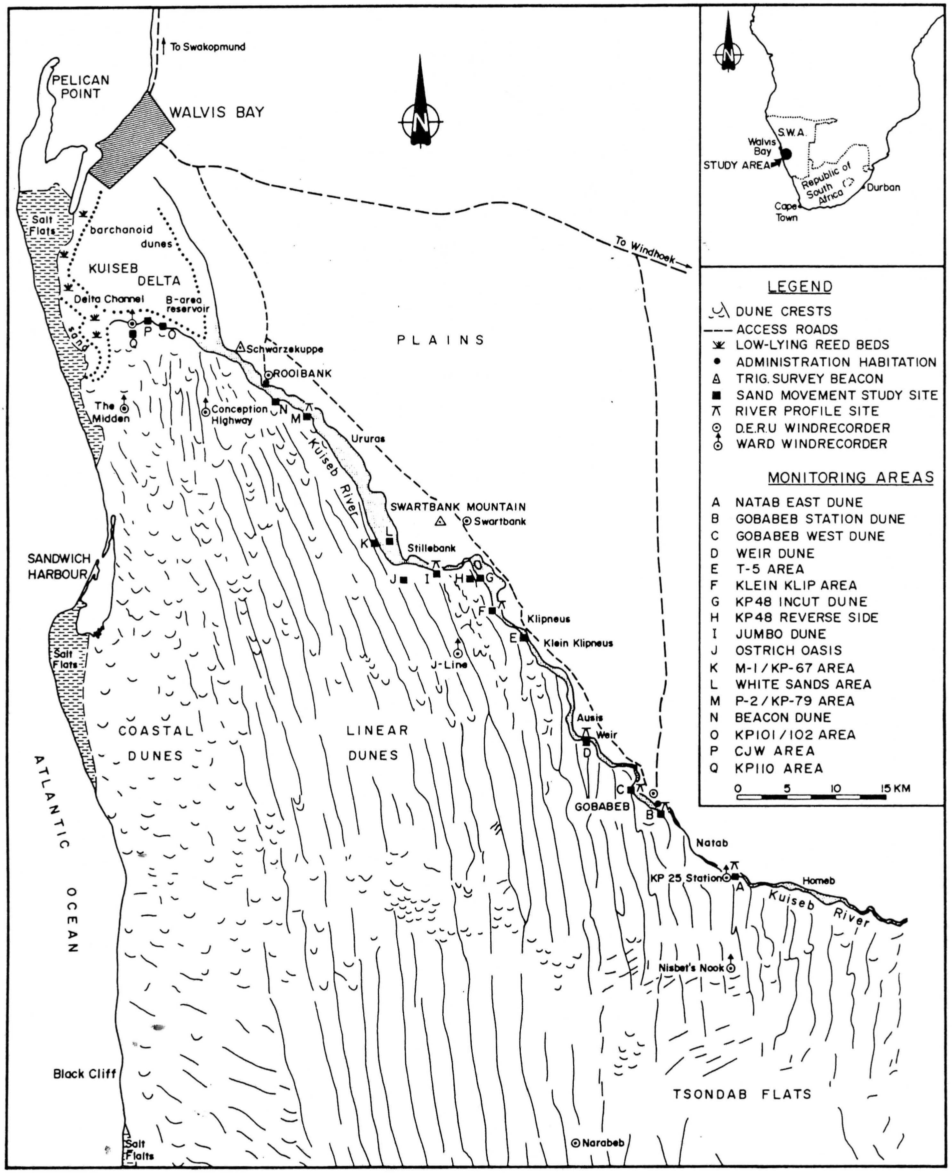

Figure 1. Study area for the sand dynamics monitoring programme in the Natab-Delta sector of the Lower Kuiseb River. The localities of the dune movement monitoring areas, river profile sites, and windrecorders are shown.

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6. SAND DYNAMICS ALONG THE LOWER KUISEB RIVER

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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

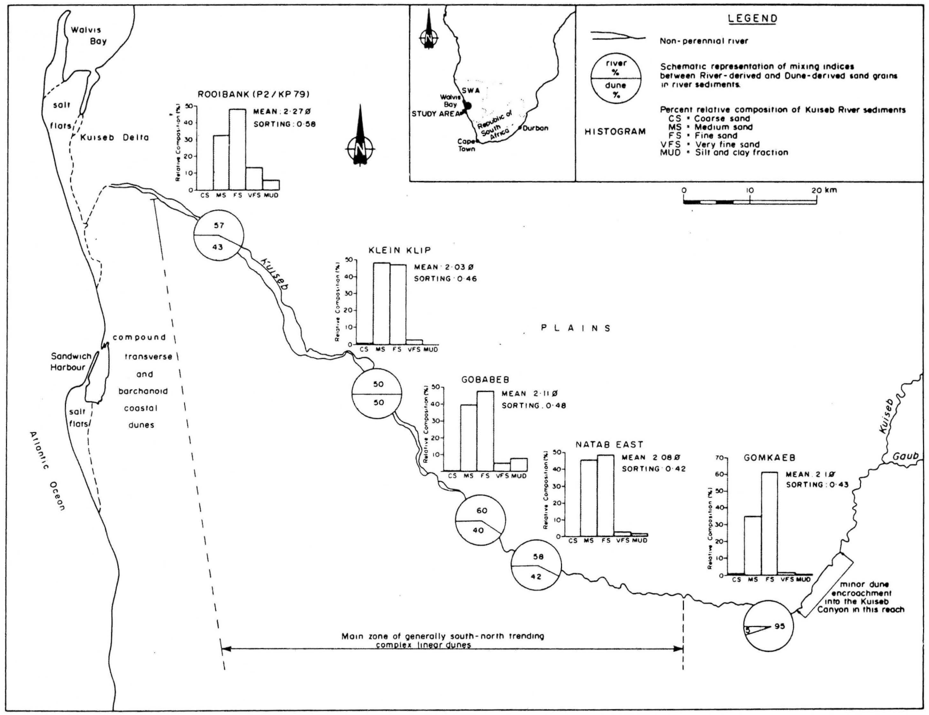

Figure 2. Estimation of the mixing between river- and dune-derived sand grains in the bedload of the Lower Kuiseb River between Gomkaeb and Rooibank. Relative composition, mean grain size, and sorting of the mixed river bedload sediment are also displayed.

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).

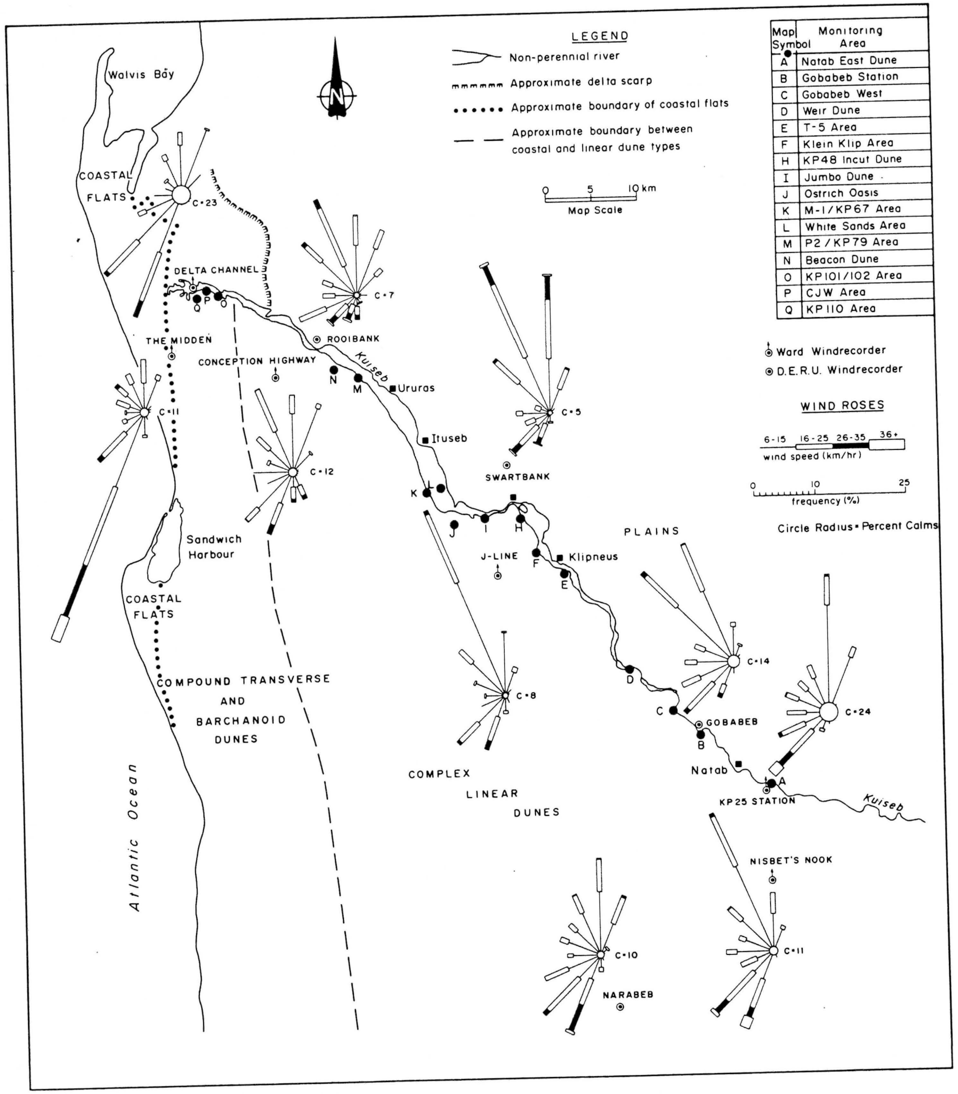

Figure 3. Regional surface airflow at ten stations in the Central Namib Desert, January (summer) 1981.

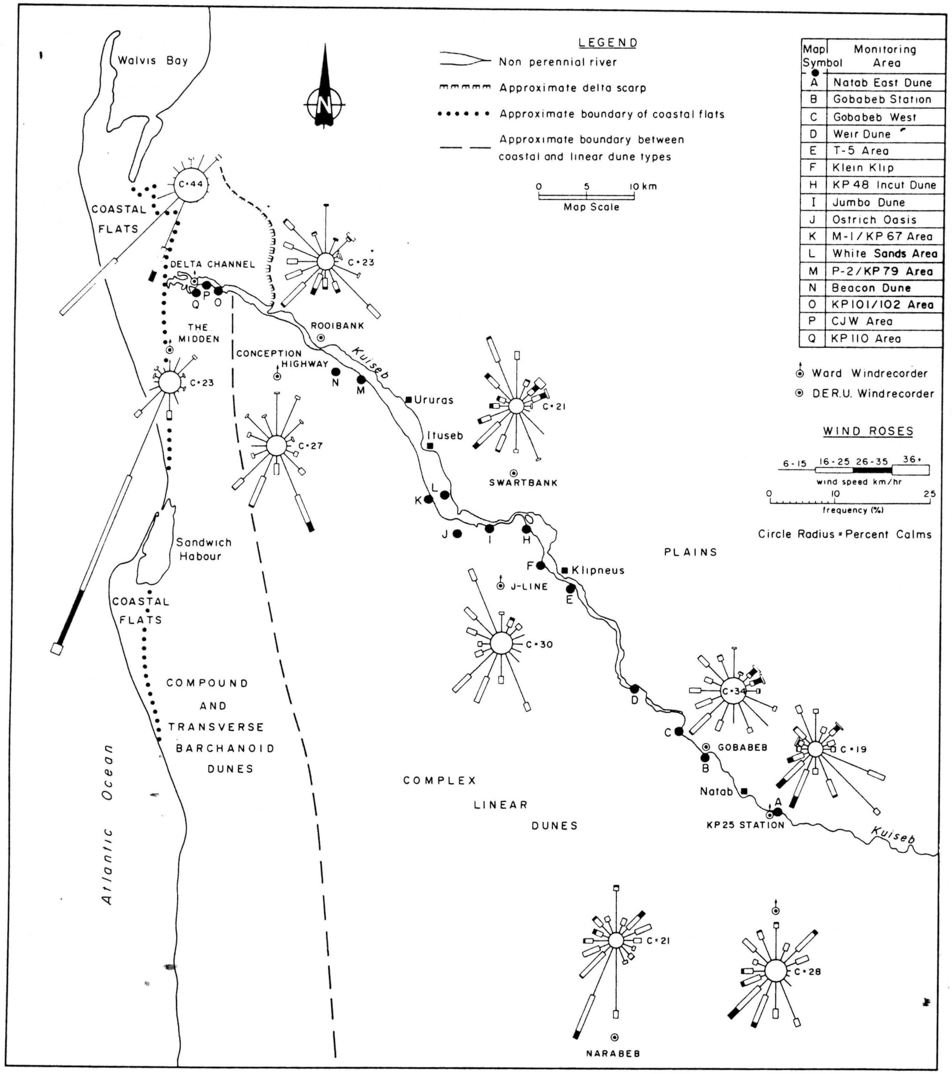

Figure 4. Regional surface airflow at ten stations in the Central Namib Desert, April 1981.

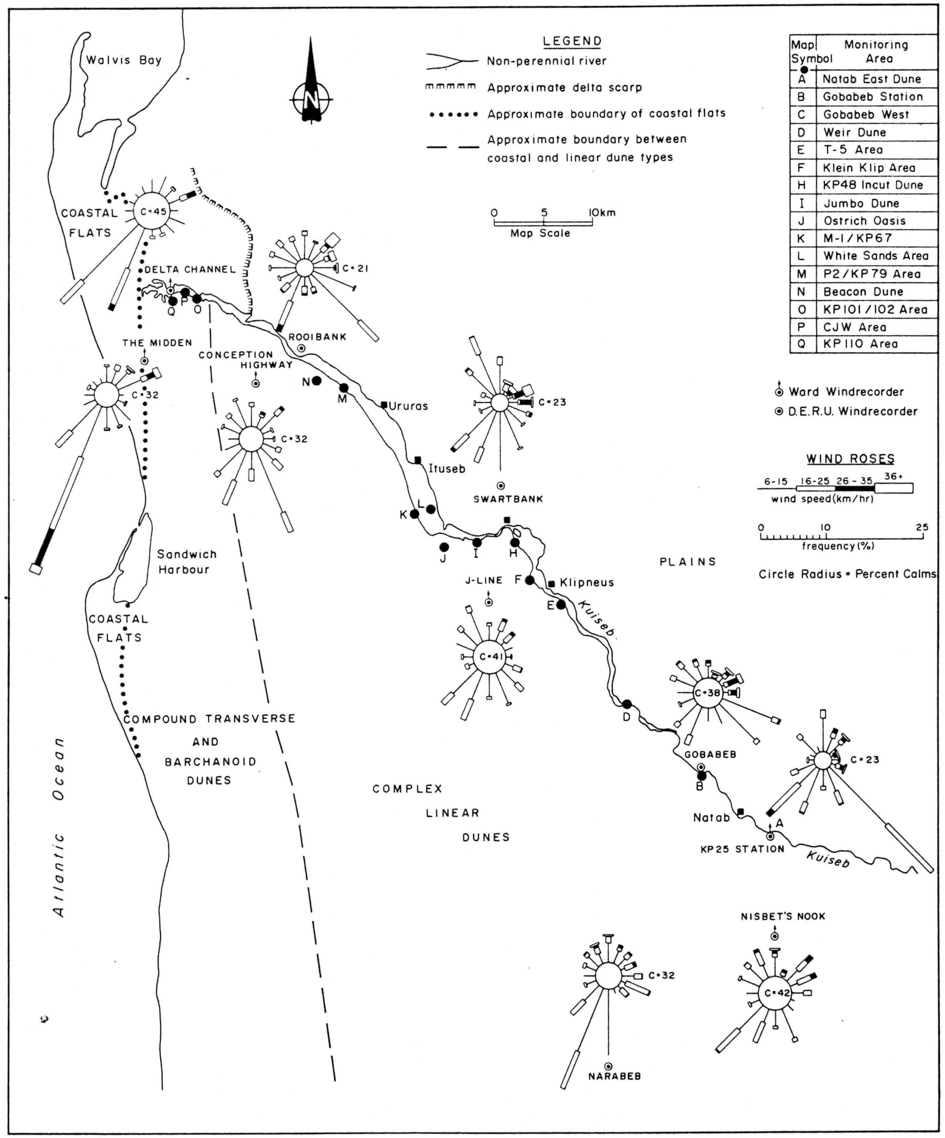

Figure 5. Regional surface airflow at ten stations in the Central Namib Desert, July (winter) 1981.

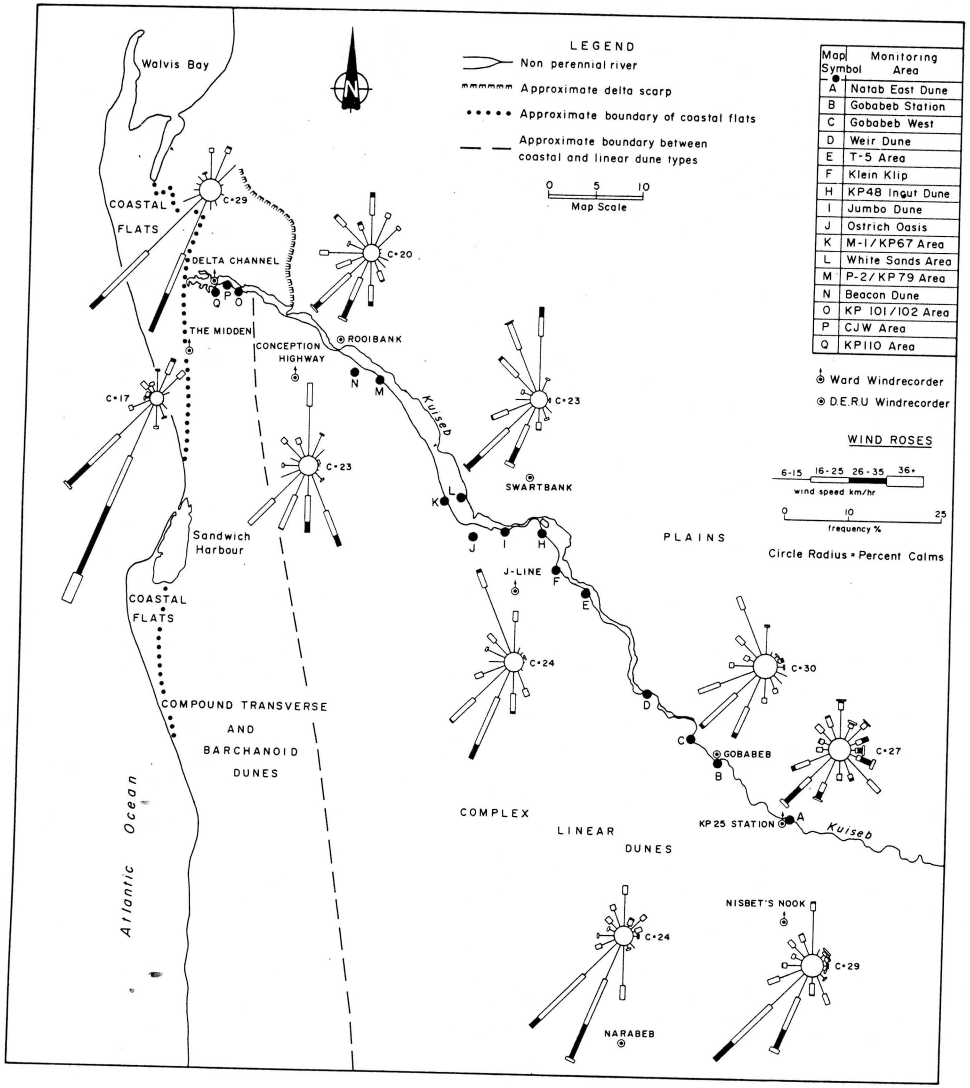

Figure 6. Regional surface airflow at ten stations in the Central Namib Desert, October 1981.

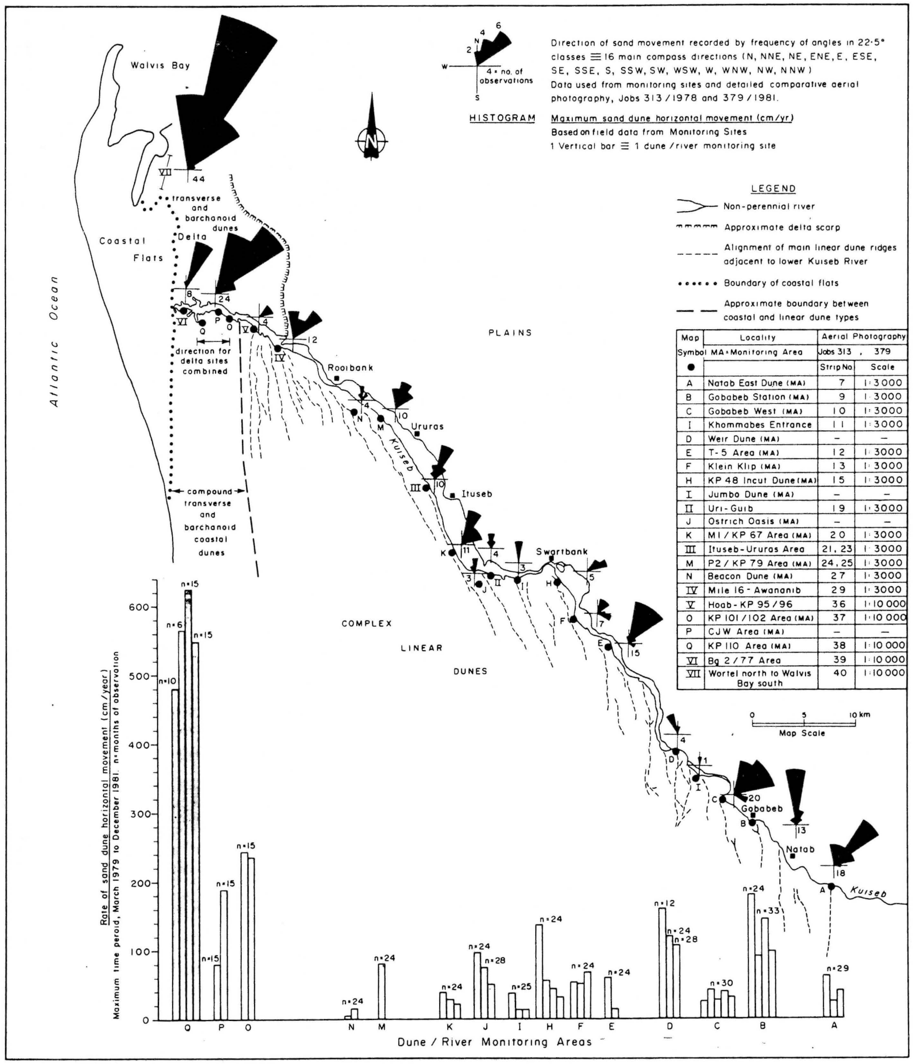

Figure 7. Estimated rates and direction of sand dune movement along the Lower Kuiseb River in the Natab-Delta sector, 1978-1981.

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

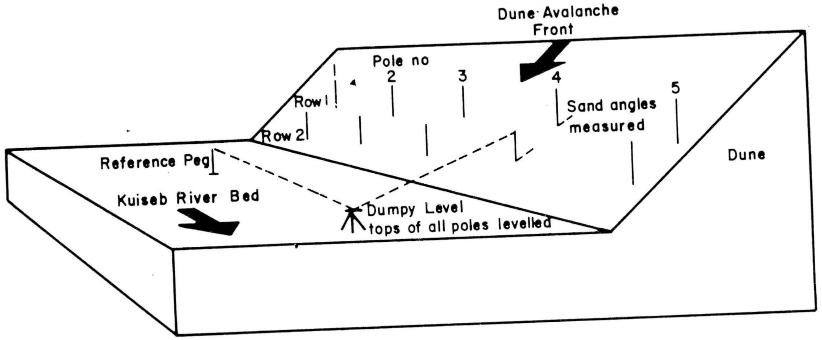

Figure 8. Schematic layout of a grid network of stakes to measure dune movement adjacent to the Lower Kuiseb River

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.

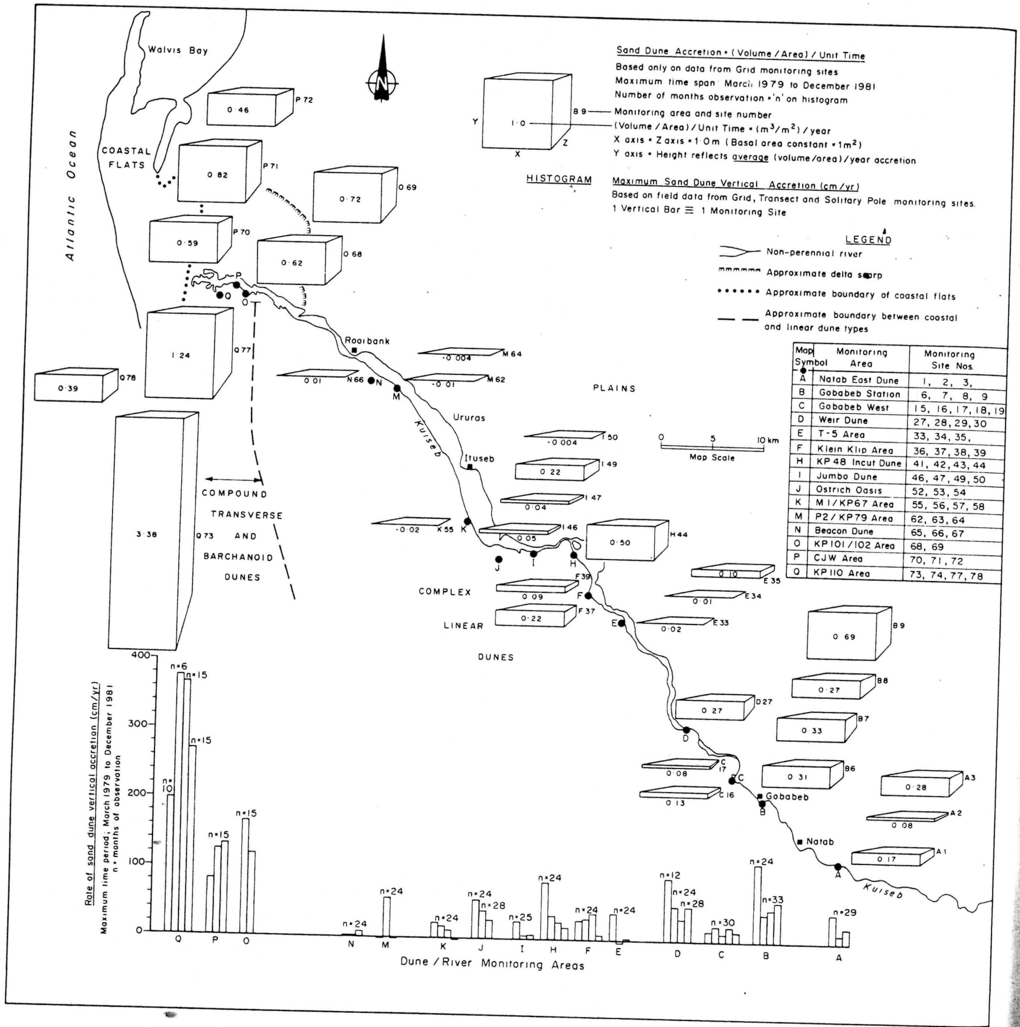

Figure 9. Rates of sand dune accretion (vertical and volume/unit area) along the Lower Kuiseb River in the Natab-Delta sector, 1979-1981.

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.

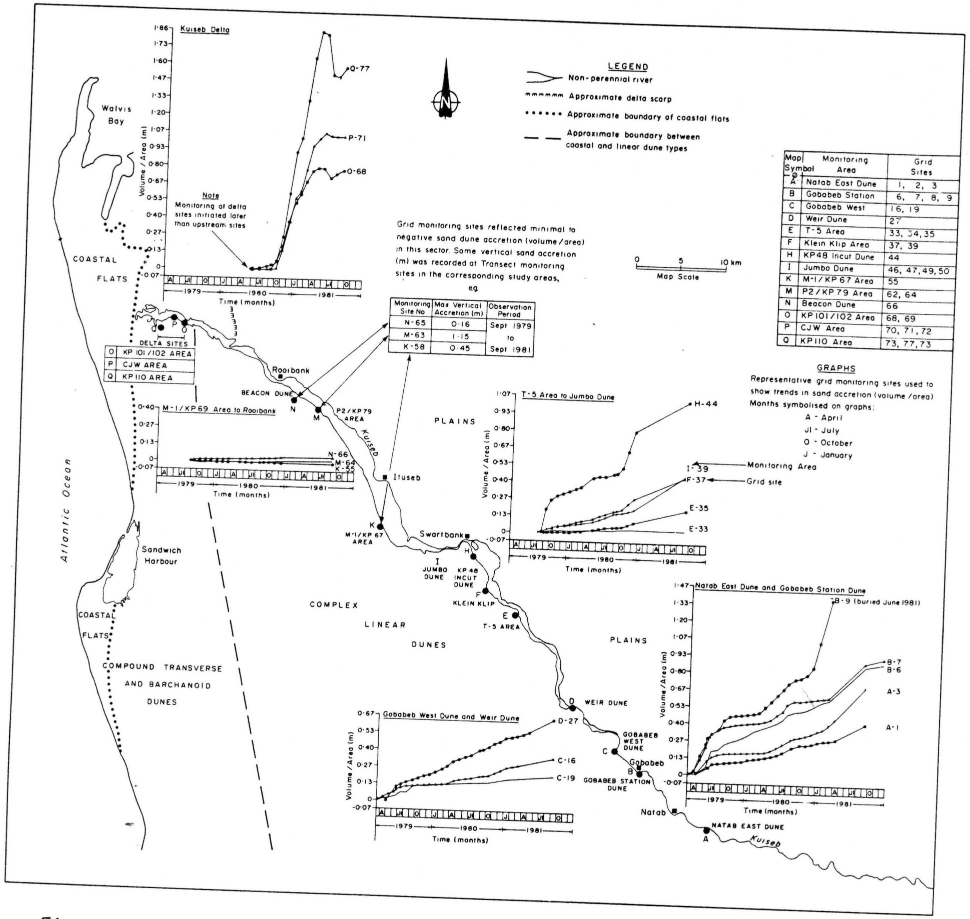

Figure 10. Trends in sand dune accretion (volume/unit area) along the Lower Kuiseb River in the Natab-Delta sector, 1979-1981.

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.

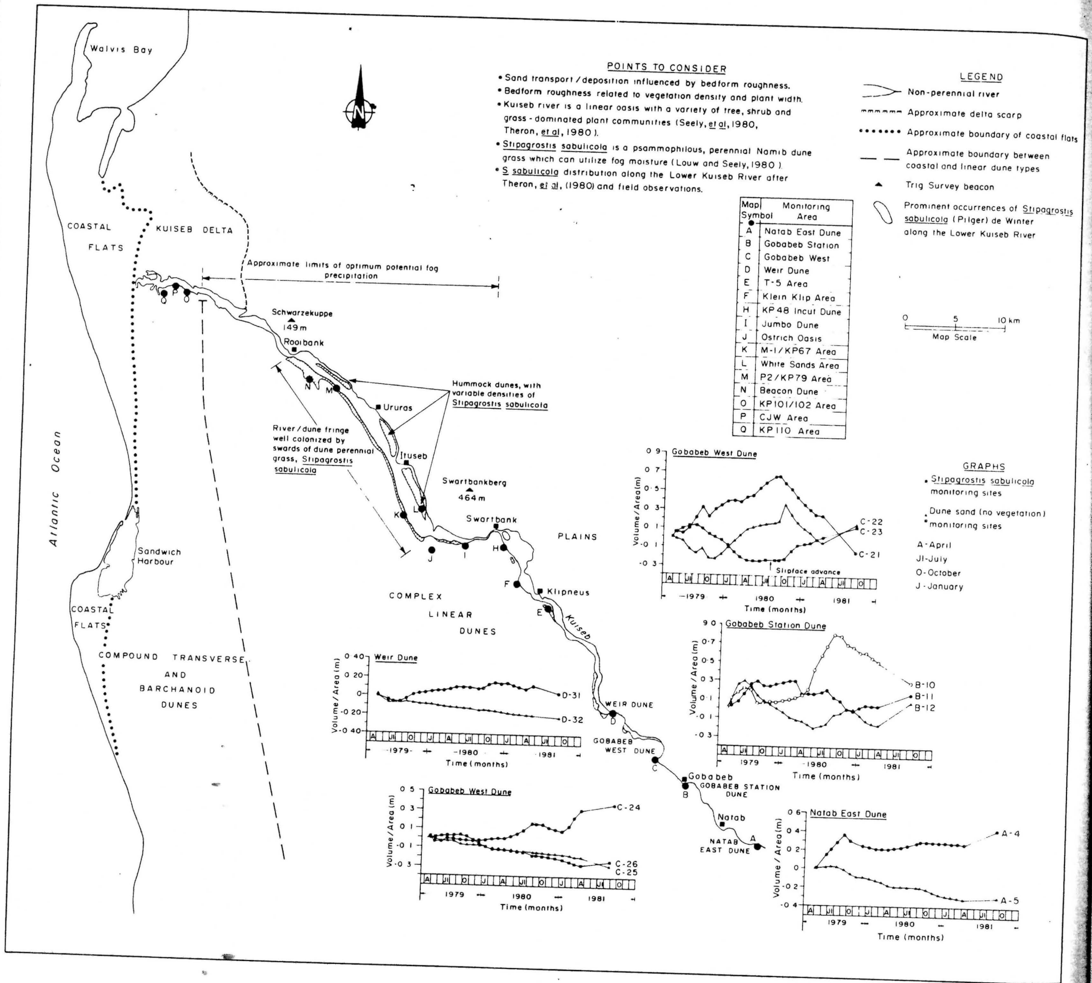

Figure 11. Trends in dune sand accretion associated with the perennial grass, Stipagrostis sabulicola, in the Natab-Rooibank sector of the Lower Kuiseb River. The distribution of extensive patches of S sabulicola along the Lower Kuiseb River is shown, as is the approximate limits of optimum fog precipitation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

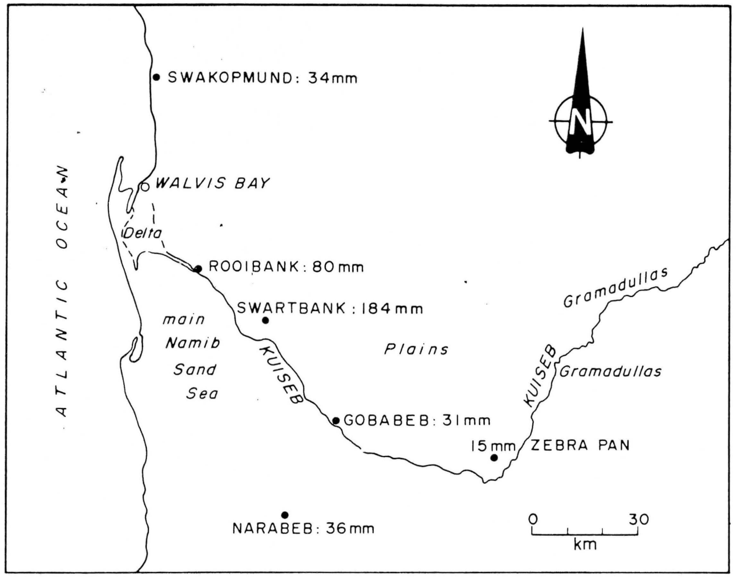

Figure 12. Mean annual fog precipitation at some DERU weather stations in the Central Namib Desert. (DERU meteorological data, unpublished, December 1982).

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

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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).