,2	0,5	Well point 16*
1980/81	1,6	minimal	Well point 06*
1981/82	0,1	1,3	Well point 12*

* Estimated from Division Geohydrology gaugings

- the relationship between sediment yield and vegetation cover over the catchment.

There have been too few runoff events and therefore too little data to evaluate at this stage.

Effect of vegetation cover on runoff

Three vegetation cover surveys have been made in the runoff-producing portion of the Kuiseb catchment. The first two were in June 1979 and September 1980 and were done using a wheelpoint apparatus and chain. Each survey covered approximately 7 km in each of the four physiographic regions gauged for runoff.

Taken for the area as a whole, the 1980 survey reflects a 27 percent reduction in basal area coverage compared to the 1979 survey.

No survey could be done in 1981, and the results of the September 1982 survey are still awaited. For this last survey, a subjective veld condition assessment technique similar to that described by Roberts and Fourie (1975) was used.

Although many years of monitoring will be required, it is expected that a reduced vegetation cover will greatly increase the sediment flow to the Lower Kuiseb. Experience throughout South West Africa/Namibia indicates that increased vegetation cover significantly reduces runoff, but this remains to be quantified.

SUMMARY

Information regarding flow in the Lower Kuiseb is scarce. There is some knowledge of the flow entering the area but the Gaub River contribution must be analysed further. The past few seasons of drought have produced so little runoff that little analysis has been possible on aspects such as flow dissipation, sediment yield and rainfall-runoff relationships.

RECOMMENDATIONS

Monitoring of runoff in the Khomas Hochland, at Schlesien and Greylingshof and in the Lower Kuiseb must be continued. As soon as there have been a few sizeable floods downstream of Schlesien and Greylingshof, the flood dissipation model must be critically tested and refined if possible. The monitoring of flows for silt content must continue, as must the surveys of vegetation cover on the Khomas Hochland.

It is unlikely that a better analysis of the surface water hydrology can be made within two or three years.

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5. GEOHYDROLOGY OF THE KUISEB RIVER

L W R Blom and P M Bouwer, Department of Water Affairs, SWA/Namibia

HISTORICAL REVIEW WITH EMPHASIS ON THE INVESTIGATION OF THE WATER POTENTIAL OF THE LOWER KUISEB

At present groundwater is abstracted from the dry bed of the Kuiseb River to supply Walvis Bay, Swakopmund, Rössing Mine and Arandis. The main areas of abstraction are A Area (Figure 1) which encompasses the section of the river upstream of Rooibank for a distance of 10 kilometres as far as the Fehlmann well, and B Area which lies approximately 13 kilometres west of Rooibank. Water from both areas is used exclusively by Walvis Bay. Water abstracted from the Swartbank area which extends from Fehlmann well upstream for a distance of 11 kilometres, is pumped to Swakopmund, Rössing Mine and Arandis.

Interest in this part of South West Africa as a source of fresh water is of long standing. It began with the Portuguese explorers, followed by that of the East India Company and the whalers. The latter were familiar with the Hottentot watering post near Walvis Bay.

It was not until the end of World War I that investigations were carried out to establish an adequate water scheme. Increased activity at the outbreak of World War II brought about new activity near Rooibank which led to the development of the A Area.

The long known presence of fresh water at Sandvis and the speculation that this might be due to under-dune Kuiseb channels initiated a programme of seismic surveys (1967, 1970), magnetic traverses (1963, 1973) and gravity surveys (1973). A large part of the investigations was carried out by the National Physical Research Laboratory of the Council for Scientific and Industrial Research under the leadership of J S V van Zijl. Results of the investigations which were on a regional scale showed broad shallow erosional depressions often more than 10 km wide. The presence of channels could only be determined by drilling in the vicinity of the Kuiseb River. Because of a lack of drilling results the course of these channels under the dunes has not been determined. The investigations resulted in the development of the Swartbank area in 1970 to meet the growing water demand. Abstraction rose annually until the requirements of Rössing Mine were supplemented by the development of the Omaruru River Delta source north of Swakopmund in 1979.

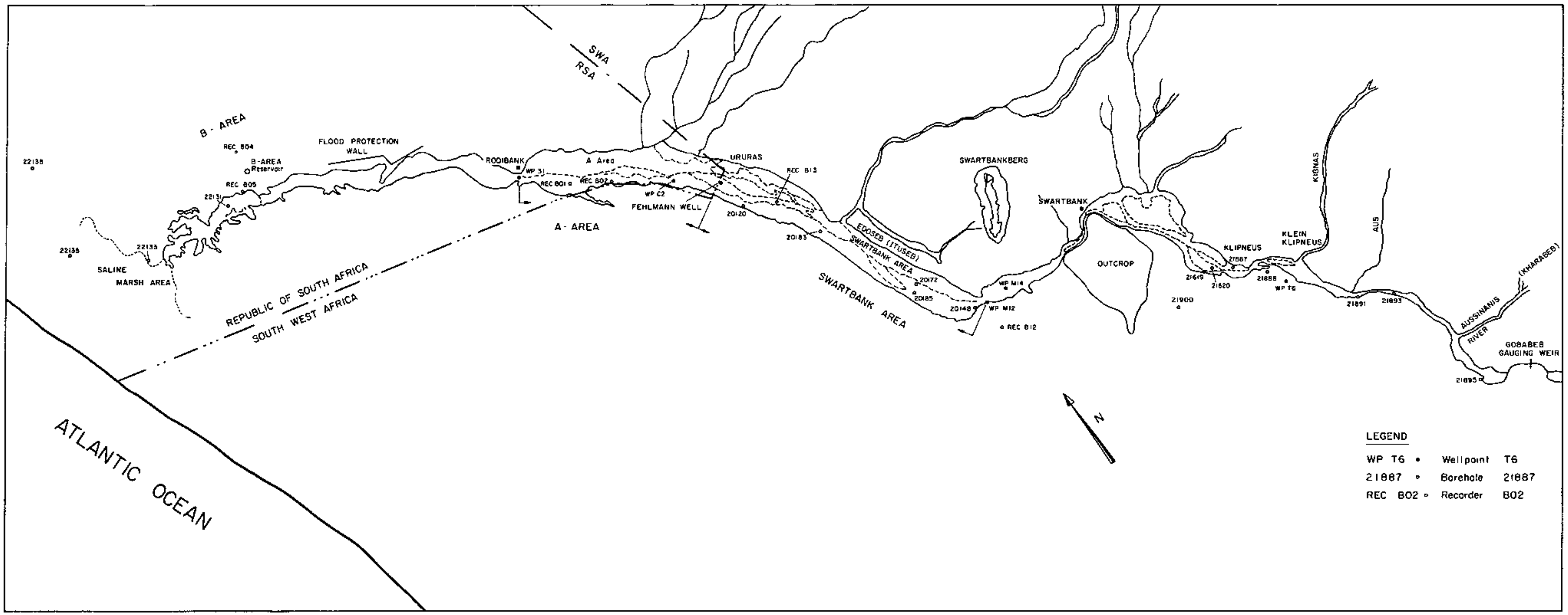

Figure 1. Locality plan of the Lower Kuiseb River west of Gobabeb.

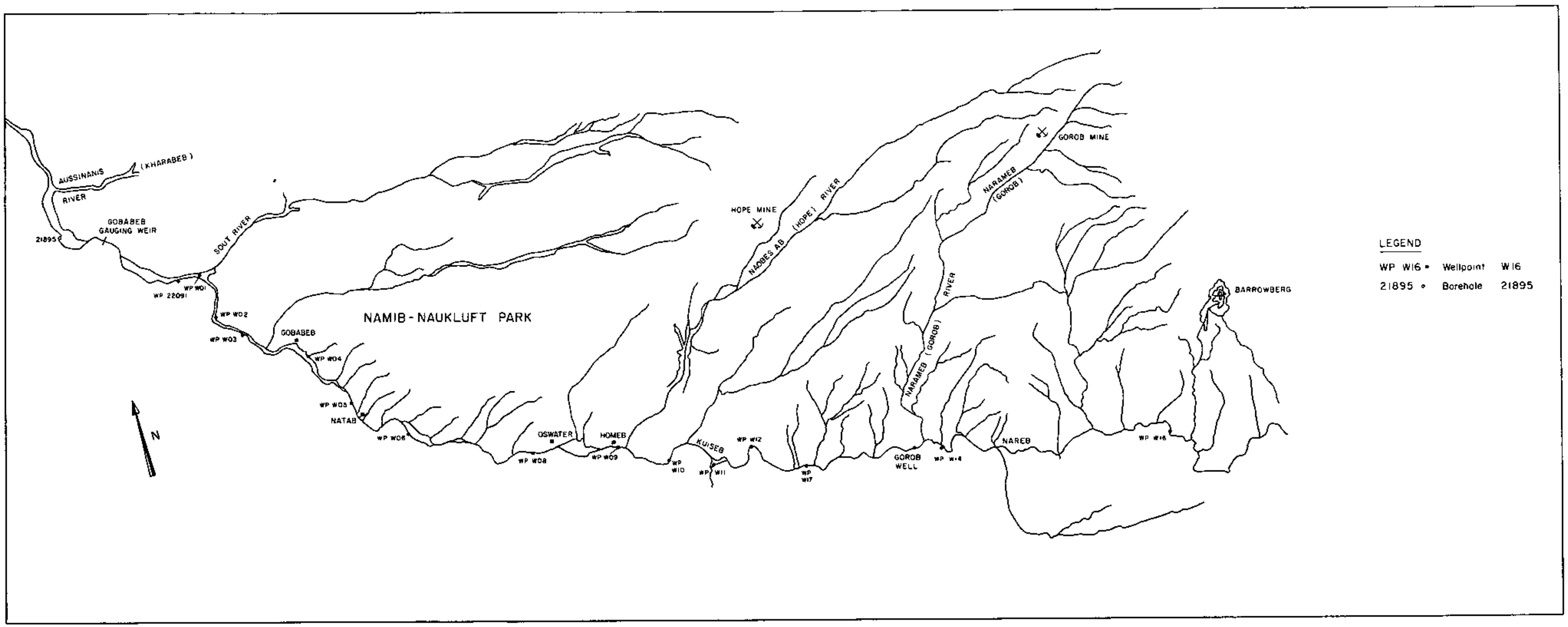

Figure 2. Locality plan of the Lower Kuiseb River east of Gobabeb.

UPSTREAM OF NARAMEB RIVER

This section of the river falls within the canyon area. Active downcutting of the river is still taking place along this section with the result that there is very little alluvium present. Gravel deposits are erratically laid down as stringers along the river as well as on the slip-off slopes of the river. Open pools of water are typical of the canyon. The water lies directly on bedrock and is lost through evaporation.

Investigational work and the monitoring of groundwater fluctuations and chemical quality have been confined to areas of interest as economically exploitable. As no groundwater abstraction is taking place in this area and the water level is not affected by the withdrawal of groundwater, only two wellpoints (W 14 and 16) approximately 1,5 and 14,5 kilometres upstream of the Narameb River have been located in this section of the river.

Wellpoints were installed in 1977 and from the water level data it can be ascertained that floods passed wellpoint W 16 (Figure 2) during the rainy season of 1978, 1979 and 1980 with small floods during 1981 and 1982. Between floods there is a linear decline in the water level of approximately 0,18 m per month. After floods the area is inaccessable with the result that no water level data are available when the water level is at its highest. The shallowest water level measured was 0,61 m below ground level during June 1978 and the deepest water level was measured during March 1982 when it was 4,11 m below ground level.

The water levels at wellpoint W 14 show floods during 1978 and 1979. Small floods passed this wellpoint during 1981 and 1982 but had no effect on the water table at the wellpoint. Between floods wellpoint W 14 has a linear decline in water level of 0,16 m per month. The highest water level was in June 1978 when a measurement of 0,7 m below ground level was recorded. In May 1982 the water table had dropped to 7,01 m below ground level.

The groundwater at both wellpoints is of class A quality. The TDS values of the water from wellpoints W 16 and W 14 vary between 200 - 400 ppm and 500 - 700 ppm respectively. The water from wellpoint W 16 however shows a steady increase in the percentage NaCl since the 1976 floods. The small flood in 1982 was therefore not of desertic origin as shown by the fact that the percentage $CaCO_3$ doubled in comparison with the sample before the flood (desertic floodwaters have a low $CaCO_3$ concentration). The Na/Ca ratio decreased from 26,09 before the flood to 14,49 after the flood. The increase in the percentage NaCl (75 percent in 1982) can be attributed to evaporation of open water near the wellpoint.

At wellpoint W 14 the water quality showed no major changes. Throughout the sampling period the percentage NaCl has also remained fairly constant varying between 37 percent and 43 percent. A water sample taken on 10 November 1981 had a percentage NaCl of 51 percent. Water level fluctuations for W 14 are illustrated by the computer printout, Figure 3.

NARAMEB RIVER TO NAROB GAUGING WEIR

From the Narameb River downstream the thickness of the alluvium increases and the presence of open water is the exception.

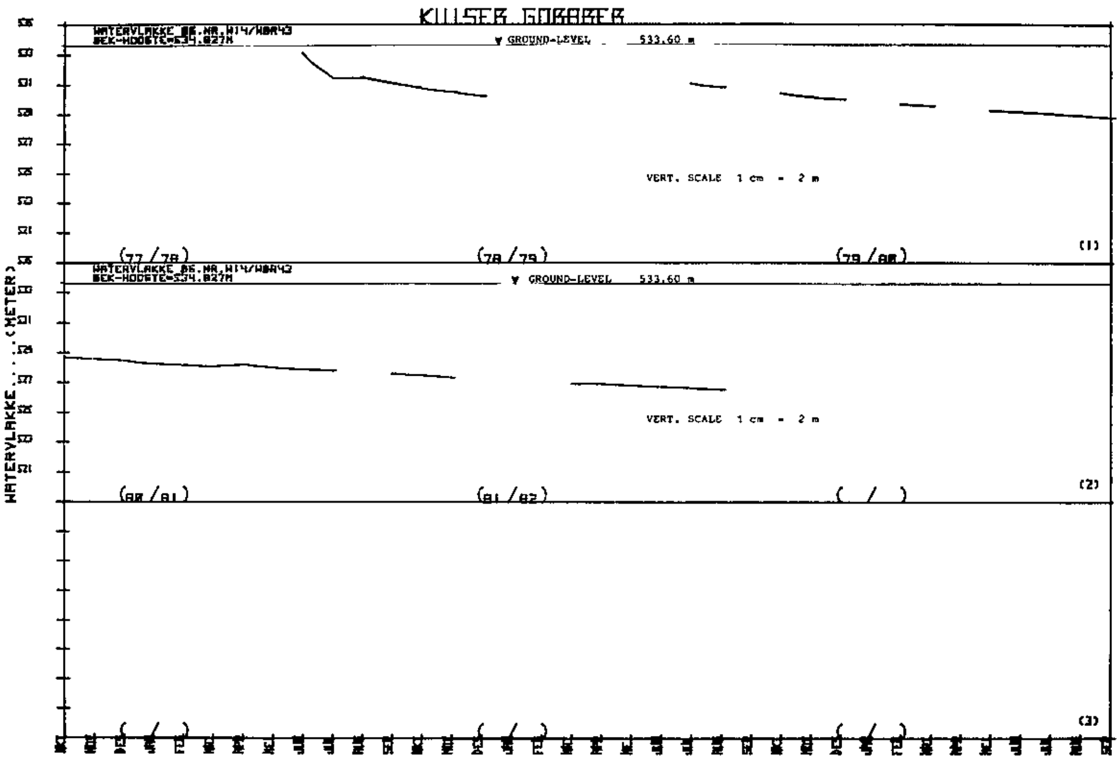

Figure 3. Water level graphs representative of WP W 14.

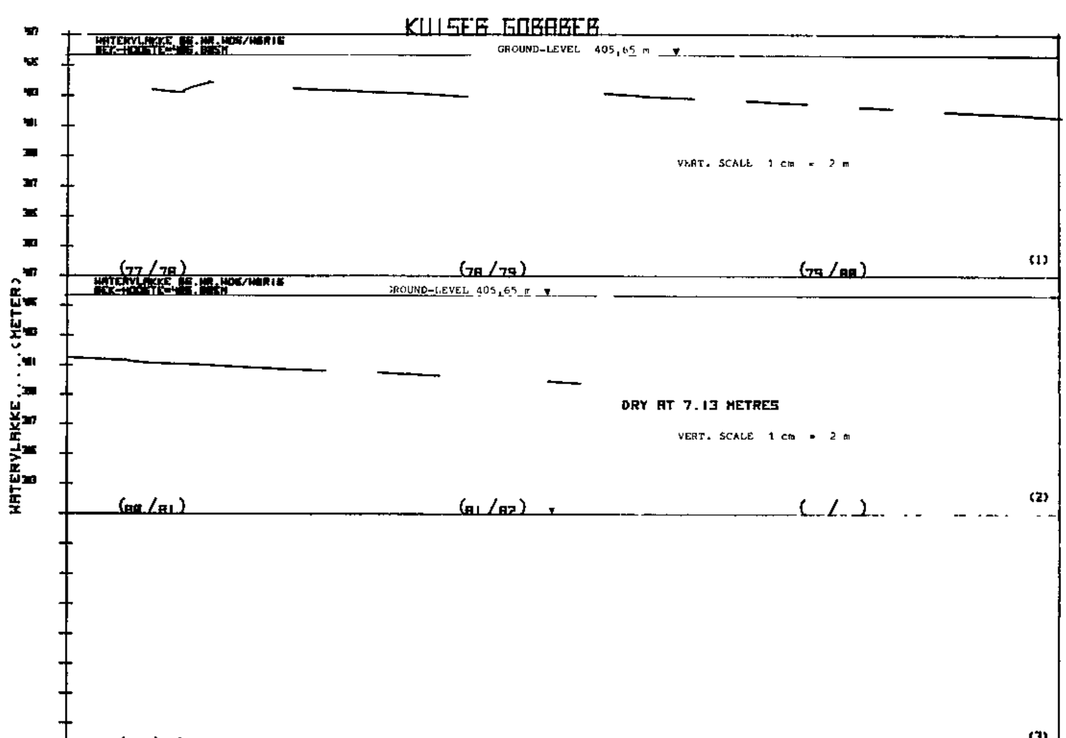

Figure 4. Water level graphs representative of WP W 06.

As from Narameb to the confluence of the Sout River the Kuiseb is confined to the channel it has carved into the underlying bedrock with steep sides adjacent to the river.

From Sout River towards the gauging weir the topography becomes more gentle and outcrops are found in the river. At the weir the river flows over outcrops across its full width. A longitudinal dune forms the left bank of the river at this site.

This is in direct contrast with the section of the river upstream of Sout River where the alluvium attains a thickness of plus-minus 20 m.

Exploratory drilling has revealed that below Sout River a deep channel is present under the floodplain south of the left bank of the river. This deep channel continues underneath the longitudinal dune against which the gauging weir abuts. West of the longitudinal dune the continuation of this channel was again determined by drilling.

As can be seen from Figure 1 the wellpoints lie downstream of rivers entering the Kuiseb from the right bank, for example the Narameb (Gorob) and the Naobes-ab (Hope) River. Runoff from these desert rivers adversely affects the water quality in the Kuiseb River. A surface water sample taken in the aftermath of heavy flooding from the desert in 1976, representative of such floods, had a TDS of 5375 ppm, the percentage of $CaCO_3$ and NaCl being 3,3 percent and 25,5 percent respectively, the Na:Ca ratio was 11,46. In comparison a typical inland flood water sample showed a TDS of 197 ppm, the percentage $CaCO_3$ being 71,4 percent, the Na:Ca ratio 0,14.

Factors that influence the water quality include type of flood water, frequency and volume of floods and rate of evaporation between floods. The 1978 and 1979 floods reached this section of the river. The small floods during 1981 and 1982 reached wellpoints W 06 and W 12 respectively. These floods caused no fluctuation in the water level. It must also be considered that wellpoints below the reach of the flood might, if the flood is of sufficient magnitude, reflect the flood water quality at a later date, the time interval depending on the distance downstream. Detailed study of the changes in chemical quality would indicate the rate of flow of the underground water; this however is beyond the scope of this report. Changes in water quality in the Kuiseb River between Narameb and the Sout River confluence are indicated in Table 1.

The water table was at the lowest ever recorded in May 1982 for all wellpoints, except W 16. This wellpoint was affected by the last small flood and the water level rose 0,03 metres over the previous month's reading. Figure 4 shows a long-term computer printout for wellpoint W 06 along this section of the river.

This overall drop in the water table and decline in quality of the groundwater are the most probable causes of the observed deterioration of the natural vegetation.

Table 1. Changes in water quality in the Kuiseb River between Narameb and the Sout River confluence.

WELL POINT	W 01	W 02	W 03	W 04	W 05	W 06	W 08	W 09	W 10	W 11	W 12	W 14	W 16	W 17
Collar height in metres	378.363	383.434												
Most recent analyses	DRY	DRY				DRY					DRY			
No of analyses	29994	28594	29990	30031	30018	29354	30008	30029	30007	29359	29306	30005	29991	30012
Date of sample	4-3-82	11-5-81	4-3-82	4-3-82	4-3-82	6-11-81	4-3-82	4-3-82	4-3-82	6-11-81	6-11-81	4-3-82	4-3-82	4-3-82
TDS	1 663	216	187	453	1 304	272	192	2 271	445	1 090	408	624	354	557
Irrigation classification	C4S3	C2S1	C2S1	C3S1	C3S2	C2S1	C2S1	un-suitable	C3S1	C3S2	C2S2	C3S1	C2S2	C3S2
Water level in metres	5.17	4.82	5.98	6.12	6.77	6.48	5.47	6.33	7.44	7.98	8.46	7.91	5.01	7.85
Earliest analyses														
No of analyses	25275	25375	25183	25309	25304	25297	25201	25273	25311	25327	25290	25195	25284	25295
Date of analyses	11-8-80	10-11-80	11-8-80	11-8-80	11-8-80	11-8-80	11-8-80	11-8-80	11-8-80	11-8-80	11-8-80	11-8-80	11-8-80	11-8-80
TDS	410	280	310	205	695	205	240	1 470	275	490	645	590	400	530
Irrigation classification	C2S2	C2S2	C2S1	C2S1	C3S4	C2S1	C2S2	C4S4	C2S2	C3S2	C3S2	C3S1	C2S1	un-suitable
Water level in metres	3.94	4.43	4.65	4.17	5.40	5.09	4.05	4.32	5.16	6.02	6.24	5.88	2.72	5.59
Lowest TDS recorded	296	124	236	155	645	170	182	947	199	334	530	540	259	472
Date of analyses	14-12-78	19-5-80	19-5-80	19-5-80	19-5-80	19-5-80	19-5-80	19-5-80	8-12-78	15-2-80	15-2-80	17-7-79	13-2-80	19-5-80
Water level in metres	3.27	3.90	4.59	3.99	5.34	4.87	3.85	3.83	3.91	5.02	5.03	3.77	3.70	5.29

NOTE ON TABLE 1

The use of the irrigation classification with reference to the groundwater upstream and downstream of Gobabeb as shown in the table is for comparative purposes only, to illustrate the degree of quality change pertinent to vegetation. These parameters are not the same as for potable water. The irrigation classification as used here relates in general to commercial crops and must be viewed as such. Apart from water quality, vegetation is influenced by water quantity, soil permeability and the natural or acquired salt tolerance of the indigenous species.

'C' refers to the salinity index and 'S' to the sodium adsorbtion ratio, both on a scale of 1 to 4. The suitability deteriorates with rising indices.

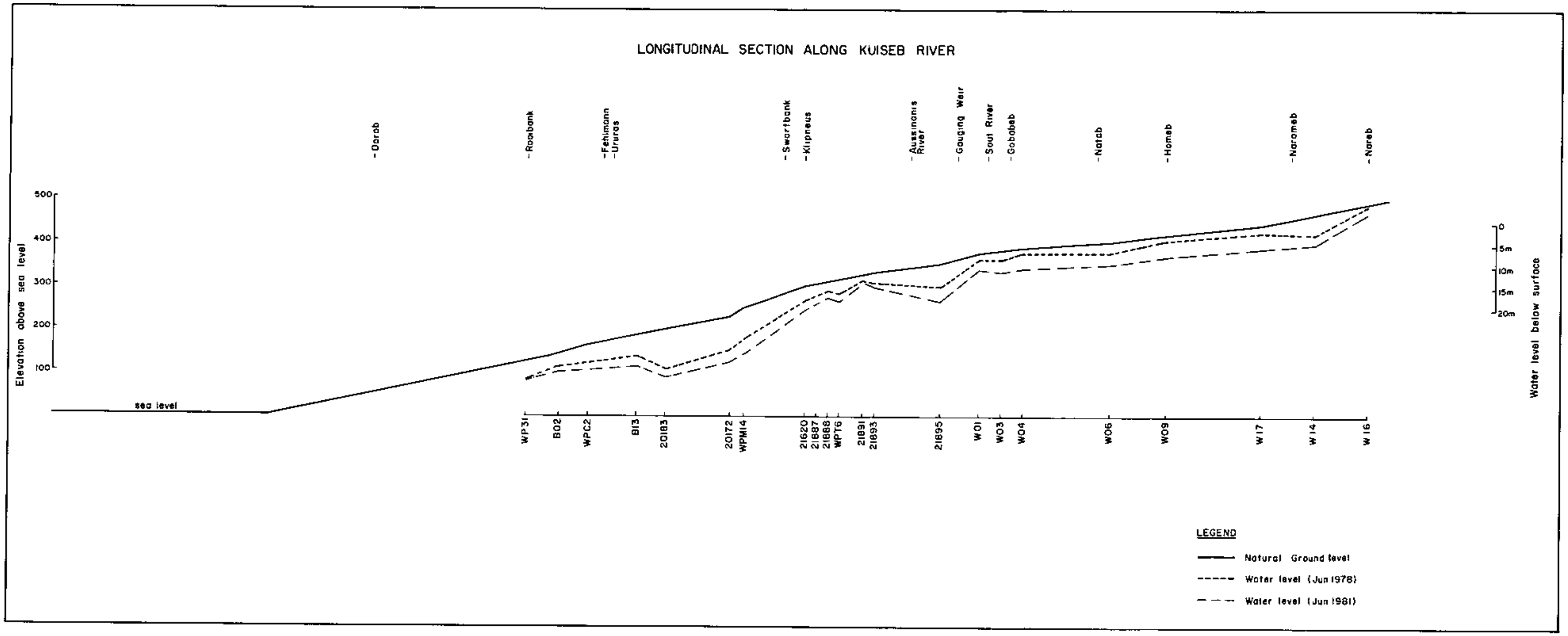

Figure 5. Longitudinal section along Kuiseb River showing water levels for June 1978 and June 1981.

NAROB GAUGING WEIR TO SWARTBANK

Along much of this section the alluvium is thin (two to three metres). Outcrops are found in the riverbed as well as on the left bank. At Swartbank Settlement a rock barrier occurs across the river. A massive outcrop approximately three to four kilometres long extends into the dunes beyond the left bank. At Klipneus a deep channel appears to be present. Indications are that this channel follows the river section over a short distance and then makes a sharp turn to the left under the dunes. Rounded pebbles and cobbles were encountered when borehole 21900, sited south of the rock outcrop was drilled. This may indicate the presence of a channel in this area.

Poor quality water is found in some localities, for example near Klipneus and Klein Klipneus and especially near the right bank at the confluence of the Kuiseb and Aussinanis Rivers where a TDS of 4465 ppm was encountered at borehole 21893. The mineralised water is derived from the schist which is found at shallow depth.

The water levels during June 1979 and June 1981 for this section of the river are shown on Figure 5. A long-term computer printout for borehole 21893 which is representative of this area is shown on Figure 6.

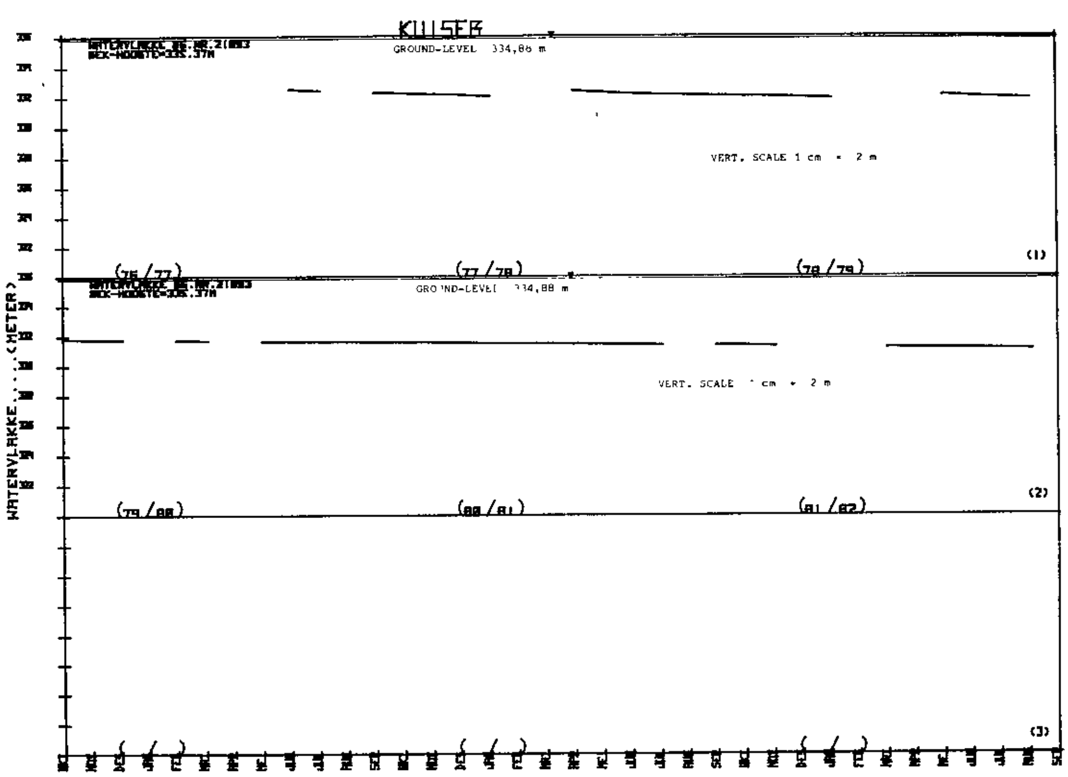

Figure 6. Water level graphs representative of borehole 21893.

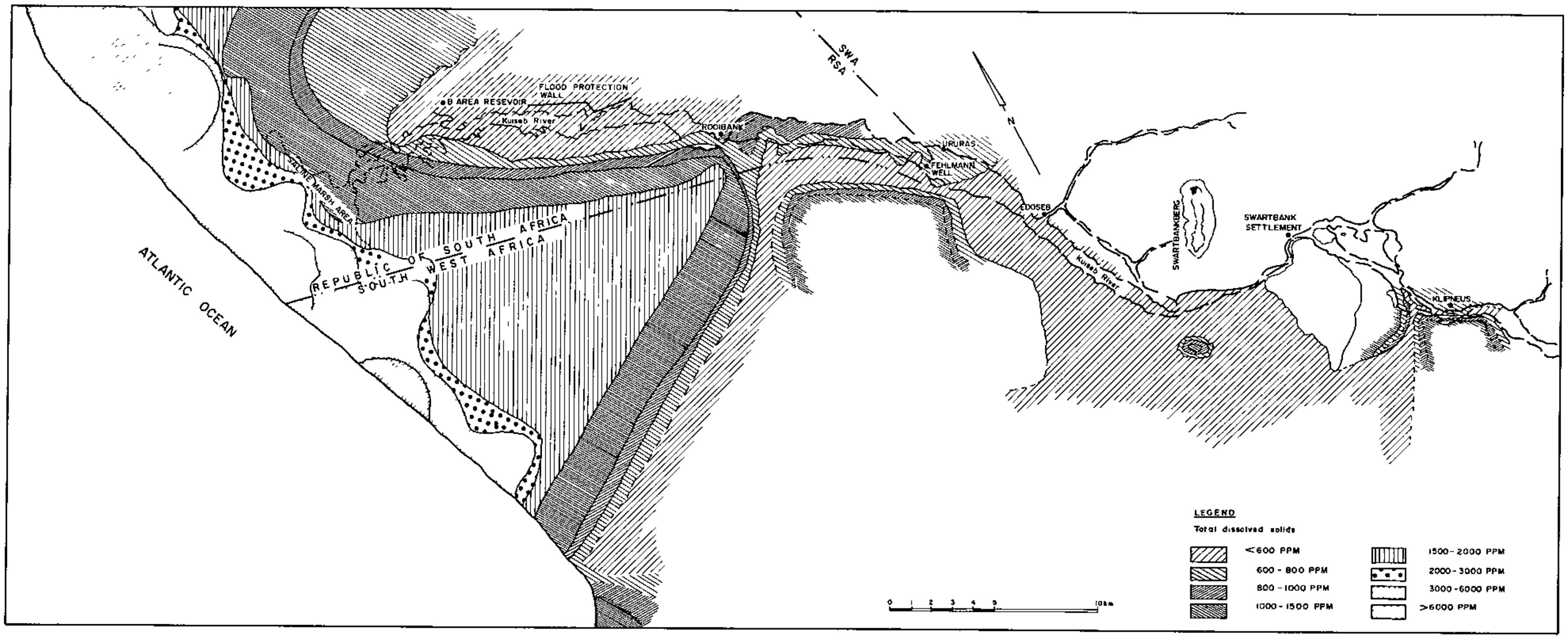

Figure 7. Kuiseb River regional ground water quality map, March 1982.

SWARTBANK TO ROOIBANK

This area covers the dunes as well as the river section west of an imaginary line drawn south of the rock barrier at Swartbank. On the right bank the river is flanked by rock outcrops and on the left bank by dunes. No outcrops are found in the riverbed or along the left bank of the river. The two major production areas are situated in this stretch of the Kuiseb River between Rooibank and Swartbank, ie the Swartbank area and the "A Area". There are certain localities in the dunes where water high in TDS is encountered. Refer to Figure 7.

River section

Downstream of the Swartbank barrier a channel has been eroded which is situated in places on the left bank of the river or under the dunes on the left bank. As Rooibank is approached it appears to veer off to the left and to enter the dunes south of Rooibank.

Dune section

An erosion channel that enters the dunes near Sout River further upstream appears to continue past the southern part of the outcrop opposite Swartbank in a westerly direction.

ROOIBANK TO THE FLOOD PROTECTION WALL

At Rooibank outcrops appear in the riverbed, the alluvium is thin and bedrock was struck at a shallow depth. From the drilling results it appears that the deep channel into which the production boreholes were drilled has veered off to the southwest and continues under the dunes.

Between the flood protection wall and the outcrop south of it the channel has not been confirmed and the inference is that it is present south of the outcrop. Away from the main channel, especially in the vicinity of the outcrops, the TDS of the groundwater increases. Some boreholes in this area are dry.

FLOOD PROTECTION WALL TO THE SALINE MARSH

Along this section the river is bounded by sand dunes along both banks. No outcrops are found in the area. The alluvium is thick and towards the saline marsh the area is underlain by marine beds. A cluster of production boreholes is situated in the vicinity of the B Area reservoir. Recorder B 05 was installed south of the B Area production boreholes and the water level graph shows that the water level in this area has fallen 1,14 m in 11 years (May 1971 to April 1982). Borehole 22133 was drilled near the edge of the saline marsh. Sea-shells were drilled out, indicating that this borehole penetrated former beach deposits.

The quality of the water in the area, although fluctuating slightly, has shown no marked deterioration since pumping began in 1966. A tongue of fresh water extends in a southwesterly direction from Rooibank towards the coast. Between this tongue and the present Kuiseb channel is a wedge of groundwater of lower quality with a TDS content of between 1500 and 2000 ppm as illustrated on Figure 7.

SALINE MARSH

This is the area west of the dune belt and it extends from Walvis Bay in the north to Sandvis Harbour in the south. Apart from three boreholes, no other drilling except for the installation of wellpoints has been carried out in the area.

This is a relatively flat lying area covered by hummocky dunes and underlain by marine beds. Flood waters of the Kuiseb occasionally spread over the area. Silt layers from previous floods are found between the hummocks. In borehole 22138 sea-sand and shells were encountered between 14 and 27 m.

The water quality contours in the saline marsh area are shown in Figure 7. The groundwater gets progressively mineralized towards the sea in the northern part of the area. In the southern part towards Sandvis Harbour (partly shown on plan) an outflow of fresh water from under the dunes was observed.

GROUNDWATER ABSTRACTION FROM THE AREA BETWEEN SWARTBANK AND ROOIBANK WITH REFERENCE TO THE WATER LEVEL FLUCTUATIONS AND CHEMICAL QUALITY OF THE PRODUCTION WATER AND THE STORAGE CAPACITY OF THE ALLUVIUM

The production boreholes were drilled in the channel that approximately follows the present river. No abstraction is taking place from under the dunes. The largest volume is abstracted from the Swartbank area, that is from the most upstream production borehole (20148) to the Fehlmann well (see Figure 1). Figure 8 shows the abstraction rates for the different areas as percentages of the maximum extraction during 1977, as well as the total volume of water abstracted. Compared to the survey of 1979 there has been little change in the overall pattern and the ground water flow is generally in a downstream direction along the river channel.

Unless replenished by flood waters, water levels in the Kuiseb River will gradually fall as the water in the alluvium drains towards the coast. The rate of fall will depend on the gradient and the transmissivity, as well as the rate of abstraction. These gradients themselves are determined by the ratio of inflow from the storage areas to the rate of gravitational drainage to the sea and to abstraction rates.

WATER LEVEL FLUCTUATIONS

In the Swartbank area there has been an average fall in the water level of around 6 m in the upper reaches of the area to approximately 3 m in the lower reaches since 1976, whereas the fall in the water level in the A Area over the corresponding period has been 2 m. Water levels measured in June 1979 and June 1981 near the 17 transects between Namib and Rooibank are given on Table 2. Long-term water level variation for two observation points, ie borehole 20183 in the Swartbank area and wellpoint C2 in the A Area are displayed in Figures 9 and 10.

Downstream in the B Area the fall of the water level since 1966 is approximately 1 m. The water level in borehole 22133 situated towards the end of the present Kuiseb channel as it enters the shifting dune area was measured for the first time in December 1979. The level was at 10,83 m below collarheight and no variations have been observed since.

From the beginning of 1980 very little water was abstracted from the upper reaches of the Swartbank area. This had no effect on the rate of fall of the water table. Likewise, the rate of fall remained constant when overall production was reduced from the time the Omaruru Delta Scheme became operational.

CHEMICAL QUALITY OF THE PRODUCTION WATER

The regional distribution of water quality between Swartbank and Rooibank shows that the water along the river and in the dune area south of Swartbankberg has a TDS of less than 600 ppm (see Figure 7). From the Fehlmann well in a downstream direction water with a higher TDS is found near the right bank of the river, as well as the dune area on the left bank. South of Rooibank a zone of groundwater with a TDS of more than 600 ppm extends under the dunes. No explanation can be given for the occurrence of poorer quality water under the dunes but the increase in TDS on the right bank can be attributed to poor quality desertic flood waters entering the Kuiseb River from the north. Thus floods that occur periodically may either improve or cause deterioration in water quality depending on the origin of the flood waters.

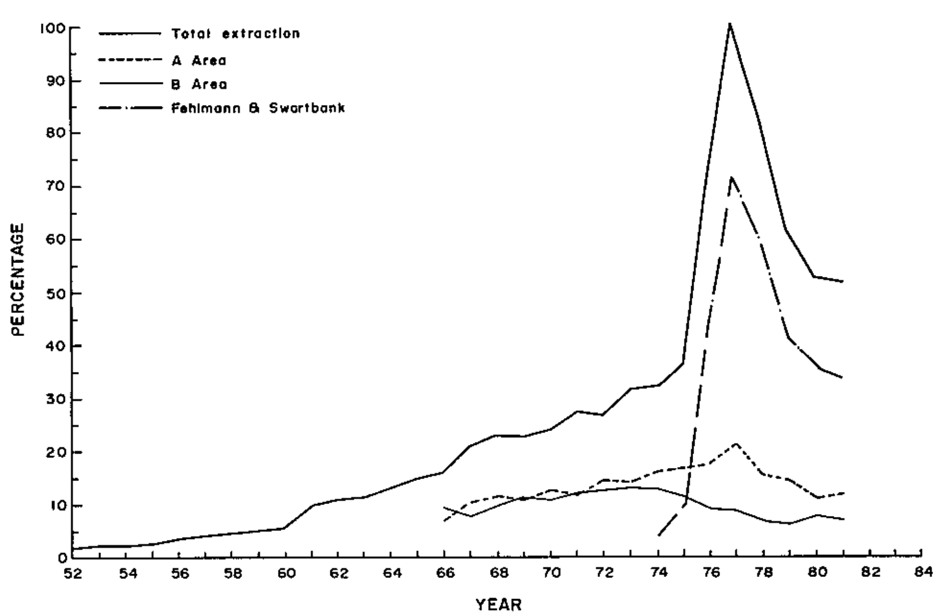

Figure 8. Graph showing extraction from 1952 to 1981 (as a percentage of the highest annual figure).

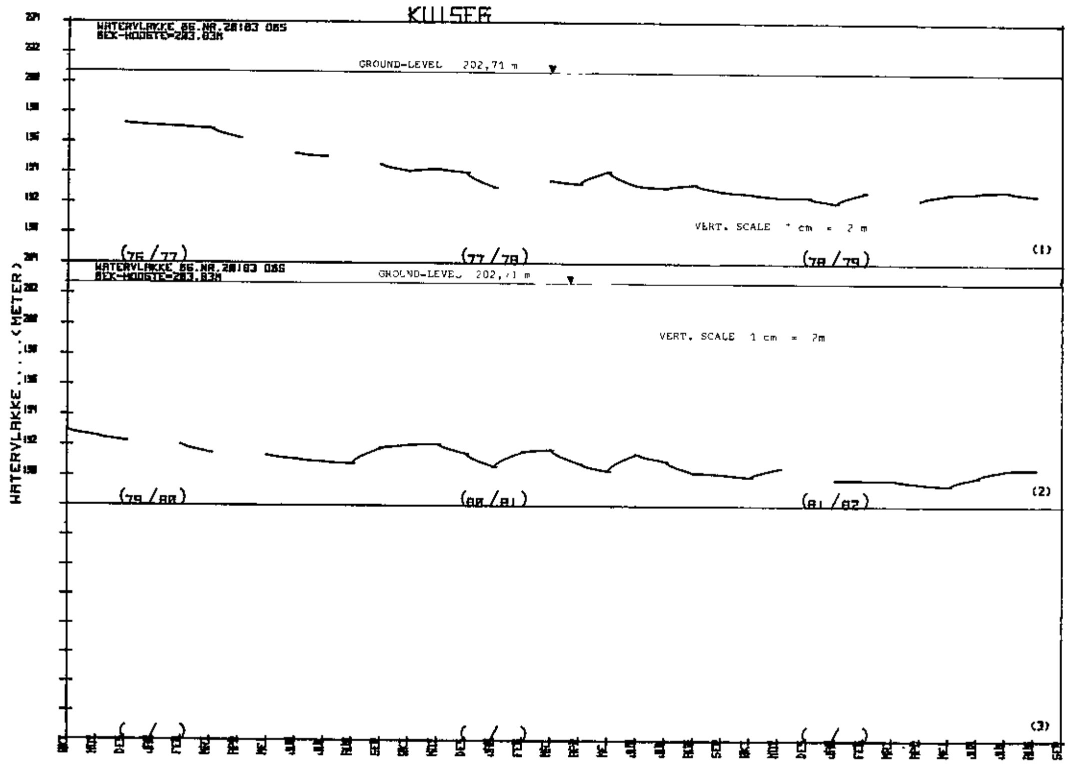

Figure 9. Water level graphs representative of borehole 20183.

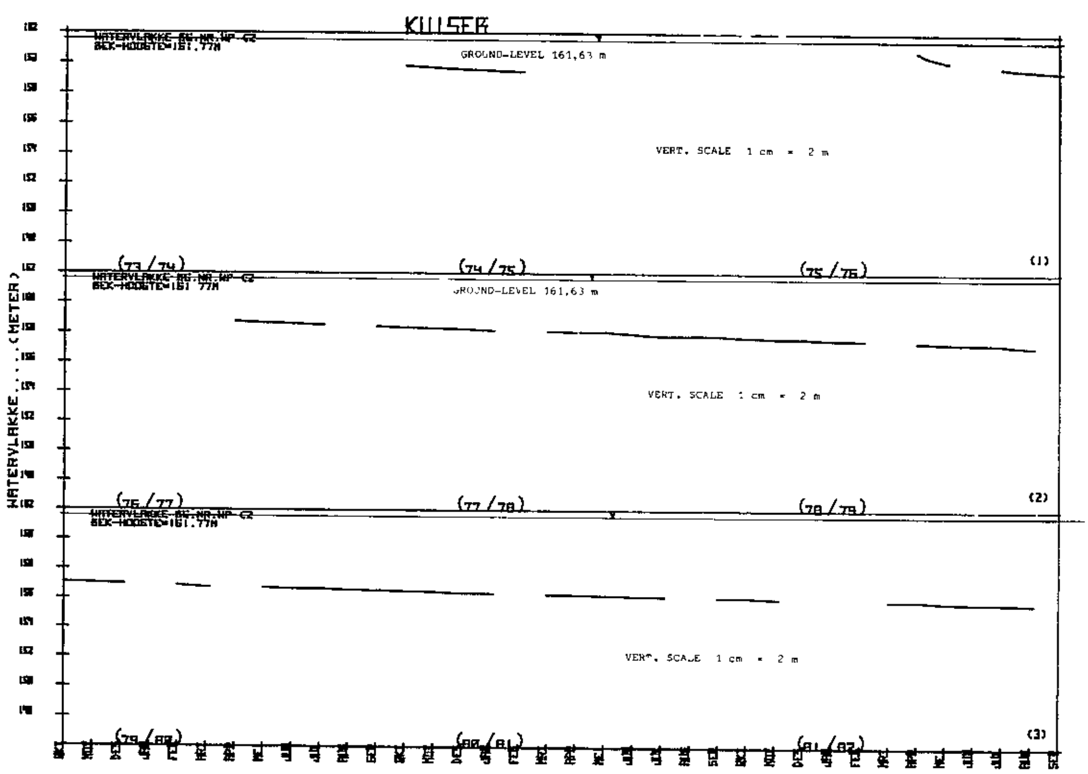

Figure 10. Water level graphs representative of wellpoint C 2.

Table 2. Water levels below ground level (M) and qualities (PPM) near transects for the months of June 1978 and June 1981.

TRANSECT NUMBER	WELLPOINT NUMBER	WATER LEVEL JUNE '78	WATER LEVEL JUNE '81	TDS JUNE '78	TDS JUNE '81
1	WP W 16	0,35	2,64	8.8.78 351	11.5.81 353
2	WP W 17	1,81	5,51	12.7.78 590	11.5.81 447
3	WP W 09	1,38	4,62	12.7.78 1 185	11.5.81 1 960
4	WP W 08	2,05	4,26	18.9.78 315	11.5.81 211
5	WP W 02	2,17	4,42	17.6.78 184	11.5.81 216
6	WP W 01	1,68	3,72	17.6.78 499	17.2.81 544
7	BH WW 21891	5,58	8,28	19.9.78 3 072	12.5.81 2 676
8	BH WW 21887	2,88	4,57	19.9.78 618	12.5.81 593
9	BH WW 21619	3,14	5,67	19.9.78 355	12.5.81 314
10	Transect not in vicinity of borehole or wellpoint				
11	WP M 12	9,17	11,85	21.6.78 404	12.5.81 254
12	BH WW 20185	9,74	12,1	6.3.78 400	12.5.81 366
13	BH WW 21608	7,72	10,18	6.3.78 475	13.5.82 288
14	RECORDER B13	4,96	7,03	20.9.78 212	13.5.81 271
15	RECORDER B02	3,20	4,17	7.3.78 455	9.9.82 375
16	WP 24			9.8.78 814	26.10.81 870
17	WP 31	4,80	4,88	17.7.79 809	24.9.82 948

(TDS = Total dissolved solids)

There is no indication that inferior quality water from the right bank has been or is being drawn into the production area. Water samples from the production boreholes, observation boreholes and wellpoints are taken regularly and a close watch is kept for any quality deterioration. The vicinity of Recorder B 12 west of Swartbank where an eye of poor quality water is found, deserves special mention. This recorder is near open water where evaporation has caused excessive salt concentration.

The following random samples from the Walvis Bay distribution system (Table 3) illustrate that quality is being maintained:

Table 3. Total dissolved solids (TDS) in water samples from the Walvis Bay distribution system.

Date	Chemical analyses number	TDS in ppm
09-11-70	C 7250	800
05-02-71	C 7519	805
30-05-73	C 10153	745
07-08-74	C 11523	975
29-01-75	C 12399	925
16-06-76	C 12428	860
04-04-77	C 15511	913
30-03-78	C 17795	729
08-08-79	C 20882	753
08-10-81	C 29112	740
19-04-82	C 30326	743

THE STORAGE CAPACITY OF THE ALLUVIUM

As described in the earlier text it is apparent that the concept of "Kuiseb groundwater" embraces not only water in the alluvium of the present Kuiseb River channel but also water under the dunes in the old erosion channels near the present river. As the position and extent of these channels is not clearly defined, the actual storage capacity, and likewise the extractable reserves cannot be estimated.

Geophysical investigations have proved the existence of valleys south of the present river and unrelated to it. The location of these valleys under the dune area makes abstraction impracticable. Downstream of Rooibank, investigational methods have not been successful and like the dune area no estimates as to the storage capacity have been put forward.

The B Area has by no means been fully developed and if water demand should increase, it could be further exploited. At present underground water drains to the coast.

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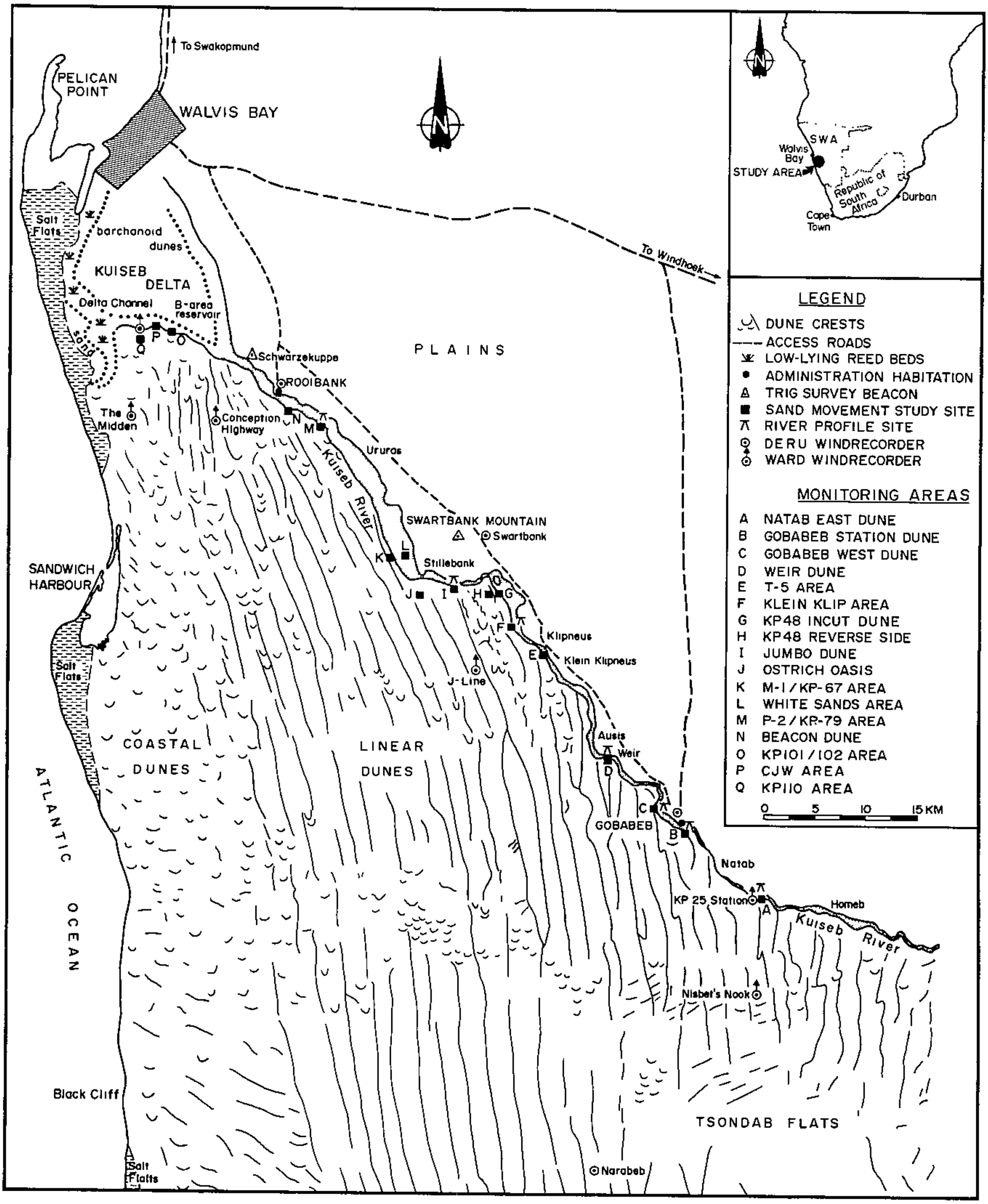

Figure 1. Study area for the sand dynamics monitoring programme in the Natab-Delta sector of the Lower Kuiseb River. The localities of the dune movement monitoring areas, river profile sites, and windrecorders are shown.

6. SAND DYNAMICS ALONG THE LOWER KUISEB RIVER

J D Ward and V von Brunn, University of Natal, Pietermaritzburg

INTRODUCTION

Much of the controversy surrounding the use of the Kuiseb basin's water resources centred on the probable impacts that reduced flooding would have on the northward movement of dunes from the Namib Sand Sea. It was popularly believed that the scouring action of floods, even at the infrequent intervals with which they occur, is sufficient to hold back the advance of the dunes. Furthermore, the dense riverine woodland was seen by some as a potent physical barrier to dune movement. The careful assessment of the roles of both flooding and vegetation on the dynamics of the dune systems thus formed an important component of the first phase of the Kuiseb Environmental Project. Key questions addressed in the study included:

- What is the rate and direction of movement of sand bodies along the Kuiseb River between Natab and the Delta section?

- What are the types of sand bodies and how are they related to this movement?

- What is the relation of sand movement to wind direction and velocity?

- What is the relation of sand movement and accretion to vegetation cover?

- How will changes in the Kuiseb riverine vegetation influence sand dynamics in the area?

- What sedimentological features reflect past changes in the geomorphological setting of the Kuiseb River drainage and how might these be used to predict possible changes in the future?

The study area comprised that section of the Lower Kuiseb River between Natab East Dune (Damaron/howati) and the southern channel of the Kuiseb Delta (Figure 1). In that reach, the Kuiseb River borders two major dune types of the main Namib Sand Sea. Coastal, transverse (Barnard 1973), or crescentic (Breed et al 1979) or transitional (Besler 1980) dunes are encountered in the delta area between Rooibank and the coastal flats, whereas longitudinal (Barnard 1973; Besler 1980) or complex linear dunes (Breed et al 1979) are found upstream of Rooibank. The trend of dune ridge alignments within the study area is depicted in Figure 1.

SANDS OF THE STUDY AREA

The sands within the study area are dominantly quartz grains, ca 90 percent (Barnard 1973) with minor amounts of ilmenite, rutile, garnet, sillimanite and biotite (Nagtegaal 1973; Harmse 1980). Two main sand populations are recognized, viz a dune-derived sand which generally has rounded to sub-rounded, often frosted, well-sorted, medium- to fine (1.8 - 2.2 diameter) grains and a river-derived sand with generally angular to sub-angular, clear, moderately sorted, fine (2.2 - 2.4 diameter) grains (Table 1). These differences, well illustrated by Harmse (1980) and further substantiated by settling-tube grain size analyses, scanning electron and optical microscopy studies in this study, were used to distinguish sand grain types in the Kuiseb River bedload. Rough estimates of the mixing between these two sand populations in the Kuiseb River bedload are shown in Figure 2, but it must be emphasized that it is the

Table 1. Summary of the differences between dune- and Kuiseb river-derived quartz sand grains.

CHARACTER	DUNE SAND	KUISEB RIVER SAND
SHAPE (after Powers 1953) (Fig 8)	Mostly rounded, ranges from well-rounded to sub-angular.	Mostly angular to sub-rounded.
SURFACE TEXTURE (Fig 8)	Low surface relief; pitted/frosted surface.	High surface relief; fresh conchoidal fractures and cleavage margins.
SIZE (Based on Udden-Wentworth scale, Blatt et al 1980, p 57)	Mostly medium- to fine-grained. (i) This study: n = 57 Mean (0) = 1.91 Range (0) = 1.39-2.47 (ii) After Harmse (1980), n = 132 Mean (0) = 2.24	Mostly fine-grained. (i) This study: n = 25 Mean (0) = 2.25 Range (0) = 1.92-2.6 (ii) After Harmse (1980), n = 76 Mean (0) = 2.44
SORTING (after Folk 1968)	Well-sorted to very well-sorted; mature. (i) This study, n = 57 Sorting x = 0.328 Range - 0.147-0.58 (ii) After Harmse (1980), n = 132 Sorting x = 0.358	Moderately well-sorted to well-sorted; sub-mature. (i) This study, n = 25 Sorting x = 0.468 Range - 0.369-0.58 (ii) After Harmse (1980) n = 76 Sorting x = 0.593

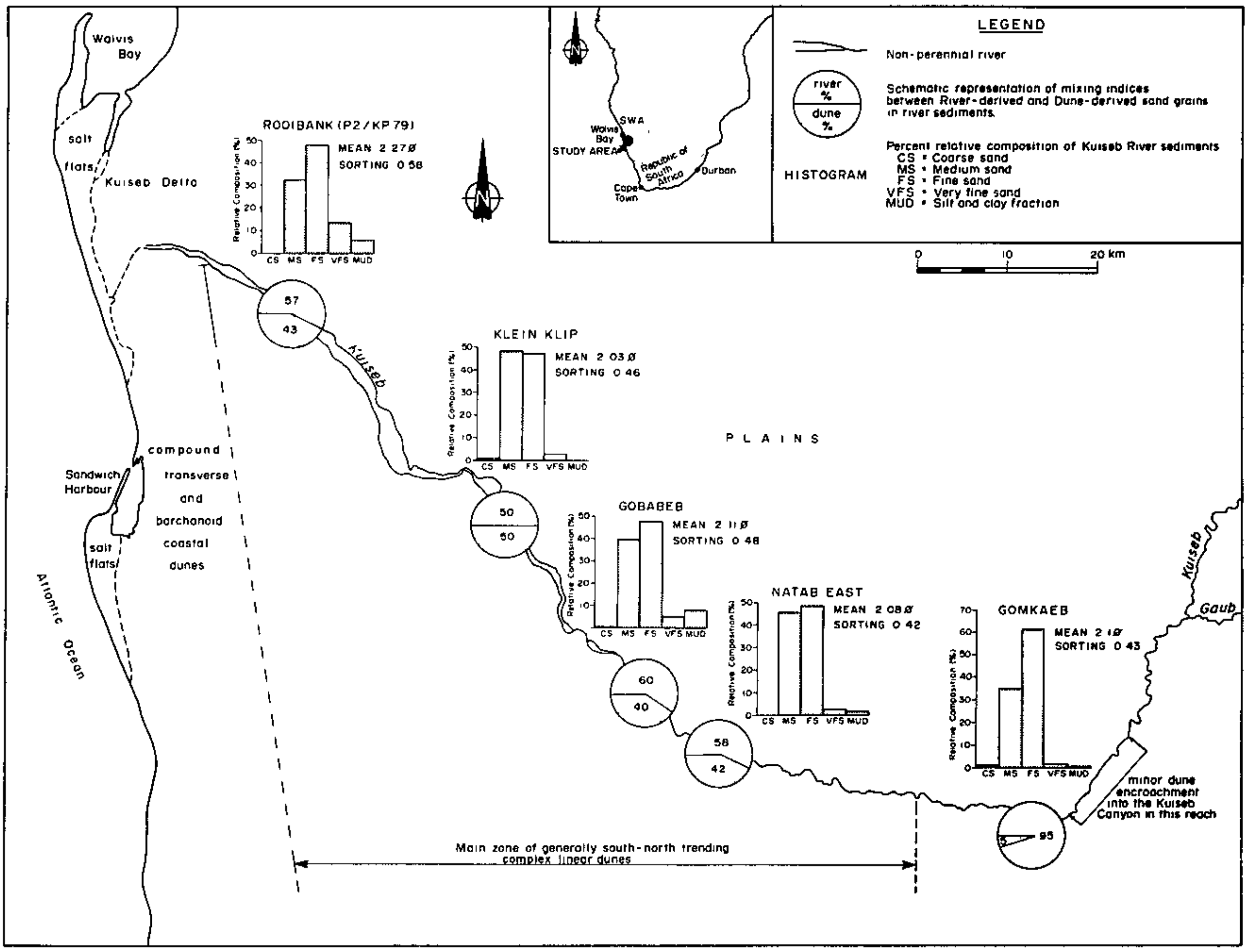

Figure 2. Estimation of the mixing between river- and dune-derived sand grains in the bedload of the Lower Kuiseb River between Gomkaeb and Rooibank. Relative composition, mean grain size, and sorting of the mixed river bedload sediment are also displayed.

trend which is more significant than the actual values because of the relatively small sample size. From Figure 2 it is readily apparent that the dune-derived sand constitutes a significant proportion of the river bedload, some 40 - 50 percent, within the study area. Moreover, the dune sand contribution would appear to be linked with the distribution of complex linear dunes and is probably introduced into the riverbed by flood erosion of those dunes fronting on the Lower Kuiseb River, particularly during the heavy floods such as 1963 (Koch 1963; Stengel 1964; Barnard 1975). The addition of dune-derived sands into the river sediment system, therefore, could be an extra factor to consider when evaluating both the convex longitudinal profile (Stengel 1964; Marker 1977) and good aquifer potential (Myburgh 1971) of the Lower Kuiseb River.

REGIONAL AIRFLOW IN THE CENTRAL NAMIB

With the relatively large amount of unconsolidated sands, mostly lightly vegetated, in both the Kuiseb River and adjacent main Namib Sand Sea, wind is an important environmental factor in sand transportation and deposition. Wind data were recorded at 10 stations, using Lamprecht windrecorders with monthly charts through the study area (Figure 1). An attempt was made to record airflow in the main Namib Sand Sea and along the Kuiseb River, as well as across a rough west-east transect. Six windrecorders were under the researcher's jurisdiction and the other four were controlled by the Desert Ecological Research Unit (DERU). Regional airflow patterns for January (summer), April, July (winter) and October of 1981 are presented in Figures 3, 4, 5 and 6 respectively, because all ten stations were operational in that year. From the wind roses illustrated in Figures 3, 4, 5 and 6, two main trends should be noted:

- a coastal, high-energy, dominantly south-southwesterly unimodal regime west of Rooibank as opposed to a low to intermediate energy, complex bimodal regime inland from Rooibank;

- the dominance of the south-southwesterly to southwesterly wind at all stations in summer compared with the general lower occurrence of those winds in winter, when high velocity, low frequency easterly quadrant berg winds are experienced.

These trends in the Central Namib wind regime have long been recognized and their potential to effect northward migration of the sand dunes from the main Namib Sand Sea across the Kuiseb River was even appreciated last century (Wilmer 1893). Subsequent workers have also appreciated the regional airflow patterns, including Goudie (1972), Barnard (1973, 1975), Seely and Stuart (1976), Breed et al (1979), Besler (1980), Lancaster (1980, 1982a and b) and Harmse (1980, 1982). Many of these workers have considered the sand-moving potential of the winds, ie those winds which exceed the threshhold velocity for the entrainment of sand particles (Bagnold 1941). Harmse (1982) has presented a synthesis of potential sand movement from geomorphically effective winds, but not all data were considered adequate. Lancaster (1982b) has presented a synthesis of more recent, comprehensive wind data for the Central Namib. In general, sand drift potentials calculated from wind data for the coastal areas have been confirmed by field observation and measurement of sand dune movement, but some discrepancy was found between these two approaches in the Rooibank - Natab East sector, where the bimodal wind regime prevails.

In the coastal areas, calculated sand drift potential shows a marked north to northeasterly trend (Barnard 1975; Fryberger and Dean 1979; Breed et al 1979; Harmse 1980, 1982; Lancaster 1982b). This trend was confirmed by fieldwork and the comparative Job 313/78 and Job 379/81 aerial photography (Figure 7). However, east of Rooibank the calculated drift potential for those stations along the north bank of the Kuiseb imply a general southwesterly to westerly movement (Harmse 1980, 1982; Lancaster 1982a), ie away from the river, in contrast to the observed movement, albeit relatively small, in a general northeasterly direction (Figure 7). However, annual resultant sand flows recently calculated from 1981 records at some dune stations south of the Kuiseb, viz the Midden, Conception Highway, Flodden Moor, Narabeb, Nisbets Nook (Figure 1) all show the general north to northeasterly trend (Lancaster 1982b). (See Table 1).

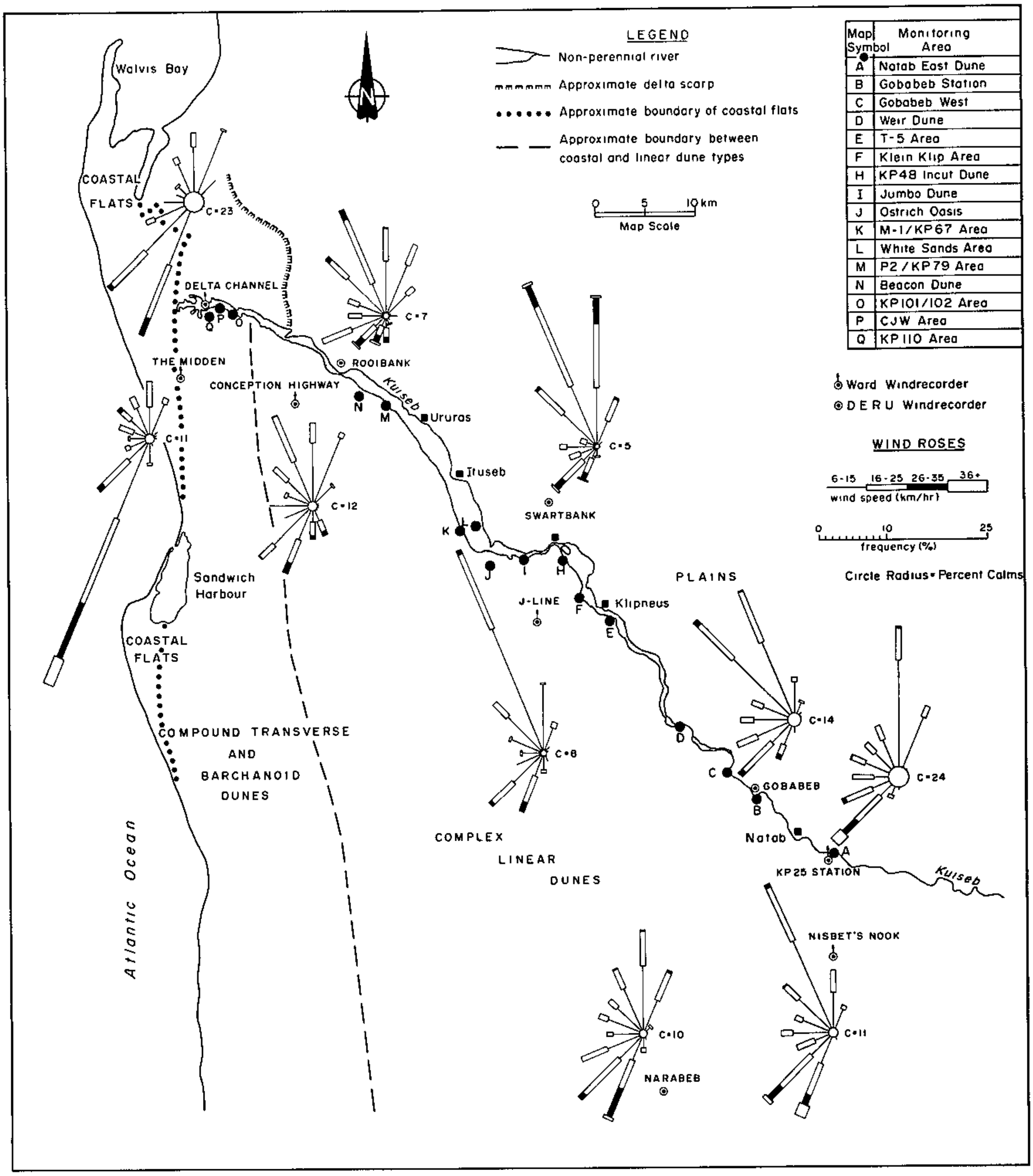

Figure 3. Regional surface airflow at ten stations in the Central Namib Desert, January (summer) 1981.

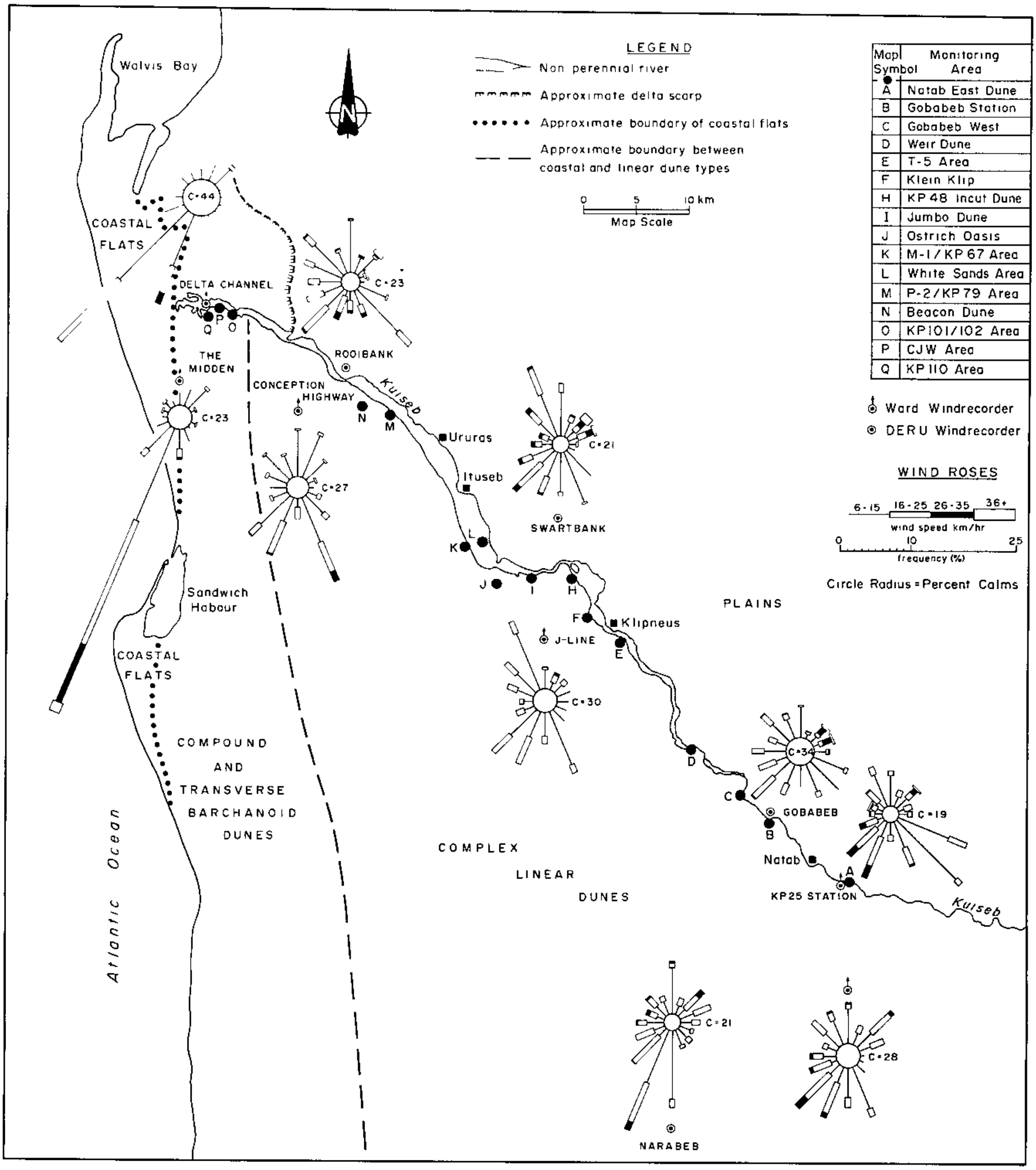

Figure 4. Regional surface airflow at ten stations in the Central Namib Desert, April 1981.

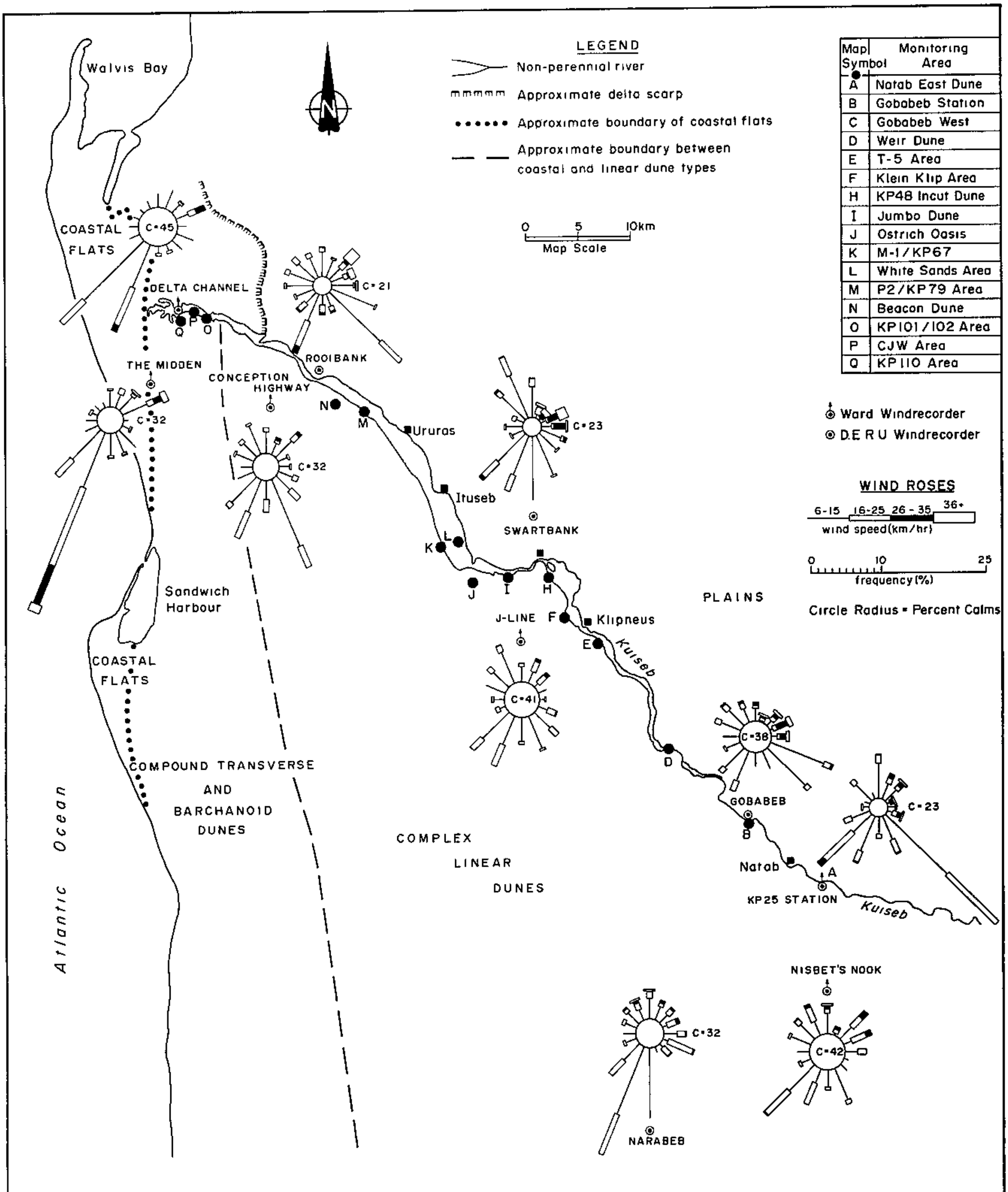

Figure 5. Regional surface airflow at ten stations in the Central Namib Desert, July (winter) 1981.

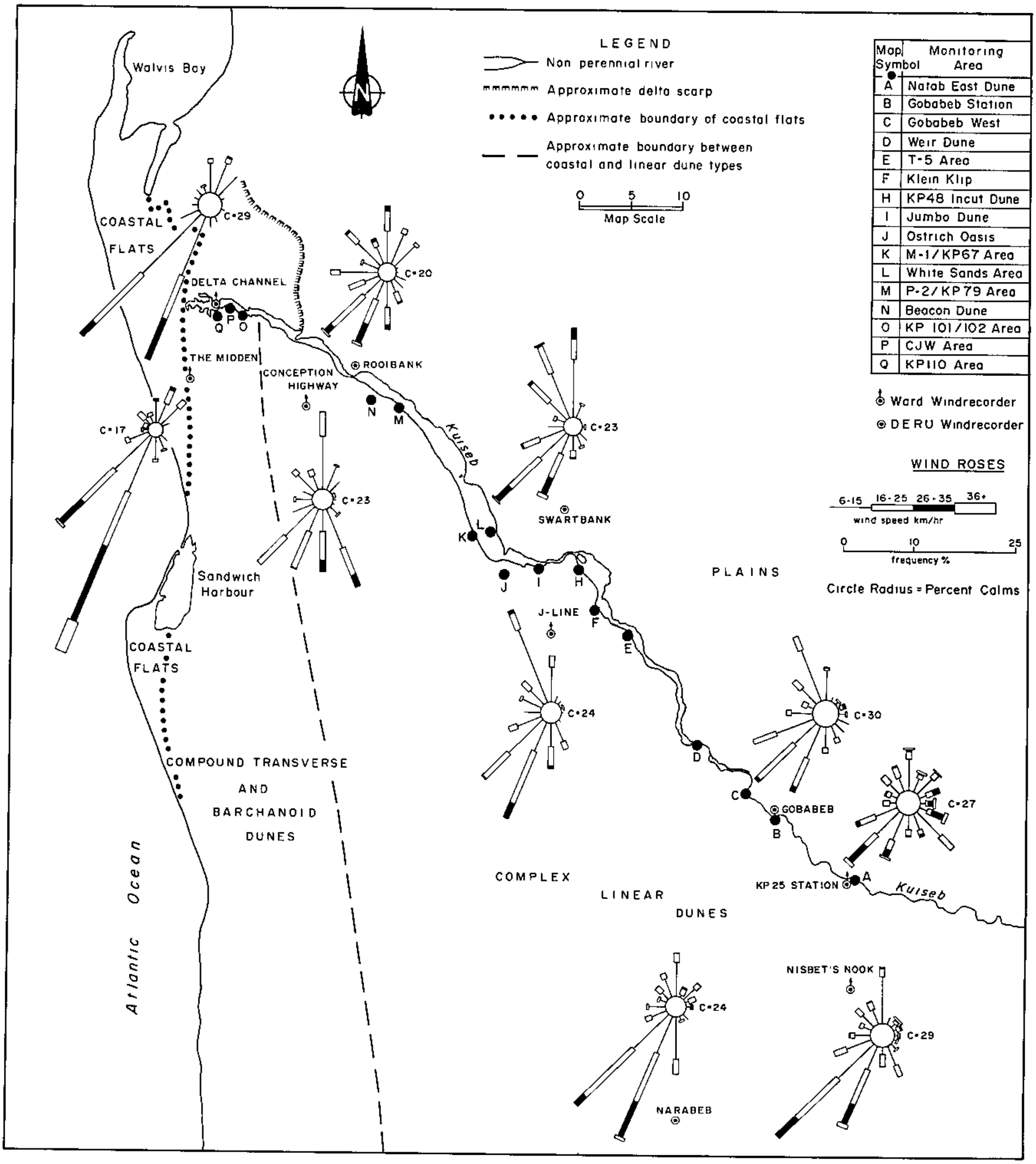

Figure 6. Regional surface airflow at ten stations in the Central Namib Desert, October 1981.

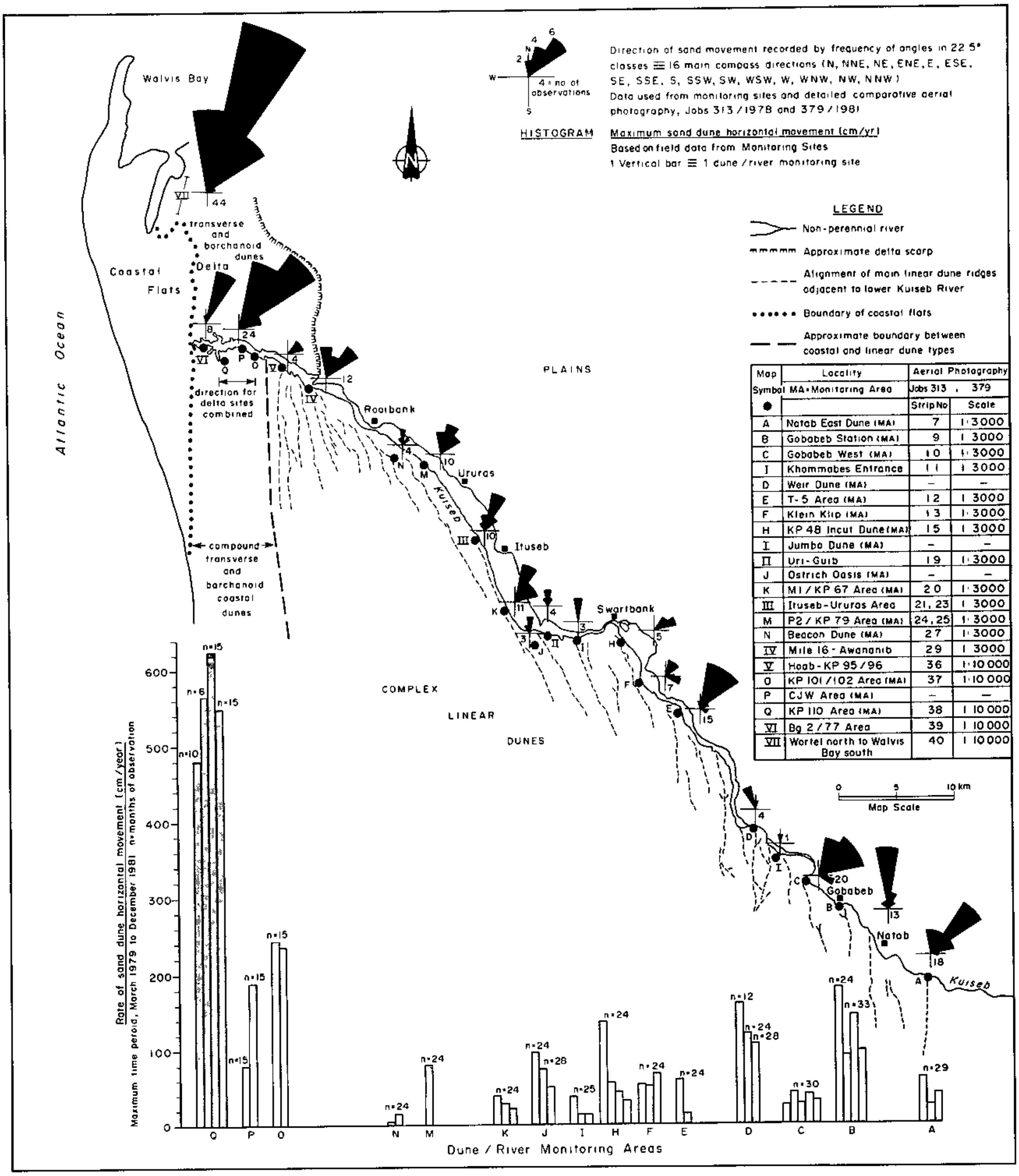

Figure 7. Estimated rates and direction of sand dune movement along the Lower Kuiseb River in the Natab-Delta sector, 1978-1981.

Table 1. Resultant annual sandflow for 1981 at some windrecorder stations south of the Kuiseb River in the main Namib Sand Sea (after Lancaster, 1982b).

Windrecorder station (see Figure 1)	Annual resultant sandflow (tonnes/m width)	Resultant direction of potential movement
The Midden	334.82	16° NNE
Conception Highway	30.42	356° N
Flodden Moor	56.09	14° NNE
Nisbet's Nook	62.6	33° NE
Narabeb	45.69	18° NNE

In general, Breed et al (1979) consider that the "observed present-day wind regimes of the Namib Desert are roughly compatible with the observed dune types in the several zones. The rapid decrease in wind energy inland from the coast, however, suggests that linear and star dunes in the interior are considerably less active than are crescentic dunes along the coast" (p 346). These observations have been borne out by the field monitoring programme carried out between March 1979 and December 1981 along the lower reaches of the Kuiseb River.

EVALUATION OF POTENTIAL SAND DUNE MOVEMENT

The quantitative and qualitative changes in sand bodies, with emphasis on the potential dune encroachment into the river were monitored using ground and remote survey techniques. These methods were supplemented by the use of the comparative vertical aerial photography of Jobs 313/78 (May 1978) and 379/81 (May 1981). Most monitoring areas were deliberately located within the detailed strips, thus providing additional control for the ground surveys. Seventeen ground monitoring areas, with a total of 84 study sites were selected for field observation. The most useful technique for estimating sand dune movement was a method using grid and transect patterns of levelled, vertical stakes in which the pole heights (sand levels) were measured monthly (Figure 8). Raw field data were then stored on the SURVEY * KUISEB 2 File at the Computer Centre, University of Natal, Durban, and subsequently reduced to determine directions and rates of horizontal and vertical sand dune movement, as well as volume changes in the sand bodies. Panchromatic and colour transparency fixed-point ground photography, supplemented by oblique aerial photography and observation, recorded the potential changes qualitatively and provided visual control for the field measurements.

DIRECTION OF SAND MOVEMENT

Observations at all study sites and a comparison of the detailed aerial photography (Jobs 313/78 and 379/81) show clear evidence of an overall northerly to northeasterly migration of both coastal, crescentic dunes and inland, complex linear dunes from the main Namib Sand Sea into the Kuiseb River, during the period May 1978 to December 1981 (Figure 7). These records substantiate Barnard's (1975) observations in the Kuiseb delta

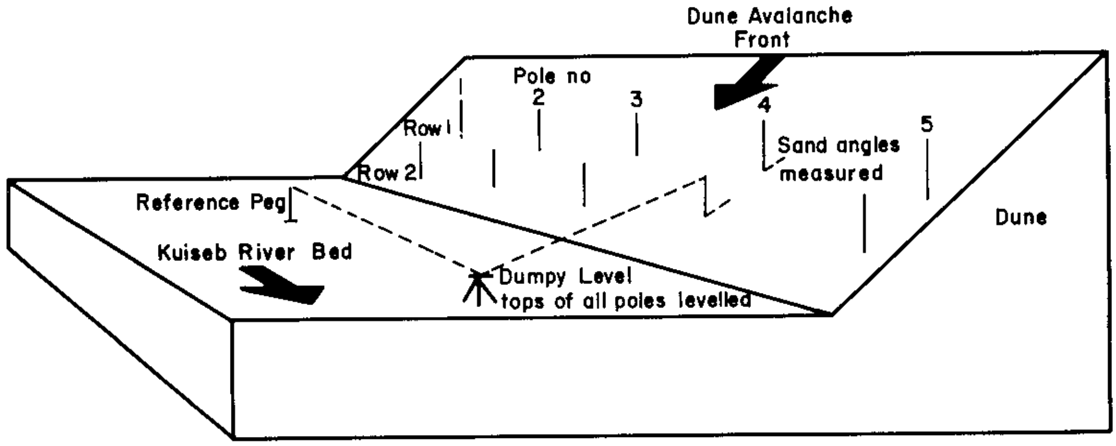

Figure 8. Schematic layout of a grid network of stakes to measure dune movement adjacent to the Lower Kuiseb River

where he noted both a northeasterly movement of transverse dunes and a northwesterly extension of some dunes when comparing the 1960 and 1969 aerial photographs. As mentioned earlier, conflicting interpretations based on wind data and fieldwork respectively have been obtained for the Gobabeb, Swartbank and Rooibank wind stations (Breed et al 1979; Harmse 1980, 1982; Lancaster 1982a), as opposed to the good correlations at the coastal stations (eg Pelican Point, in Barnard 1975; Breed et al 1979; the Midden in Lancaster 1982b; Walvis Bay Radio in Harmse 1980, 1982). The sand directions recorded during the monitoring programme suggest that a degree of caution should be exercised when interpreting sand drift potential values calculated from wind data, particularly where the wind regime is bimodal. Fryberger and Dean (1979) in their world-wide summary of dune forms and wind regime also consider the most reliable comparisions, based on wind data only, to be between dunes and wind environments with high drift potentials.

RATES OF SAND MOVEMENT

Estimates of the rate of sand dune horizontal movement (cm/yr) are also given in Figure 7 for all the field monitoring sites. These trends reflect the difference between the more competent, unidirectional coastal wind regime and the weaker, more variable inland pattern. In the delta, horizontal movement ranged from ca 80 cm - 630 cm/yr, with the westernmost monitoring area in the vicinity of the KP110/111 aerial survey pegs having the maximum rates. Barnard (1975), in comparing 1960 and 1969 aerial photographs of the delta area, estimated forward (ie northeasterly) dune movement to range from -7 m to 137 m (average 84 m) for sand dunes 10 - 13 m high, an average of 930 cm/yr. Although somewhat higher than the 630 cm/yr measured in the KP110 area, Barnard's (1975) values are probably a reasonable estimate because visual stereoscopic comparison of strip 40 of Jobs 313/78 and 379/81 over a three-year period show large amounts of movement in those westernmost crescentic dunes between Walvis Bay and Wortel. Upstream of Rooibank, estimated sand dune horizontal movement rates ranged between 0 and 180 cm/yr. These values were recorded for large, complex linear dunes fronting onto the Kuiseb River in that reach.

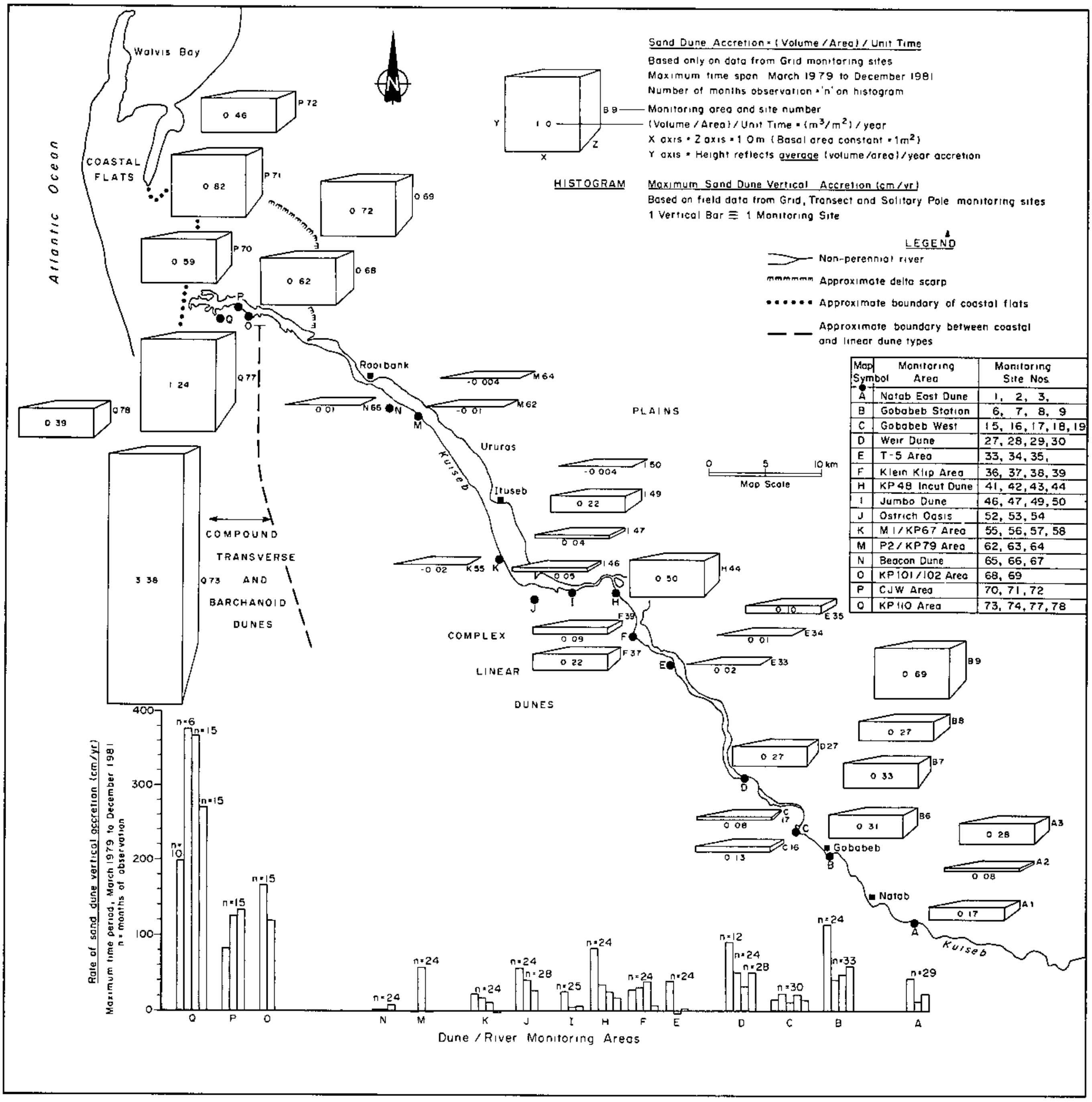

Figure 9. Rates of sand dune accretion (vertical and volume/unit area) along the Lower Kuiseb River in the Natab-Delta sector, 1979-1981.

Rates of 300 - 400 cm/yr have been recorded over a four year period in the Gobabeb area (Besler 1975). However, the dune measured was a narrow (less than 3 m high) tip of a small linear dune just south of the Kuiseb River, and is not considered representative of the main bulk of linear dunes entering the Kuiseb River along its left bank. The vertical accretion rates (cm/yr) followed a very similar trend (Figure 9), although values were less than horizontal rates due to the angle of repose of dry sand.

The trend in sand dune accretion (volume/area) with time is shown in Figure 10, where representative sites only could be illustrated. Again, the major difference between sand movement in the delta area and sites upstream from Rooibank is clearly reflected. The important point to note, however, it that the delta sites show a maximum movement in the summer months, when the south-southwesterly to southwesterly winds are dominant (Figures 3, 4 and 6), as opposed to a standstill in sand accretion during winter brought about by the easterly quadrant berg winds (Figure 5). The effect of the berg winds was profound in the delta, where even erosion can occur (KP110 area, site 77 in Figure 10). The winter standstill was probably enhanced by the general northwest-southeast alignment of the crescentic dunes, ie normal to the berg winds, as well as the relatively low dune height (5 - 30 m).

In contrast, the sites upstream of Rooibank do not reflect any strong correlation between maximum sand movement and season (Figure 10). In fact, several sites, eg Natab East Dune (site 3), Gobabeb Station Dune (sites 6, 7 and 9) even show maximum rates of sand accretion during berg winds in the winter of 1979. This anomalous situation was probably the result of airflow divergence caused by the main linear dune ridges, and as these winds are invariably strong to very strong (Figure 8, and measured short-term velocities of 75 - 90 km/hr in May 1979), a greater proportion of sand (Bagnold 1941, reprinted 1973) could be transported in the Kuiseb River.

THE INFLUENCE OF VEGETATION ON SAND MOVEMENT

Another important feature to note is the apparent lack of sand movement in the Rooibank - Kuiseb II beacon sector, ie monitoring areas K, M and N (Figures 7, 9 and 10). In that reach of the Kuiseb, a maximum horizontal rate of ca 80 cm/yr was measured at monitoring area M (site 63), but overall the rate varied from 0 cm/yr to ca 20 cm/yr. This is another anomalous situation as the wind strength should increase towards the coast (Breed et al 1979; Harmse 1982), thus facilitating sand movement. This lack of movement has been attributed to several factors, including:

- main linear dune ridge alignment sub-parallel to the Kuiseb course in that sector (Figures 1 and 7);
- occurrence of relatively low velocity northerly quadrant winds (Figures 3, 4, 5 and 6);
- the relatively large stands of the coarse dune perennial grass, Stipagrostis sabulicola (Pilger) de Winter along the left bank, which has a semi-stabilising effect on sand movement (Figure 11), and probably was the most important hindrance to sand movement in that area.

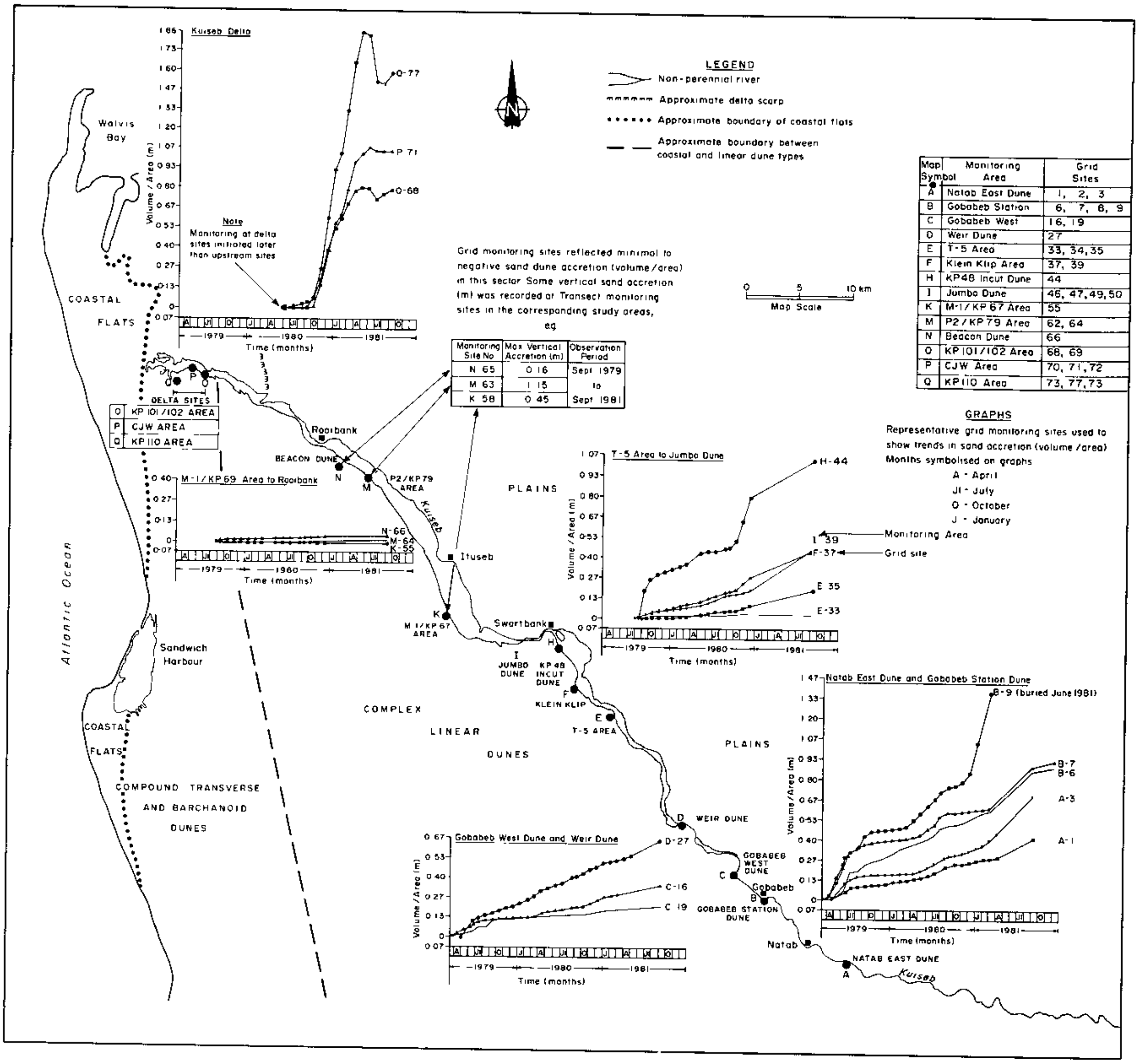

Figure 10. Trends in sand dune accretion (volume/unit area) along the Lower Kuiseb River in the Natab-Delta sector, 1979-1981.

In general, vegetation increases bedform roughness, facilitating sand deposition (Bagnold 1941, reprinted 1973; Hesp 1981), and vegetation density, not necessarily height, is the more important factor to consider in this process (Bressolier and Thomas 1977).

Sand accretion around clumps of Stipagrostis sabulicola and on adjacent, uncolonised sand within the dunes was monitored at plots laid out at Natab East Dune (monitoring area, MA = A), Gobabeb Station Dune (MA = B), Gobabeb West Dune (MA = C) and Weir Dune (MA = D). The results are graphed in Figure 11, and although not immediately striking, the trends show some dune surface stabilization and even sand build-up around Stipagrostis sabulicola clumps relative to the adjacent sand control plots. Harmse (1980) mentions the potential build-up of dune sand around Stipagrostis sabulicola clumps but no measurements were made. Field observations made on 5 September 1979 during a strong southerly wind at Rooibank first drew the researcher's attention to the semi-stabilisation potential of S sabulicola. Thereafter, this effect was noted on several occasions during strong easterly berg winds as well as strong south-southwesterly winds in the Rooibank vicinity. Furthermore, Stipagrostis sabulicola has the ability to exploit fog water (Louw and Seely 1980), and thus the potential to survive many years with little or no rain. It is also probably independent of the Kuiseb River ground water. Fog data kindly provided by Dr M K Seely (DERU meteorological data, in press, December 1982), show that maximum annual fog precipitation along the Kuiseb Valley occurs at Swartbank, some 180 mm/yr, followed by Rooibank, some 80 mm/yr (Figure 12). These data confirm field observations made between 1979 and 1981 that fog precipitation was probably heaviest in the reach between Rooibank and Swartbank - the area in which Stipagrostis sabulicola occurs in relative abundance in the Kuiseb River and adjacent left-bank floodplain, as well as along the dune bases (personal observations; map of Theron et al 1980).

The effect of vegetation on sand movement was also noted at other monitoring areas, particularly where the riparian woodland fringe was evident (eg Gobabeb West Dune, MA = C). It would appear that the trees primarily affect the airflow patterns, thereby influencing sand movement, and do not necessarily physically trap the sand to the same degree that was observed with Stipagrostis sabulicola. Furthermore, it appears with the lack of rain in the Central Namib Desert subsequent to the unusual rains of 1976 and 1978, the dune vegetation is dying back, particularly since mid-1981 (personal observation; M K Seely, pers comm 1982). The decrease in dune vegetation, notably Stipagrostis sabulicola, appears to have been enhanced by the grazing pressure by stock and game during the recent drought years. A possible result of this situation might be found in the Aub area (aerial survey pegs KP9 and KP10 of strip 3, Jobs 313/78 and 379/81), where fixed photopoints show a greater increase of red dune sand in the Kuiseb canyon between December 1981 and December 1982, than between July 1979 and December 1981. There is a distinct time lag between reduction of vegetation cover and the last good rains (1978) and it was also observed that even dead vegetation, eg Eragrostis spinosa, was still effective in binding and even trapping sand in the Swartbank area (J-line interdune valley) and in the riverbed in the vicinity of Klein Klipneus.

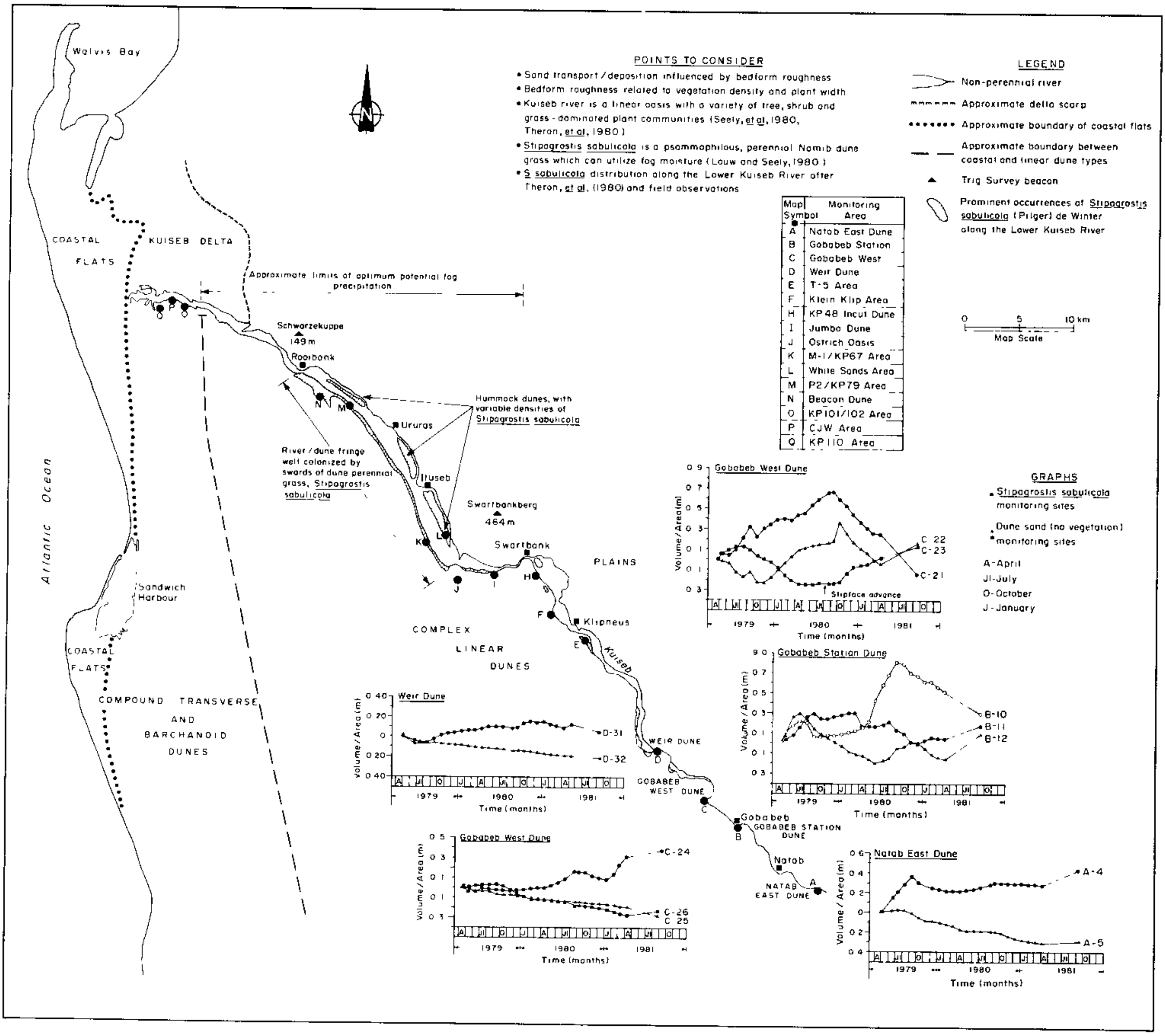

Figure 11. Trends in dune sand accretion associated with the perennial grass, Stipagrostis sabulicola, in the Natab-Rooibank sector of the Lower Kuiseb River. The distribution of extensive patches of S sabulicola along the Lower Kuiseb River is shown, as is the approximate limits of optimum fog precipitation in the Kuiseb Valley.

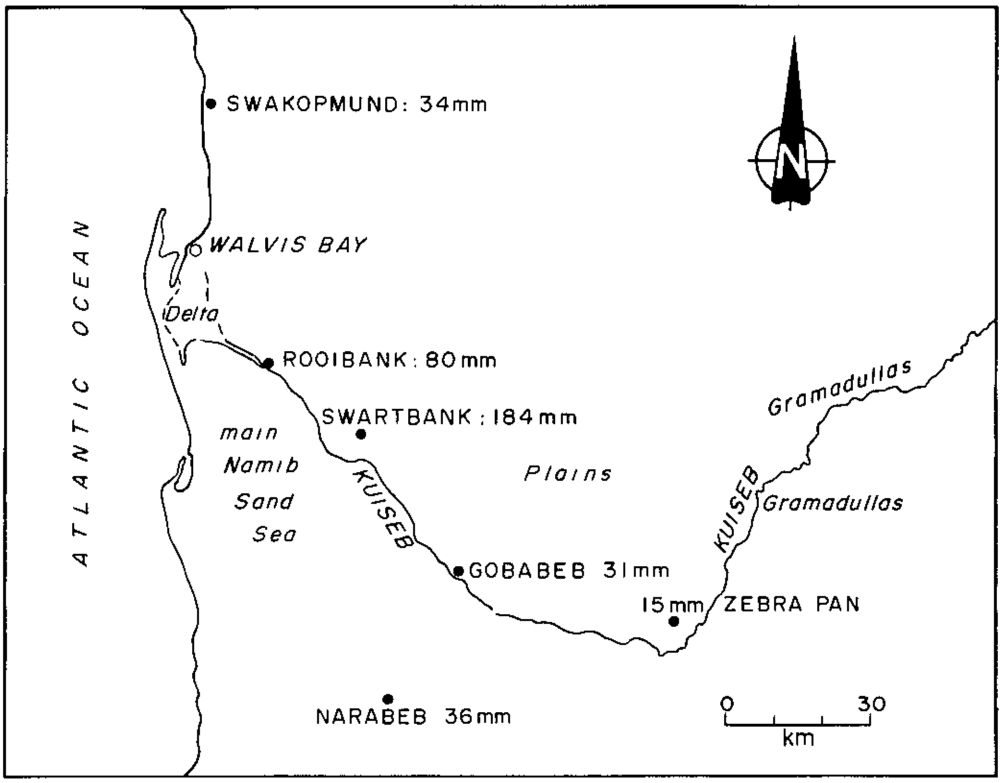

Figure 12. Mean annual fog precipitation at some DERU weather stations in the Central Namib Desert. (DERU meteorological data, unpublished, December 1982).

ZONES OF SAND MOVEMENT

When the rate of sand dune accretion, (volume/area) per unit time is considered, then three general zones of overall sand movement can be recognized (Figure 9). Maximum accretion rates were recorded in the delta, ranging from 0.39 - 3.38 (m^3/m^2)/year, although the upper value is an over-estimation due to total burial of the study site during the early summer months of 1980. A more realistic value is probably in the order of 2.2 (m^3/m^2)/yr. At most grid sites in the Rooibank-Swartbank sector there was minimal accretion, and even deflation (erosion). In the Swartbank - Natab East sector accretion rates were variable, ranging from 0.01 - 0.69 (m^3/m^2)/yr.

The trends in sand dune movement observed in the period May 1978 to December 1981 are summarised:

Delta area

Maximum rates of movement are in a northerly to northeasterly direction, mostly in summer when the high-energy, south-southwesterly to southwesterly coastal wind regime is dominant. The lack of dune vegetation in this area probably enhances sand movement. Estimated time for dunes to cross the southern delta channel is ca 100 years in the

B-area reservoir vicinity and probably less than 25 years in the Bg 2/77 borehole vicinity, if uninterrupted by floods. However, these dunes are relatively small, 5 - 30 m high, with their crescentic alignment roughly parallel to approximate Kuiseb River flow. It should be noted that this southern delta channel has been re-activated since the completion of the diversion wall in 1962 (Stengel 1964; L Blom, pers comm 1982).

Rooibank-Swartbank (Kuiseb II beacon) sector

Mostly minimal rates of sand movement into the Kuiseb River were recorded, although up to ca 80 cm/yr horizontal movement was noted at site 63 in the P-2/KP79 area. However, even in a comparison between relevant strips of Jobs 313/78 and 379/81, the changes observed were mostly on the dune flanks adjacent to the river floodplain. The relatively minor dune encroachment of the river course has been attributed to:

- large stands of the dune perennial grass Stripagrostis sabulicola, along the river margin and dune bases in that reach, forming a potential semi-stabilising cover to sand movement;

- alignment of the main linear dune ridges sub-parallel to the Kuiseb course;

- possible influence of low velocity northerly winds in retarding the general northerly to northeasterly dune movement.

A tentative estimate of 1500 - 2000 years is suggested here for the dunes to cross the Kuiseb River in this broad, shallow valley reach.

Swartbank - Natab East Dune sector

Variable rates of movement and accretion were recorded in this sector, mostly in a northerly to northeasterly direction, into the Kuiseb River. However, in the T-5 and Klein Klip areas sand dune movement in an east-southeasterly direction was noted (Figure 7). No definite seasonal trend in sand dune accretion was apparent in this sector, in comparison with the summer maximum evident in the delta area (Figure 10). Contrary to expectations, strong easterly berg winds have caused maximum deposition at some sites, and dune sand movement in those areas is probably related to the main linear dune ridge alignment perpendicular to the river course. Riparian vegetation retards the sand dune movement into the river, mostly by disruption of the airflow patterns (ie bedform roughness is increased). Estimated time for the dunes to cross this reach of the river is problematical because of the variable rates measured. In the Natab East Dune area, 500 - 800 years is tentatively proposed, whereas at Gobabeb Station Dune 200 - 300 years appears to be a more reasonable estimate. At the Weir Dune, 100 years at the present rate, with no floods, would appear to be sufficient time for the dune to cross the Kuiseb. It must be appreciated that the dunes in this reach are relatively large linear types, mostly ca 70 - 110 m high, although Jumbo Dune has been recorded as ca 145 m high (Water Affairs, detailed maps). Therefore, these dunes have the potential to affect the Kuiseb River course to a greater extent than the more rapidly moving, but smaller, dunes of the delta.

The tentative estimates of time for the dunes to encroach upon, and cross the Kuiseb River must be accepted with caution. These estimates were determined from measurements taken over a relatively short time span, viz March 1979 to December 1981, and under field conditions that can be considered unusual, namely the lack of Kuiseb floods below the canyon reach.

KUISEB RIVER FLOW

Floods were recorded at Gobabeb every year from 1963 to 1979 (Seely et al 1981), but the recent drought has resulted in very poor runoff in the summer seasons of 1980, 1981 and 1982 (Seely et al 1981; personal observation). Consequently, no substantial flooding occurred in the study area during the monitoring period (Table 2). However, the potential effect of the Kuiseb floods, particularly on the erosion of sand dunes along the left bank, was personally observed at Gobabeb in the relatively heavy 1976 floods and can be gleaned from the various published accounts, notably Koch (1963), Stengel (1964), Seely (1973), Barnard (1975) and more recently a summarised account of the Kuiseb flood history in Seely et al (1981). It would appear that although the bimodal, low- to moderate energy wind regime inland from the delta and the riverine vegetation play an important role, it is dominantly the erosive flushing action of the Kuiseb River floods that constitutes the major barrier to the general northerly to northeasterly movement of the sand dunes of the main Namib Sand Sea.

Table 2. Summary of the Kuiseb River floods at Gobabeb, 1961/1963-1982/1983 (mostly from Seely et al, 1979/1981).

Year	Total no of days
1962/63	68
1963/64	No record
1964/65	26
1965/66	18
1966/67	22
1967/68	11
1968/69	18
1969/70	1
1970/71	34
1971/72	43
1972/73	15
1973/74	102
1974/75	10
1975/76	61
1976/77	8
1977/78	7
1978/79	8
1979/80	No flow
1980/81	No flow
1981/82	No flow
1982/83	No flow
1983/84	4

CONCLUSIONS

Dune sand was moved in a dominant northerly to northeasterly direction, into the Kuiseb River during the monitoring programme, March 1979 to December 1981. This movement, measured in the field, is confirmed in the detailed comparative aerial photography of Jobs 313/78 (May 1978) and 379/81 (May 1981). The greatest rates of movement and accretion were measured in the delta, where the coastal, high-energy, unidirectional south-southwesterly wind regime is dominant. Inland from Rooibank, sand movement rates were considerably less than in the delta, due to a less effective, bimodal low to intermediate energy wind regime and relatively extensive vegetation cover along the Kuiseb course. The anomalous minimum amounts of movement observed in the Swartbank (Kuiseb II beacon) - Rooibank sector are attributed to large stands of the dune perennial grass Stipagrostis sabulicola, which have apparently semi-stabilised the dune bases and river floodplain margin in that reach, the alignment of main linear dune ridges sub-parallel to the river and low velocity, northerly to northwesterly winds. The high velocity, low frequency, easterly quadrant berg winds of winter cause a major halt in the northerly movement of the smaller, crescentic dunes in the delta. However, these winds can accelerate sand movement into the Kuiseb River in the upper reaches of the study area, because of apparent airflow divergence on the large, linear dune ridges, particularly those perpendicular to the river course. Therefore, caution must be heeded when interpreting sand drift potentials determined only from wind data, with no ground control.

The flooding of the Kuiseb River is probably the most important factor in checking the northerly no northeasterly migration of sand dunes from the main Namib Sand Sea under the present conditions. However, evidence from the Late Cenozoic geological record suggests that this has probably been the case for at least the last 500 000 to 1 000 000 years, except along the immediate coastal tract.

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7. VEGETATION OF THE LOWER KUISEB RIVER

G K Theron, N van Rooyen and Margaretha W van Rooyen, University of Pretoria

INTRODUCTION

Prior to the initiation of a detailed programme to monitor changes in the structure and vitality of the riverine woodland of the Lower Kuiseb River, the major vegetation units were classified and mapped. The description of the communities given in this chapter are taken directly from Theron et al (1980). Further information on the vegetation of the Lower Kuiseb may be found in Seely et al (1979) and Robinson (1976).

Physiognomic-structural areas were distinguished on aerial photographs taken in October 1976. These areas were examined in the field for homogeneity and woody species composition. Units with the same structure and species composition formed a variation and several variations were grouped into a community. With the exception of a few herbaceous species eg Eragrostis spinosa, Stipagrostis sabulicola, Odyssea paucinervis and Zygophyllum simplex, only woody species were used for the characterization of the vegetation units. The vegetation map of the area between Nareb* and Rooibank (Figure 1) was compiled and 14 different communities were distinguished. Some of the communities were subdivided into variations and a total of 40 variations were distinguished (Table 1). Four additional units, consisting mainly of dead herbaceous species, were mapped between Gobabeb and Rooibank.

THE COMMUNITIES

Acacia albida community

This community, characterised mainly by large trees, occupies the riverbanks, although a number of large Acacia albida individuals often occur in the riverbed. The A albida community is well-developed between Nareb and Swartbank, whereas from Swartbank to Rooibank A albida often occurs as solitary individuals.

The Acacia albida variation, consisting of virtually pure stands of A albida, is well-represented upstream of Narob. In the vicinity of Homeb trees often reach 21 m in height. The Acacia albida - Salvadora persica variation is mainly found between Nareb and Natab where the

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*Nareb is perhaps more correctly called Sarib or Sariep (J D Ward, pers comm).

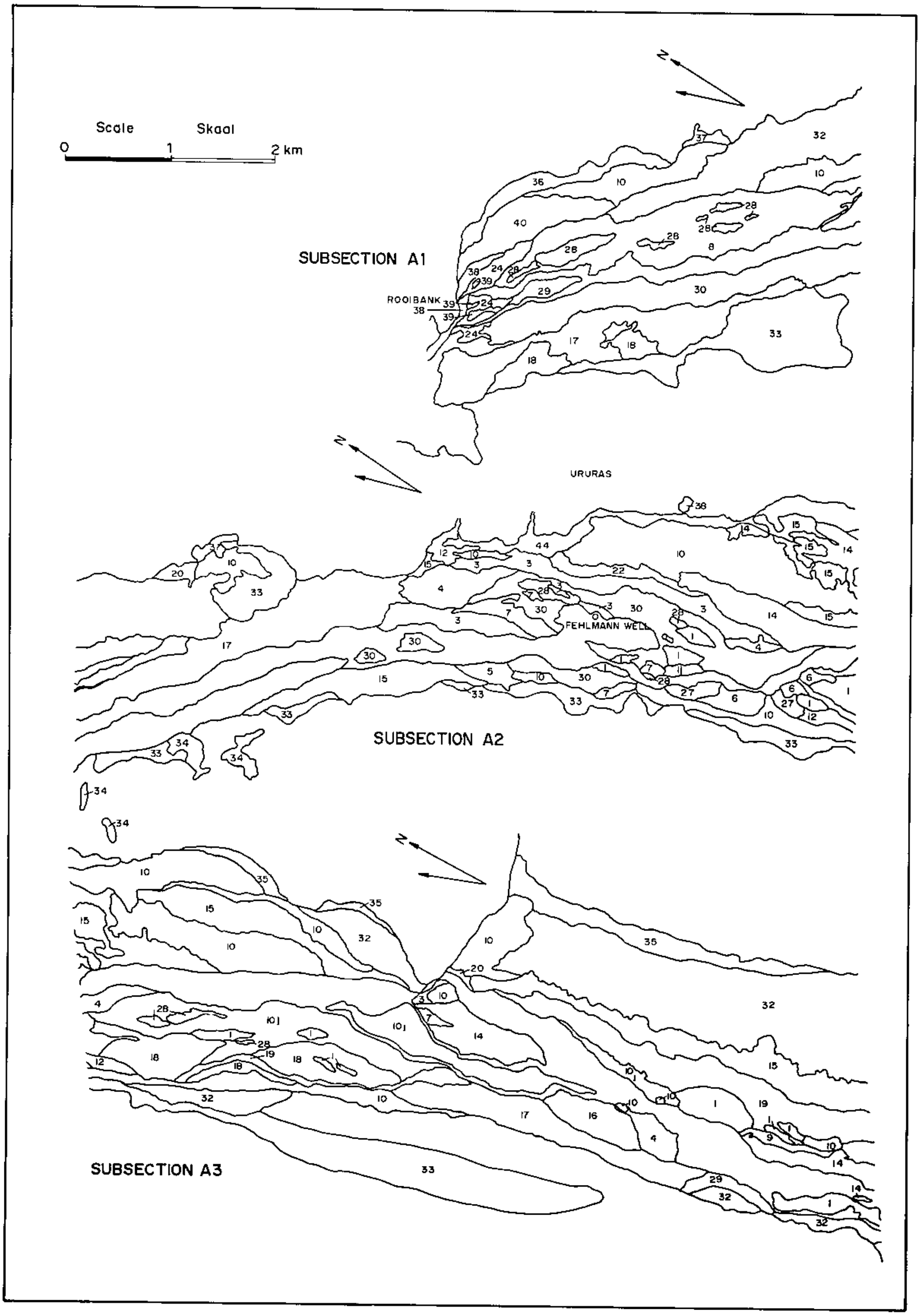

Figure 1. Extract of a vegetation map of the Lower Kuiseb River (Theron et al 1980).

Table 1. Plant communities of the Lower Kuiseb River.

ACACIA ALBIDA COMMUNITY

1. Acacia albida variation
2. Acacia albida - Salvadora persica variation
3. Acacia albida - Tamarix usneoides variation
4. Acacia albida - Eragrostis spinosa variation
5. Acacia albida - Stipagrostis sabulicola variation
6. Acacia albida - Suaeda plumosa variation
7. Acacia albida - Tamarix usneoides - Acacia erioloba variation (sometimes with Eragrostis spinosa or Suaeda plumosa)
8. Acacia albida - Eragrostis spinosa - Pechuel-loeschea leubnitziae variation
9. Acacia albida - Pechuel-loeschea leubnitziae variation

ACACIA ERIOLOBA COMMUNITY

10. Acacia erioloba variation
11. Acacia erioloba - Salvadora persica variation
12. Acacia erioloba - Suaeda plumosa variation
13. Acacia erioloba - Suaeda plumosa - Pechuel-loeschea leubnitziae variation
14. Acacia erioloba - Pechuel-loeschea leubnitziae variation
15. Acacia erioloba - Stipagrostis sabulicola variation
16. Acacia erioloba - Eragrostis spinosa - Pechuel-loeschea leubnitziae variation
17. Acacia erioloba - Acacia albida - Pechuel-loeschea leubnitziae variation
18. Acacia erioloba - Acacia albida variation
19. Acacia erioloba - Eragrostis spinosa variation

TAMARIX USNEOIDES COMMUNITY

20. Tamarix usneoides variation
21. Tamarix usneoides - Salvadora persica variation
22. Tamarix usneoides - Acacia erioloba variation
23. Tamarix usneoides - Acacia erioloba - Salvadora persica variation
24. Tamarix usneoides - Suaeda plumosa variation

25. SALVADORA PERSICA COMMUNITY

26. SALVADORA PERSICA - ACACIA ERIOLOBA - TAMARIX USNEOIDES - EUCLEA PSEUDEBENUS DUNE COMMUNITY

27. SUAEDA PLUMOSA COMMUNITY

28. ERAGROSTIS SPINOSA COMMUNITY

PECHUEL-LOESCHEA LEUBNITZIAE COMMUNITY

29. Pechuel-loeschea leubnitziae variation
30. Pechuel-loeschea leubnitziae - Eragrostis spinosa variation
31. Pechuel-loeschea leubnitziae - Eragrostis spinosa - Stipagrostis sabulicola variation

32. KNOB DUNE COMMUNITY: STIPAGROSTIS SABULICOLA, ACANTHOSICYOS HORRIDA, ACACIA ERIOLOBA, ADENOLOBUS GARIEPENSIS, LYCIUM TETRANDRUM

ACANTHOSICYOS HORRIDA DUNE COMMUNITY

33. Acanthosicyos horrida variation
34. Acanthosicyos horrida - Stipagrostis sabulicola variation

35. PSILOCAULON sp cf SALICORNIOIDES COMMUNITY

36. ZYGOPHYLLUM STAPFII COMMUNITY

37. ZYGOPHYLLUM SIMPLEX COMMUNITY

ODYSSEA PAUCINERVIS COMMUNITY

38. Odyssea paucinervis variation
39. Odyssea paucinervis - Suaeda plumosa variation
40. Odyssea paucinervis - Lycium tetrandrum variation

DEAD PLANT AREAS

41. Eragrostis spinosa, Datura spp, Nicotiana glauca, Ricinus communis
42. Dead Eragrostis spinosa with living Acacia erioloba
43. Dead Eragrostis spinosa with living Acacia albida
44. Eragrostis spinosa, Zygophyllum simplex, Suaeda plumosa

floodplains are very narrow or absent. The Acacia albida - Tamarix usneoides variation is more conspicuous upstream from Gobabeb where it occurs in narrow out-stretched strips along the riverbank. Downstream from Gobabeb this variation consists mainly of young individuals of both species. These often occur upstream of rocky outcrops or water barriers across the riverbed. The other variations of the A albida community are mainly found downstream from Gobabeb.

Acacia erioloba community

The Acacia erioloba community is a characteristic of the silt floodplains but also occurs in the central area on the larger islands. This community is represented by only a few individuals in the Nareb area, whereas downstream from the Gorob Well, where the floodplains become wider, more extensive stands of this community occur. From Homeb downstream to Narob, the community is represented primarily by large old trees. In this area the number of large dead A erioloba trees is very conspicuous. Downstream from Swartbank relatively young plants of A erioloba form dense stands.

The Acacia albida community is the predominant vegetation type in the upper part of the study area where the floodplains are very narrow. Further downstream where the floodplains become progressively broader the Acacia erioloba community predominates.

As in the case of the Acacia albida community all the variations within the Acacia erioloba community between Swartbank and Rooibank are not clearly delineated in the field, nevertheless they show up as distinct physiognomic-structural units on aerial photographs.

Acacia erioloba is not confined to the floodplains, but is also found on the dunes on the southern side of the river as well as on the hummock dunes on both sides of the river in the Rooibank area.

Tamarix usneoides community

After the two above-mentioned communities the Tamarix usneoides community is the most striking of the Lower Kuiseb River and occurs on the riverbanks, floodplains as well as the foot of the dunes. Immediately above the outcrops jutting into the river, dense stands of relatively young plants of Tamarix usneoides are found in the riverbed. On the floodplains T usneoides appears as individual plants or as dense impenetrable stands. Big old plants of T usneoides are found on the hummock dunes and also at the foot of large sand-dunes.

Between Gobabeb and Swartbank groups of young Tamarix usneoides plants grow directly downstream of Acacia albida individuals in the riverbed. Silt accumulation between these dense stands of T usneoides gradually leads to the formation of islands.

Seedlings of Tamarix usneoides are found in large numbers in the riverbed and it appears that they are dependent for establishment on the moist conditions inherent in the riverbed. If this is so, the older individuals and thickets of T usneoides occupying the floodplains possibly indicate an earlier course of the river.

Salvadora persica community

Although this community is seldom present as extensive stands, Salvadora persica forms localised mats. The community consists of pure stands of S persica which occur on the steep dunes between Nareb and Gobabeb and in isolated patches down to Swartbank. It is also found on the floodplains, outcrops and occasionally on the hummock dunes on the northern side of the river.

Salvadora persica - Acacia erioloba - Tamarix usneoides - Euclea pseudebenus dune community

This community occurs mainly on the southern side of the river, on the sand-dunes. The individual plants are widely spaced and each plant usually forms a large clump with numerous stems. All the above-mentioned species do not occur in each of the mapped units of this community - sometimes only two of these species occur within a unit.

Suaeda plumosa community

The Suaeda plumosa community occurs downstream from Homeb and is especially well-represented in the vicinity of the Aussinanis River, Klipneus, Swartbank and upstream of the Fehlmann Well. The community consists of almost impenetrable thickets of Suaeda plumosa reaching 2 m in height. However, in more open patches Cyperus marginatus and Pechuel-loeschea luebnitziae are frequently found in association with Suaeda plumosa. The S plumosa community is often found where brackish conditions exist and small rivers or streams from the gravel plains join the Kuiseb River.

Eragrostis spinosa community

This community covers the riverbed from Narob to Rooibank. In this area the floodwater is apparently not strong enough to sweep the plants away. Other species that are locally conspicuous in this community are Psoralea obtusifolia and Heliotropium ovalifolium.

Pechuel-loeschea leubnitziae community

This community occurs on the floodplains, especially between the Klipneus area and Rooibank. Although P leubnitziae can form pure stands it usually grows in association with Eragrostis spinosa and/or Blumea gariepina. Where this community borders on the hummock dune community, Stipagrostis sabulicola is frequently found among the other species. The species in this community are probably associated with a high water table and it was noted that plants of P leubnitziae have a higher vitality in the Klipneus area than further downstream near Rooibank.

Hummock dune community: Stipagrostis sabulicola, Acanthosicyos horrida, Acacia erioloba, Adenolobus gariepensis, Lycium tetrandrum

This group of plants occurs mainly between Swartbank and Rooibank on the hummock dunes on both sides of the river. The community is characterized by Stipagrostis sabulicola, Acanthosicyos horrida, Acacia erioloba, Adenolobus gariepensis and Lycium tetrandrum, occurring individually or in groups on a hummock dune. Between these dunes Stipagrostis sabulicola and Eragrostis spinosa are frequently found.

Acanthosicyos horrida community

Strictly speaking this community does not form part of the river communities, but can be regarded as a pure dune community (Robinson 1976). The possibility does however exist that the roots of A horrida reach the underground water reserves of the river. The community occurs on the dunes on the southern side of the river, occasionally on the hummock dunes on both sides of the river as well as in the dune streets at Narra Valley and also opposite Ururas. Acanthosicyos horrida is important as a sand binder and occurs on its own or in association with Stipagrostis sabulicola. In certain areas S sabulicola predominates but these units were not mapped as separate units or variations.

Psilocaulon sp cf salicornioides community

This community, consisting of pure stands of Psilocaulon sp cf salicornioides has a limited distribution and is found mainly in the riverbed of the Aussinanis River as well as in the area upstream from Ururas. This community, like the Suaeda plumosa one, favours brackish conditions. The existence of this community probably depends on local rainfall to provide a runoff from the gravel plains.

Zygophyllum simplex and Zygophyllum stapfii communities

Both communities are found between Ururas and Rooibank along the border of the hummock dunes and the gravel plains. They depend largely on the runoff from the gravel plains.

Odyssea paucinervis community

This community occurs on the northern side of the river in the Ururas area and is found sporadically downstream to Rooibank. According to Robinson (1976) O paucinervis is associated with marshy conditions. In certain areas it appears that this community indicates previous moist conditions. In areas rich in silt, Suaeda plumosa occurs together with O paucinervis, whereas Lycium tetrandrum is found with O paucinervis on small sand heaps.

Dead plant areas

Such areas occur on the floodplains and in the riverbed and are characterized by the remains of species such as Datura spp, Ricinus communis, Nicotiana glauca, Eragrostis spinosa and Cynodon dactylon.

GENERAL

Although this was not a quantitative study, the different communities and variations were easily distinguishable on the basis of their floristic composition, because of the very limited number of species involved. In most cases the variations consist only of the species included under the name of the variation. Some of the variations are closely related to one another but differ only in the relative dominance of the different species. These variations are nevertheless all clearly distinguishable on aerial photographs.

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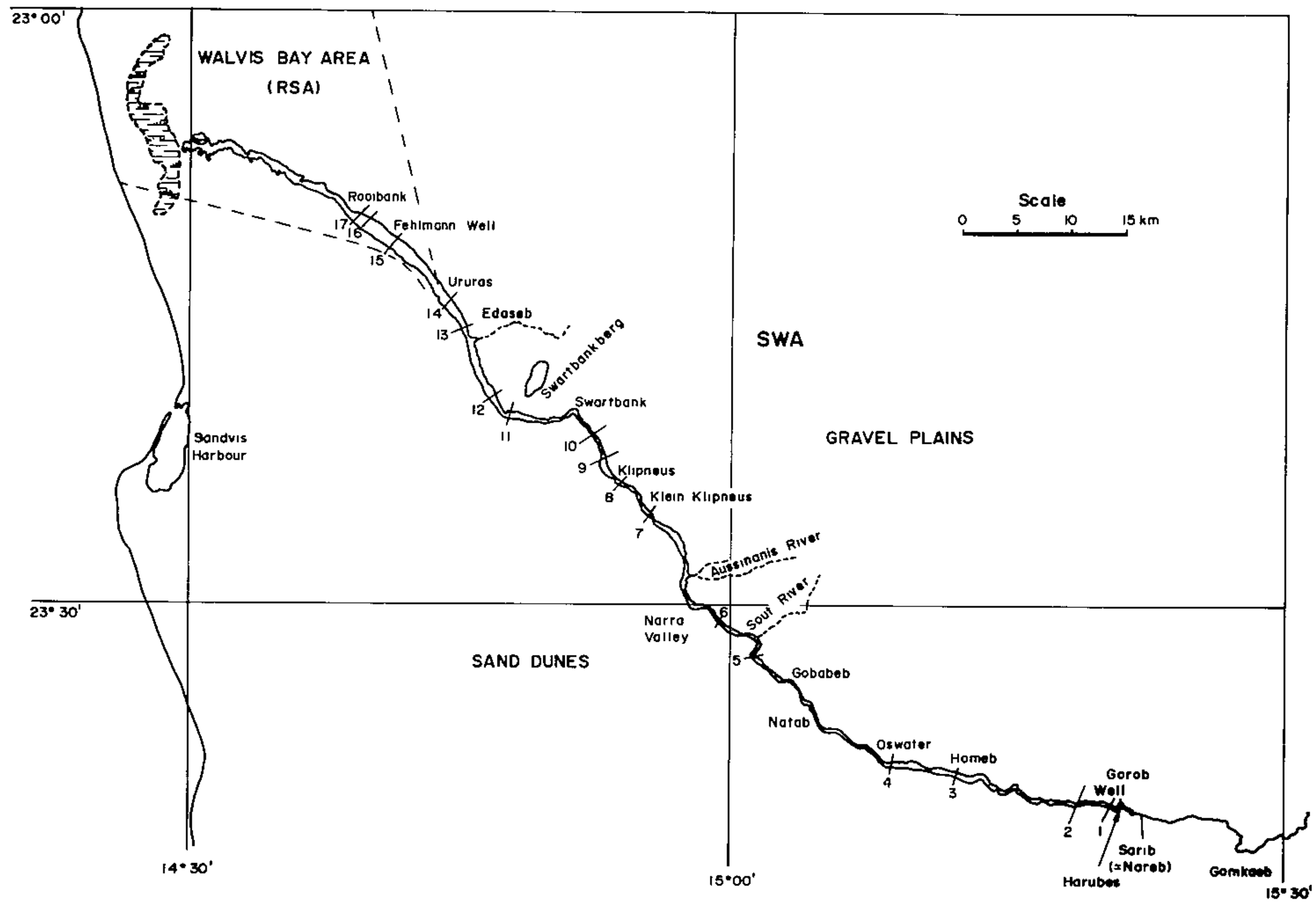

Figure 1. The Lower Kuiseb River, indicating the position of transects 1 to 17.

8. VEGETATION STRUCTURE AND VITALITY IN THE LOWER KUISEB

G K Theron, N van Rooyen, Margaretha W van Rooyen, University of Pretoria and W J Jankowitz, Department of Agriculture and Nature Conservation, SWA/Namibia

INTRODUCTION

The Lower Kuiseb River receives, on average, less than 50 mm rainfall per annum. The robust riverine woodlands which occupy its banks over a distance of some 150 km are clearly dependent for their survival on infrequent floods and sub-surface waterflow. In the last 146 years these floods have reached the Atlantic on only 15 occasions, but flooding within the woodland area is much more frequent - from 1963 to 1983 floods have reached Rooibank on eight occasions. It is nevertheless apparent that should the frequency and duration of flooding, or the level of the water table in the various hydrologic compartments of the Lower Kuiseb be significantly reduced, major changes in the structure and vitality of the Riverine Woodland might be expected.

Following the survey of major vegetation types of the Lower Kuiseb (Theron et al 1980 and Chapter 7, this volume) a series of transects and quadrats were established in the Upper, Middle and Lower Riverine Woodland divisions. The surveys were undertaken in July 1978 and July 1981.

TRANSECTS AND QUADRAT SURVEYS

In order to study the vegetation structure, canopy distribution, density and vegetation composition was examined. In the case of vitality, the percentage dead material in the crown of each woody plant individual was recorded while the standing and lying dead material was also recorded. The presence or absence of seedlings was also regarded as a reflection of the regeneration potential of the vegetation communities.

Seventeen transects of 10 m breadth were studied between Sarib and Rooibank (Figure 1). All species in successive 5 x 10 m intervals in the transects were recorded and the percentage dead material in the crown of each individual was estimated. The crown diameter and height of every woody individual was also determined. The total crown cover for each herbaceous species was estimated as well as that of Salvadora persica, Suaeda plumosa, Acanthosicyos horrida and Pechuel-loeschea leubnitziae. The number of seedlings of all woody species in every 5 x 10 m sub-sample was recorded. The standing dead material of each herbaceous and shrub species was recorded while an estimate of lying dead material was made. Each sub-sample was divided into ten equal sectors and the frequency of litter in each of these was recorded.

Forty quadrats were examined in the study area between Sarib and Rooibank in the area of transects 1 to 17. The crown spread at different heights and the density of the tree, open shrub and shrub growth forms for the various species and height classes were determined by the variable quadrat method of Coetzee and Gertenbach (1977). In addition, the percentage live material in each height class was determined as a measure of the vitality of each species.

The results of the survey were summarized within the three main study areas as follows:

1. Upper Riverine Woodland (transects 1 to 6, 11 quadrats).
2. Middle Riverine Woodland (transects 7 to 10, 10 quadrats).
3. Lower Riverine Woodland (transects 11 to 17, 18 quadrats).

The boundaries of these study areas differ slightly from those described in Chapter 2 in that the lower limit of the upper riverine woodland was taken to be the Aussinanis River and not Gobabeb in this survey.

CHANGES MEASURED BETWEEN 1978 AND 1981 - TRANSECT SURVEYS

Density

In all three study areas but especially in study areas 1 and 2, a decrease in the total number of living plants was recorded between 1978 to 1981, while an increase in standing dead material was recorded (Table 1). The greatest decreases were measured in Acacia albida and Tamarix usneoides. Acacia erioloba increased in study areas 2 and 3, especially in those areas where water was abstracted. This increase can be ascribed to the success of seedling establishment since the flood of 1974 (cf Table 3). In contrast, the number of dead individuals increased from 15 to 20 individuals per hectare in study area 3, while in study area 2 the increase was from 45 to 69 individuals per hectare. The smallest increment in standing dead was measured in study area 1, which is however more frequently flooded than the areas of the Middle and Lower Riverine Woodland.

Table 1. The average number of woody plants per hectare in the Upper, Middle and Lower Riverine Woodland sectors during July 1978 and July 1981.

	Upper		Middle		Lower	
	'78	'81	'78	'81	'78	'81
Acacia albida	178	108	138	103	40	36
Acacia erioloba	110	92	189	194	122	128
Euclea pseudebenus	136	42	60	36	3	3
Tamarix usneoides	297	75	162	109	26	23
Ficus sycomorus			1			
Prosopis sp						1
Standing dead	34	42	45	69	5	20
Total	755	359	595	510	196	211

Percentage dead material in canopy

As illustrated in Table 2, the percentage dead material in the canopy of trees increased in study areas 2 and 3 but decreased in study area 1. The most striking increase in dead material occurred in *Acacia albida* in all three study areas and in *Euclea pseudebenus* in study areas 1 and 2.

Table 2. The average total percentage dead material per transect in the canopy of woody species in the Upper, Middle and Lower Riverine Woodland sectors, July 1978 and July 1981.

	Upper		Middle		Lower	
	'78	'81	'78	'81	'78	'81
Acacia albida	15	33	6	47	10	35
Acacia erioloba	27	24	17	29	10	21
Euclea pseudebenus	6	16	8	32	9(33)	7(49)
Tamarix usneoides	7	8	15	33	2(4)	14(33)

Seedlings

From Table 3 it is clear that in comparison with 1978 far fewer woody plant seedlings were recorded in the 1981 survey of study areas. This decrease in seedlings can be attributed to the preceeding dry seasons.

Table 3. The average number of seedlings per transect in the Upper, Middle and Lower Riverine Woodland sectors, July 1978 and July 1981.

	Upper		Middle		Lower	
	'78	'81	'78	'81	'78	'81
Acacia albida	18	1	14	1	5	2
Salvadora persica	44	32	2	0		
Euclea pseudebenus	59	6	19	2		
Acacia erioloba	16	1	23	3	5	1
Datura stramonium	1	0				
Tamarix usneoides	2		1	1	1	
Nicotiana glauca	1	0				
Zygophyllum stapfii					122	28
Lycium tetrandrum					2	

Litter

In study areas 1 and 2 the percentage cover of litter remained constant from 1978 to 1981, while it decreased appreciably in study area 3, which can be ascribed to a lower herbaceous cover (see Table 4). The decrease in the number of sampling units with dead material in study areas 1 and 2 can probably be ascribed to the large herds of goats occupying the area, while the increase in study area 3 is probably the consequence of the death of herbs and small shrubs in the area.

Table 4. Average values for dead material per transect in the Upper, Middle and Lower Riverine Woodland sectors, July 1978 and July 1981.

	Upper		Middle		Lower	
	'78	'81	'78	'81	'78	'81
Percent cover per sub-sample	16,3	17,2	7,3	7,5	12,7	6,5
Frequency per sub-sample	6,0	6,3	3,4	4,3	3,5	3,8
Frequency of sub-samples with dead material	60,9	47,8	42,5	45,8	16,3	34,2

Number of sub-samples with shrubs and herbs and the average percentage crown cover of shrubs and herbs

With the exception of a few species, shrubs and herbs were found in fewer sub-samples in 1981 than in 1978. The decrease in shrubs and herbs can be attributed to the preceding dry period as well as to the reduced flow of the Kuiseb during the intervening period. In particular, *Pechuel-loeschea leubnitziae*, *Suaeda plumosa*, *Blumea gariepina* and *Eragrostis spinosa* died off rapidly between 1978 and 1981, possibly as a consequence of a shallow root system which could not keep pace with a lowering water table.

CHANGES MEASURED BETWEEN 1978 AND 1981 - QUADRAT SURVEYS

Only woody plants were included in the studies on permanent quadrats and in particular these included *Acacia albida*, *Acacia erioloba*, *Euclea pseudebenus* and *Tamarix usneoides*.

Canopy spread

The total canopy spread decreased between 1978 to 1981 in all height classes (Table 5) with the most marked decrease having been measured in study area 2 where there was also a marked decrease in the number of woody individuals (Table 6) and a sharp increase in the number of standing dead trees (Table 7).

Table 5. The average total canopy spread and living canopy spread and percentage living material at different height classes in the woody plants of the Upper, Middle and Lower Riverine sectors in July 1978 and July 1981.

Height class	Total 1978	Living 1978	% Living 1978	Total 1981	Living 1981	% Living 1981	Increase+ Decrease-
Upper Riverine Woodland (11 quadrats)							
5 m	24,5	18,5	75,2	19,3	3,7	9,2	56,0 -
4-5 m	44,9	26,8	59,7	25,2	0,7	2,6	17,1 -
3 m	41,8	17,5	41,9	41,3	0,9	0,8	8,9 +
2 m	40,1	12,4	30,9	41,1	7,5	2,7	11,8 +
1 m	34,9	10,3	29,6	41,5	5,2	6,6	7,0 +
0,5 m	26,0	5,1	19,7	36,5	9,7	6,7	7,0 +
Middle Riverine Woodland (10 quadrats)							
5 m	5,5	3,7	75,0	2,8	2,4	7,1	12,1 +
4-5 m	22,3	12,3	55,2	8,6	6,8	9,1	23,9 +
3 m	40,5	17,3	42,8	17,6	2,7	1,8	25,0 +
2 m	45,1	13,1	29,1	22,5	1,0	9,2	20,1 +
1 m	32,3	6,9	21,6	17,6	4,6	6,3	4,8 +
0,5 m	17,2	3,4	19,7	16,5	1,2	7,6	12,1 -
Lower Riverine Woodland (18 quadrats)							
5 m	0,4	0,1	42,2	0,3	0,2	5,0	32,8 +
4-5 m	7,7	5,8	75,3	4,4	2,9	5,9	9,4 -
3 m	62,8	22,1	35,3	26,0	9,0	3,2	40,9 +
2 m	31,3	18,5	59,1	38,3	2,8	9,6	0,5 +
1 m	28,6	8,6	30,2	35,5	2,1	4,3	4,1 +
0,5 m	14,0	3,6	26,2	14,2	3,7	6,3	0,1 +

Table 6. The average density (in individuals per ha) of the tree (T), open shrub (O) and dense shrub (S) growth forms in different height classes of the woody plants of the Upper, Middle and Lower Riverine Woodland sectors, July 1978 and July 1981.

Height class	1978			1981			Total		
	T	O	S	T	O	S	1978	1981	Change
Upper Riverine Woodland (11 quadrats)									
5 m	82	3	6	15	24	2	91	41	50 -
4-5 m	80	30	9	34	11	8	119	53	66 -
3 m	41	12	18	145	25	30	71	200	129 +
2 m	12	3	7	25	4	8	22	37	15 +
1 m	14	2	10	10	2	6	26	18	8 -
0,5 m	66	19	6	11	2	2	91	15	76 -
Total	295	69	56	240	68	56	420	364	56 -
Middle Riverine Woodland (10 quadrats)									
5 m	16	T	0	7	1	0	16	8	8 -
4-5 m	58	26	17	14	5	6	101	25	76 -
3 m	147	25	22	123	23	23	194	169	25 -
2 m	43	3	5	24	3	6	51	33	18 -
1 m	38	4	8	6	2	2	50	10	40 -
0,5 m	32	8	15	6	2	4	55	12	43 -
Total	334	66	67	180	36	41	467	257	210 -
Lower Riverine Woodland (18 quadrats)									
5 m	1	T	0	2	0	0	1	2	1 +
4-5 m	68	9	5	16	2	1	82	19	63 -
3 m	150	40	31	114	35	25	221	174	47 -
2 m	8	4	4	27	9	9	16	45	29 +
1 m	16	4	3	6	3	1	23	10	13 -
0,5 m	7	2	3	7	1	2	12	10	2 -
Total	250	59	46	172	50	38	355	260	95 -

Table 7. The density (in individuals per ha) of tree (T) open shrub (O) and dense shrub (S) growth forms, standing dead and fallen dead material in the Upper, Middle and Lower Riverine Woodland sectors, July 1978 and July 1981.

Species	1978			1981			Total		
	T	O	S	T	O	S	1978	1981	Change
Upper Riverine Woodland (11 quadrats)									
Acacia erioloba	103	29	4	120	39	3	136	162	26 +
Acacia albida	110	14	13	38	11	6	137	55	82 -
Euclea pseudebenus	62	22	3	40	12	3	87	55	32 -
Tamarix usneoides	19	3	36	25	4	42	58	71	13 +
Falling dead	1						36	99	63 +
Standing dead							8	8	0
Middle Riverine Woodland (10 quadrats)									
Acacia albida	136	20	6	41	5	5	162	51	111 -
Acacia erioloba	139	34	39	57	10	19	212	86	126 -
Euclea pseudebenus	9	T	3	9	0	11	12	20	8 +
Tamarix usneoides	49	2	27	23	2	10	78	35	43 -
Salvadora persica			1			3	1	3	2 +
Falling dead								1	1 +
Standing dead							2	37	35 +
Lower Riverine Woodland (18 quadrats)									
Acacia erioloba	210	53	41	135	45	35	304	215	89 -
Acacia albida	17	1	1	14	0		19	14	5 -
Euclea pseudebenus	2	2	2	6	3	2	6	11	5 +
Tamarix usneoides	18	4	3	11	3	2	25	16	9 -
Standing dead							1	14	13 +

Table 8. Number of individual trees measured in each Riverine Woodland sector during stem circumference class study.

	Upper	Middle	Lower
Acacia albida	2493	970	599
Acacia erioloba	1226	801	801
Euclea pseudebenus	649	95	16

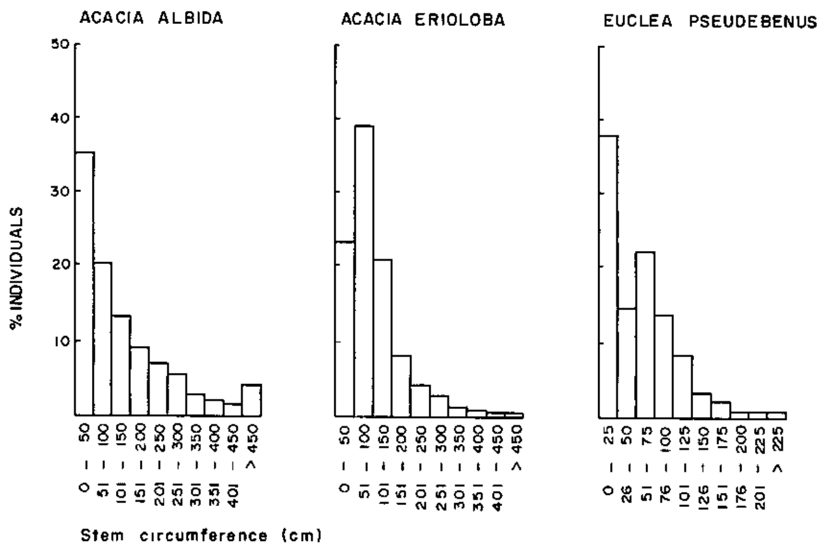

Figure 2. The stem circumference class distribution of Acacia albida, A erioloba and Euclea pseudebenus in the Lower Kuiseb River.

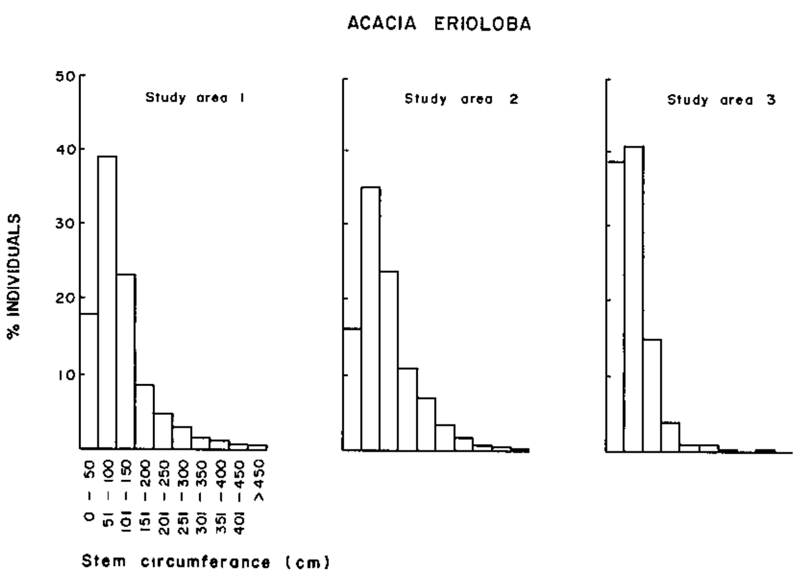

Figure 3. The stem circumference class structure of Acacia erioloba in the Upper, Middle and Lower Riverine Woodland sectors.

Density

The greatest number of individuals per hectare occurred in study area 2 during 1978 and in study area 1 during 1981 (Table 6). From this table it is also clear that the greatest number of individuals disappeared from study area 2 from 1978 while the numbers of standing dead individuals remained constant in study area 1 (Tables 6 and 7). Although there was an actual overall decrease in the number of individuals of all height classes in all three of the study areas, there was in fact a sharp increase in the individuals of the 3 m height class in study area 1 (Table 6). The greatest decrease of individuals in study area 2 were principally of Acacia albida and Acacia erioloba in the Swartbank area (transects 7 and 8) (Table 7).

The two most important tree species A albida and A erioloba had, with the exception of A erioloba in study area 1, decreased in all three study areas. Euclea pseudebenus had increased in study areas 2 and 3, but decreased in study area 1, while Tamarix usneoides followed the opposite pattern (Table 7).

Stem diameter classes

In order to determine size classes of the various populations of A albida, A erioloba and E pseudebenus, a large number of individuals were measured at random. The stem diameter of individuals were measured in the areas of transects 1 to 17. Between Sarib and Gobabeb additional individuals were measured between transects as the area appeared to have a greater size diversity than general. The number of individuals measured per species are indicated in Table 8. The total population for A albida, A erioloba and E pseudebenus show an increasing stem diameter structure (Figure 2). The decrease in the number of individuals of A erioloba in the 0 to 50 cm interval is probably due to the effects of the preceeding dry period.

Similar stem diameter classes were characteristic of A albida and A erioloba in all three study areas (Figures 3 and 4) and for E pseudebenus in study area 1 (Figure 5). The unusual stem diameter structure for E pseudebenus in study areas 2 and 3 can possibly be ascribed to the smaller sample size for these two areas.

CONCLUSIONS

From the results described above it would appear that the vegetation (perennial woody species) underwent in general similar changes between 1978 to 1981 in the three study areas. It is thus possible that all negative changes in the area were the result of the droughts preceeding 1981 rather than the secondary factor of water abstraction.

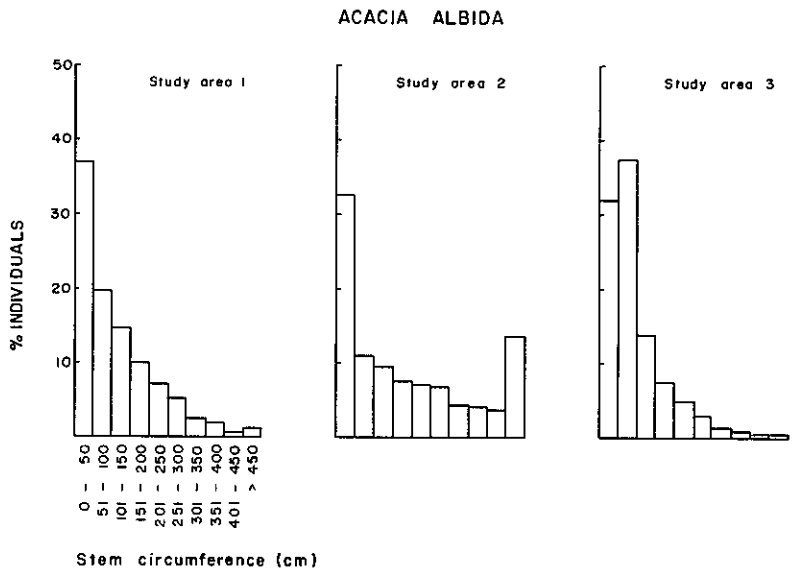

Figure 4. The stem circumference class structure of Acacia albida in the Upper, Middle and Lower Riverine Woodland sectors.

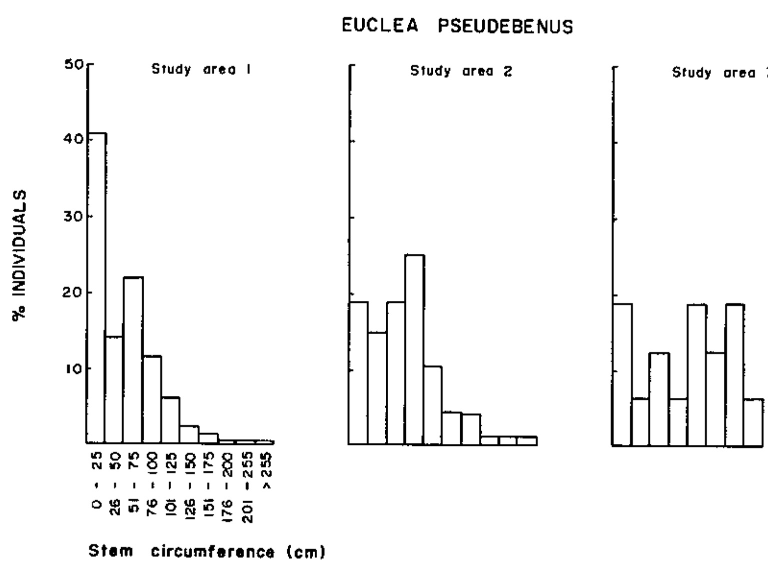

Figure 5. The stem circumference class structure of Euclea pseudebenus in the Upper, Middle and Lower Riverine Woodland sectors.

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Coetzee B J and Gertenbach W P D 1977. Technique for describing woody vegetation composition and structure in inventory type classification, ordination and animal habitat surveys. Koedoe 20, 67-75.

Theron G K, Van Rooyen N and Van Rooyen M W 1980. Vegetation of the Lower Kuiseb River. Madoqua 11(4), 327-345.

9. AERIAL PHOTOGRAPHIC MONITORING OF VEGETATION STRUCTURE AND VITALITY

C J Ward and D A Scogings, University of Durban-Westville

INTROUCTION

Aerial photography of the Lower Kuiseb Valley and environs was undertaken in May 1978 as a service for field workers, active or potential, representing various disciplines involved in the Kuiseb Environmental Project. With only minor variations, made with a view to improving economy or data collection, the aerial survey was repeated in May 1981, thus allowing comparisons to be made and a better understanding of the dynamics of such features as vegetation and sediments or land usage to be gained.

In addition to the provision of the aerial photographs for other workers, an investigation into the use of these aerial photographs for detecting and quantifying various ecological data such as the occurrence and distribution of various plant species, the vitality of individuals or groups thereof and possible changes in composition or other parameters concerning plant communities was undertaken; as was also the practicability of extrapolation of these data from sample sites to the whole study area.

MATERIALS AND METHODS

Aerial surveys in May 1978 and May 1981 followed the marking of fixed points along the Kuiseb Valley from the Sarib (Nareb) area (approximately 23°40'S; 15°22'E) to the coast. These points, by appearing in relevant photographs (and there being sufficient that were already coordinated), acted as control point for the main aerial triangulation which, in turn, provided coordinates for the control points used to map detailed sample areas.

Three types of film emulsion were employed to record data, namely, black-and-white panchromatic, colour negative and colour infra-red positive film. The scale of contact photographs varied from 1:3000 to 1:15 000 for the major exercise, although scales up to 1:25 000 were used where overall data rather than details were required. The disposition of the strips, film emulsion types and scales of photography are indicated in Figure 1. The camera used was a Wild RC5a 15Ag42, f = 152,68 mm.

1:10 000 or, more generally, 1:15 000 colour negative film was used for the primary survey and covered the whole of the study area. 1:5000 colour negative and 1:3000 to 1:5000 black-and-white panchromatic and colour infra-red film covered the sample areas, although colour infra-red was omitted from those sample strips where vegetation monitoring was not the prime objective.

Sample areas, or detailed strips, were located over the vegetation transects as kindly indicated by Professor G K Theron on earlier aerial photographs prior to the 1978 aerial survey. Other detailed strips were flown primarily to record possible dune movement, whilst yet others were flown for both dune and vegetation data or vegetation data only outside the Sarib (Nareb) - Rooibank section studied by Theron et al (1980).

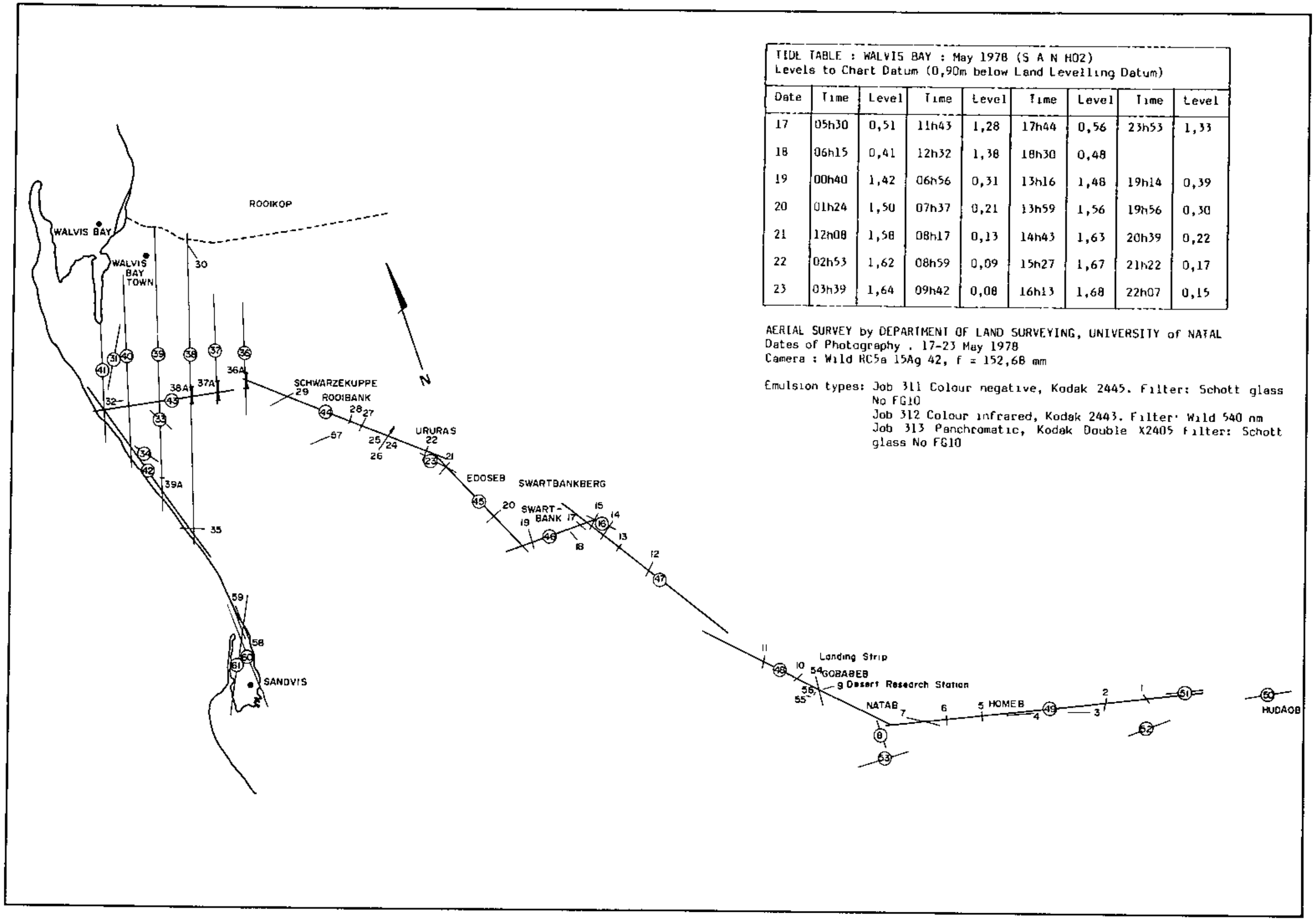
Following the 1978 aerial photography and subsequent development and processing of the films, control points were fixed in the field where this had not been effected earlier. In addition, photo-interpreted data were verified and photographs annotated in the field.

Terrestrial and oblique aerial small-format photographs and other recordings at selected sites, taken more frequently, supplemented topographical and vegetational data derived from the two main aerial surveys of 1978 and 1981. These photographs and notes have been used also as aids to aerial photo interpretation.

With the production of diapositives from the 1978 photography and using coordinates of those pre-marked points able to be seen in the photographs, triangulation, followed by mapping of the detailed strips, was undertaken. This resulted in the production of a series of contoured base maps at a scale of 1:2000 showing the main topographical features, outlines of as much of the vegetation as feasible and, most importantly from the point of quantification of ecological or other data, a common coordinate grid. The grid used was the National Trigonometrical Grid. Mapping was undertaken with a Wild A7 Stereoplotter.

These base maps were fundamental for data recording and quantification and for the production of other means of recording or communication. In this instance, this included the production of tilt-corrected photographs of known scale and orthophotographs. A Zeiss P40 Orthophoto was used for the production of the orthophotos. Transparent overlays of the relevent base maps were produced to facilitate use of the enlarged prints and orthophotos. In the latter case the transparent overlay with mapped features, it was considered, was more suitable than an orthophotomap, wherein certain vegetation or other data might have been obscured by the topographical mapped data.

For the subject of this report, pairs of overlapping aerial photographs of selected sample areas were examined stereoscopically using a Wild mirror stereoscope with a x3 and x8 optics. All three different film types were used: prints from the negative films or, in the case of the colour infra-red film, prints from the positive film (produced primarily for field use) as well as transparencies which were segments of the positive film cut into individual photographs for stereo viewing over a light-table. Assisted by field work, plants were identified on these photographs.



TIDE TABLE : WALVIS BAY : May 1978 (S A N HO2)
Levels to Chart Datum (0,90m below Land Levelling Datum)

Date	Time	Level	Time	Level	Time	Level	Time	Level
17	05h30	0,51	11h43	1,28	17h44	0,56	23h53	1,33
18	06h15	0,41	12h32	1,38	18h30	0,48		
19	00h40	1,42	06h56	0,31	13h16	1,48	19h14	0,39
20	01h24	1,50	07h37	0,21	13h59	1,56	19h56	0,30
21	12h08	1,58	08h17	0,13	14h43	1,63	20h39	0,22
22	02h53	1,62	08h59	0,09	15h27	1,67	21h22	0,17
23	03h39	1,64	09h42	0,08	16h13	1,68	22h07	0,15

AERIAL SURVEY by DEPARTMENT OF LAND SURVEYING, UNIVERSITY of NATAL
Dates of Photography . 17-23 May 1978
Camera : Wild RC5a 15Ag 42, f = 152,68 mm

Emulsion types: Job 311 Colour negative, Kodak 2445. Filter: Schott glass No FG10
Job 312 Colour infrared, Kodak 2443. Filter: Wild 540 nm
Job 313 Panchromatic, Kodak Double X2405 Filter: Schott glass No FG10

Figure 1. Map showing position of job numbers and strips.

FLIGHT INDEX FOR JOBS 311, 312 and 313

	EMULSION TYPE								
	COLOUR, JOB No 311			COLOUR INFRARED, JOB No 312			PANCHROMATIC, JOB No 313		
Number	Photo No	Scale	Date/Time	Photo No	Scale	Date/Time	Photo No	Scale	Date/Time
1	117 - 119	1 : 5000	17.5 13.10	676 - 678	1:3000	19.5 10-12	1085-1088	1:3000	21.5 12.00
2	120 - 122	"	" 13.15	680 - 682	"	" "	1082-1084	"	" 11.55
3							1074-1081	"	" 11.50
4							1097-1103	1:5000	" 12.10
5	123 - 125	"	" 13.20	683 - 685	"	" "	1070-1073	1:3000	" 11.45
6	126 - 128	"	" 13.30	686 - 691	"	" "	1066-1069	"	" 11.40
7							1104-1112	1:5000	" 12.10
8	520 - 528	"	18.5 15.50				1113-1121	1:5000	12.15
9							1058-1065	1:3000	11.35
10	129 - 131	"	17.5 13.30	692 - 696	"	" "	872 -876	"	20.5 10.20
11	478 - 480	"	18.5 14.45	563 - 566	"	" "	1053-1057	"	21.5 11.30
11	154 - 157	"	17.5 14.10						
12	158 - 161	"	" 14.15	567 - 572	"	" "	1047-1052	"	" 11.20
13	162 - 167	"	" 14.25	573 - 580	"	" "	1040-1046	"	" 11.25
14	168 - 174	"	" 14.30	581 - 591	"	" "	1030-1039	"	" 11.15
15	175 - 180	"	" 14.35	592 - 599	"	" "	1022-1029	1:3000	" 11.12
16				829 - 835	1:10000	" 13-15	955 -962	1:10000	" 11.10
17							1015-1021	1:3000	" "
18							1006-1014	"	" 11.10
19	181 - 185	"	" 14.40	600 - 606	1:3000	" 10-12	877 -884	"	" 11.05
20	186 - 192	"	" 14.45	607 - 619	"	" "	886 -897	"	20.5 10.40
21	193 - 200	"	" 14.50	620 - 631	"	" "	898 -909	"	" 10.45
22	201 - 207	"	" 14.55	632 - 641	"	" "	910 -918	"	" 10.50
23				663 - 672	"	" "	919 - 929	1:5000	" 11.00
24				642 - 652	"	" "	2011-2022	1:3000	21.5 10.55
25				653 - 662	"	" "	2000-2010	"	" 10.45
26	208 - 214	"	" 15.00						
27	220 - 226	"	" 15.10	821 - 828	1:3000	" 13-15	991 -999	"	" 10.45
28				816 - 819	"	" "	986 -990	"	" 10.40
29	319 - 327	"	18.5 11.00	802 - 815	"	" "	970 -985	"	" 10.30
30				836 - 843	1:5000	" "	1131-1138	1:5000	" 13.15
31							1413-1424	"	22.5 11.30
32	350 - 353	"	" 11.18	761 - 769	1:3000	" "	1154-1161	1:3000	21.5 15.10
33	343 - 349	"	" 11.10	747 - 760	"	" "	1165-1179	"	" 15.15
34							1180-1198	"	
35	450 - 455	"	" 12.55	736 - 744	"	" "	1209-1218	"	" 15.30
36	13 - 19	1:15000	17.5 11.20				1401-1412	1:10000	22.5 11.15
36A	328 - 331	1:5000	18.5 11.05	789 - 801	"	" "	946 -950	1:3000	20.5 11.15
37	4 - 12	1:15000	17.5 11.10				1389-1400	1:10000	22.5 11.10
37A	236 - 240	1:5000	" 15.15	780 - 788	"	" "	939 - 945	1:3000	20.5 11.10
38	382 - 407	1:15000	18.5 12.05				1353-1388	1:10000	22.5 11.00
38A	241 - 247	1:5000	17.5 15.20	770 - 779	"	" "	930 -938	1:3000	20.5 12.05
39	408 - 427	1:15000	18.5 12.20				1321-1352	1:10000	22.5 10.45
40	428 - 442	"	" 12.30				1298-1320	"	22.5 10.30
41	443 - 449	"	" 12.40						
42							1256-1282	"	21.5 16.00
43	457 - 471	"	18.5 13.10						
44	20 - 38	"	17.5 11.30						
45	39 - 47	"	" 11.45						
46	48 - 57	"	" 12.00						
47	58 - 70	"	" 12.05						
48	71 - 87	"	" 12.15						
49	88 - 106	"	" 12.35						
50	107 - 112	"	" 12.40						
51	113 - 116	1:5000	" 13.10						
52	481 -487	1:10000	18.5 15.00						
52	1456-1463	"	23.5 10.00						
53	491 - 508	1:15000	18.5 15.30						
53	1469-1481	1:15000	23.5 10.35						
54	488 - 490	1:20000	18.5 15.13						
54	1465-	"	23.5 10.20						
55							1425-1428	1:3000	
56							1429-1440	"	22.5 16.10
57	472 - 477	1:5000	18.5 13.25						
58	367 - 376	"	" 11.40				1287-1297	1:5000	22.5 10.15
59				716 - 735	1:3000	" 13.45	1291-1239		21.5 15.35
60							1240-1255	1:10000	" 15.45
61							1122-1130	1:25000	" 12.55
39A							1199-1208	1:3000	" 15.20

The 1:2000 base maps were examined in detail and outlines of plants were carefully added or corrected using data derived directly from stero-pairs of photographs. Woody plants were entered as individuals wherever possible or, for the more gregarious, as clumps in as small a discrete unit as possible. The base maps were then annotated. Similarly, orthophotographs or tilt-corrected prints of known scale were annotated. A refinement of this was to produce an annotated overlay of desired scale from magnified stereoscopic viewing of pairs of suitably enlarged tilt-corrected prints of the sample area. Concurrent stereoscopic viewing of transparencies or contact prints of aerial photographs of the sample area facilitated annotation and data transfer.

Lines were drawn on the base maps and/or on the overlays between points indicating the ends of the vegetation transects of Theron et al (1980). An exception to the positioning of these lines on those of Theron et al was in Strip 21, where only the western end of Vegetation Transect 13 (Theron et al 1980) coincided with the flight line. Consequently Line 21 lies just up-river of Vegetation Transect No 13, diverging more towards the eastern end. These marker points of the vegetation transects were observed in the field and/or as premarked points on the 1981 aerial photography. A later refinement of the mere drawing of a line included over-laying on positive photographic transparencies a transparent material on which a very fine line had been scratched with the tip of a fine needle and then, under magnification, considering those plants which were intercepted by ony one side of the fine line. With such a fine line and with suitable magnification and measuring aid, individuals too small to be shown on a map were able to be measured or counted. The lines were used to determine cover and frequency of individuals which were also assessed for their relative vitality.

Cover and vitality data as well as density values were obtained also from quadrats. These quadrats were chosen to be 100 m x 100 m, ie 1 ha each. In the case of Strip 1, five 1 ha quadrats were placed, without bias towards vegetation data, by choosing those five squares on the National Trigonometrical Grid which were immediately adjacent to Vegetation Transect No 1 of Theron et al (1980). Elsewhere, the quadrats were chosen differently. For those that will be discussed in this report, other than in Strip 1, the quadrats were placed contiguously as a belt whose centre line was predetermined by type position of the line used for the line intercept method mentioned above.

Density values were derived from counts of individuals, wherever this was possible, or of clumps for the more gregarious species, viewed through a magnified stereoscope. Where bases of plants could not be seen, if less than 50 percent of the crown lay outside of a quadrat, that plant was not counted as being "present" for that quadrat; the amount of cover, however, was included in that quadrat's record of data.

Cover was measured directly from corrected base maps or from the overlays of sample areas constructed with the aid of a magnified stereoscope. A transparent overlay with a 1 mm^2 grid (which represents 4 mm^2 at 1:2000) facilitated these measurements. For herbs, juveniles or similarly small objects not able to be shown satisfactorily on maps, a photographically reduced overlay grid provided more refined but similar data. In this later grid the squares were 0,04 mm^2 and it was used directly, under suitable magnification, on the transparencies of the aerial photographs, the scale of which required to be determined for each sample, but were mostly 0,5 ± 0,05 m^2 at the scale most frequently used. At such a scale, this fine grid readily allowed plants of 15 cm diameter to be recorded quantitatively. Initial studies using semiquantitative cover-abundance scales, such as that of Braun Blanquet (Meuller-Dombois and Ellenberg, 1974), were superseded by more quantitative recording as indicated in the tables included herewith.

Using colour infra-red photography an attempt was made to assess and quantify the condition, or degree of vitality, of those individuals or discrete clumps encountered by the line intercept method or occurring within the quadrats. This assessment was based on the degree of redness, or the lack thereof, as seen in colour infra-red photographs viewed with a (magnified) stereoscope. The following general scale was used in this respect:

very good	:	bright, deep red
good	:	dull red or brownish red
moderately good	:	dull red with signs of grey or, in the 1978 photographs, green
poor	:	± equal mixture of pink and green/grey
very poor	:	considerably more green or grey than pink
dead	:	fully dark green (1978) to dark grey-black

RESULTS

The results of the aerial surveys, namely the production of vertical aerial photographs, diapositives, lists of co-ordinates, contoured base maps, corrected photographs and orthophotographs, form the "materials" used in the extrapolation of information for woodland ecology and, consequently have been referred to in the previous section of this report.

From the plant ecological point of view data concerning numbers, density ha^{-1}, cover and frequency were obtained and, from this, importance values based on the relative values of two or all three of these parameters were calculated. Such data were gathered for nine entities of woody plants (six species and juveniles of three), one subwoody species and several herbs of which eight were identifiable to species. Other herbs, although not identified, were recognizably different from others while some were grouped together as "unidentified grasses and forbs" (if both forms were present). In some cases, since the emphasis for this report was on woody components, all herbs were groupd merely as "herbs" even though at least one species was distinguishable amongst the "herbs". An admixture of such robust ephemerals as Datura stramonium, D ferox, Ricinus communis and similar fast growing leafy herbs along the river course presented problems in separation into species, and even into individuals, at the scale of photography and with the time available; since these plants indicate apparently similar ecological factors their being grouped together is seen as being acceptable.

Data are available for all entities per line and per quadrat and the latter grouped into belts traversing the Kuiseb River valley. The lines and belts have been further grouped into "upper" (ie, from just below Gobabeb up river) and "lower" (ie, from the water extraction area below Swartbank)

Table 1. Numerical and cover data for plants intercepted on line equivalent to Vegetation Transect 3 (Theron et al 1980). Line approximately 602 m long. Data from aerial photographs taken in May 1978 and May 1981 (Strip 5). Vitality based on infra-red reflectance (see text) graded as: A: very good, B: good, C: moderately good, D: poor, E: very poor, F: dead.

Key: N = number of individuals intercepted; %N = percentage based on numbers

L i = length of line intercepted by entity; % L i = percentage based on L i

% all = entity value as percentage of total numbers, or total distance intercepted

% w/h = entity value as percentage of total woody plants or herbs respectively

Vitality class values = absolute and relative (%) values of numbers or cover.

SPECIES		%	%		%	%	VITALITY CLASSES 1978						VITALITY CLASSES 1981					
or ENTITY	N	all	w/h	L i	all	w/h	A	B	C	D	E	F	A	B	C	D	E	F
WOODY (alive 1978)																		
Acacia albida	8	8,33	30,10					1 12,50	1 12,50	2 25,00	4 50,00				3 37,50	1 12,50	3 37,50	1 12,50
				85	39,65	48,43		4 4,70	12 14,12	23 27,06	46 54,12				30 35,29	9 10,59	39 45,88	7 8,24
A erioloba	1	1,04	4,76							1 100							1 100	
				22	10,26	12,54				22 100							22 100	
Euclea pseudebenus	4	4,17	19,05					4 100						1 25,00	1 25,00	1 25,00	1 25,00	
				17,5	8,16	9,97		17,5 100						7,5 42,86	4 22,86	4 22,86	2 11,43	
Salvadora persica	3	3,13	14,29				2 66,67	1 33,33						1 33,33	2 66,67			
				17	7,93	9,69	3 17,65	14 82,35						14 82,35	3 17,65			
Tamarix usneoides	5	5,21	23,81					4 80,00		1 20,00				4 80,00		1 20,00		
				34	15,86	19,37		30 88,23		4 11,76				30 88,23		4 11,76		
TOTAL: WOODY PLANTS	21	21,86	100				2 9,52	10 47,62	1 4,76	4 19,05	4 19,05			6 28,57	6 28,57	3 14,29	5 23,81	1 4,76
				175,5	81,86	100.	3 1,71	65,5 37,32	12 6,84	49 27,92	46 26,21			51,5 29,34	37 21,08	17 9,69	63 35,90	7 3,99
HERBS Asthenatherum glaucum	2	2,08	2,67									2 100						2 100
				0,45	0,21	1,16						0,45 100						0,45 100
Mesembryanthemum geurichianum	14	14,58	18,67							1 7,14	2 . 14,29	11 78,57						14 100
				18,5	8,62	47,56				1,75 9,46	4 21,62	12,75 68,92						18,5 100
Zygophyllum simplex	57	59,38	76,00						12 21,05	41 71,93	3 5,26	1 1,75						57 100
				18,7	8,72	48,07			4,30 22,99	12,75 68,18	1,45 7,75	0,20 1,07						18,7 100
Unidentified grasses and forbs	2	2,08	2,67					1 50,00			1 50,00							2 100
				1,25	0,58	3,21		1 80,00			0,25 20,00							1,25 100
TOTAL : HERBS	75	78,13	100					1 1,33	12 16,00	42 56,00	6 8,00	14 18,67						75 100
				38,9	18,14	100		1 2,57	4,3 11,05	14,5 37,28	5,7 14,65	13,4 34,45						38,9 100
GRAND TOTAL	96						2 2,08	11 11,46	13 13,54	46 47,92	10 10,41	14 14,58		6 6,25	6 6,25	3 3,13	5 5,21	76 79,17
				214,4 (= 35,61% cover)			3 1,40	66,5 31,02	16,3 7,60	63,5 29,62	51,7 24,11	13,4 6,25		51,5 24,02	37 17,26	17 7,93	63 29,38	45,9 21,41
GRAND TOTAL %'s as (%N + % L i)/2							1,74	21,24	10,57	38,77	17,26	10,42		15,14	11,75	5,53	17,30	50,29

groups (see Figure 1). For this report, only woody plants and the subwoody, Acanthosicyos horrida, were considered for the lower strips.

Examples of data collected and synthesized are given in Tables 1 to 4 and Figure 2. In these, individual species are mentioned only in Tables 1 and 3, which are line and belt transect data respectively for Strip 5. For brevity, for this report, all woody plants are grouped together for the other two tables and figure.

DISCUSSION

For quantification and meaningful spatial and temporal comparison of ecological or other data within the whole study area it was essential that base maps of known scale and a known, and preferably common, co-ordinate grid were to be produced. The National Trigonometrical grid not only satisfies these criteria, but also permits extrapolation into areas beyond the range of the detailed field studies of this project. It was also essential that the control points were marked in the field prior to the aerial photography on both occasions.

A scale of 1:2000 for the base maps, and orthophotos, was chosen as a compromise between the need for recording or determining relatively detailed data, on the one hand, and convenience and economy on the other. Reduction for more general studies would present little difficulty. Enlargement involves more paper work and additional problems involved with handling the greater amount of paper itself. For more detailed studies, orthophotos at a scale of 1:1200 are able to be produced, using data already derived during this project and with available facilities. Larger scales necessitating the use of costly equipment can be produced, but not by the University of Natal's Department of Surveying and Mapping, which is a teaching and research department not equipped with such apparatus.

One of the problems with orthophotos is that, while the ground data may be correct for a certain scale, the tops of the vegetation will be of a different scale and, unless there is a much greater than normal overlap of the aerial photographs, there is likely to be displacement of the crowns so that they may appear to be outside of a particular sample area. This is not important for low vegetation, but it may present problems for accurate measurements where taller plants are concerned; as, for example in the Acacia albida woodland in the canyon section of the Kuiseb River such as in Strip 5 (near Homeb) where the top of the canopy is some 18 m above the ground. This is partly overcome by viewing stereoscopic images concurrently with the orthophoto.

Most of the more commonly used methods of vegetation analysis, ie the random, systematic or other placing of points, lines, quadrats or belts, are able to be used with aerial photographs and base maps, but only in respect of those subjects that are able to be seen in the photographs. Unless the canopy is relatively sparse and sufficient light is able to penetrate, subcanopy features are generally not able to be seen or, if so, are not readily quantified.

Table 2. Summary of numerical and cover data for all woody and subwoody plants living in May 1978 and their changes in condition (vitality) in May 1981. Data obtained by the line intercept method from aerial photographs taken in May 1978 and May 1981. (See Table 1 for detailed data of one line transect). Vitality based on infra-red reflectance, graded as : A: very good, B: good, C: moderately good, D: poor, E: very poor, F: dead.
Key : L = length of line in metres
%L = percentage of line occupied by woody vegetation
N = number of individuals intercepted
L i = total length of line, in metres, occupied by woody plants
p = level of significance (Kolmogorov-Smirnov test, Siegel 1956)
With Line no, figure in brackets = Vegetation Transect no (sensu Thereon et al 1980); "13" = near Vegetation Transect 13.
Vitality class values are numbers of individuals followed by the respective distances (metres) intercepted per line.
Vitality class values = absolute and relative (%) values of numbers or cover.
%* = Vitality class values as mean of percentage based on numbers + percentage based on length of line intercepted.

Line No	L	%L	N	L i	VITALITY CLASSES 1978						VITALITY CLASSES 1981					
					A	B	C	D	E	F	A	B	C	D	E	F
1 (1)	322	58,70	15	189	4 79	8 72	2 30	1 8				4 73	1 10		10 106	
5 (3)	602	29,15	21	175,5	2 3	10 65,5	1 12	4 49	4 46			6 51,5	6 37	3 17	5 63	1 7
10 (5)	900	30,48	27	274,3	1 21	4 46,3	5 36,1	10 70,9	7 100			4 41	4 44	7 33,3	10 149,7	2 7,7
20 (12)	2420	7,19	27	174	1 4,5	2 21	12 99,5	11 45	1 4			1 4,5	5 50	14 94,5	7 25	
21 "13"	2500	4,14	18	103,5		4 32,5	11 40	2 26	1 5				8 47	8 49,5	2 7	
22 (14)	2240	16,12	41	361		12 102	18 161	9 83	2 15			2 27	19 160,5	15 122,5	4 44	1 7
TOTALS: (1+5+10)	1824	35,02	63	638,8 %*	7 03 3,62	22 183,8 31,85	8 78,1 12,46	15 127,9 21,92	11 146 20,16			14 165,5 24,04	11 91 15,84	10 50,3 11,87	25 318,7 44,73	3 14,7 3,53
(20..22)	7160	8,92	86	638,5 %*	1 4,5 9,34	18 155,5 22,64	41 300,5 47,37	22 154 24,85	4 24 4,21			3 31,5 4,21	32 257,5 38,77	37 266,5 42,38	13 76 13,51	1 7 1,13

CHANGE IN VITALITY (%*VALUES):(A+B+C):(D+E+F)	1978	1981	SHIFT (%)	MAX SHIFT = %	P
TOTAL (1+5+10):	58 : 42	40 : 60	18	(A+B+C+D:E+F) 28	0,01
TOTAL (20..22):	71 : 29	43 : 57	28	AS GIVEN	0,01

Table 3. Quantitative data for plants collected from six contiguous quadrats, 100 m x 100 m, as belt transect 600 m long, centred on Line 5 (equivalent to Vegetation Transect 3 of Theron et al 1980). Woody plants living, at least partly so, in May 1978. Data from aerial photographs taken in May 1978 and May 1981. Vitality based on infra-red reflectance, graded as : A: very good, B: good, C: moderately good, D: poor, E: very poor, F: dead.

Key: N = number of individuals or clumps for whole belt; R D = relative density ha^{-1} (%)
C = total cover (m^2) per entity for whole belt
R C = relative cover (%)
P = number of quadrats in which a particular entity occur
F = frequency (%) (=P as %); R F = relative frequency (%)
I V = importance value
for woody plants this is (R D + R C + R F)/3
for herbs this is (R C + R F)/2
%N = percentage based on numbers of individuals or clumps
%C = percentage based on cover; vitality class values: for woody plants these are (%N + %C)/2
for herbs these are absolute values of cover per entity per class.

SPECIES OR ENTITY	N	R D	C	R C	P	F	R F	I V	1978 A	1978 B	1978 C	1978 D	1978 E	1978 F	1981 A	1981 B	1981 C	1981 D	1981 E	1981 F
WOODY PLANTS																				
Acacia albida	49	11,67	6698	37,22	2	33,33	8,00	18,96		4,08	10,35	41,68	43,89				10,54	24,16	60,87	4,43
A albida (juvenile)	1	0,24	1	0,01	1	16,67	4,00	1,41			100						100			
A erioloba	38	9,05	3248	18,05	6	100	24,00	17,03	9,28	34,72	24,69	27,40	3,92		1,82	30,23	14,26	20,10	33,59	
Euclea pseudebenus	51	12,14	1741	9,68	4	66,67	16,00	12,61	11,68	52,65	22,97	12,70			5,87	35,52	23,08	26,11	8,27	1,15
Salvadora persica	123	29,29	2665	14,81	5	83,33	20,00	21,37	18,37	16,15	23,49	23,89	18,09		3,33	10,72	10,75	31,32	42,43	1,45
Tamarix usneoides	156	37,14	3640	20,23	6	100	24,00	27,12	17,48	46,91	22,95	9,67	3,00		2,14	28,16	22,91	25,04	19,37	2,38
T usneoides (juvenile)	2	0,48	1	0,01	1	16,67	4,00	1,49		100							100			
TOTAL WOODY PLANTS	420		17994		25	16,67		100	11,36	28,32	20,65	23,77	15,89		2,18	17,52	15,88	25,76	36,48	2,20
HERBS																				
Asthenatherum glaucum			25	0,98	1	16,67	6,67	3,83	0,5			2		22,5						25
Mesembryanthemum guerichianum			1595,5	62,80	5	83,33	33,33	48,07	15,5	12	25	77	173	1293						1595,5
Zygophyllum simplex			827	32,55	5	83,33	33,33	32,94	8	27	43	728,5	20,5							827
Unidentified grasses and forbs			92,5	3,64	3	50,00	20,00	11,82	21	29	11,5	5,5	1	24,5						92,5
Robust riverine ephemeral			0,5	0,02	1	16,67	6,67	3,34		0,5										0,5
TOTAL HERBS			2540,5		15	250			45	68,5	79,5	813	194,5	1340						2540,5

TOTAL WOODY PLANTS : degradation of vitality, as seen in shift of ratio of class values (A+B+C) : (D+E+F) 1978: 60 : 40 1981: 35,5 : 64,5
Shift = 24% (significant at 0,1% level : Kolmogorov-Smirnov test, Siegel 1956)

Table 4. Summary of numerical and cover data for all woody and subwoody plants living in May 1978 and their changes in condition by May 1981. Data from quadrats, 100 m x 100 m, in six belts across the Kuiseb River valley obtained from aerial photographs taken in May 1978 and May 1981. (See Table 3 for detailed data for one belt and Figure 1 for location of belts, one per strip shown.)
Vitality based on infra-red reflectance, graded as : A: very good, B: good, C: moderately good, D: poor, E: very poor, F: dead.
Key: S = strip number; Q = number of quadrats per strip; N = number of individuals or clumps; MD = mean density per hectare; TC = total cover (m^2); C% = cover % per hectare; %N = percentages based on numbers; %C = percentages based on cover; p = level of significance (Kolmogorov-Smirnov test, Siegel 1956)
Vitality class values = absolute values of numbers or cover of all woody and subwoody plants per strip or groups thereof.

S	Q	N	MD	TC	C%	VITALITY CLASSES 1978						VITALITY CLASSES 1981					
						A	B	C	D	E	F	A	B	C	D	E	F
1	5	142	28,40	21365	42,73	33 7042	32 3407	42 6207	25 3936	10 773		1 176	18 3493	38 5822	20 1893	65 9981	
5	6	420	70,00	17994	29,99	56 1690	140 4195	95 3361	76 5299	53 3449		11 312	70 3305	76 2457	122 4042	128 7644	13 234
10	9	334	37,11	22647	25,16	18 953	70 2688	124 6561	76 6654	46 5791		2 145	32 1615	71 3972	124 8084	98 8880	7 128
TOTAL	20	896	44,80	62006	31,00	107 9685	242 10290	261 16129	177 15889	109 10013		14 633	120 8413	185 12251	266 14029	291 26505	20 362
20	24	470	19,58	17431	7,26	35 3812	101 3611	140 5711	155 3854	39 443			32 1721	121 6827	181 6882	136 2001	
21	25	439	17,56	12709	5,08	30 2343	68 3034	190 3340	126 3624	25 368		1 162	24 886	119 3363	199 6064	91 2086	5 148
22	22	364	16,55	30462	13,85		77 7677	170 12707	74 7195	43 2883			5 616	181 13090	119 11967	45 3992	14 797
TOTAL	71	1273	17,93	60602	8,54	65 6155	246 14322	500 21758	355 14673	107 3694		1 162	61 3223	421 23280	499 24913	272 8079	19 945

VITALITY CHANGES :: (A+B+C):(D+E+F)

	VALUES BASED ON:	1978	1981	SHIFT(%)	MAX SHIFT = %	P
TOTAL (1+5+10)	NUMBERS: COVER: (%N+%C)/2:	68 : 32 58 : 42 63 : 37	35,5 : 64,5 34 : 66 35 : 65	32,5 24 28	AS GIVEN (A+B+C+D):(E+F) 27 AS GIVEN	0,001 0,001 0,001
TOTAL (20+21+22)	NUMBERS: COVER: (%N+%C)/2:	64 : 36 70 : 30 67 : 33	38 : 62 44 : 56 41 : 59	26 26 26	AS GIVEN (A+B):(C+D+E+F) 28 AS GIVEN	0,001 0,001 0,001

It is imperative that a stereoscope, preferably with suitable magnification, be used. Diapositives or positive transparencies have a better resolution than prints, therefore a tracing table is necessary. Prints, however, are valuable for field work, including the very necessary annotation, and general communication and handling.

Vertical aerial photographs have a considerable advantage in that, once annotated or interpreted, data from a wide area in difficult terrain are able to be recorded with less discomfort and fewer personnel than would be the case in the field. Furthermore one can always return to the aerial photography to modify, refine or completely alter methods of analysis and know that one is dealing with the same individuals. In this exercise 100 m wide belts, as well as lines, were chosen as samples: the base maps, however, cover a minimum of 500 m of river length; the large scale photographs cover this and more. Therefore detailed work over a much wider area than the 100 m belts mentioned herein can be undertaken. This would allow other methods of analysis and other statistical tests to be employed. On the other hand, with the same proviso as mentioned, ie that the subject is able to be seen in the photographs, the whole length of the Kuiseb Valley that was photographed is able to be analysed. This would certainly suffice for number of individuals, or clumps, of woody plants and their crown cover, the accuracy of measurement of which would vary with change in scale.

Cover is the fundamental parameter that is able to be seen in vertical photographs. Since individuals, especially in pure stands of even size, are not always able to be distinguished, numbers (of individuals) are not always accurate. However, since the number of data entries is important for statistical tests and since each square metre of cover was not considered to be a separate entry (because each plant or discrete clump/tuft was assessed for vitality as a unit on its own and plants varied in their cover values) numbers were recorded as well. "Numbers" in this case are not necessarily of individuals, although this was desired, but rather of either individuals or of discrete clumps of as small a size as possible.

One cannot always identify to species when using one photograph or even one stereoscopic pair of the same date, but, when two photographs of the same subject at two different dates are viewed simultaneously in a stereoscope, interpretation is facilitated. This was especially the case in using colour infra-red transparencies. As an example of this, a very small Acacia albida occupying less than 0,25 m^2 in 1978 could have been overlooked if it occurred amongst herbs, but its growth by 1981 (frequently to several metres in height, accompanied by an increase in cover, with the characteristic colour and texture of A albida) confirmed its presence in 1978.

Likewise the pattern of growth or behaviour under stress, especially with colour infra-red transparencies, helped to distinguish herbs present in 1978 when viewed simultaneously with 1981 photography; eg Stipagrostis lutecens was distinguished from small S sabulicola in Strip 10.

It is the repetition of scale of photography which permitted such stereoscopic viewing and which so greatly facilitated interpretation and also the assessent of vitality and any changes therein.

Several of the above remarks are not reflected directly in the data used for compiling Tables 1 to 4 and Figure 2, but, indirectly, the summations of data have depended upon such observations.

The data presented show changes in vitality between May 1978 and May 1981. These changes have been tested for significance. All, especially the quadrat derived data (due essentially to the larger number of observations) are highly significant according to the Kolmogorov-Smirnov test (Siegel 1956). These changes, therefore, should not be ascribed to chance and one must conclude that they result from changes in ecological factors. Although the ecological implications of these findings will be dealt with elsewhere, one is tempted to suggest that the changes reflected a reduction in growth water between May 1978 and May 1981; however, other climatic factors as well as biotic factors were also seen to have had adverse effects on the vegetation.

SUMMARY AND CONCLUSIONS

Although time taking in their production, base maps or orthophotos with overlays or even orthophoto maps (provided that over-printed data do not obscure features) together with aerial photographs, particularly when viewed stereoscopically, provide valuable sources of data for several disciplines. Aerial photographs are the foundation for the base maps and they also provide archival records of features as they occurred at a particular date. For quantification of data, it is essential that control points in the field are marked prior to aerial photography.

Although prints are more suitable for field use and general handling, diapositives or positive transparencies are more suitable for data extraction since their resolution surpasses that of prints. However, for many types of data, prints are adequate.

Apart from the production of the base maps by a photogrammetrist, unsophisticated equipment other than a good stereoscope with suitable magnification was deliberately used for the collection of data of which only a sample are presented here.

The most suitable means of data recording proved to be: a base map of known and suitable scale; aerial photographs in black-and-white panchromatic colour negative and colour infra-red taken at the two dates chosen for this project; black-and-white tilt-corrected prints enlarged to exact scale; a personally constructed overlay with data pertaining, in this case, to vegetation; a means of measuring the area occupied by the various entities and, as mentioned, a stereoscope over a light-table as well as adequate magnification facilities.

Output depends upon the training in the relevant discipline, experience, powers of observation and interpretative ability of the worker as well as upon the scale of aerial photographs and the subsequent enlargement of data optically, graphically or photographically.

Prints at a contact scale of 1:15 000 gave a good indication of features along the valley, and the 1:5000 colour prints of each strip across the valley were useful for more detailed data. The 1:300 black-and-white as contact prints or preferably, enlarged acted as very good data sources both in the field and in the laboratory during analysis. The 1:3000 colour infra-red was best left as transparencies in which form they were invaluable for specific interpretation as well as for assessment of

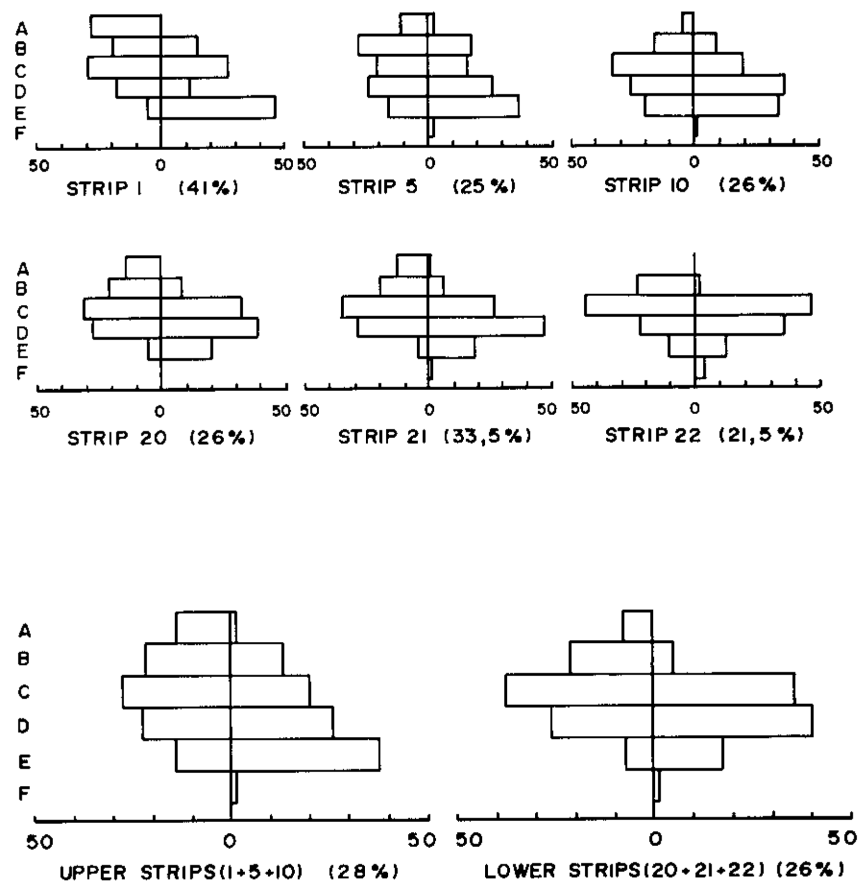


Figure 2. Comparison of vitality of all woody and subwoody plants living in May 1978 with that in May 1981. 1978 values on left, 1981 values on right of central reference line. Data from contiguous quadrats in six belts, 100 m wide, across the Kuiseb River valley obtained from aerial photographs taken in May 1978 and May 1981. (See also Table 4 for numbers and total cover involved). Vitality based on infra-red reflectance, graded as: A: very good, B: good, C: moderately good, D: poor, E: very poor, F: dead. Value per grade determined as mean of percentages based on numbers and cover.
Key: x-axis: percentage; y-axis: vitality classes; value in brackets after strip number - maximum shift between 1978 and 1981 values.

vitality of the various components. With suitable magnification the transparencies also acted as a source of data for objects too small to be represented directly on maps.

For the best results, annotation in the field should occur concurrently or follow as soon as possible after the aerial photography and be as detailed as possible for each sample area. Extrapolation is then facilitated.

Where vegetation ecology is concerned, the aerial surveys of 1978 and 1981 have provided quantitative as well as qualitative data for those plants that can be seen in the photographs. Components of strata below the canopy, where this is continuous, are not able to be satisfactorily detected.

The vegetation data obtained included species recognition and vitality as well as such criteria of abundance as density, cover and frequency. These parameters have been stored or presented as such or used in calculations of importance values for the various components.

Density, as numbers of individuals per unit area presented difficulties since individuals were not always able to be distinguished. Isolated or loosely assembled plants were not difficult to count, but gregarious species or those in dense pure stands offered problems which were partly overcome by referring to numbers as numbers of individuals or clumps/tufts, the latter which were considered, for woody and subwoody plants, in as small as possible a discrete unit.

Cover or crown spread was easily determined if this concerned upper canopy or open community species. For trees, crown spread would be a more accurate term since the crowns do not always have 100 percent true cover. For low-growing vegetation, wherever possible, cover is as stated.

Frequency, as presence of an entity in a number of samples expressed as a percentage of the total number of sample of canopy or open community components was readily determined. As a value it could be improved by subsampling, especially of the quadrats each of which was 1 hectare.

Vitality and changes thereof were best determined from stereoscopic viewing of stereo pairs of colour infra-red transparencies of one date, or one photograph of one date simultaneously viewed with another photograph of the same subject at the second date.

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10. AVAILABILITY, QUALITY AND UTILIZATION OF THE RIVERINE VEGETATION OF THE LOWER KUISEB AND CANYON AREA

A J van Wyk, D P J Opperman and O B Kok, University of the Orange Free State

INTRODUCTION

In view of the importance of the Kuiseb riverine vegetation as a forage resource for game during dry periods, it was important to determine the forage production and availability of key forage plants. Other factors of importance included species preference, area preference and the influence of the availability of water on the use of riverine vegetation. Furthermore, the influence of the domestic stock of the Topnaar Hottentot communities on riverine vegetation and on the utilization of this by game animals was important.

The boundaries of the study area were determined as 78 km upstream from Gobabeb to 30 km downstream from Gobabeb. The most important woody species within this area included Acacia albida, A erioloba, Euclea pseudebenus, Tamarix usneoides and Salvadora persica, of which A albida and A erioloba were considered the most important forage plants.

Although the river flowed very weakly during the study period, the canyon area was flooded annually as follows:

1979: during February and March to approximately 30 km upstream of Gobabeb

1980: during March to approximately 50 km upstream of Gobabeb

1981: during April to approximately 10 km upstream of Gobabeb

1982: during March to approximately 35 km upstream of Gobabeb

During the last three years the flow was, however, very weak.

The larger herbivores of the area comprised goats, sheep, cattle and donkeys of the Topnaar Hottentots as well as oryx, springbok, steenbok, klipspringers and ostriches. Zebras visited the river only for water. A few kudus were also noted in the study area.

PHENOLOGY

Observations on the presence or absence of new shoot growth, inflorescences, fruit and green pods were made on marked trees in the vicinity of Gobabeb. The pattern of pod fall was determined for trees in exclosures.

The peak flowering period for A albida was found to be June to August with a few inflorescences present until February. Green pods peak between September and October with some still being found as late as March. Although pods can fall all through the year, the greatest pod fall occurs during December and January.

The flowering period of A erioloba peaked in November to January, but trees in full flower can be found throughout the year. Pods fall throughout the year but with the peak fall during March to August (Table 1).

Table 1. Phenophases of woody species in the vicinity of Gobabeb.

	J	F	M	A	M	J	J	A	S	O	N	D
<u>Acacia albida</u>												
Shoot growth	x	x	x							x	x	x
Inflorescence	x	x				x	x*	x*	x	x	x	x
Green pods	x	x	x					x	x*	x*	x	x
Pod fall	x*	x	x	x	x	x	x	x			x*	x*
<u>Acacia erioloba</u>												
Shoot growth	x	x	x						x	x	x	x
Inflorescence	x*	x	x	x			x	x	x	x	x*	x*
Green pods	x*	x*	x*	x*	x	x	x	x	x	x	x	x
Pod fall	x	x	x*	x*	x*	x*	x*	x*		x	x	x
<u>Euclea pseudebenus</u>												
Shoot growth	x	x	x	x								
Inflorescence								x	x	x	x	
Fruit	x	x	x	x						x	x	x
<u>Salvadora persica</u>												
Shoot growth	x	x	x	x								
Inflorescence	x	x	x	x	x							
Fruit			x	x	x	x	x					
<u>Tamarix usneoides</u>												
Shoot growth	x	x	x	x								
Inflorescence				x								

x = present
x* = peak time

FORAGE AVAILABILITY

Pods were collected under trees within exclosures, dried and weighed. Leaf production and availability was determined bi-annually by manually removing the leaves of branches within exclosures. The oven dry mass of the leaves was determined. The leaves were collected in two strata, from 0 to 1,1 m and from 1,1 to 1,8 m. The trees were classified within three classes in terms of their size and form, namely class 1 - trees higher than 3 m with a round umbrella form; class 2 - trees higher than 3 m with an upright form; and class 3 - trees lower than 3 m (generally with an upright growth form).

The availability of A albida pods showed a seasonal peak during November to January while the seasonal peak of A erioloba occurred between March and August. The two species therefore complement one another in terms of pod availability. The annual pod availability of A albida and A erioloba in different communities is indicated in Tables 1, 2 and 3. Class 1 trees provide the greatest contribution to pod production.

Table 2. Average annual pod availability (kg ha^{-1}) of Acacia albida in different communities.

Community	Class 1 1980/81	Class 1 1981/82	Class 2 1979/80	Class 2 1981/81	Class 2 1981/82
Riverbed	330	35	0,86	0,18	0,05
A albida	7 623	839	12,78	2,30	0,77
A erioloba	43	3	0,00	0,00	0,00
A albida - A erioloba	1 761	193	1,11	0,23	0,06
Tamarix - A albida	2 257	247	0,00	0,00	0,00
Tamarix - A erioloba	38	3	0,00	0,00	0,00
Tamarix	58	5	0,12	0,05	0,003
Euclea	304	32	0,00	0,00	0,00
Salvadora	38	3	0,82	0,18	0,05
All communities	594	64	2,06	0,40	0,12

Table 3. Average annual pod availability (kg ha^{-1}) of Acacia erioloba in different communities.

Community	Class 1 1979/80	Class 1 1980/81	1981/82	Class 2 1980/81	Class 2 1981/82
Riverbed	11	1	4	0,00	0,00
A albida	115	11	50	0,00	0,01
A erioloba	289	28	126	0,00	0,07
A albida - A erioloba	29	2	12	0,00	0,01
Tamarix - A albida	238	23	104	0,00	0,01
Tamarix - A erioloba	362	35	145	0,00	0,07
Tamarix	8	0	3	0,00	0,02
Euclea	0	0	0	0,00	0,00
Salvadora	2	0	1	0,00	0,003
All communities	146	14	64	0,00	0,03

Leaf availability shows a seasonal peak during February, which corresponds with the phenological observations of shoot growth and leaf development. Despite the large size of many of the acacia trees, the proportion of leaves which are available to the large herbivores is very limited. Most of the branches were out of the reach of the animals, while many of these branches within reach had died off. The increased utilization of Salvadora leaves during the dry period indicated the importance of Salvadora as a drought reserve during the winter of 1982 when 291 kg per hectare of Salvadora leaves were available.

UTILIZATION AND SPECIES PREFERENCE

Utilization was determined on eight occasions using the estimation technique described by Walker (1976). Oryx grazing showed a seasonal pattern (Figure 1). Forage utilization by goats did not show such a clear seasonal pattern due to the dry circumstances and because they were not moved from their grazing areas. The utilization by goats showed a decrease towards the limits of their grazing area with a peak around water points. This tendency is particularly clear in the case of Tamarix usneoides. Both oryx and goats exhibited preference for A albida, A erioloba and Euclea pseudebenus. As the drought advanced, the utilization of Salvadora persica increased.

AREA SELECTION

Area selection was determined by making a monthly game and domestic stock count in the study area. The area selection by goats was determined by the distance they could cover in their daily wanderings from their holding pens, and by the availability of forage. During times of peak pod fall, especially of A albida, the grazing area of goats was much smaller than otherwise. During dry conditions the diminishing availability of food led to their having much expanded grazing areas.

Oryx, springbok and ostriches exhibited preferences for specific areas. It was notable that their grazing areas did not overlap with those of the goats, although springbok and ostriches frequently used the same grazing area.

CHEMICAL COMPOSITION OF THE FORAGE

Samples of the five most important woody species were collected monthly and analysed for moisture content, digestible organic matter, crude protein, acid digestible fibre and ash. The maximum and minimum nutrient values of five species of woody plants are indicated in Table 4. The maximum and minimum values of digestible organic matter, crude protein and acid digestible fibre show a large variation and this is due to a decrease with the advance of dry conditions. The moisture content was largely influenced by the environmental conditions and in particular fog. Dry pods normally had a moisture content of 3 to 5 percent but during foggy weather this could increase to as much as 24 percent and during dry, hot periods could drop to below 1 percent. This variation was not so clearly observed in other plant parts.

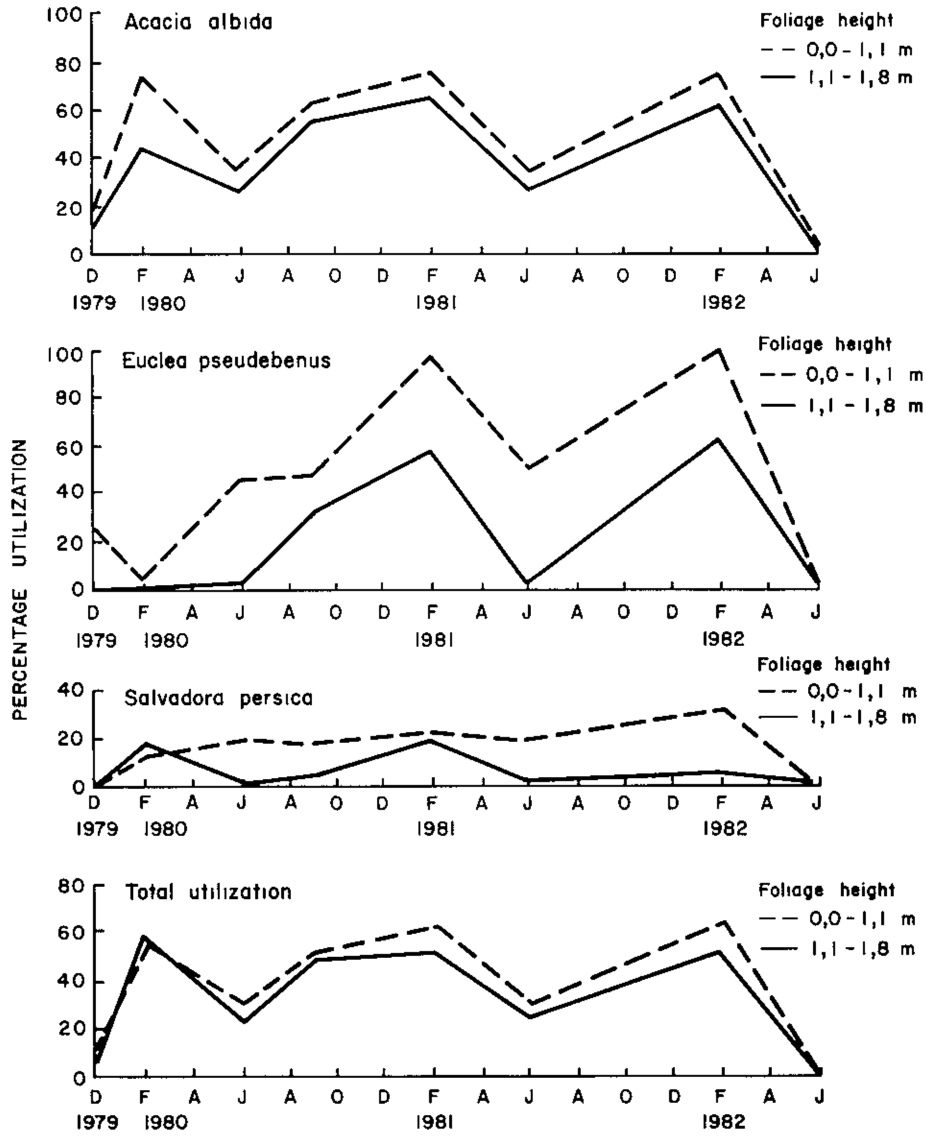

Figure 1. Seasonal utilization of leaf material in oryx grazing area.

POD AND SEED DAMAGE

A sample of A erioloba and A albida pods was collected monthly and examined for damage.

The total pod damage in A albida ranged from 72 to 93 percent and can mainly be attributed to damage by insects of the family Bruchidae. Rodents (Thallomys sp and Rhabdomys sp) also play a role in pod damage. Seed damage is due primarily to insects and varies between 7 and 30 percent.

Pod damage in A erioloba varied between 71 and 90 percent. It was mainly due to insects (Bruchidae), although rodents such as Thallomys and Rhabdomys also played a role. Insect damage counted for 70 to 84 percent of the pods examined. Seed damage, principally due to insects, range from 17 to 44 percent.

Table 4. Maximum and minimum values of the chemical analyses of different organs of five woody species.

	% Moisture		% Organic material		% Digestible organic material		Crude protein		Acid digestible fibre	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
<u>Acacia albida</u>										
Shoots and leaves	74	47	97	91	47	23	18	7	57	30
Leaves	65	50	96	89	49	20	17	6	58	35
Green pods	75	64	89	94	61	43	8	5	40	27
Dry pods	23	0	97	93	69	53	10	4	41	26
Litter	8	1	87	66	45	23	-	-	-	-
<u>Acacia erioloba</u>										
Shoots and leaves	65	38	97	91	52	25	13	5	54	21
Leaves	67	42	97	91	50	29	13	7	61	32
Green pods	66	29	97	93	71	40	9	6	41	24
Dry pods	24	0	98	92	81	39	11	6	39	30
Litter	7	1	83	74	34	13	-	-	-	-
<u>Euclea pseudebenus</u>										
Shoots and leaves	56	41	97	90	32	10	7	3	67	25
Leaves	57	35	95	90	30	10	14	3	61	25
Berries	57	40	97	90	64	23	10	2	66	36
Litter	7	0	90	78	45	13	5	2	63	48
<u>Tamarix usneoides</u>										
Shoots and leaves	64	48	92	83	46	28	10	3	51	35
Litter	10	3	82	66	57	28	-	-	-	-
<u>Salvadora persica</u>										
Shoots and leaves	84	66	87	65	91	66	25	8	33	18
Leaves	82	57	84	57	93	70	21	8	24	12
Berries	76	58	92	79	91	67	-	-	-	-
Litter	11	1	66	52	92	62	-	-	-	-

Pod damage by both insects and rodents varied between 0 and 32 percent for <u>A erioloba</u> and 11 and 42 percent for <u>A albida</u>.

The pod and seed damage influenced the digestibility and germination of the seeds. Rodent damage to pods caused the seeds to fall out and therefore made them more rapidly available for germination. The examination of goat droppings indicated that 100 percent of the <u>A albida</u> and <u>A erioloba</u> seeds present showed no signs of damage, suggesting that all damaged seeds had been digested.

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11. AVAILABILITY OF WATER IN THE LOWER KUISEB AND ITS USE BY LARGE VERTEBRATES

A J van Wyk, D P J Opperman and O B Kok, University of the Orange Free State

AVAILABILITY AND QUALITY OF WATER IN THE KUISEB RIVER

Although the Kuiseb is normally dry, the river generally flows each year during the seasonal rains from December to March in the Khomas Hochland catchment area. As the water table falls, the available water is limited to isolated pools, and later even to a few gorras (excavations by game). According to the number of water holes and total water surface in the various sections of the river, the valley and lower lying areas dry up much quicker than those further upstream (Table 1), so that by the end of the dry season no open water surfaces are available within the first 70 km upstream from Gobabeb. Relatively large quantities of water do however occur in the narrow, inhospitable middle section of the ravine throughout the year. According to track surveys made on a regular basis at all open water holes and gorras in the riverbed, it is mainly the mountain zebra, and to a lesser extent the klipspringer and spotted hyena which utilize this water (Table 2). This is in agreement with the curious ability of the mountain zebra and klipspringer to surmount steep, rocky areas, while the rocks occurring scattered in the riverbed (making vehicle transport impossible) provide on ideal hiding-place and shelter for hyenas. Most other game species, especially oryx and springbok, are confined to the easily accessible valley-like areas of the riverbed. Direct observation confirms that inter-species competition amongst the most important herbivores utilizing the Kuiseb is reduced to a large extent, as mountain zebra and klipspringer are limited to the upper well-watered sections of the canyon, while oryx and steenbok occur in the lower lying, well vegetated areas. It is significant that on account of the disturbance caused by the Topnaar settlements, no game was observed in the immediate environment of Homeb, Oswater and Natab.

Chemical analysis revealed that the water of sampled pools and gorras in the Kuiseb River is generally alkaline, with high alkalinity and hardness values. As might be expected, no difference worth mentioning could be indicated in the water quality of the various sections of the canyon (Table 3). The water composition of specific water holes which remained intact long enough to make possible repeated sampling over a period of months, however, shows a definite increase in ion concentration as the dry season progresses (Table 4). Nevertheless the quality of the water remained remarkably high (75 percent of all Kuiseb samples indicate South West Africa grade A standard).

Table 1. Seasonal variation in the relative availability of water in different parts of the Kuiseb River during 1977/78 and 1978-79.

Point of time	Valley (0-40 km) Number	surface (m^2)	Lower (40-80 km) Number	surface (m^2)	Middle (80-120 km) Number	surface (m^2)	Upper (120-160 km) Number	surface (m^2)
1977 Aug	11	92	62	4025	-	-	99	1694
Sept	12	48	64	562	-	-	74	1016
Oct	10	11	63	473	-	-	45	656
Nov	9	5	39	185	234	6446	39	413
Dec	7	1	23	119	-	-	29	334
1978 Jan	4	1	23	31	163	4182	10	185
Aug	9	64	76	3318	-	-	54	824
Sept	8	29	67	1094	328	13221	44	493
Oct	6	16	53	544	232	11702	33	291
Nov	3	7	32	216	198	7015	19	192
Dec	2	2	20	107	179	5204	15	144
1979 Jan	0	0	18	45	167	3316	14	109

Table 2. Occurrence of game tracks associated with water holes in different parts of the Kuiseb River during 1977-79.

Animal species	Valley section n=56	Lower section n=184	Middle section n=1640	Upper section n=251
Mountain zebra	0	151	1164	238
Baboon	15	39	49	40
Oryx	38	79	81	68
Hyena	12	11	201	13
Jackal	41	22	77	42
Klipspringer	0	37	203	66
Kudu	0	0	4	11
Springbok	21	0	0	4
Ostrich	3	0	0	0
Unidentified	0	0	26	3

Table 3. Chemical properties of water pools in different parts of the Kuiseb River as determined in 1977-78.

Parameter	Valley section n=1	Lower section n=21	Middle section n=14	Upper section n=30
pH	7,5	8,2	8,2	8,2
Conductivity	5993	1390	1425	1123
TDS	3369	967	991	814
Na	1310	220	273	175
K	208	37	31	31
Sulphate	-	76	159	133
Nitrate	-	1,1	0,3	1,0
Nitrite	-	0,1	0,2	0,1
Si	8	11,1	4,9	7,9
F	0,1	0,2	0,3	0,3
Cl	2260	327	296	229
Alkalinity	1380	329	213	252
Total hardness	1475	338	231	268
Ca-hardness	63	153	106	164
Mg-hardness	1412	185	141	102

INFLUENCE ON GAME NUMBERS AND DISTRIBUTION

The most prominent seasonal effect regarding the distribution of game species comprises the regular occurrence of especially oryx in the linear oasis of the Kuiseb River. As the dryness and the average temperature increase towards the end of the year, the oryx numbers in the lower lying areas of the canyon increase on a large scale (see Table 5). A sudden decrease in numbers is however experienced with the first rain of the season, after which only a very few individuals are spotted sporadically in the riverbed. As the oryx in the adjoining gravel plains reveal a relative movement towards the brackish water hole north of Mirabib or even further to the north in the corresponding period, and the remaining individuals concentrate mostly in the immediate region of the easily accessible Zebra Pan (Table 5), this group is probably not part of the Kuiseb population. The river is apparently mainly utilized by oryx of the more southerly dune population during this period in the year.

Approximately 80 percent of all oryx observed entering or leaving the riverbed did so from the southern (dune) side. It is clear that water, despite its poor quality, is the primary attraction for oryx visiting the canyon (see Table 6 and Figure 1).

INFLUENCE ON FORAGE UTILIZATION

The effect of the available water on forage utilization is clearly illustrated by the increased utilization at and in the vicinity of water. Since the beginning of 1981 the pattern has however changed.

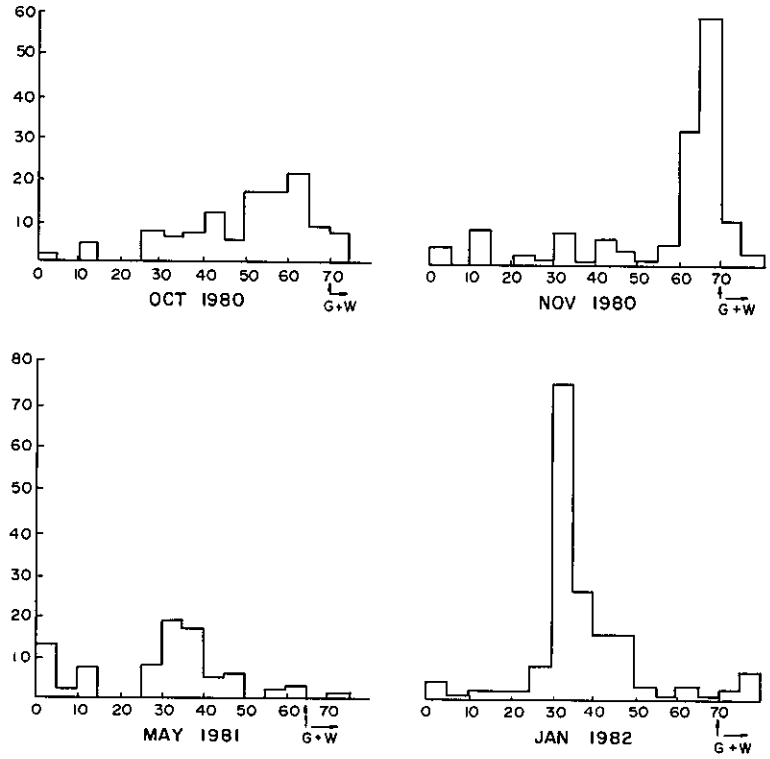

Figure 1. Distribution of oryx in the lower sections of the Kuiseb River.

Table 4. Monthly variation in the chemical composition of specific water holes in the Kuiseb River at the end of the dry season of 1977-78.

Parameter	Nov	Dec	Jan	Nov	Dec	Jan	Nov	Dec	Jan	Nov	Dec	Jan	Nov	Dec	Jan
pH	7,4	8,2	7,2	7,7	8,3	7,4	8,2	6,8	7,4	7,9	8,9	8,2	8,3	8,0	8,8
Conductivity	730	922	1090	767	751	650	705	783	900	917	865	840	1105	1162	1140
Alkalinity (as CaCO3)	220	244	280	265	276	280	144	239	280	190	291	255	245	276	520
Na	92	136	163	92	74	56	40	78	97	127	102	107	152	174	186
K	30	26	36	36	26	24	17	19	30	27	19	18	25	19	39
Ca	36	37	60	34	37	39	80	86	91	40	78	74	80	74	88
Mg	15	27	34	31	38	32	22	17	24	22	21	17	12	20	41
C1	115	175	185	95	80	58	83	115	125	163	135	130	210	210	230
SO_4	12	13	16	34	48	22	46	68	76	78	54	54	72	80	15
NO_3	-	7,8	-	2,1	-	-	-	1,8	5,0	-	2,0	3,0	-	3,7	-

INFLUENCE ON THE UTILIZATION OF PODS

Observations show that until the middle of 1981 pods were minimally utilized in the absence of water, but completely utilized at or in the vicinity of water. From the middle of 1981 the utilization of pods in the absence of water increased drastically. The increased uptake of Salvadora apparently compensated for the low moisture content of the pods.

Table 5. Seasonal occurrence of oryx in the Kuiseb River and Zebra Pan area during 1977-78.

Month	Rainfall (mm)	Temperature (°C)	Kuiseb River	Zebra Pan
July 1977	0	26,0	5	40
August	0	27,2	7	47
September	0	25,2	14	57
October	0	28,5	69	65
November	0	28,6	101	69
December	0	30,4	109	92
January 1978	1,0	29,8	118	80
February	49,3	30,1	11	15

Table 6. Seasonal distribution of oryx in the Lower Kuiseb River. Asterisks indicate location of first open water holes and/or gorras.

Distance (km)	1978	1979				1980		
	Jan	Jan	May-Sept	Nov	Dec	Jan	Feb	March
5	5	1	0	0	8	6	6	2
10	0	8	0	0	0	0	3	6
15	0	0	0	0	7	3	9	3
20	41	0	0	0	1	0	0	0
25	10	0	0	1	0	14	7	2
30	2	0	0	20	26	3	20	16
35	3	6	0	5	46	38	15	6
40	50*	31	0	6	29	3	12	4
45	1	8	0	13	33	8	9	33
50	3	8	17*	48	7	2	2	5
55	1	34	7	30	8	4	2	2
60	0	62*	0	28*	42*	27	9	31
65	0	43	1	7	43	114	156	157
70	0	14	0	16	25	21*	11*	3*
75	0	1	0	6	1	7	14	2

12. VEGETATION TYPES OF THE GRAVEL PLAINS

P S Nel and D P J Opperman, University of the Orange Free State

INTRODUCTION

Giess (1971) described the broad vegetation types of South West Africa (Figure 1). Three main types are found in the study area, ie the Semi-desert and the adjacent Savanna transition region (also called the plateau border area), the Central Namib and the Southern Namib. The main types in the study area were subdivided in different subtypes on the basis of differences in vegetation composition, soil type, geological formation and topography, after observations were made along transect lines at kilometre intervals. Based on this the boundaries of nine subtypes were indicated on an aerial photo mosaic.

Many of the vegetation communities, as identified by Robinson (1976), were grouped according to the occurrence of key pasture plants. These subtypes correlate with the natural game habitats, eg typical zebra habitat in the northeastern corner of the study area, which is characterized by the presence of Stipagrostis uniplumis and S hirtigluma vegetation. The subdivision of the main vegetation types in the study area into nine subtypes is indicated in Figure 2.

CENTRAL NAMIB

According to the vegetation map of Giess (Figure 1) the gravel plains of the Namib Naukluft Park occur mainly in his Central Namib division. The plains which occur in the transition area between the real desert and the plateau border area consist mainly of Stipagrostis obtusa, S ciliata and Eragrostis nindensis. These are perennial grasses which grow in stony calcareous areas. They are also the main pasture plants for this vegetation type. The Central Namib is subdivided into the following subtypes:

Stipagrostis hochstetterana grassland of the Pro-Namib

This subtype occurs on the eastern border of the Namib-Naukluft Park, extending some ten kilometres west of the eastern boundary of the Park, and the 100 mm isohyet may be taken as the western boundary. It stretches from the Swakopmund-Windhoek road in the north southward to the Uspas road (Figure general map).

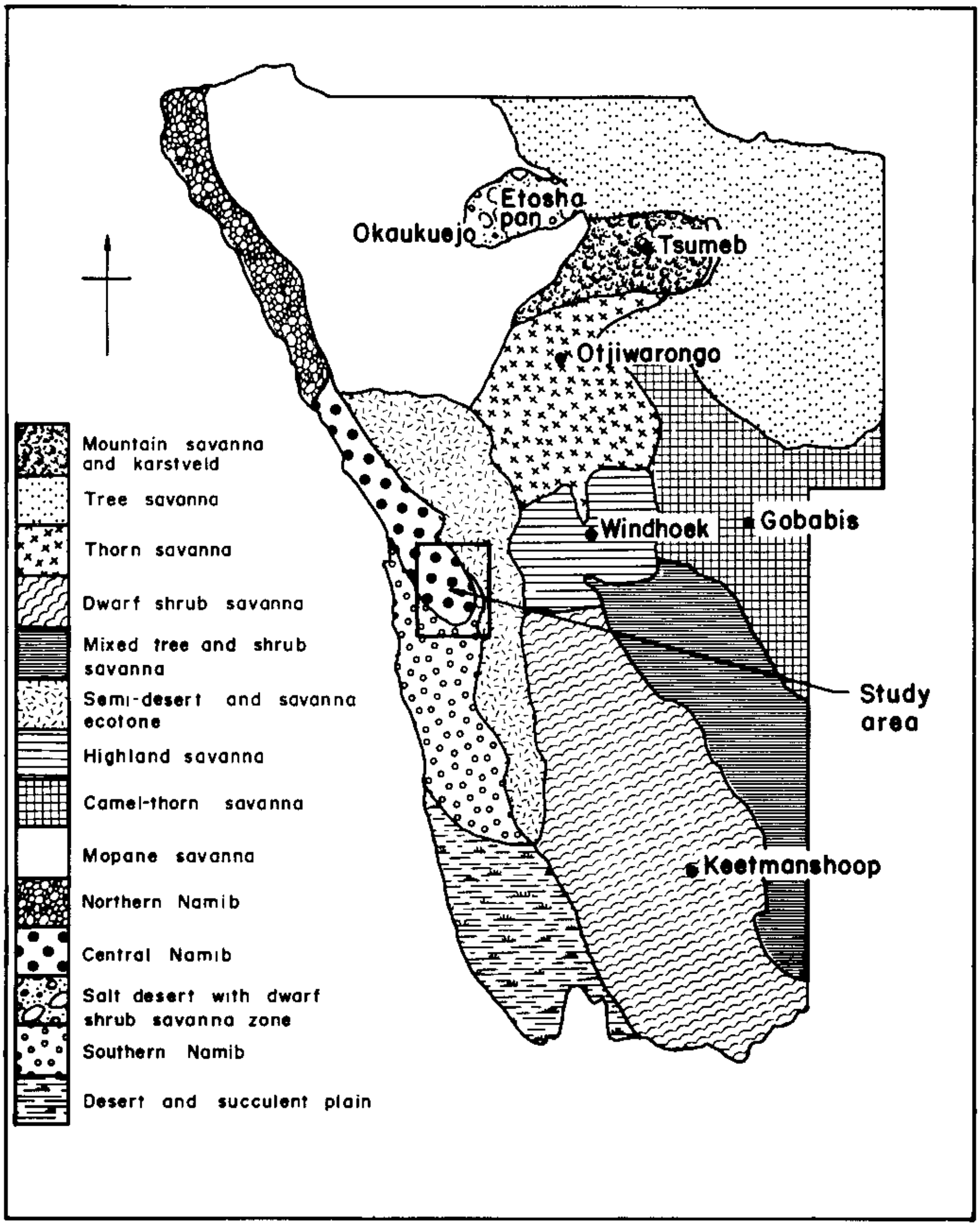

Figure 1. Vegetation map of South West Africa (Giess 1970).

The deep sandy soil type originated as a result of sand being blown against the Arachadomab Mountains by the prevailing southwesterly winds. Together with this, alluvial soil depositions from the abovementioned mountain range also occur.

Stipagrostis uniplumis, S hochstetterana and Eragrostis nindensis are the key pasture grasses and comprise 80 percent of the vegetation. This subtype has the highest fodder production of all subtypes. Monechma arenicola and Petalidium setosum are herbs which are well-utilized. Acacia erioloba is the most important forage tree occurring in this subtype. In addition to the key pasture plants, the following species are utilized:

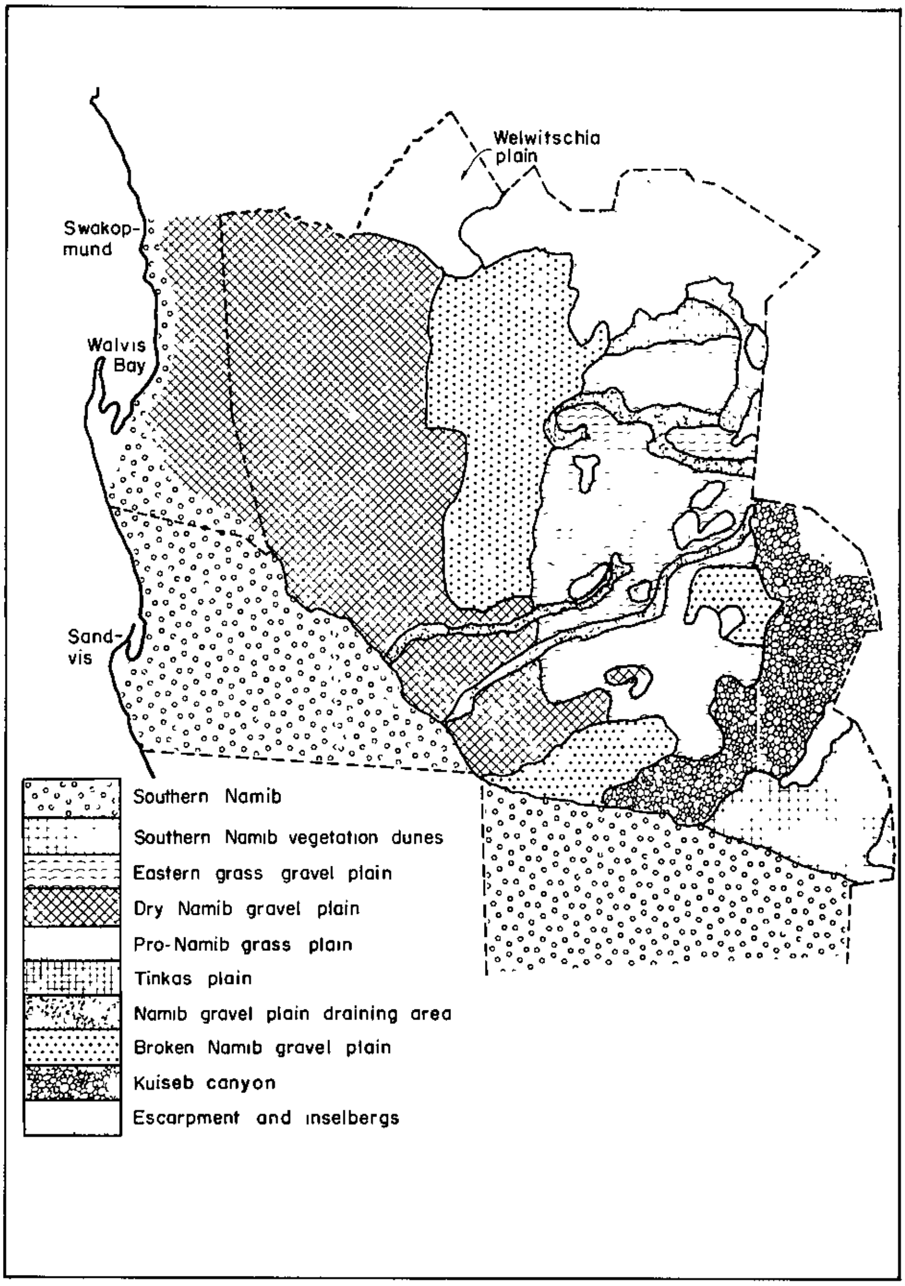

Figure 2. Veld types of the study area.

Adenolobus pechuelii, Anthephora pubescens, Boscia foetida, Cenchrus ciliaris, Eragrostis annulata, Euclea pseudebenus, Geigeria ornativa, Ptycholobium biflorum, Salsola tuberculata, Ziziphus mucronata, Zygophyllum simplex.

Eragrostis nindensis eastern grassland

The eastern grass gravel plain stretches from the Swakopmund-Windhoek road in the north to the edge of the Kuiseb canyon in the south. To the west it stretches to approximately 10 km west of Hotsas, SAP Hill and to 30 km west of Mirabib.

The soil type of this subtype varies, but the description of two profile pits by Robinson (1976) can be taken as a good indication. The first profile was in the vicinity of Amichab bank (Figure general map), on a level plain, 1 000 m above sea level with the following profile characteristics:

0 - 0,05 m	-	quartz, gravel and pale brown, fine loose soil
0,05 - 0,20 m	-	pale brown, fine, loose loamy soil
0,20 - 0,5 m	-	pale brown, fine, compact to very compact loamy soil

The second profile was 75 km northeast of Gobabeb and the profile characteristics are as follows:

0 - 0,05 m	-	grey-brown, fine grained, compact soil
0,05 - 0,15 m	-	grey-brown, fine grained, loose soil with pebbles - the soil is looser in areas with vegetation
0,15 m	-	impenetrable calcrete

Often the top soil is absent due to wind and water erosion with the calcrete visible at soil surface.

Key pasture plants in this subtype are Stipagrostis ciliata, S obtusa, S hochstetterana which occur in the sandy drainage lines, while S uniplumis occurs in deeper sand. Salsola tuberculata and Calicorema capitata occur on the gravel plains. Eragrostis nindensis also occurs, but disappears at the 50 mm isohyet. Petalidium setosum and Monechma arenicola dominate in the sandy drainage lines which traverse the plain.

Acacia erioloba, Ziziphus mucronata and Euclea pseudebenus are fodder trees occurring in this subtype. Other plants occurring in this type are Adenolobus pechuelii, Boscia albitrunca, Boscia foetida, Commiphora saxicola, Enneapogon brachystachyus and Stipagrostis namaquensis.

Stipagrostis uniplumis drainage line grassland

This subtype represents all sandy drainage lines and large sand washes. Its distribution is shown in Figure 2. These areas drain to the Kuiseb and Swakop Rivers. Some end as blind beds approximately 60 km from the sea, as the rainfall is not sufficient for the runoff water of the sandy beds and drainage areas to break through to the sea.

The characteristic soil type is a deep alluvial soil. The alluvial fan-type drainage plains may have a sand mantle as deep as 6 m overlying the calcrete. In the drainage lines however, the water has eroded through the calcrete. A deep layer of alluvial sand on mica schist, quartz or granite drainage line beds frequently occurs.

The drainage plains are characterized by key forage plants such as Stipagrostis ciliata, S hochstetterana, S uniplumis and Eragrostis nindensis. The density of the key forage plants do however decrease drastically to the west, and approximately 80 km from the sea no forage grasses occur. The network of sandy beds, which cover approximately 30 percent of the area of this subtype, are characterized by forage trees such as Acacia erioloba, Euclea pseudebenus and Ziziphus mucronata. The above-mentioned Stipagrostis species also occur here generally, as well as Stipagrostis namaquensis, Asthenatherum mossamedense, Petalidium setosum, Monechma arenicola, Ptycholobium biflorum subsp biflorum, Otoptera burchellii and Aptosimum lineare. These species again decrease drastically towards the west, until they disappear completely. Other forage plants which occur in the sandy beds include Cucumis spp.

Stipagrostis obtusa grasslands of the Tinkasvlakte

The distribution of this subtype is indicated in Figure 2. It occurs north of the Swakopmund-Windhoek road. To the east this subtype borders on the Pro-Namib subtype. To the north it is surrounded by the escarpment subtype (northeastern corner of the park). Towards the west it borders on the mica schist brokenveld.

The soil types comprise granitic/quartzitic coarse to fine sand, on calcrete. The depth of the sandy mantle can vary from 5 cm to 1,5 metre. To the north, mica schist, granite and quartz outcrops occur. Coarse alluvial sand is characteristic of the sandy drainage lines.

The key forage plants include a large sward of Eragrostis nindensis, which however disappears towards the west. In the mountainous areas E nindensis is replaced by Enneapogon brachystachyus. On the plains, where the soil type is characterized by a shallow calcrete horizon, Stipagrostis obtusa is dominant. Approximately 3 percent of the area of this type is traversed by sandy drainage lines. The vegetation is the same as that described as drainage line grassland. Stipagrostis ciliata dominates on the sandy plains. Other forage plants occurring here are: Commiphora glaucescens, C saxicola, C virgata, Geigeria ornativa, Phaeoptilum spinosum, Stipagrostis hirtigluma, Tribulus terrestris, T zeyheri and Zygophyllum simplex.

Commiphora saxicola brokenveld

The location of this subtype is indicated in Figure 2. This subtype is primarily a transition from the flat gravel plains in the north to the canyon terrain in the south. The area is not as broken as in the Kuiseb and Swakop canyons, and not as mountainous as the Escarpment, but occurs on the edge of the Kuiseb canyon. A bend of the Swakop River to the south, which includes the Witpoortjie Mountains and Leeukop, also comprises brokenveld.

The region is undulating with mica schist platforms. Quartz and granite ridges also appear on the soil surface. Weathered conglomerate indicates the course of extinct rivers. Shallow calcrete platforms with adjacent sandy drainage lines occur generally.

Stipagrostis uniplumis, S ciliata, S obtusa, S hirtigluma and Enneapogon brachystachyus occur here in general. The staple fodder of the area is Zygophyllum cylindrifolium, Petalidium setosum, Salsola tuberculata, Monechma arenicola and Zygophyllum simplex. During the dormant period zebras move out of the canyon to this subtype. Should it rain, however, they move back to their preferred habitats, in the Kuiseb canyon and escarpment areas. A much utilized forage shrub, Adenolobus pechuelli, occurs in certain parts of this subtype. Other forage plants occurring here are Aptosimum lineare, and also Petalidium canescens, which is not utilized very much.

Petalidium canescens dwarf shrubland of the Kuiseb canyon

This subtype occurs along the heavily eroded upper tributaries of the Kuiseb and Gaub Rivers. The area includes the inaccessible and inhospitable Kuiseb canyon. It is a deeply dissected area with conglomerate outcrops. There is very little or no top soil. Weathered coarse gravel, sand and mica dust occur on the riverbeds.

Grasses commonly on the canyon slopes include Stipagrostis hirtigluma, S obtusa, S uniplumis, S ciliata, Eragrostis nindensis and Triraphis ramosissima. Vegetation in this section of the Kuiseb River is very sparse. A few trees such as Acacia albida, A erioloba, Ziziphus mucronata and Adenolobus garipensis occur on the sandy beds. Moringa ovalifolia and Maerua schinzii occur on the slopes. The less important forage plants are Adenia repanda, Commiphora virgata, Curroria decidua, Petalidium canescens and Sterculia africana.

Salsola sp desertic dwarf shrubland

This subtype occurs from west of the 50 mm isohyet to the coastal dunes. The coastal dunes, which occur as a north-south strip along the coast from Walvis Bay to Swakopmund was not included in the study area, as it contains very little vegetation and game species occur only sporadically.

According to Giess (1971) plants occurring here include amongst others: Zygophyllum clavatum, Psilocaulon salicornioides, Salsola spp, Zygophyllum stapfii, Arthraerua leubnitziae, Stypertelis caespitosa, Parmelia spp, Telochistis capensis, Usnea spp, Asclepias buchenaviana, Citrullus ecirrhosis, Aristida parvula, Triraphis pumilis, Sporobolus nebulosus, Stipagrostis namibensis, S hirtigluma subsp hirtigluma, S hirtigluma subsp pearsonii, S uniplumis, S subacaulis and Sutera maxii.

SOUTHERN NAMIB

According to Giess (1971) this area stretches from the Kuiseb River southward to the border of the winter rainfall area at Luderitz Bay, a dune strip which is approximately 320 km long and 120 km wide (see Figure 1).

The soil type is represented by high, red sand dunes with hard calcrete and/or quartz/granite dune streets between the dunes.

The unstable linear dunes provide little grazing for game. The most important grasses occurring here are Astenatherum glaucum, Stipagrostis gonatostachys and S lutescens. Stipagrostis sabulicola and Eragrostis spinosa, which occur generally, are utilized to a very limited extent, except in the dry season. Acanthosicyos horrida (Naras) is an important source of food for man and game. The other most important forage plants occurring here are Stipagrostis subacaulis and Trianthema hereroensis.

Stipagrostis ciliata vegetated dunes of the Southern Namib

In contrast to the vegetation map of Giess (1971) this subtype is here included under his Southern Namib vegetation type, the reason being that these dunes are semi-stabilized and covered by vegetation. Sand covered dune streets which carry perennial vegetation occur, as opposed to the typical vegetation dunes and dune streets of the Southern Namib.

These vegetated dunes occur on the southern side of the Middle Kuiseb canyon and south of the Gaub River, between the Kam- and Saag Mountains. The dunes do however stretch further south and can be regarded as a transition between the Pro-Namib (escarpment area) and the Southern Namib. The southern border of the Southern Namib vegetated dunes is at Aus.

Soil on the vegetated dunes consists of fine red quartz sand. They are overgrown and therefore much more stable than the Southern Namib dunes. The dune streets are covered with similar red sand, and at some places the gravel bottom is laid bare. The occurrence of inselbergs is very characteristic of this area. These mountains are usually meta-quartzites and micaceous schist hills.

This area provides the largest forage availability in the study area. The most important key forage plant is Stipagrostis ciliata, which covers the dunes as well as the dune streets. As a consequence of the relatively high rainfall of up to 100 mm, Stipagrostis ciliata can produce up to 6 tonne of fodder per hectare in this subtype. Where calcrete occurs near to the surface, S obtusa occurs generally. Acacia erioloba, Euclea pseudebenus and Parkinsonia africana occurs on or amongst the dunes. Other plants occurring on this subtype are Eragrostis spinosa and Stipagrostis uniplumis.

SEMI-DESERT AND SAVANNA TRANSITION

Escarpment and inselberg shrub and tree savanna

Although this vegetation type is included within the Central Namib type according to Giess (1971), it is more appropriately included in his Semi-desert and Savanna transition type. This type extends over the northeastern corner of the Namib-Naukluft Park. The undulating and mountainous veld of the upper course of the Kuiseb River is also included in this type, and all inselbergs occurring in the study area are situated within the boundaries of this subtype. The most important inselbergs are: Arachadamab, Tumasberg, Heinrichsberg, Amichab, Kamberg, Saagberg, Goagasberge, Bakenkop, Mirabib and Krummelkop (Figure 2 and general map).

Where soil is present, it includes very shallow micaceous, quartzose or granitic coarse topsoil on one of, or a mixture of the above-mentioned formations. Shallow sandy beds or intermontane plateaux are formed by the accumulation of eroded rock material. It is in these areas where most plants in the region occur.

The most important grasses occurring in the intermontane plateaux are: Stipagrostis hirtigluma, S ciliata, S obtusa, Eragrostis nindensis and Enneapogon brachystachyus. Triraphis ramosissima, Anthephora pubescens and Cenchris ciliaris can occur on the mountain slopes as single tufts.

Stipagrostis uniplumis can be found where there is also an accumulation of soil. Acacia erioloba, Euclea pseudebenus, Ziziphus mucronata, Acacia reficiens, Commiphora glaucescens, C saxicola and Maerua schinzii are the most important fodder trees in this subtype. A few other less important fodder plants occurring here are Monechma arenicola, Petalidium setosum, P variabile and Salsola spp.

This subtype is pre-eminently a zebra habitat. Kudu, oryx, springbok and ostriches also occur sporadically in this area. Baboons cause considerable damage to fodder trees during periods of drought when they debark the trees for want of alternative food.

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13. FORAGE AVAILABILITY AND UTILIZATION AND LARGE HERBIVORE DISTRIBUTION ON THE GRAVEL PLAINS

P S Nel, D P J Opperman and O B Kok, University of the Orange Free State

INTRODUCTION

The study area includes those sections on which the biggest percentage of the larger herbivores on the gravel plains occur. The western boundary is a line which stretches from the mountain range Langer Heinrich east of Vogelvederberg to Gobabeb. The northern and eastern boundaries are the borders of the Namib-Naukluft Park, while the southern boundary is the Kuiseb River. The study area includes the following water points: Zebra Pan, Ganab, Gemsbokwater, Hotsas, Groot Tinkas, Springbokwater and Soutwater.

The fluctuations in quality and availability of forage on the gravel plains and dunes over time were investigated, as well as the reasons for the fluctuations. Preference of the larger herbivores regarding areas and plant species and the percentage utilization of the various plant species by larger herbivores were studied.

FORAGE AVAILABILITY AND UTILIZATION

Rainfall

The rainfall was monitored by means of 100 rain meters distributed over the whole study area, and rainfall distribution maps were compiled. The total rainfall per season for the experimental period is indicated in Table 1.

Vegetation composition and cover

Twenty-five transects with a total of 41 500 point readings were made in all the vegetation subtypes. Cover surveys were also made in the protected production plots in subtypes and surrounding areas. The average percentage basal coverage decreased considerably over the experimental period (see Table 2).

Herbage production

Representative areas of the main grazing regions and vegetation types were fenced off in 10 m x 50 m exclosures. Nineteen exclosures were

Table 1. The average monthly rainfall for the study period November 1978 - December 1981.

Month	Average
November 1978	0,0
December 1978	0,46
January 1979	6,98
February 1979	23,22
March 1979	0,0
April 1979	2,45
May 1979	26,29
June 1979	0,0
February 1980	12,50
March 1980	7,40
August 1980	7,10
October 1980	2,80
December 1980	0,80
January - December 1981	0,00

Table 2. Average percentage basal cover within a 10 km radius of different water points on the gravel plains, July 1978, 1979, 1980 and 1981.

Water point	1978	1979	1980	1981
Ganab	2,87	2,72	1,29	0,51
Hotsas	1,98	1,76	0,90	0,98
Gemsbokwater	3,85	3,35	2,01	0,80
Groot Tinkas	2,80	1,57	1,07	0,30
Zebra Pan	1,10	0,77	0,41	0,26
Springbokwater	1,57	0,57	1,11	0,74
Soutwater	1,28	0,23	0,14	0,20

constructed (see Table 3). The clipping technique applied is similar to that described by Grunow and Bosch (1978). Tuft production proved to be ineffective and only the quadratic technique was used.

Table 3. Distribution of exclosures in different vegetation types.

Vegetation type	Exclosure
Stipagrostis hochstetterana grassland	A
Eragrostis nindensis eastern grassland	G, J, K, H, O
Stipagrostis uniplumis drainage line grassland	L, B, R
Stipagrostis obtusa grassland	C, D
Shrub and tree savanna of the escarpment and inselbergs	S, R
Commiphora saxicola brokenveld	E, I
Petalidium canescens shrubland of the Kuiseb canyon	I
Salsola sp desertic dwarf shrubland	K, Q
Stipagrostis ciliata duneveld of the Southern Namib	M, N

Fodder production determinations were made five times during the season. The amount of forage available for the Pro-Namib gravel plains (plot A) for the experimental period is presented as an example in Figure 1.

A total rainfall of 94 mm in two showers of 60 mm in February 1979 and 34 mm in May 1979 resulted in total phytomass yield of 1 400 kg ha^{-1}. During the very dry period with less than 15 mm rainfall in 1980/81 the production within the exclosures dropped to below 200 kg ha^{-1} with a yield of only 107 kg ha^{-1} outside of the exclosures. Rainfall of less than 15 mm had very little or no influence on fodder production in this area. The amount of forage available in the study area from 1979 to 1981 is presented in Table 4.

The subtypes represented by enclosures M and N in the Southern Namib vegetated dunes and plot L in a drainage line produced the highest fodder yield, ie 5191 kg ha^{-1}, 2854 kg ha^{-1} and 1347 kg ha^{-1} respectively. The fodder yield on the other subtypes varied from 1347 kg ha^{-1} and 89 kg ha^{-1} for plots A and B (Namib gravel plain drainage lines) and 54,3 kg ha^{-1} for plot E (brokenveld) respectively.

Table 4 indicates that a total collapse of forage availability took place from 1981 to 1982. This applies particularly to the grass component. Shrubs and herbage do not indicate this drastic decline in forage availability, and they serve as forage reserves in periods of drought.

Table 4. Forage availability (in kg ha^{-1}) in and around the different exclosures during the period 1979 to 1981.

Exclo-sure	Grasses			Shrubs and herbs			Non-forage species			Total phytomass inside exclosure			Total phytomass outside exclosure		
	1979	1980	1981	1979	1980	1981	1979	1980	1981	1979	1980	1981	1979	1980	1981
A	669,5	292,0	36,7	27,5	22,5	31,5	355,5	257,7	202,0	1052,5	570,2	270,2	868,0	367,5	180,0
G	182,0	76,0	20,8	73,5	56,0	40,0	16,0	-	-	271,0	137,0	60,8	78,0	58,0	13,0
J	218,0	8,2	9,8	-	-	-	-	-	-	218,0	8,2	9,8	28,0	10,0	4,0
K	224,7	53,0	9,0	-	-	-	-	-	-	224,7	53,0	9,0	86,0	18,0	3,0
H	293,0	27,0	11,0	-	-	-	-	-	-	293,0	27,0	11,0	67,0	11,0	3,0
Q	773,0	359,0	130,0	326,0	212,0	89,0	71,0	33,0	6,0	1170,0	604,0	225,0	517,0	437,0	163;0
L	1347,0	632,0	399,0	-	-	-	126,0	6,0	0,0	1473,0	638,0	399,0	574,0	415,0	199,0
B	89,0	23,0	2,5	56,6	23,0	-	158,6	94,0	16,5	303,6	140,0	19,0	148,0	37,5	21,0
C	206,0	41,3	5,3	40,5	20,3	41,5	80,3	43,8	17,5	326,8	105,4	64,3	53,0	35,0	26,0
D	286,0	50,8	11,0	-	-	-	-	-	-	286,0	50,8	11,0	79,0	30,5	3,5
S	282,0	94,0	10,0	0,0	3,0	0,0	0,0	0,0	3,0	282,0	97,0	13,0	78,0	49,0	2,0
R	435,0	179,0	72,0	0,0	14,0	2,0	-	-	-	435,0	193,0	74,0	42,0	13,0	8,0
E	54,3	6,8	3,3	-	-	-	-	-	-	54,3	6,8	3,3	15,0	5,0	3,5
Q	136,0	14,0	8,0	-	-	-	-	-	-	136,0	14,0	8,0	17,0	3,0	3,0
M	5191,0	3938,0	2524,0	-	-	-	-	-	-	5191,0	3938,0	2524,0	3896,0	3287,0	1827,0
N	2854,0	1876,0	1317,0	-	-	-	-	-	-	2854,0	1876,0	1317,0	2052,0	1740,0	1110,00

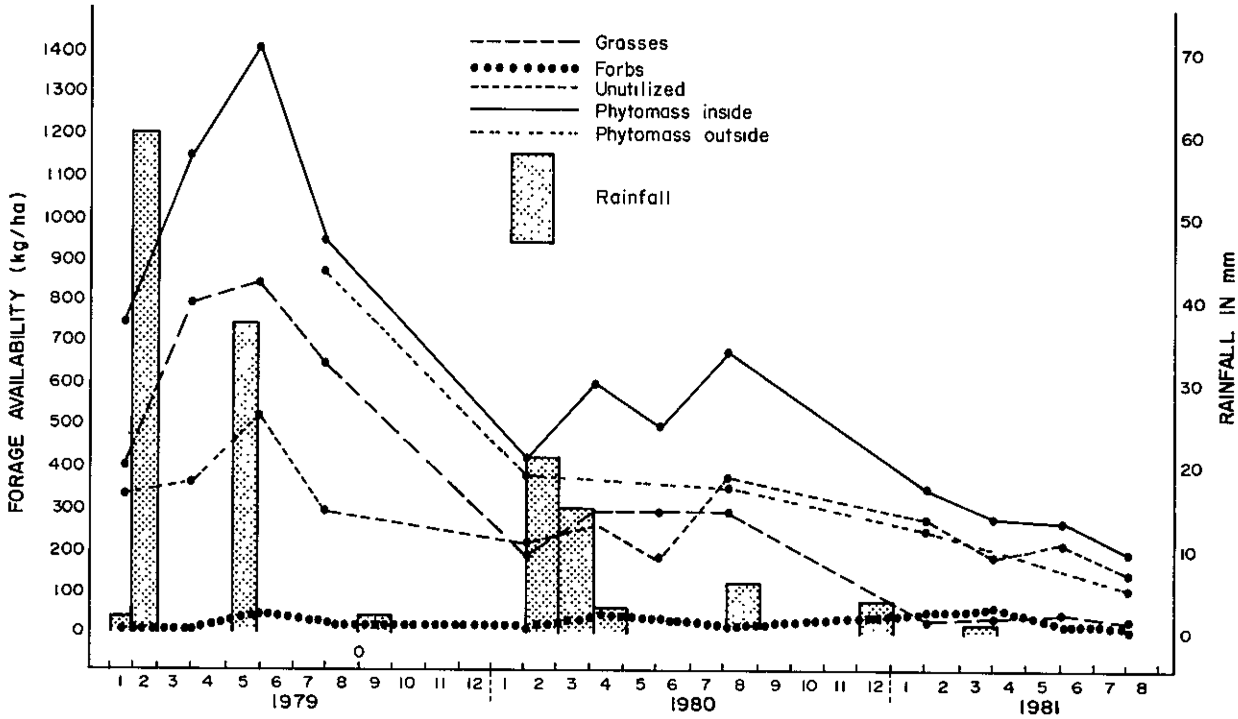

Figure 1. Forage availability in kg ha^{-1} for exclosure A for the period January 1979 to July 1981.

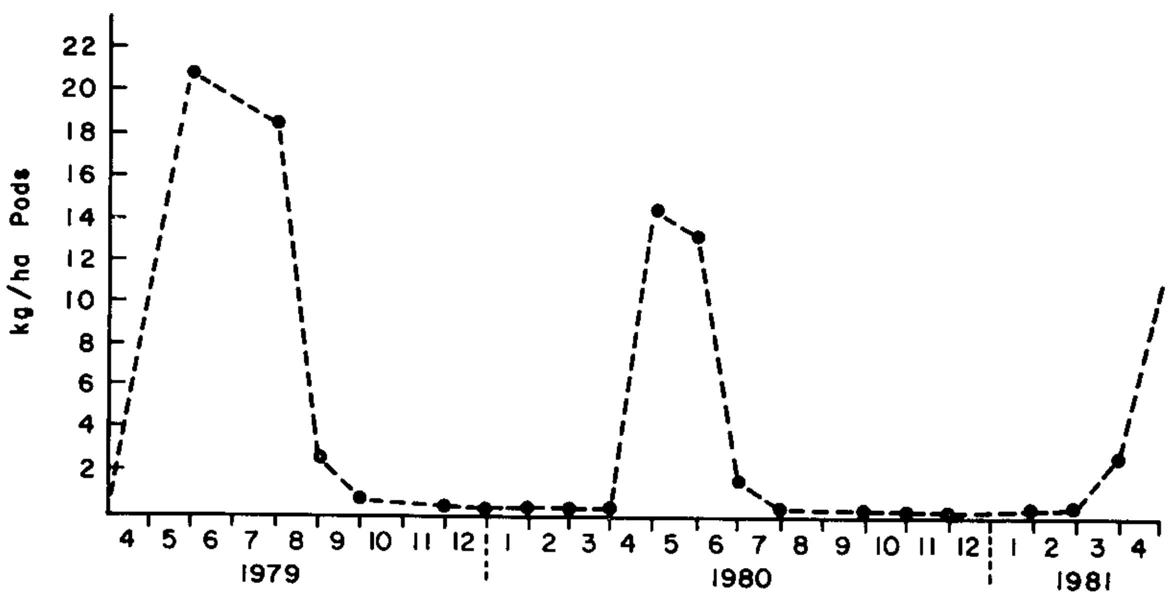

Figure 2. Pod availability, in kg ha^{-1}, of *Acacia erioloba* for the period March 1979 to July 1981.

Phytomass within plots is generally higher than phytomass outside plots. This can be ascribed to heavy utilization by game. Decline in phytomass within plots is caused by termite damage and wind erosion.

Leaf, shoot and pod availability of Acacia erioloba

There was a moderately constant shoot and leaf availability (0,13 kg ha^{-1}) during 1979/80 and a decline thereafter, ie 0,09 kg ha^{-1} in 1981. Pod availability data presented in Figure 2 show that a peak was reached during April/May of each year, which coincided with the prevailing east winds, which then started blowing strongly, as well as the ripening of the pods. A gradual decrease in pod availability occurred during the study period. It would appear as if trees go through a period of higher pod production, and then a resting period. Adjacent trees which originally produced very few pods, later produced maximally. Peak pod production decreased from 21 kg ha^{-1} during 1979 to 9 kg ha^{-1} during 1981.

Utilization and preference studies

The greatest concentration of herbivores occurred around the following water points in the study area: Zebra Pan, Ganab, Gemsbokwater, Hotsas, Groot Tinkas, Springbokwater, Soutwater and other isolated areas. The utilization study therefore was undertaken around these concentration points, even though with the decrease in forage availability the game only made use of Gemsbokwater, Ganab, the Gaub fountains and water points in the upper course of the Kuiseb River.

Utilization and plant preference surveys were done according to the method of Kruger and Edwards (1972), as modified by Grunow (1979 personal comm).

Point readings were noted every 50 m and the nearest plant to each key plant was identified and recorded within utilization classes. The percentage relative utilization of the vegetation in 2 km zones around each water point was calculated, as illustrated in Figure 3.

The relative utilization in the 1-2 km zone from the water point increased from 72 percent to 90 percent, while the whole area was utilized more than 90 percent during July 1981. This tendency was the same throughout for the whole study area.

The results further show the interesting tendency that certain zones, namely 1-2 km and 7-8 km from the water points initially were utilized most severely. The distribution pattern of the animals has also changed and zebras had moved onto the plains, whereas they were confined previously to the mountainous and surrounding areas. The January 1981 survey showed that at most water points, eg Zebra Pan, Soutwater and Hotsas the veld was utilized more than 90 percent. Termites and wind however played an important role in the total defoliation of the veld. Key forage plants occurring here are Stipagrostis ciliata, S obtusa, S uniplumis, Monechma arenicola and Petalidium setosum.

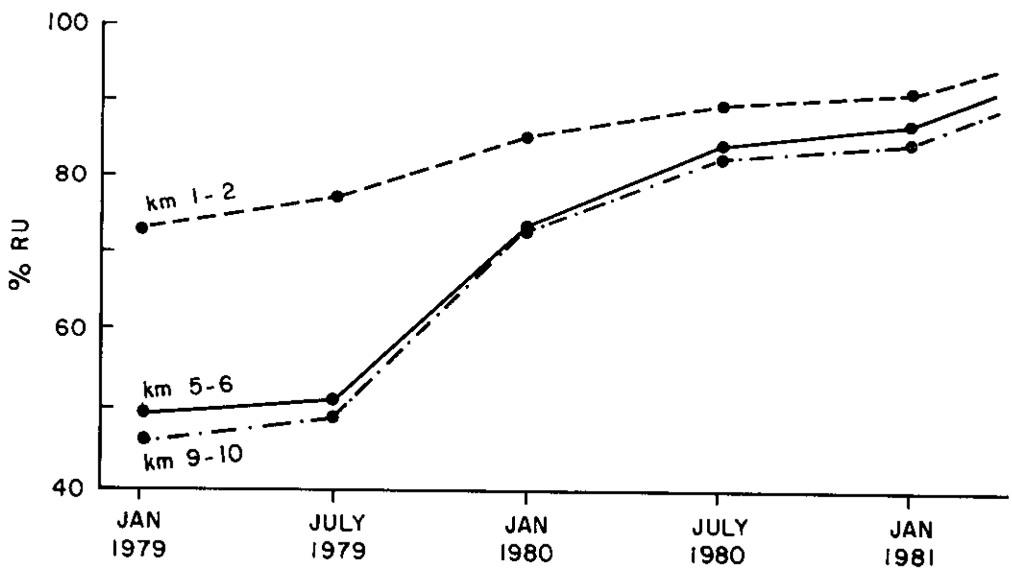

Figure 3. Percentage relative utilization of vegetation at different distances from the Hotsas waterpoint.

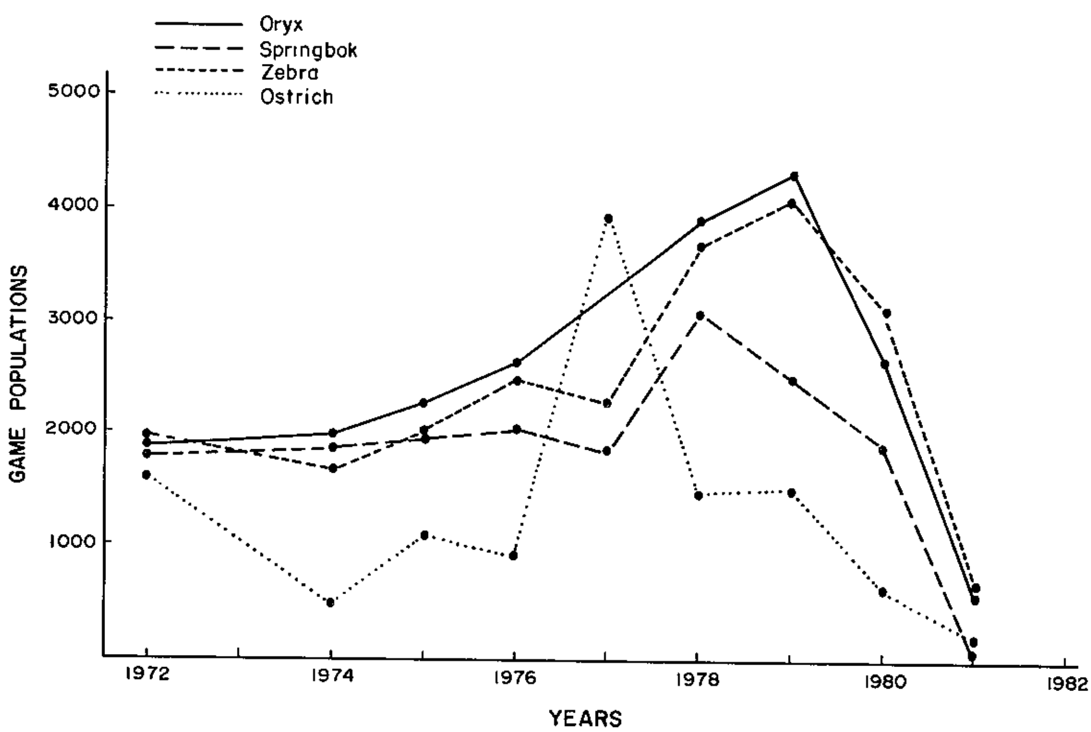

Figure 4. Large herbivore population estimates, Namib Naukluft Park, 1972 to 1981.

Chemical composition of forage

Samples of the key forage species were analysed chemically for percentage crude protein content and percentage digestible organic water. The nutritional value of the grass species Stipagrostis ciliata, S uniplumis and S obtusa declined considerably from the summer (percentage CP ± 8-14 percent, percentage DOM 60 percent) after the dry season and crude protein values of as low as 3 percent and percentage DOM values of only 30 percent were obtained.

Large herbivore population distribution and migration

Population estimates of the larger herbivores for the period 1972 to 1981 are presented in Table 5. The average increase of game from 1972 to 1979 was 48 percent. From 1979 to 1982 the average decline was 90 percent. Game populations from 1972-1981 are graphically presented in Figure 4. The seasonal migration of game is west to east and back. As soon as rain occurs on the gravel plains, there is a movement to the west and the game disperse over the gravel plains. The eastern park border fence line prevents the eastern migration route to be completed, which results in a local overpopulation of game. Destruction of vegetation, soil loss as a result of trampling and wind erosion, and game loss as a result of mortalities or movement of game out of the park then occur. Table 6 presents an estimate of maximum and minimum carrying capacities of different vegetation types within the Namib-Naukluft Park, while in Table 7 the estimated maximum and minimum stocking rates in numbers of animals for large herbivores is indicated.

Table 5. Estimated populations of large herbivores in the Namib-Naukluft Park during the period 1972 to 1981.

Date	Oryx	Springbok	Zebra	Ostrich	Total	Total as large stock units
June 1972	1 851	1 796	1 958	1 602	7 207	3 717
March 1974	1 945	1 848	1 620	486	5 899	3 062
July 1974	2 115	1 493	2 123	1 726	7 457	4 004
May 1975	2 274	1 888	1 976	1 115	7 253	3 799
January 1976	2 454	2 024	2 485	944	7 907	4 363
November 1976	2 403	1 733	2 312	3 926	10 377	5 110
December 1978	3 940	3 088	3 717	1 452	12 197	6 686
October 1979	4 375	2 552	4 079	1 560	12 566	7 212
October 1980	2 662	1 912	3 322	665	8 561	5 192
June 1981	591	86	666	199	1 542	1 039
% increase, 1972 to 1979	53	30	52	x 59 (1976)		
% decrease, 1979 to 1981	85	96	84	95		

(1) One large stock unit equals 1 Hartmann's zebra, 2 oryx, 3 ostrich, or 6 springbok.

Table 6. The estimated maximum and minimum carrying capacities, in large stock units, of different vegetation types within the Namib-Naukluft Park.

Vegetation type	Area, ha	Max grazing capacity, LSV	Min grazing capacity LSV
Stipagrostis hochstetterana grassland	11100	120	74
Eragrostis nindensis eastern grassland	230300	507	144
Stipagrostis obtusa grassland	15500	44	16
Shrub and tree savanna of the escarpment	120500	279	73
Commiphora saxicola brokenveld	93400	66	31
Petalidium canescens shrubland of the Kuiseb canyon	94500	216	48
Salsola sp desertic dwarf shrubland	40200	82	26
Stipagrostis ciliata duneveld of the Southern Namib	53900	1552	1107

Table 7. The estimated maximum and minimum stocking rates in numbers of animals and in large stock units, for different large herbivores in the Namib-Naukluft Park.

	Maximum		Minimum	
	Number	LSV+	Number	LSV
Oryx	2700	1350	1800	900
Springbok	2000	333	1500	250
Zebra	1000	1000	600	600
Ostrich	2100	700	750	250

LSV+ follows the definition of Meissner (1982).

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AUTHORS' ADDRESSES

Mr L W R Blom
Department of Water Affairs
Private Bag X13193
WINDHOEK
9000

Mrs P M Bouwer
Department of Water Affairs
Private Bag X13193
WINDHOEK
9000

Mr A Hattle
Department of Water Affairs
Private Bag X13193
WINDHOEK
9000

Mr B J Huntley
Manager: Ecosystem Programmes
Foundation for Research Development
CSIR
P O Box 395
PRETORIA
0001

Dr W J Jankowitz
Department of Agriculture and
Nature Conservation
Private Bag X13306
WINDHOEK
9000

Dr O B Kok
Department of Zoology
University of the Orange Free State
P O Box 339
BLOEMFONTEIN
9300

Mr P S Nel
Department of Agriculture and
Nature Conservation
Private Bag X13306
WINDHOEK
9000

Professor D P J Opperman
Department of Pasture Science
University of the Orange Free
State
P O Box 339
BLOEMFONTEIN
9300

Professor D A Scogings
Department of Surveying and
Mapping
University of Natal
King George V Avenue
DURBAN
4000

Professor G K Theron
Department of Botany
University of Pretoria
Brooklyn
PRETORIA
0181

Mrs M W van Rooyen
Department of Botany
University of Pretoria
Brooklyn
PRETORIA
0181

Mr N van Rooyen
Department of Botany
University of Pretoria
Brooklyn
PRETORIA
0181

Mr A J van Wyk
Department of Pasture Science
University of the Orange Free
State
P O Box 339
BLOEMFONTEIN
9300

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