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D. H. Swart

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ABSTRACT

All available literature pertaining to the physical processes operative at the Sondags River Mouth is reviewed. Best estimates are obtained for fluvial, wind-blown and wave-driven longshore transport rates which lead to a sediment budget for the area.

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1. BACKGROUND

The Sondags estuary enters the sea 50 km east of Port Elizabeth in Algoa Bay, which faces the Indian Ocean on the South African east coast (see Figures 1). The area is renowned for its scenic beauty as the Sondags is wedged between two impressive dune fields, the Schelmhoek dune field to the west and the Alexandria dune field to the east, the latter being the largest coastal dune field in southern Africa.

Most of the research in the Sondags estuary is carried out by the University of Port Elizabeth, (co-ordinated by its Institute for Coastal Research). Until recently attention was devoted largely to biotic factors, whilst the physical environment was hardly studied. Notable exceptions were studies on sedimentation in the Sondags estuary by Reddering and Esterhuysen (1981) and on the hydrology/hydraulics of the Sondags, by Perry (1983).

Considerable attention has been given to the beaches and inshore zone in the vicinity of the Sondags estuary. The occurrence and extent of surf phytoplankton blooms in this area rate amongst the highest on the southern African coastline. For more than ten years the departments of Zoology and Botany at the University have been studying the beach fauna and flora in the area. For the last three years attention has been directed more at the nearshore zone. The biological work of the University of Port Elizabeth was complemented by research on the physical nearshore environment, carried out by the National Research Institute for Oceanology of the CSIR (Swart, 1984). Extensive measurements of surf zone dynamics were done during two separate field exercises during 1983/1984.

Biological processes are really responses to changes in the physical environment, which in the case of the Sondags is governed to a large extent by the sand balance between the dunes, the estuary and the coastal region. This paper, therefore, represents a first attempt at quantifying the sediment budget and pathways of the Sondags mouth region.

2. SITE DESCRIPTION

2.1 Sondags Catchment

The Sondags, which originates north of Graaff Reinet, has a fairly large catchment. Perry (1983) quotes 20 990 km^2 and Reddering (1981) 20 719 km^2. Major dams in the catchment are the Van Ryneveldspas Dam, capacity 53 × 10^6 m^3, and Lake Mentz, capacity 206 × 10^6 m^3 (Reddering and Esterhuysen, 1981). According to Reddering the geological substrate of the basin consists largely of shaly material. Downstream of the Mentz Dam the Cape Fold Belt consists of shales and sandstones which weather readily to yield a clay-rich sediment load with a subordinate sand fraction. Data compiled by Rooseboom and quoted by Middleton et al. (1981) show that the average estimated sediment yield from the whole catchment is about 16 × 10^6 tonnes per year, or about 9 × 10^6 m^3/yr. The corresponding figure for the area downstream of the dams in the catchment is 1,2 × 10^6 m^3 /yr. It is uncertain what percentage of this load consists of sand. However, the data contained in Reddering and Esterhuysen (1981) show an extensive distribution of mud in the lower estuary. The data appear to indicate that the concentration of fines (less than 50 µm) in the sediment yield from the drainage basin could be substantially higher than 70 per cent. This is in line with experience in other eastern Cape estuaries. For these reasons the percentage of fines in the Gouritz river was estimated to fall between 88 and 95 per cent (Martin; Van Heerden, CSIR, pers. comm.).

The average rainfall over the catchment is low (323 mm/yr according to Reddering and Esterhuysen (1981) and 334 mm/yr according to Perry (1983), and erratic.

2.2 Sondags Estuary

Chapman (unpublished note), as quoted in Perry (1983), gave a good summary of the evolution of the Sondags over geological times. The main points from his summary are the following:

- The Quaternary features are emplaced within an environment provided by the dissection of a terrace which appears to be of marine origin.

- The terrace strongly resembles uplifted marine abrasion terraces seen elsewhere in the world in fine sandy sediments of Tertiary or Cretaceous age.

- The terrace slopes from about MSL + 150 m at its landward extremity to about MSL + 80 m at its termination about 11 to 13 km from the present shoreline. Its width is about 3,4 km.

- Repeated down-cutting of the terrace by the Sondags and its tributaries occurred during the Pleistocene and Holocene. At present this incised course forms a broad flood plain filled with predominantly fluvial sediments of various ages.

- The curious dogleg pattern of the lower Sondags estuarine channel is the result of the lower reach being constrained by an active dune field.

- The mouth of the Sondags was most probably deflected eastwards at the beginning of the present stillstand, that is, when sea level first approached its present level about 6 000 years ago.

- Geomorphological features indicate that the dominant wind and longshore drift directions have been from west to east which since that late Holocene sea-level stillstand has ensured that the channel of the Sondags has remained firmly positioned against the incised marine terrace of the east bank.

The Sondags is tidal for 21 km from the mouth, with its upstream limit variable. The river channel is incised for most of its reach. Over its lower 12 to 15 km the channel displays a classic funnel shape.

According to Perry (1983) the channel area has remained almost constant over the time period 1939 to 1976, namely between 300 and 314 ha. Perry showed by measurements from aerial photographs covering this period, which had been carefully corrected for distortion by comparison with the 1 to 10 000 orthophotos for the area, that

- the sinuosity over the estuarine reach varied between 1,38 and 1,42;

- the average river width over the estuarine reach varied between 53 m and 82 m, although the average width over the lower 2 km of the estuary varied between 82 and 227 m;

- the estuarine area showed an average lateral displacement over the period of 29 m, which was related mainly to shifting tidal shoals near the mouth;

- judged overall, the Sondags estuary had been fairly stable for the period under review.

She also identified the following human influences, which are considered to have had little effect on the estuary:

- Some **cultivation** to the channel edge, the **road and rail bridges** with embankments at the head of the reach.

- The **national road and freeway** with their embankments across the flood plain, 8,5 and 7,8 km from the mouth, respectively.

- **Jetties** on the left bank about 3 to 7 km from the mouth, which create minor channel constriction but which aid side-bar formation.

- **Dams** in the catchment, namely, Mentz (1922) and Van Ryneveldspas (1924), which catch most of that portion of the sediment yield from the catchment which originates from upstream of the dams (Annandale, 1980).

Reddering and Esterhuysen (1981) concluded on the basis of grain size analyses of samples over the upper 50 cm of the bed over the whole estuarine reach that

- the mud and sediment distributions patterns observed in the estuary exhibit a trend common to eastern Cape estuaries;

- sand becomes finer-grained from the inlet up into the estuary as a result of sediment availability and the hydrodynamics of the system;

- marine sand extends up the estuary to about 1,5 km from the mouth whereas aeolian sand is usually found on the south-western (right) bank of the lower estuary and within 70 m of that bank;

- floods scour the channel bottom until a resilient horizon is reached, which is usually characterized by a lag gravel of pebbles and coarse shell fragments but which in some locations is also found in the form of a very compacted clay;

- the shallow sediment cover over this erosion base is indicative of little sediment accumulation in the estuary.

They also concluded that:

- The estuary was at its widest at the mouth and could be up to 800 m wide but that the actual channel was only about 45 m wide.

- About $0{,}9 \times 10^6$ m^3 of sediment was flushed from the lower estuary during a flood in 1971.

- The amount of wind-blown sand entering the estuary annually is about 25 000 m^3 (Rust and Reddering, pers. comm., have since indicated that this was a typing error and should have read 250 000 m^3/yr).

If one considers the interaction between the variable water discharge down the river and the morphological and topographical features of the estuary, it is apparent that the estuary has a natural tendency to become silted up. Most of the change towards this inevitable situation takes place during floods. The mud concentrations found by Reddering and Esterhuysen (1981) upstream of the dogleg and to some extent also below it indicate the areas where deposition will naturally take place. The flood waters then have excess capacity to carry sediment and the lower reaches are scoured out.

Reddering (pers. comm.) is of the opinion that very little sediment is brought down in the Sondags at present. This observation is supported by data from Middleton et al. (1981), which indicate that only 2,3 × 10^6 tonnes per year (1,2 × 10^6 m^3/yr) of sediment is produced by the catchment downstream of Lake Mentz.

Fromme (in Swart, 1985a) studied the dynamic behaviour of the mouth region of the Sondags with the aid of 22 sets of aerial photographs covering the period 1939 to 1983. The main features, as observed by Fromme, are:

- The mouth always remains open although the growth of sand spits and flood-tidal shoals have a tendency to constrict the inlet.

- The large inner shoal, which was always present, was particularly prominent during 1983 when the river discharge was very low.

- Sand spits develop on both the eastern and the western bank at the mouth in such a manner that the estuary is either funnel-shaped or has overlapping spits at the mouth.

- Observations on the ground during 1983 indicated that although both sand spits contained sand of aeolian origin, the eastern spit consisted typically of marine sediment whilst the western spit, which was situated in a more landward position, consisted typically of aeolian sand blown across from the Schelmhoek dune field.

- The dominant position of the estuary mouth is about 200 m west of the centre line through the lower estuary (below the elbow), but the actually observed mouth position regularly varied by about 100 to 200 m and occasionally by more than 300 m.

The above description from various sources typifies an estuary which is clearly very dynamic but reasonably stable and which apparently maintains a dynamic balance between the various forces acting on it which are the water and sediment discharge from the river and specifically the floods with their scouring capability, the aeolian drift originating from the dune fields and the tidal action and marine sediment influx.

2.3 Beaches

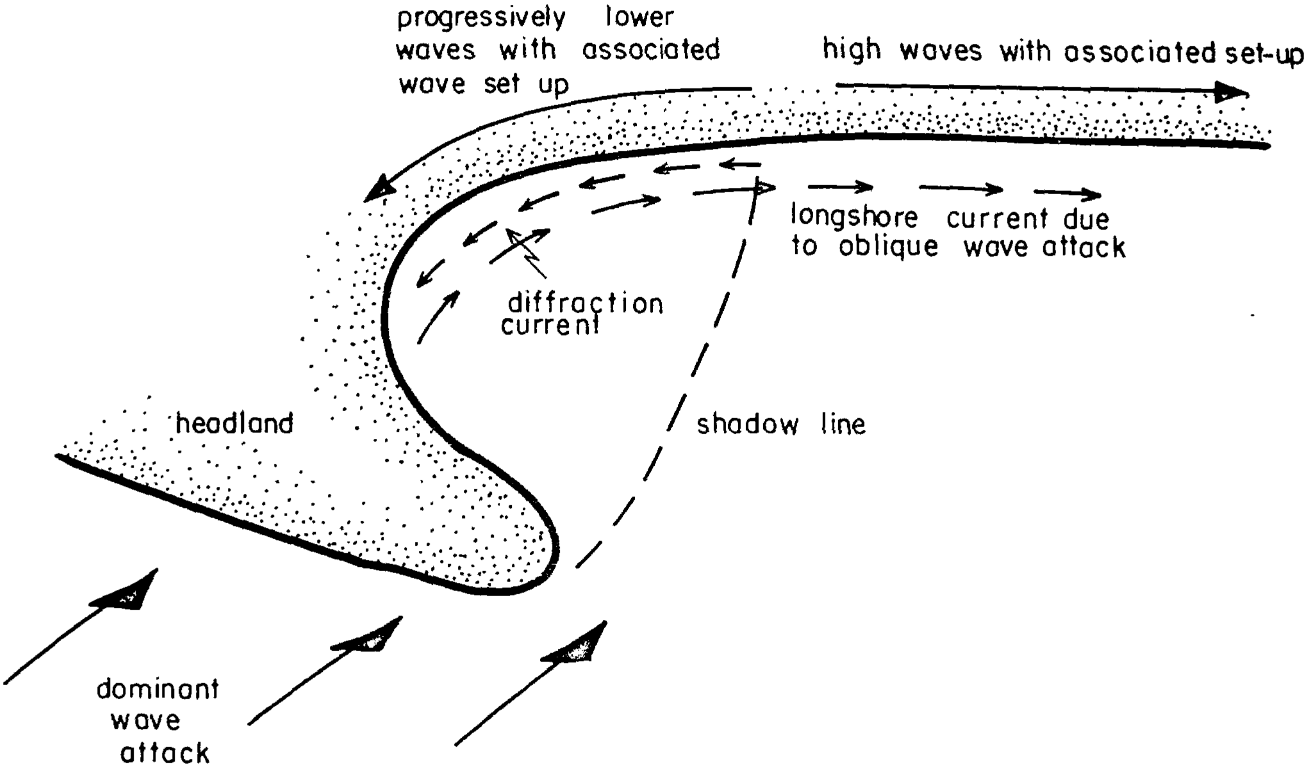
The Sondags/Schelmhoek area is situated on Algoa Bay, which is a logarithmic spiral (halfheart-shaped or crenulate) bay facing the Indian ocean. The bay stretches over a distance of about 73 km at an orientation of 66° from Cape Recife to Woody Cape, while the bayshore is about 110 km long. The shore distance of the Sondags from Cape Recife is about 58 km. The Sondags is situated near the point of largest indentation in the bay and lies about 22 km from the connecting line between Cape Recife and Woody Cape.

Logarithmic spiral bays are formed between headlands by the action over prolonged periods of time of obliquely-incident waves. The greater the obliqueness, the greater the curvature of the bay, provided that non-erodible promontories do not prevent erosion from creating such a curvature. The shape of Algoa Bay was formed and is maintained by the dominant swells from the south-westerly quarter, generated in the southern oceans. Bremner (1983) did extensive geophysical investigations in Algoa Bay and specifically investigated the degree to which Algoa Bay fits the theoretical long-spiral curve. He concluded, *inter alia*, that:

- local perculiarities in the bathymetry, and particularly in the geometry of the headlands, are aspects that cause considerable deviation from the theoretical log-spiral curvature;
- provided that the areas between Cape Recife and Port Elizabeth and between Woody Cape and Cape Padrone are excluded, a very good log-spiral fit was found in the intermediate area;
- to all intents and purposes Algoa Bay may be regarded as having reached equilibrium with its environment.

Diffraction around Riy Bank and as a result of the shallow regions around the islands in Algoa Bay as well as the effect of wind-driven transport could be other reasons for divergence from the theoretical, ideal curvature.

Waves approaching the shore obliquely cause a longshore current which flows in the down-wave direction in and near the breaker zone. The longshore current increases amongst others when the angle of approach and the wave height increase. Because the dominant deep-sea approach direction of the waves in Algoa Bay is from the south-westerly sector the longshore currents will flow predominantly from west to east along the open part of Algoa Bay, such as at the Sondags estuary mouth. As one approaches Woody Cape the mean angle of approach decreases owing to the curvature of the bay; the mean longshore current strength would therefore also decrease in that direction.



In the shadow zone behind Cape Recife another process should also be considered. The wave height at the breaker line becomes progressively lower as one moves further (west) into the shadow zone. Because waves sustain a higher mean water level inside the breaker zone (the so-called **wave set-up)**, the extent of which is directly related to the wave height at breaking, the mean water level inside the breaker zone slopes down into the shadow zone. This sloping water level causes a diffraction current which is directed into the shadow zone. The magnitude of this current is greatest at the point where the longshore change in the breaker height is greatest. Inside the shadow zone the longshore currents due to the oblique wave attack and that due to the change in the wave set-up oppose each other. Usually the current resulting from the wave obliquity is predominant but it is possible that in the case of some locations inside and usually close to the edge of the shadow zone deep-water angle of approach and the incident wave height are such that the dominant current is in the reverse direction when compared with the rest of the bay. The size of the shadow zone changes with the deep-sea approach direction of the waves.

Sediment is brought into suspension owing to the high turbulence which results from wave breaking. This suspended sediment and other sediment inputs into the nearshore zone are transported along with the dominant longshore currents. The rate at which sediment is transported increases with increasing current velocity. Alongshore variations in the longshore transport rate lead to either erosion or accretion, depending on whether the transport rates increase or decrease in the downdrift direction. Under the influence of variations in the longshore current, as explained above, a bay such as Algoa Bay will become more convex until a dynamic balance is reached between the wave-induced sediment transport processes and other inputs of sediment into the nearshore zone.

In a situation such as exists on the eastern Cape coastline, with a number of crenulate bays nested side by side, the headlands have an important function to fulfil. The degree to which sediment can bypass the headlands depends on the extent to which the headlands project out of the coastline and also on the topography at these headlands. In some cases headland bypassing takes place readily whereas in others sediment accumulation takes place updrift of the headland (Flemming and Martin, 1985). In the latter case beaches in this area will grow and the wind will blow sand across the headland into the downdrift bay, provided that the headland is not extensively vegetated. Lord et al. (1985) showed that the **Cape Recife headland has been alternately vegetated and denuded over the centuries.** This means that sand will have been supplied to Algoa Bay in the area just north of Cape Recife at times whereas these beaches would have been denuded at other times. Engels (1985) did a similar study on the effect of vegetation on the nature of the adjacent coastal strip at Quoin Point near Cape Agulhas. He showed that the beaches in the downdrift bay grow while sand is being blown across the headland. At each given location in the downdrift bay the beaches reach a maximum width at some stage after the stabilization of the headland had been completed. This implies that the wind blows more material into the bay than could normally be transported by the waves in the lee of the headland. The material then moves alongshore as a pulse which manifests itself as a bulge in the coastline or a slug which flattens progressively as it moves alongshore.

Applied to Algoa Bay this would mean that a slug of sand would have moved through the bay first causing accretion and then erosion back to the original situation at some time after the 1980's when stabilization of Cape Recife commenced. The removal of the sand, either by stabilization of the headland or by the construction of structures such as Port Elizabeth harbour, initiates beach erosion which soon dominates throughout the bay. Thus, for example, Prestedge et al. (1985b) show progressive erosion at a rate of about 3 to 4 m/yr, taking place at New Beach opposite Blue Lagoon. The area of maximum erosion is moving along eastwards.

It is also possible, as has been maintained for a long time by Crews (pers. comm.), that material which bypasses the headland at Cape Recife is moved across the bay floor to the beaches in Algoa Bay further to the east. Mineragraphic Report No. 635 of the Australian CSIRO (1957) showed that a similar mechanism is operative in Portland Bay in the State of Victoria in Australia (see Appendix A). However, Hesp (pers. comm.) and Chapman (pers. comm.) who are Australian coastal scientists well informed on the Portland Bay situation, both indicated that there is still considerable debate as to the interpretation of the available information.

A similar mechanism to that referred to above was also deduced for the Durban Bight on the basis of textural and colour analyses of numerous systematic samples in the bight (CSIR, 1963). It was established that the coarse material is preferentially moved as bed load in this manner. Although it appears reasonably that this mechanism contributes to the sand budget of Algoa Bay, its relative contribution cannot be assessed on the basis of our present information. This may be a field for future research.

According to Chapman (in Perry, 1983) the tidal shoals in the bottom 1 km of the Sondags could store about 0,5 to 1,0 × 10^6 m^3 of sediment, which would be flushed from the mouth during major fluvial floods and which would then augment the sediment budget of the adjacent beaches. The sediment thus flushed out would be taken up in the littoral system as a slug, behaving very much in a manner similar to that described above.

Long-term fluctuations such as those described above could in part explain why the wreck of a heavy sailing vessel, referred to by Crews (1985), lies about 200 m landwards of the present high-water line.

Super-imposed on these long-term trends are shorter-term fluctuations, of the order of months to days, due to seasonal wave height variations or storm events which only last a few days. Offshore-directed movement of sand takes place during periods of high wave intensity when the wave steepness is high whilst onshore-directed transport occurs during the calmer periods when the wave steepness is low. On the beaches off Schelmhoek the offshore loss of material during storm events is curtailed to some degree by a clay horizon a few metres below the present beach level (Crews, 1985). In general more than 80 per cent of the offshore-directed losses take place during as little as 10 per cent of the time. During most of the rest of the time a gradual onshore transport takes place during calmer weather and restores the on/offshore balance. Evidence suggests that this is also the case along the beaches in the vicinity of the mouth of the Sondags.

Calculations by Prestedge _et al_. (1985a) using the method for the prediction of on/offshore sediment transport rates, developed by Swart (1974), showed that the position of the mean water line at Joorst Park just east of the Swartkops mouth could vary by about 60 m during a representative year. This figure could be taken as a first estimate of the shorter-term fluctuations of the beach at Schelmhoek, although the restricting effect of the clay layer mentioned above could reduce it.

Short and Wright (1983) have classified beach types that exist in wave environments ranging from low, with wave heights less than 1 m, to high, with wave heights in excess of 2,5 m. Three basic types were identified, namely, reflective, intermediate and dissipative. Each beach state can be classified by its wave-sediment characteristics. The Sondags estuary is situated on the exposed northern coastline of Algoa Bay where it is afforded little protection against south-westerly swells. It can therefore be termed a high-energy beach which is usually of the intermediate to dissipative type, as described by Short and Wright (1983) and numerous other papers on this subject.

McLachlan and Bate (1984) classified the beach as intermediate whereas Chapman, as quoted in Perry (1983), observed dissipative conditions in all 15 sets of photography which he studied. The area has a flat offshore topography and a breaker zone which typically varies between 150 m and 300 m. Very strong pulsating rip currents, which occur at regular distances alongshore, appear to be one of the main mechanisms for moving sediment offshore (Swart, 1984).

The beaches at Schelmhoek are gently sloping and very wide. They can be as wide as 160 m (Crews, 1985), measured from the edge of the littoral dune to the low-water line.

2.4 Dunes

McLachlan *et al*. (1982) also refer to the effect of sea level on the area as a whole, in a manner similar to that of Chapman (in Perry, 1983). They say that limestone benches were formed seawards of the shoreline during periods of slightly higher sea level. In addition, raised beaches occur as a result of eustatic changes in sea level. Limestone benches occur at elevations of 240 m, 200 m and 90 m and raised fossil beaches at 30 m, 15 m and 5 m. The high sea levels were followed by drops to about -80 m, which exposed the continental shelf. They state that the winds were onshore during such periods, which caused the dunes to build up.

Chapman (in Perry, 1983) indicates that there are at least four and possibly five, generations of sand dunes. These, in descending order of age, are the following (refer to Figure 1(iv)):

- In the environs of Aloedence Farm and to the west of the lower floodway of the Sondags river is a field of roughly parallel linear features spaced about 400 to 500 m apart. These features are sub-parallel to the present shoreline and may be Pleistocene beach ridges of a very subdued type.

- Immediately to the east of the lower two kilometres of the Sondags river channel is the remnant of a formerly much more extensive field of high parabolic dunes. The remnant is at a modal elevation of 50 to 80 m and quite clearly represents the terminal inland margin of a dune field which must have extended some distance further westward at one time. Although this dune field could conceivably be coexistent with (3) below, its form suggests that it was developed in an era of more abundant sand supply than the dune field described in the following paragraph.

- By far the most extensive of the present coastal dune features is a dune field of low parabolic dunes and dune ribbons formed by the exhaustion of parabolic dunes extended headward. This dune field certainly underlies the inner transgressive dune sheet described below and may also underlie most of the outer transgressive sheet described below. The lower parabolic dune field is at a modal elevation of less than 30 m, with local relief generally less than 15 m. In drier periods, deflation has occurred to levels lower than the present dune water table, with the result that deflation hollows developed at that time are now occupied by swamps. On both sides of the river the lower parabolic dune field terminates in a striking long-walled terminal ridge up to 60 m high.

- By far the most spectacular of the dune forms is the inner transgressive dune sheet. This feature, which has the classic form of a mobile transgressive dune sheet, rises to heights of over 30 m to the west of the Sondags river channel, and over 60 m to the east. In places the swales of this dune field expose the upper surface of the buried lower parabolic dune field beneath. The remains of buried vegetation appear to be exposed in some of the swales although, if the sand is carbonate or calcrete rich, the exposures may represent dissected aeolianite. Although the transgressive sheet is obviously mobile, the area covered by it has not expanded greatly since 1939 when the first set of aerial photographs were taken. As sand moves through the mobile sheet it re-enters the beach system by means of the river. In the lower 3 km of channel, and also opposite the settlement of Cannonvale, there are prominent slip faces representing the discharge points for sand transported through the dune field and entering the river channel. Sand supplied to the river in this way will ultimately be transported downstream and provide supplementation for the beach sediment budget. Hence, in the long term, it would appear that sand is recycled through the dunes by means of a system as follows: beach - deflation to dunes - dunes migration into estuary - flood flushing to surf zone - wave action to beach.

The area of this dune sheet to the east of the channel has decreased since 1939, almost certainly as a response to sand-drift fencing and revegetation works carried out since that time.

- Finally, there is an outer transgressive dune sheet immediately behind the present shoreline. This dune sheet has subdued linguoid dunes of very minor relief, being generally below 15 m in elevation and in places probably below 8 m. To the east of the Sondags river the outer transgressive sheet abuts the inner transgressive sheet and probably supplies sand to the latter. However, on the western side of the channel the outer transgressive sheet, whilst abutting the inner transgressive sheet for a distance of about 1 km, appears to be a discrete feature, with sand transport moving from the back-beach, through the dune field, and into the lowermost 1 km of river channel for recycling into the beach system. Again, although this dune field has expanded slightly in area since the 1939 photographs, the expansion has not been significant.

According to Fromme (as quoted in CSIR, 1984a) several ridges of barrier dunes were formed along the coast in the 5 000 years since the Flandrian Transgression. This is the fifth type identified by Chapman. It is shown in CSIR (1984) that 70 per cent of the farm Schelmhoek is covered by sand dunes and that the dunes along the edge of the river are much higher than along the shoreline.

A striking feature is the high stabilized dune on the western boundary of Hougham Park. Crews (1985) describes how this dune was built up over a period of 30 years to a level of up to 40 m. Over the years 25 fences consisting of Acacia cyclops poles, interlaced with branches of the same trees, have consecutively been built on top of the growing dune. In this way sand moving along from the south-westerly sector has been caught.

As the dunes on Hougham Park have been extensively stabilized by using Acacia cyclops (Rooikrantz), it is possible that windblown seeds will in time cause the stabilization by means of Rooikrantz to extend downwind to Schelmhoek.

Crews (1985) also supplies evidence which shows the extent to which a littoral dune had been built up by onshore winds over a period of three years with the aid of a similar fence.

McLachlan et al. (1982) measured the average rate of advance of dunes in the Alexandria dune field to the east of the Sondags. Although their data showed considerable scatter, they found mean advance rates of between 0,1 m/yr and 4,0 m/yr depending on the type of dune and extent of vegetation. Appropriate dune heights are not given for these advance rates but further in the text an advance rate of 1 m/yr is used in conjunction with a dune 30 m in height to predict landward sediment flux. This figure represents a landward volumetric growth of the edge of the dune field of 30 000 m^3/yr/km. For eastward movement within the dune field they quote a figure of 7 000 m^3/yr/km (3,5 m/yr advance of 2 m high dunes) but it is not clear what dunes are referred to.

Measurements of dune advance rates on the Cape Recife headland point to a volumetric eastbound transport rate of 68 000 m^3/yr /km. Recent work by McLachlan et al. (1985) as referenced in Prestedge et al. (1985a) shows that dunes 5 to 6 m high in the Sondags area have advance rates of approximately 7 m. This would indicate an eastbound volumetric transport rate of the order of 35 000 to 42 000 m^3/yr.

Crews (1985) relates, on the basis of experience on his farm Hougham Park in the area, the erratic movement of the dunes. He states that the larger dunes move slowly, but that sometimes, due to the configuration of the dunes, gaps are formed through which the wind funnels, thereby increasing the advance speed of dunes in its path.

Reference is made in several publications to a high water table in the coastal dune area. In CSIR (1984a) this is ascribed to seepage from the Sondags through the dunes to the sea. A comparison of the relevant levels shows that this cannot be the case. Albertyn (1966) did a geological survey in the area and found a fairly extensive weathered shale layer above the level of the lower reaches of the estuary. Because of this he concluded that the water table was perched above the Sondags. It would appear, therefore, that the only known source of fresh water in the area is rain water. McLachlan et al. (1982) also refer to a high water table in the Alexandria dune field. They indicate that the series of wet slacks between the dunes, which become less distinct and drier as the distance from the present mouth of the Sondags increases, were formed when the mouth of the Sondags was in this area. However, the source of fresh water must again be rain water.

3. ENVIRONMENTAL DATA

3.1 Wind

Rates of wind-blown (aeolian) sand transport can only be estimated once wind statistics are available for the area.

Various sources of wind data, which could be of relevance to the Schelmhoek area, are readily available and are tabulated below.

Source/Location	Period of coverage	Remarks
HF Verwoerd Airport; Weather Bureau	1951-1970	-
Lighthouse data Cape Recife	1976-1980	Visual estimates
VOS wind data 33°-35°S; 25°-26°E	1961-1979	Shipborne anemometer, usually hand-held
SOROS data on St Croix	Jan, Feb 1971	Hand-held anemometer
SOROS data on mainland opposite St Croix	1971	On frontal dune, affected by topogaphy
CSIR data, west of Swartkops estuary, on shore	1964, 1965	

Irrespective of their value and quality, the wind statistics marked either SOROS data (2 sets) or CSIR data (1 set) cannot be used for the prediction of aeolian sand transport due to their limited duration. The lighthouse data are rejected because they have been visually estimated.

The two most extensive data bases are those from HF Verwoerd Airport and the Voluntary Observing Ships (the so-called VOS data). It is concluded in CSIR (1965) that the wind data collected near the mouth of the Swartkops indicate that the general wind pattern experienced during the two-year period conformed closely to that indicated by the airport data. Although it would appear that this is not strictly true on a day-to-day basis, it certainly holds true for bulk statistics. It can therefore safely be assumed that the airport wind data will give a good first estimate of the wind field at Schelmhoek.

Crews (1985) argues that the wind pattern experienced at St Croix island, directly in the passage of the south-westerly winds as seen relative to Schelmhoek, will be more applicable in establishing the incident wind field. This is certainly a valid argument. The available data in this location unfortunately are not very extensive, covering only a two-month period. However, in this respect the VOS data should also be useful as it was gathered in the coastal area of Algoa Bay. To investigate this, the VOS data for the area 33°-35°S, 25°-26°E were extracted from the data bank of the South African Data Centre for Oceanography (SADCO) and wind roses were drawn. These are shown in Figures 2(i) and 2(vi).

Figures 3(i) and 3(ii) contain a comparison of the bulk VOS and airport wind statistics for the whole year. These figures show that the distribution of direction is roughly similar for the two data sources, but that the wind speeds as observed on the VOS ships (referred to as sea-based data in the figures) are substantially higher than those recorded at the airport (land-based data). This is to be expected in the light of the different wind boundary layer development over land and over sea. Other such similar comparisons for land and sea-based wind data on the SA coastline show the same tendency and suggest the following averaged relationship to simulate land-based wind speeds (v_{LB}) on the basis of VOS wind data (v_{SB}).

$$v_{LB} = 0{,}6v_{SB} \qquad \ldots (1)$$

To obtain some idea of the variability of the longer-term wind statistics, as could be obtained over a period of (say) one year, wind roses were drawn based on the VOS data source

(33°-35°S, 25°-26°E) for each individual year from 1965 to 1975. These wind roses are shown in Figures 4(i) to 4(xi). Although the individual roses appear to be very similar, with only minor shifts in the distribution pattern, it will be shown in Section 4 that the resulting aeolian transport rates from each of these roses can vary by a factor of two to three. This emphasizes the need for long-term wind statistics as input to wind-blown transport calculations.

A test was done to investigate the regional distribution of wind speeds within the larger VOS square. For this purpose two areas were identified, namely,

VOS Area 1:	33°40'	to	34°S
	25°40'	to	26°E
VOS Area 2:	34°	to	34°30'S
	25°10'	to	25°40'E

Area 1 is situated off the Sondags River in Algoa Bay and Area 2 is off Cape Recife and to the west of it. The resulting wind roses for the average year, based on data for the period 1961 to 1979, are given in Figures 5(i) and 5(ii). Although Area 1 did not contain many data points, it is interesting to note that it exhibits a more south-westerly bias than the data from Area 2.

On the basis of the above information, it is felt that the HF Verwoerd Airport data and the VOS data, after correction by Equation (1), will yield resonably accurate limits to the possible wind statistics at Schelmhoek.

3.2 Waves

The sources of wave data are less abundant than those of wind data. Although there are wave records available for clinometer stations at Cape St Francis and Mossel Bay, these were rejected because it has been shown by Rossouw (1984) that measurements taken by clinometer (graded telescope used to estimate wave height, period and directions 2 and 3 times per day) are unreliable. For the same reason observations by lighthouse keepers are also discounted. The only remaining sources of wave data are the following:

- SOEKOR Waverider data (wave height and period), measured in an area bounded by 35°-36°S, 21°-23°E off Mossel Bay for the period October 1978 to February 1981.
- Visual estimates of wave height, period and direction, done by the Voluntary Observing Ships, this being the so-called VOS data.
- The SOROS data, measured for the period November 1970 to May 1971 during the course of the feasibility study for the St Croix harbour project.

Figure 6 gives the exceedance curves for wave height determined for these two data sources. Also drawn in is a "corrected" VOS curve after Nicholson (1984) (labelled VOS-corrected SEDCO-K) which is a first estimate of the corresponding "instrument" wave height derived by Nicholson from the VOS wave data with a relationship that is assumed valid for the whole SA coast. It can be seen that the agreement between SOEKOR Waverider and VOS corrected data is fairly good. The real value of the VOS data, however, lies in the fact that it provides observation of wave direction. Rossouw (1984) has shown that the VOS wave direction distributions around the SA coast are consistent with the driving weather patterns.

The SOEKOR data referred to above were measured in an area just inside the Agulhas Current where, according to Schumann (1975) the wave height is increased owing to current refraction and trapping at the edge of the current. For this purpose Swart in CSIR (1985a) has related the VOS data to Waverider data collected off Mossel Bay in 60 m of water during 1973 and 1974. The exceedance curve based on this relationship is also given in

Figure 6 and is labelled **(VOS-corrected MB).** It is immediately apparent that this curve, which corresponds closely to the observed Waverider data in 60 m off Mossel Bay, predicts much lower wave heights. It is considered reasonable to assume that the input waves into Algoa Bay is bracketed by the **VOS-corrected SEDCO-K** and **VOS-corrected MB** curves. The following table gives a brief summary of the simulated deep-sea wave data on the basis of the above assumption.

Deep-sea angle of approach (° to N)	Percentage occurrence	Equivalent deep-sea significant Waverider height (m)		Peak wave period (s)*
		Corrected SEDCO-K	Corrected MB	
90°	8,4	2,7	1,8	12,6
120°	4,8	2,6	1,7	13,0
150°	4,5	2,8	1,9	13,0
180°	9,9	2,9	2,0	13,7
210°	24,7	3,4	2,3	14,0
240°	55,5	3,3	2,3	13,5
calms	22,4	-	-	-

* Determined after Nicholson (1984) from VOS observed wave periods.

3.3 Run-off

According to DWA (1968, 1878a, 1978b) the following run-off data are available for the Sondags River (see Figure 7(i) for location of gauging stations).

Gauging station	Location	Duration	Catchment size (km^2)	MAR ($\times 10^6 m^3$)
N2M01	Darlington	1918-1922	16047	22,1
N2M02	Jansenville	1923-1960	11395	90,1
N2M02	Waterford	1928-1948	13419	97,3
N1R01	Van Rynevelds-pasdam	1925-1960	3681	28,0
N2R01	Mentz Dam	1923-1970	16826	148,3

In the case of the Mentz Dam, data are also available for the period after 1970 but this is not yet in published form.

Reference to Figure 7 indicates that observations at none of these stations are really applicable to the river mouth. Perry (1983) produced simulated run-off figures at the mouth of the Sondags on the basis of actual rainfall data covering the whole catchment for the period 1921 to 1976, by using the model developed by Middleton et al. (1981). Her data are available for a catchment size of 20 990 km^2 and yield a simulated MAR of 202,3 × 10^6 m^3. Figure 7(ii) contains the simulated monthly run-off figures (after Perry, 1983) for the period 1921 to 1976. The erratic nature of the rainfall and the corresponding run-off which exceeds 50 per cent of the MAR occurred for 26 months, while a monthly run-off higher than the MAR occurred for 12 months. On the other side of the scale one sees that the annual run-off was less than 20 per cent of the MAR on 9 occasions (19 per cent of all years) and less than 10 per cent of the MAR on 6 occasions (13 per cent of all years).

Comparison of the simulated run-off data with the inflow data at Lake Mentz, as given in DWA (1978b), shows that the trends in the Lake Mentz data are reproduced fairly well in the simulated records. The only notable exception appears to be for the 1931 hydrological year, when the worst recorded flood occurred. The simulated records, however, show only about half the expected run-off. This is ascribed to the distribution of the rain through the catchment during this event.

According to Harvey (pers. comm.) who has been a resident in the area since the 1920's, the 1932 flood was the worst recorded, with the 1928 flood slightly lower and the 1921 flood again slightly lower. In his opinion no flood has been higher since, although he considers the 1971 flood the most severe recent flood. This ties in fairly well with the data in Figure 7(ii).

4. SEDIMENT BUDGETS AND PATHWAYS

4.1 Aeolian Transport Rates

When the shear stress exerted by the wind on the sandy surface on the beach or in a dune field exceeds a certain critical value sand particles are brought into motion. Numerous researchers have studied this phenomenon either theoretically or experimentally in the laboratory and the field, and have come up with expressions for the rate of wind-blown or aeolian sand movement under given wind conditions. A study of the literature revealed the following 16 formulae for the prediction of aeolian transport rates:

Formula	Reference	Comments
BAGNOLD	Bagnold (1954)	
KAWAMURA	Kawamura (1950)	
OBRIEN	O'Brien & Rindlaub (1936)	Valid for $U_* \geq 0{,}2$ m/s
HSU	Hsu (1974)	
MOSSA	Mossa (1981)	
CHIU1	Chiu (1970)	Neglects particle distribution
CHIU2	Chiu (1970)	Incorporates particle distribution
KADIB	Kadib (1970)	Expressions fitted to graphical curves by Swart (1985)
NAKASJIMA	Nakasjima (1979)	
TSUCHIYA1	Tsuchiya & Kawata (1975)	As interpreted from the Japanese by Swart (1985b)
TSUCHIYA2	Tsuchiya & Kawata (1975)	
TSUCHIYA3	Tsuchiya & Kawata (1975)	
ZINGG	Zingg (1952)	
ZANKE1	Zanke (1980)	
SANKE2	Zanke (1980)	
MBKS	Hotta *et al*. (1984) Horikawa *et al*. (1983, 1984) Kubota *et al*. (1982)	Modified Bagnold-Kawamura formula, further adapted by Swart (1985b)

The abovementioned aeolian transport predictors were all rewritten by Swart (1985b) to give volumetric transport rates. The independent variables which are used in these formulae in one way or another, are:

- The shear velocity at the bed U_*.
- The median grain size D_{50} or in some cases the particle size distribution D_i.
- The mass density of the air ρ_a and the particles ρ_s.
- Gravitational acceleration g.
- Kinematic viscosity of air ν_a.

Horikawa et al. (1984) showed that air temperature and humidity and the moisture content of the sandy surface are also important variables, but as yet there is no reliable theory to incorporate them into predictive equations and, in any case, concurrent data of the nature necessary to do predictions with such improved predictors are not available at present. The type and extent of vegetation cover on the sandy surface also affects the aeolian transport rates. McLachlan et al. (1982) provided some quantitative data to show the extent of the reduction in the unhindered transport rate due to vegetation.

A computer program was written which computes for each direction/velocity combination in a wind statistics table the aeolian transport rate according to each of the abovementioned 16 formulae. These transport rates are then ranked in order of descending magnitude and the highest three as well as the lowest three transport rates rejected. The average of the remaining 10 predictions is then taken as the best estimate of the transport rate of the specific direction/velocity combination. By repeating this procedure for every velocity interval for a given direction and by taking due cognizance of the frequency of occurrence of each direction/velocity combination, the total aeolian drift for the given direction is found. The results are given in m^3/km/yr. Swart (1985b) defined an aeolian creep diagram, which is a visualization of the aeolian drift rates for all wind directions (see for example Figure 8(i). The hatched area represents the amount of drift, which is plotted from the edge of the circle inwards, that is, in the direction in which the sand will be blown, on the basis of calculation in 22,5° direction sectors.

On the basis of the results in Section 3.1, aeolian creep diagrams were produced for the airport wind data and for the adapted (with expression (1)) VOS data and are given here as Figures 8(i) and 8(ii).

The creep diagrams for the whole year are very similar, except that the diagram based on the VOS data shows a slightly more westerly predominance. If these two diagrams are used to calculate the component of the eastbound aeolian drift which would blow across into the Sondags from the Schelmhoek dunefield, the airport data indicate a drift rate of 78 000 m^3/km/yr and the VOS data a drift rate of 62 000 m^3/km/yr, with an average of 70 000 m^3/km/yr.

To assess the effect of shifts in the wind climate on a year-to-year basis the VOS data for the period 1965 to 1975 were used to predict aeolian creep diagrams for each year (refer also to Figures 4(i) to (xi)). The results are shown here as Figures 9(i) to (xi). The maximum eastbound transport rate, which is comparable to the figures quoted above, for each of the 11 years, is given below:

Year	Eastbound component of aeolian drift (m^3/km/yr)
1965	64 800
1966	51 400
1967	72 100
1968	62 100
1969	57 600
1970	109 900
1971	40 800
1972	59 900
1973	72 200
1974	79 100
1975	67 600
Average	67 000
Standard deviation	17 700

The above data indicate that the 95 per cent confidence band of the result is 33 000, 101 000, or 67 000 m^3/km/yr ± 50 per cent. This is a very interesting result as it indicates that qualitative comparison of wind roses can be deceptive. It also shows the temporal variability of the aeolian drift over long periods of time.

On the basis of the above results it seems reasonable to use the airport wind data to obtain a first indication of long-term average aeolian drift rates in the Sondags/Schelmhoek area.

Four different components were established from the aeolian creep diagram in Figure 8(i), as follows:

- Eastbound and westbound components perpendicular to the Sondags over its lowermost stretch, downstream of the dog-leg.

- Onshore and offshore components perpendicular to the shoreline west of the Sondags mouth.

The following results were obtained:

Component	Aeolian drift rates (m^3/km/yr)
Eastbound	78 000
Westbound	33 000
Onshore	27 000
Offshore	9 000

The above data indicate a net eastbound drift of 45 000 m^3/km /yr, which is in good agreement with the data presented by McLachlan _et_ _al_. (1985). The eastbound transport rate agrees well with data quoted for Cape Recife by Lord _et_ _al_. (1985).

The onshore component is in excellent agreement with data in McLachlan et al. (1982) and the results in general agree with the observations on site over many years by Crews (1985).

4.2 Longshore Transport Rates

The wave conditions listed in Section 3.2 were converted to breaker zone values by means of a finite element combined refraction/diffraction technique of Perlin and Dean (1983). The breaker zone wave characteristics can be summarized as follows:

Deep-sea angle of approach (° to N)	Based on SEDCO-K		Based on Mossel Bay	
	Significant breaker height H_{bsi} (m)	Breaker* angle θ_{bi} (°)	Significant breaker height H_{bsi} (m)	Breaker angle θ_{bi} (°)
90	1,6	- 16	1,1	- 11
120	2,2	- 13	1,4	11
150	2,8	- 8	2,2	- 8
180	3,0	0	2,4	0
210	3,3	+ 9	2,5	+ 8
240	2,7	+ 14	2,1	+ 12

* Negative angles imply approach from north of the normal to the beach.

These breaker zone values can be used to estimate the gross longshore transport rate S_{gp} by using the method of Galvin (1967) in the following manner:

$$S_{gp} = \sum_i k_g \, k_w \, k_c \, f_i \, H^2{}_{bsi} \qquad ...(2)$$

In this equation H_{bsi} refers to the significant wave height at breaking for wave condition i, f_i represents the fractional frequency of occurrence of each wave condition, k_w is an empirical parameter related to the type of input wave data used, which is 0,3 for deep-water VOS data, k_g is an empirical coefficient shown by Galvin (1967) to vary between 0,83 × 10^6 and 1,66 × 10^6, and k_c is the percentage of time that obliquely-incident waves occur.

Assuming that the wave data for Mossel Bay deep-sea as given in Section 3.2 represent the most realistic lower limit and those for SEDCO-K the most realistic upper limit for the input waves at Port Elizabeth it is possible to use Equation (2) to estimate the potential gross transport rate at the Schelmhoek/Sondags mouth. The best estimate of possible gross transport rates found in this manner varies between 0,95 × 10^6 m^3/yr to 1,56 × 10^6 m^3/yr. These figures are based on the assumption that there is abundant sediment available for transportation in the nearshore zone. This may not always be the case, as there are indications of erosion horizons on the beaches in the area.

Data reproduced in the Shore Protection Manual (SPM) (1973) show that the longshore sediment transport is directly related to the longshore component of the energy flux. It is therefore possible to obtain a first estimate of the amount of sediment moved upcoast and downcoast, by assuming that the gross transport figures computed above are valid.

The longshore component E_{fi} of the energy flux can, according to relationship given in SPM (1973), be approximated by:

$$E_{fi} = 0{,}5\ \rho g\ H_{bsi}^{5/2} \sin 2\theta_{bi} \qquad \ldots (3)$$

where ρ is the mass density of sea-water and g is the gravitational acceleration.

Using the breaker zone data given above and the gross transport rates calculated on the basis of Equation (2), it is found that:

	Longshore transport (m^3/yr × 10^6)	
	Upper estimate	Lower estimate
Gross	1,56	0,95
Eastbound	1,33	0,84
Westbound	0,23	0,11
Net	1,10	0,73

The above figures indicate a net transport rate of between 730 000 and 1,1 × 10^6 m^3/yr. If the availability of sediment for transportation is taken into account, it seems reasonable to say for the purpose of this paper that the order of magnitude of the net eastbound longshore drift is 0,5 to 1,0 × 10^6 m^3/yr.

Research on longshore transport rates is being undertaken by the consulting firm Watermeyer, Halcrow and Partners in collaboration with the NRIO. Because the input waves are characterized by full directional and frequency spectra other than by regular waves as in the present study this research will most probably in time refine these estimates.

4.3 River Sediment Discharge

In Section 2.1 the sediment yield from the Sondags catchment was estimated at about 9 × 10^6 m^3/yr, of which 1,2 × 10^6 m^3/yr originates from downstream of Mentz Dam (Middleton et al., 1981). Annandale (1980) showed that Mentz Dam is silting up. The average rate of siltation since 1923 is about 2,5 × 10^6 m^3 /yr, while the initial siltation rate was 4,8 × 10^6 m^3/yr. Annandale (1980) also shows that this siltation rate would represent about 90 per cent of the total sediment yield in the catchment upstream of the dam, with the remaining 10 per cent not being trapped by the dam. If one assumes that the estimate of the total yield from the catchment after Middleton et al. (1981) remains valid, this would mean that immediately after dam construction about 4,2 × 10^6 m^3/yr of sediment could reach the estuary. The corresponding average value for the period 1923 to the present would be about 6,5 × 10^6 m^3/yr. This last figure is based on the assumption that the sediment yield from the catchment has remained constant over the 60-year period, which is shown by Annandale (1980) to be valid. This is in contradiction to results for the Orange, for example, where a more than two-fold reduction in sediment yield has taken place between 1935 and 1967, which is ascribed to an exhaustion of the available topsoil (CSIR, 1985b).

In an effort to get some impression of the manner in which the volumes of sediment referred to above arrive at the estuary, the following approach is followed. It is assumed that

$$S_f = aQ^b \qquad \ldots (4)$$

In this expression S_f represents the fluvial sediment load arriving at the estuary, Q is the discharge and a b are constants. Nicholson quotes in CSIR (1984b) a relationship between S_f and Q derived for the Tugela on the basis of actual data in which b = 1,8. In CSIR (1985b) it is shown, however, that for the Orange river b = 1. Zuo-Sheng et at. (1983) quote, on the basis of extensive data for pre- and post-flood as well as flood conditions on the Yangtze river in China, that b = 2,25. Comparison of all the above references indicates that there is no apparent relationship between the value of b and the median sediment size. It can therefore be concluded that the possible range of b is between about 1 and 2. On the basis of this assumption and the monthly run-off figures as depicted in Figure 7(ii) an exceedance curve for fluvial sediment discharge was drawn up and is given here as Figure 10. The normalized sediment yield shown in this figure is the monthly sediment yield divided by the median annual sediment yield. It is based on the simulated data for monthly run-off normalized by the median annual run-off (see Figure 7(ii)).

This figure shows, for example, that the sediment discharge can once in 10 years be between 4 and 14 times the median annual sediment yield. It is therefore apparent that the sediment load is very strongly concentrated in episodic events.

On the basis of data included in CSIR (1984b) and CSIR (1985e) the sand content (particle size 63 m) of the sediment is estimated at between 5 and 12 per cent (also Martin, Van Heerden, pers. comm.). This means that on average 0,3 to 0,8 × 10^6 m^3 of sand arrives at the estuary, mostly during floods.

4.4 Discussion

The results given in Sections 4.1 tot 4.3 allow a first assessment of the relative importance of the various sources of sand supply in the Sondags mouth/Schelmhoek area. Figure 11 was drawn up on the basis of these results and represents the long-term trends that can be expected. This figure indicates the following:

- On the basis of the unit transport rates (that is, volumetric transport rate/km) mentioned earlier and the actual size and planshape of Schelmhoek, the area is being depleted at an average long-term rate of 160 000 m^3/yr owing to wind erosion.

- This figure is made up of a net gain from the beach owing to onshore sand movement of 80 000 m^3/yr and a loss of material into the Sondags of 240 000 m^3/yr.

- Sand is brought down to the estuary in the Sondags at a long-term average rate of 300 to 800 × 10^3 m^3/yr, mostly during floods.

- The erratic nature of the Sondags run-off data shows that loads in excess of this annual figure can readily be brought down in one month.

- The wind-blown sand influx into the Sondags estuary is lower than, but of the same order of magnitude as, the fluvial sand discharge.

- Whereas the sediment movement in and out through the mouth during normal (non-episodic) events is tide-dominated, the main supply of sand from the Sondags to the coastal area takes place during river floods, when a volume of sand in the form of a slug is supplied to the littoral system, thereby substantially increasing the available load.

- The wind-blown component of the sediment supplied to the littoral system from the Sondags is between 20 and 40 per cent of the total fluvial sand supply.

- On average 15 per cent of the sand supplied by the Sondags to the littoral system will recycle onto the beaches west of the mouth.

In the above synthesis no mention is made of short-term on/off-shore sediment transport due to variations in the incident wave climate. These will, however, take place and lead to short-term and seasonal variations in the beach width.

5. CONCLUSIONS

The main conclusions reached in this study regarding the present-day sediment dynamics of the Sondags mouth/Schelmhoek area are the following:

(1) Algoa Bay appears to be in a state of dynamic equilibrium with the forces acting on it.

(2) Long-term variations (of the order of decades) in the beach width at any given site in the bay can be expected because of variations in the supply of sand to Algoa Bay, for example, by the stabilization or destabilization of the dunes on Cape Recife.

(3) The beaches at Shelmhoek appear to have become wider since the beginning of this century, which is most probably related to a higher supply of sand across Cape Refice to the bay up to the early part of this century.

(4) In addition, the construction of the harbour breakwaters at Port Elizabeth has interrupted the longshore wave-driven supply of sand from the Cape Recife area into Algoa Bay.

(5) As a result, substantial beach build-up has occurred at Kings Beach while corresponding beach erosion was initiated towards the north-east of the harbour.

Erosion at a rate of 3 to 4 m/yr is occurring at New Beach west of the mouth of the Swartkops estuary; this area of worst erosion is migrating alongshore in an easterly direction and may in time affect the Schelmhoek beaches.

(6) Although the relative importance of this mechanism is not known, it is felt that the slow migration across Algoa Bay of (most probably) the coarser fractions of beach material accumulating at Cape Recife does account at least partly for the relative dynamic stability of the central and eastern portions of

Algoa Bay. Other areas where a similar mechanism has been observed is at Durban, Natal and at Portland Bay, in the State of Victoria, Australia.

(7) The best estimates of wind-blown sand transport rates at Schelmhoek, based on HF Verwoerd Airport wind data and computations with 16 different predictive techniques are:

Component	Aeolian drift rate (m^3/km/yr)
Eastbound	78 000
Westbound	33 000
Northbound	27 000
Southbound	9 000

The calculations show that variations in the year to year weather pattern could lead to variations in the annual drift rate of up to 50 per cent of this mean rate.

The abovementioned values are supported by observations on dune migration in the area, which also show large spatial variations in migration rate even on a local scale.

(8) On the basis of these unit transport rates and the actual size and planshape of the Shelmhoek property, as shown in the attached figure, it is estimated that this area is being depleted at an average rate of 160 000 m^3/yr.

(9) On the basis of available long-term wave statistics it is estimated that the gross longshore transport rate at the Sondags mouth is of the order of 1,0 to 2,0 × 10^6 m^3/yr, with the best estimate of the net drift rate being 0,5 to 1,0 × 10^6 m^3/yr. Research being undertaken by Watermeyer, Halcrow and Partners in collaboration with the CSIR will most probably refine these estimates.

(10) The best estimate of the long-term fluvial sediment load from the Sondags catchment is 6,5 × 10^6 m^3/yr, with the sand fraction most probably constituting about 0,3 to 0,8 × 10^6 m^3/yr of this load. Owing to the erratic nature of the run-off this sand supply takes place mostly during floods and will vary substantially from year to year.

(11) The Sondags is in a state of dynamic equilibrium, with its mouth configuration being governed by the relative supply rates of river-borne, windblown and littoral sediments.

(12) Between 20 and 40 per cent of the sand fraction flushed through the mouth of the Sondags by floods is of aeolian origin.

(13) About 15 per cent of the sand fraction supplied to the littoral system from the Sondags, be it of fluvial or aeolian origin, recycles back on to the beaches west of the mouth.

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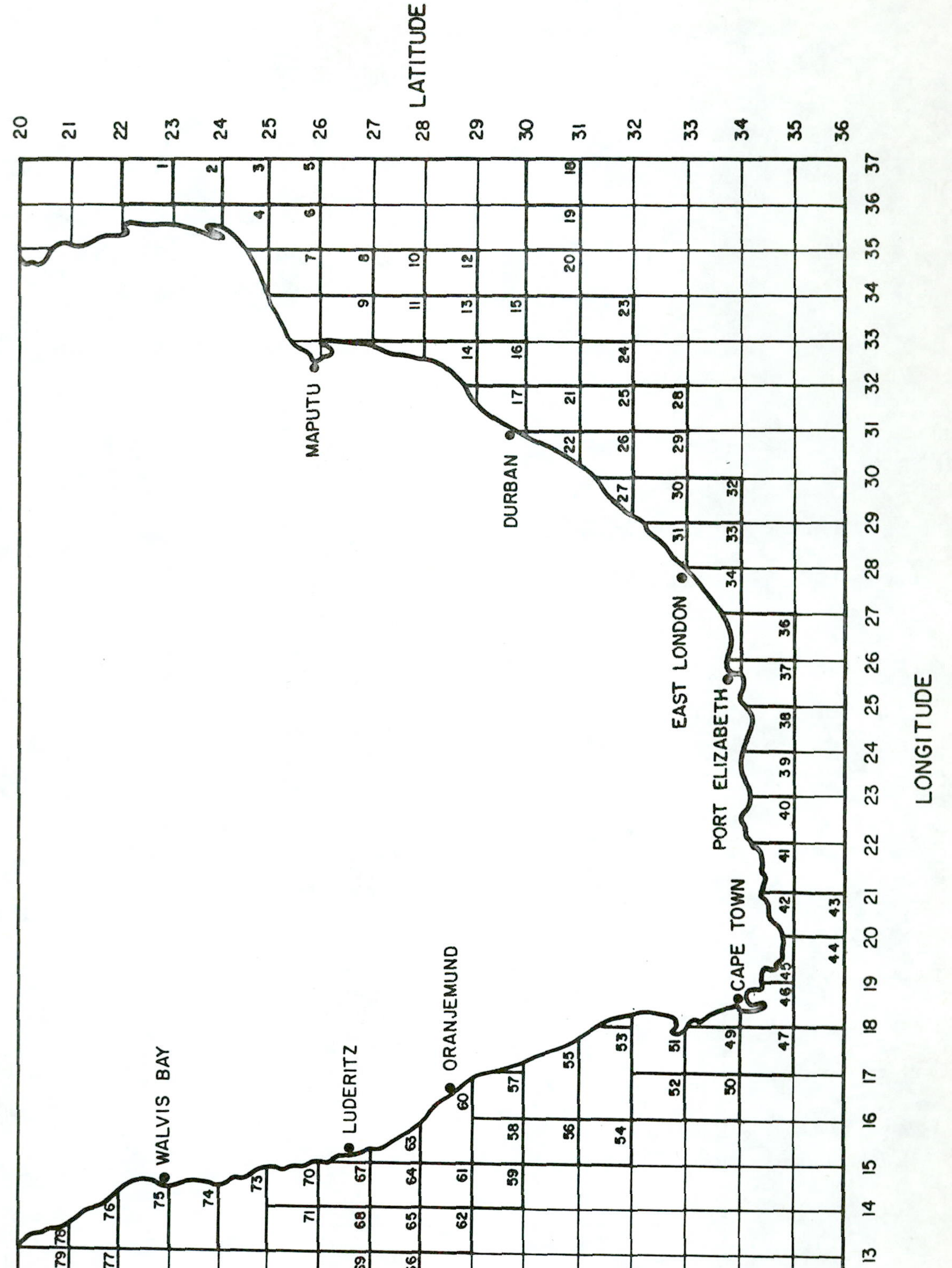
DEMARCATION OF ZONES FOR *VOS* - WAVEDATA



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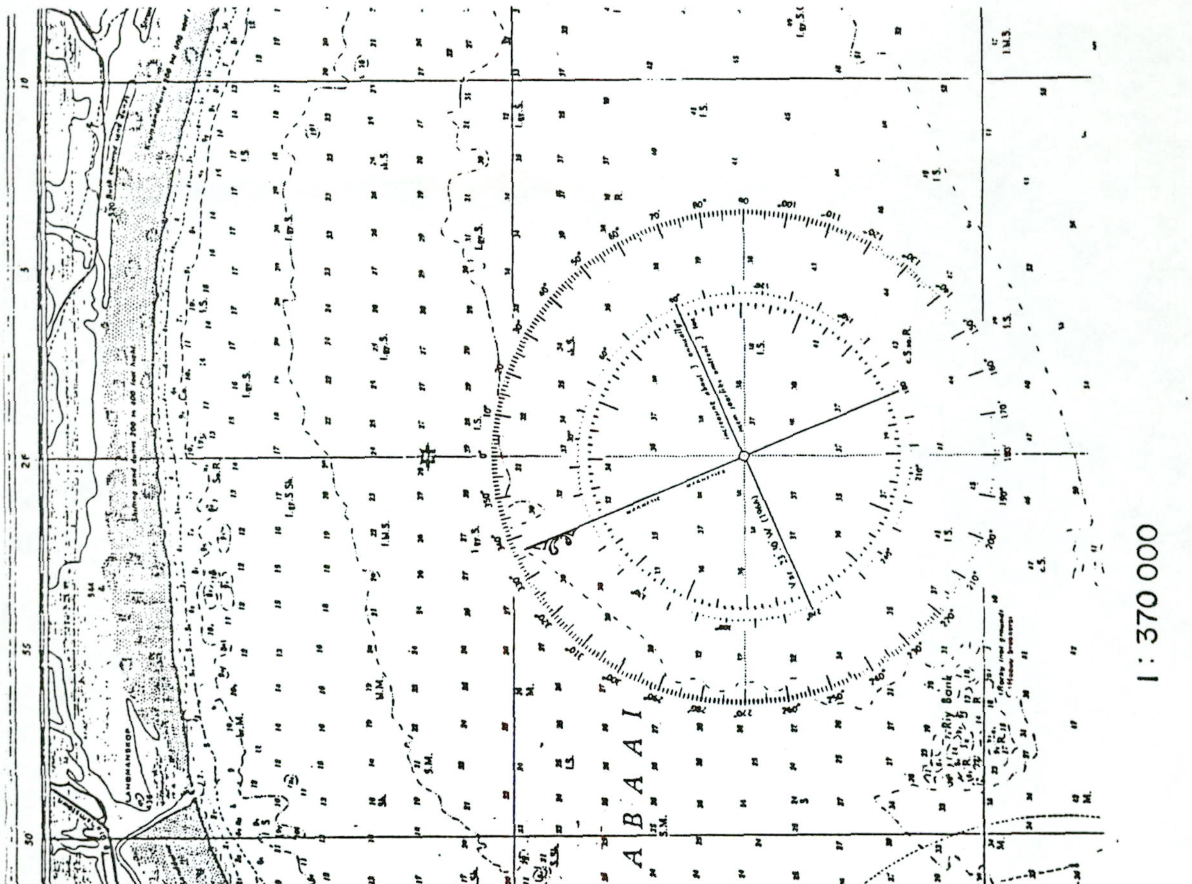

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LOCALITY PLAN (2)

FIGURE
1(ii)

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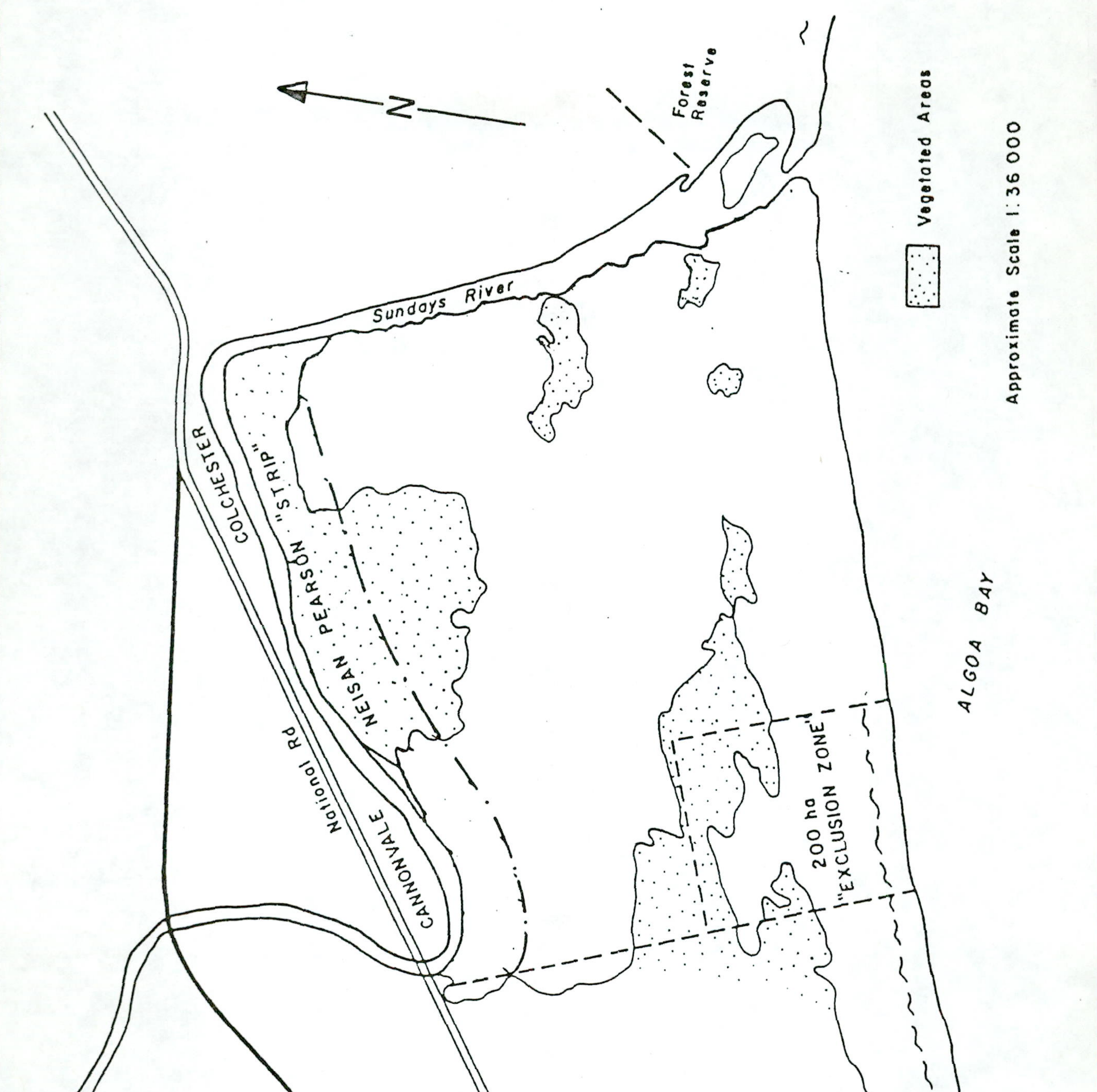

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LOCALITY PLAN (3)

FIGURE
1(iii)

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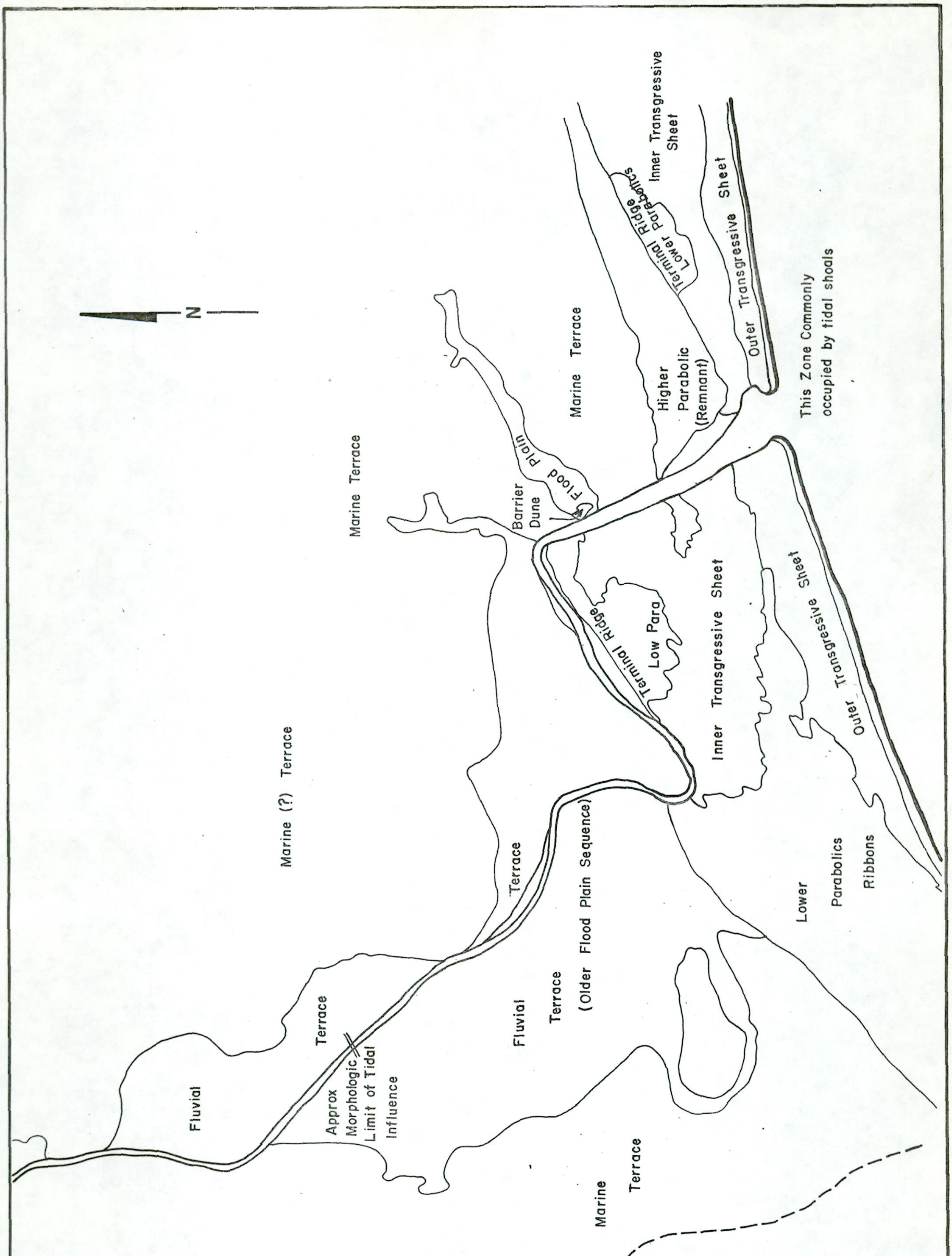

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LOCALITY PLAN (4)

FIGURE
I (iv)

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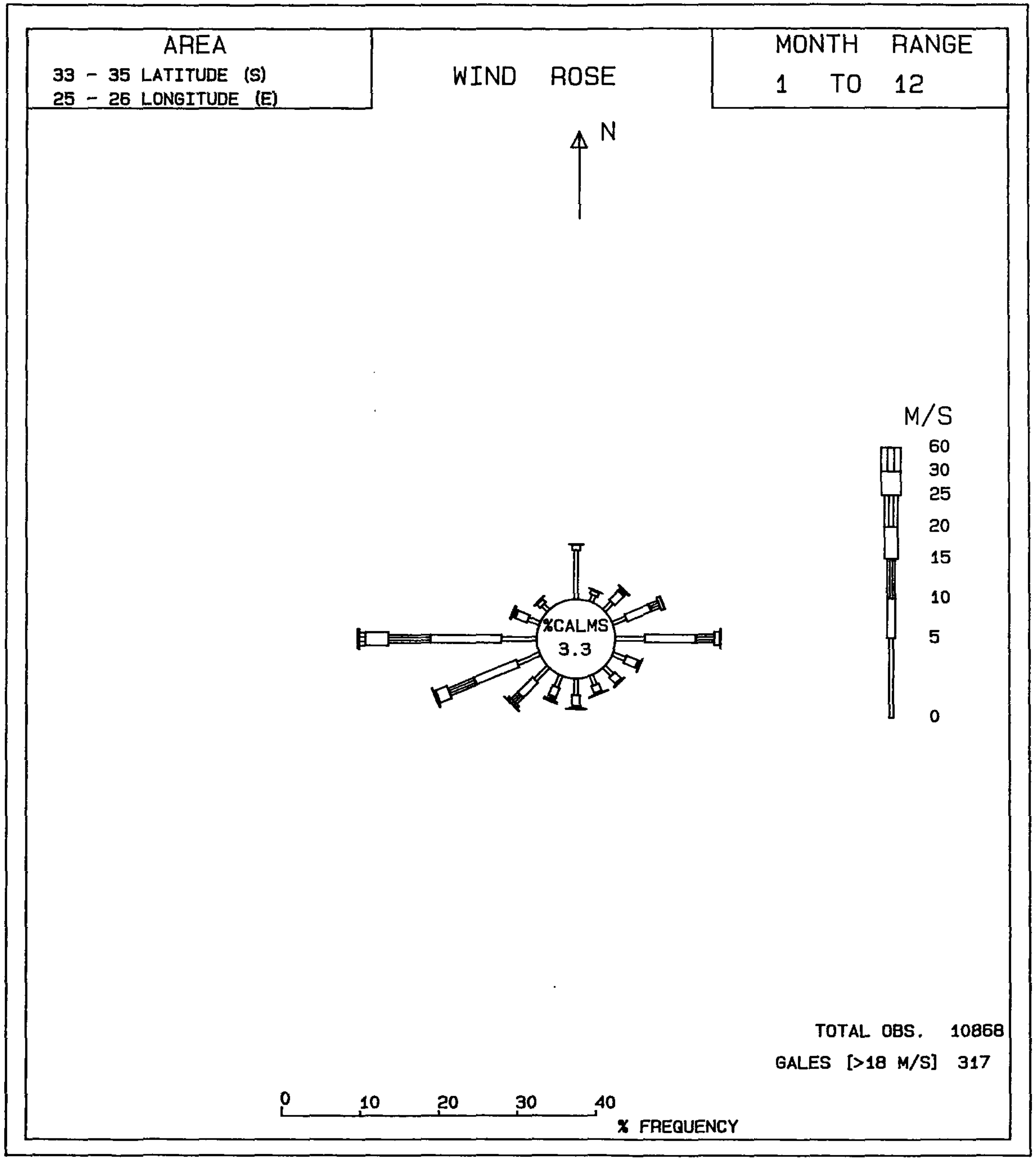

Figure 2(i)

VOS Wind rose for year (1961-1979)

Area: 33°-35°S
25°-26°E

FIGURE 2(i)

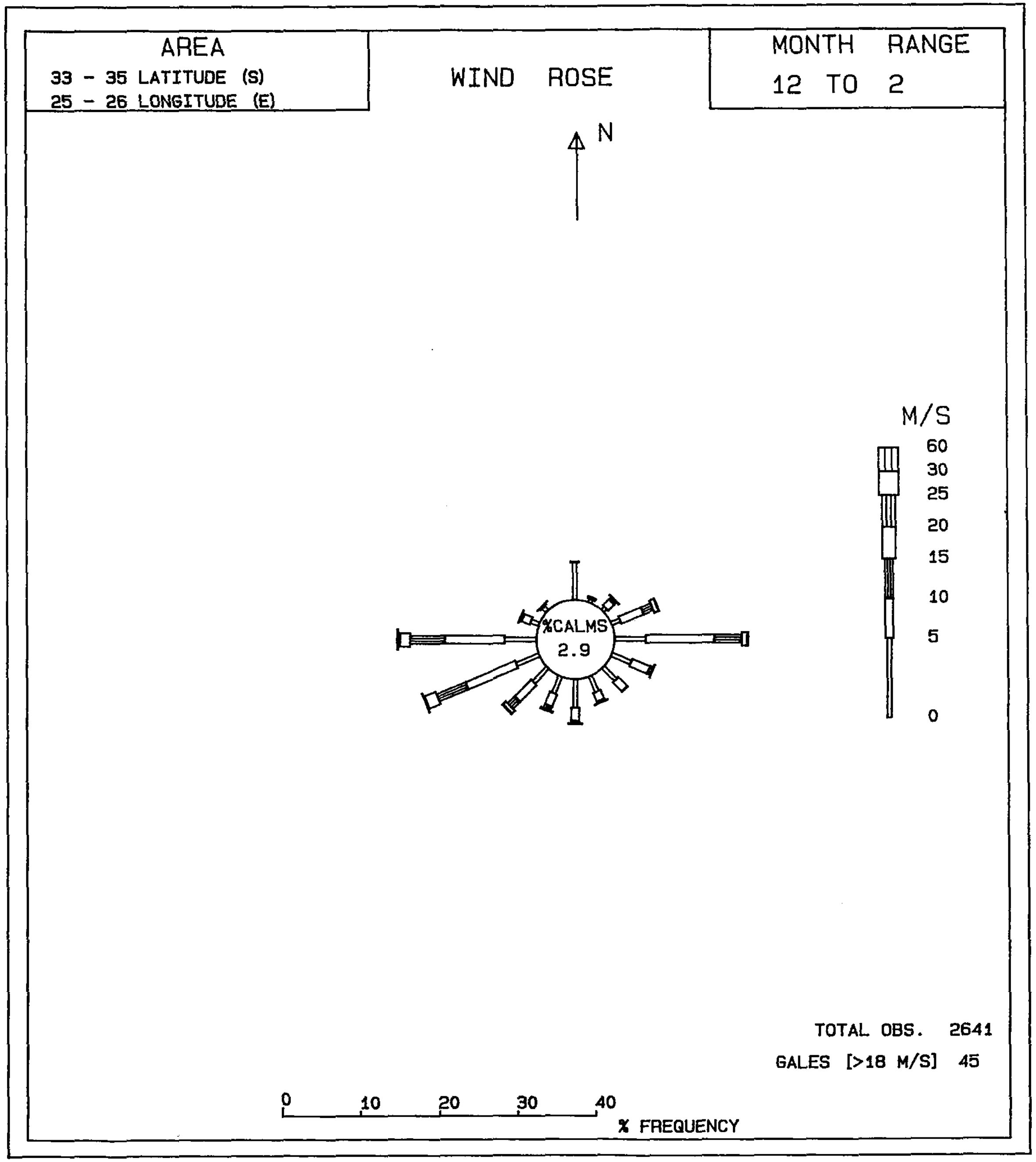

Figure 2(ii)

VOS Wind rose for Summer (1961-1979)

Area: 33°-35°S

25°-26°E

FIGURE 2(ii)

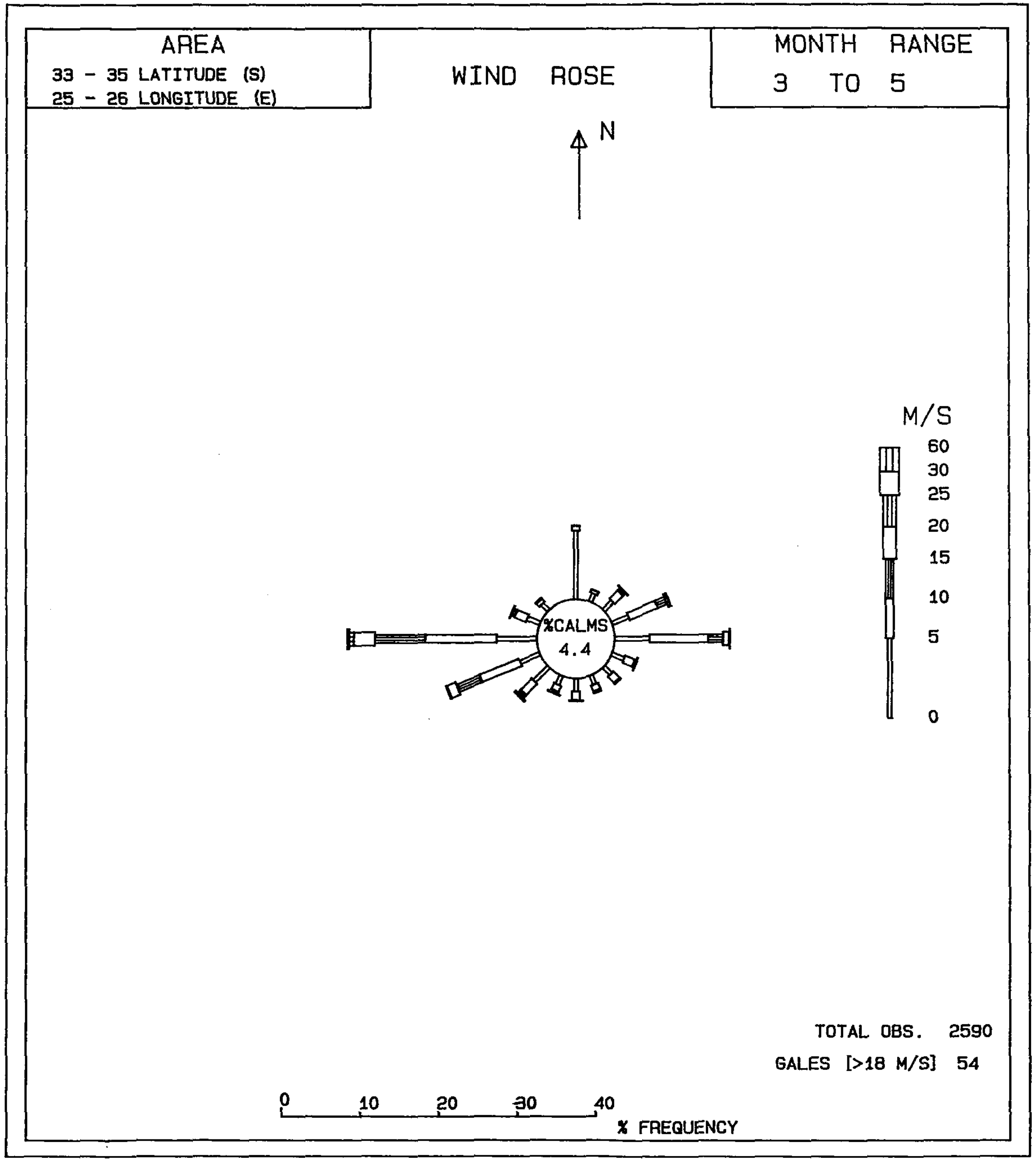

Figure 2(iii)

VOS Wind rose for Autumn (1961-1979)

Area: 33°-35°S
25°-26°E

FIGURE 2(iii)

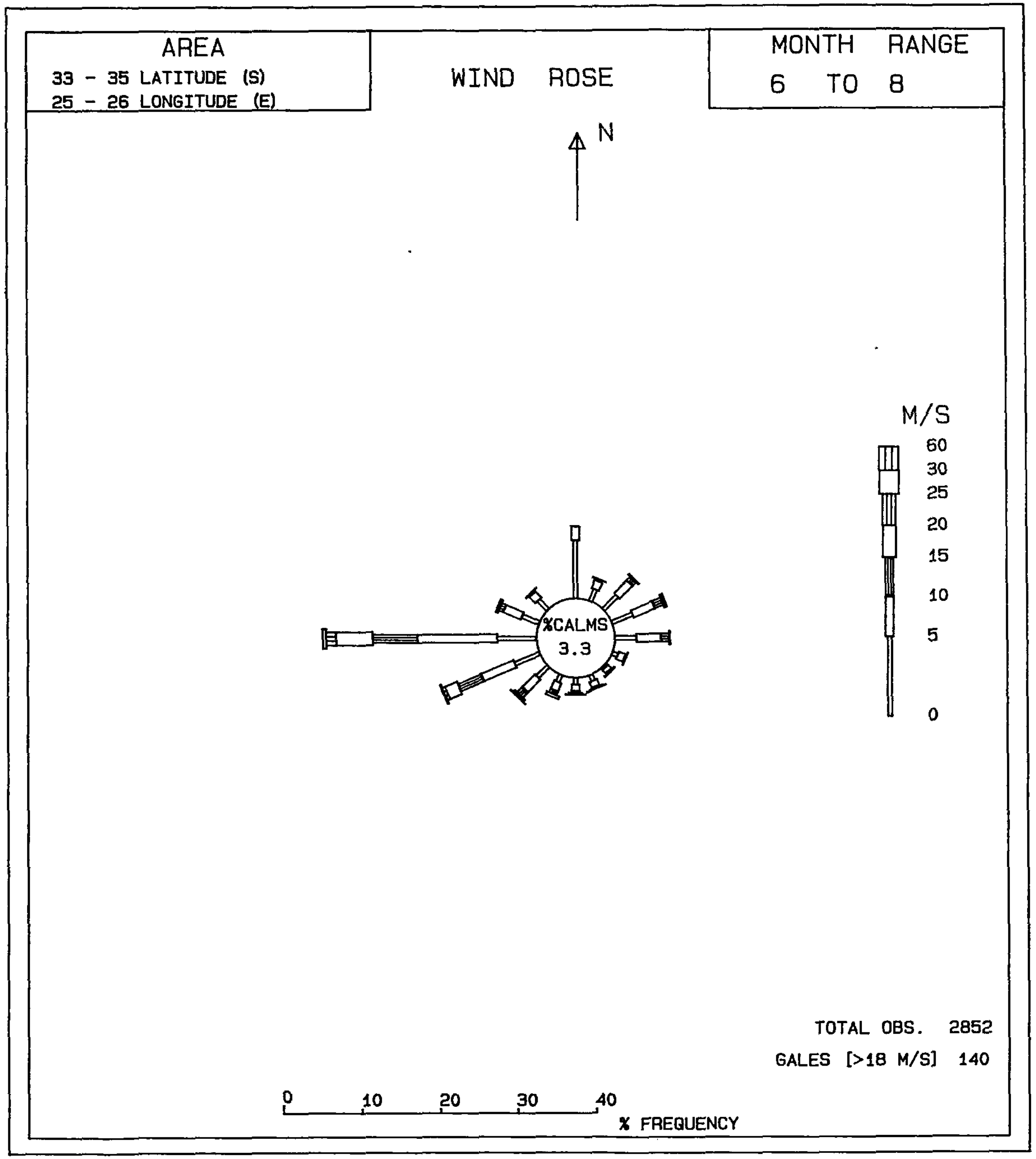

Figure 2(iv)
VOS Wind rose for Winter (1961-1979)
Area: 33°-35°S
25°-26°E

FIGURE 2(iv)

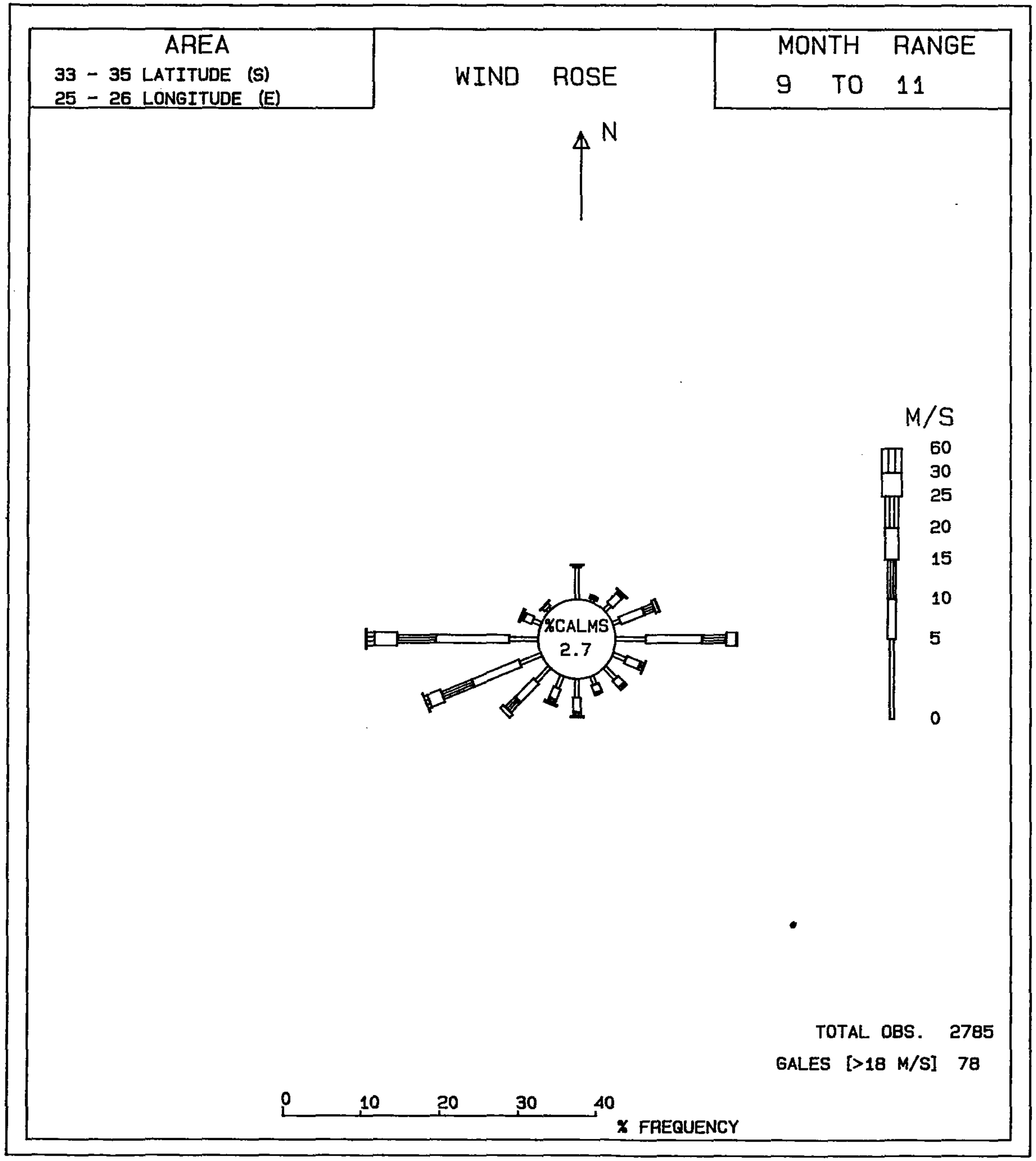

Figure 2(v)

VOS Wind rose for Spring (1961-1979)

Area: 33°-35°S

25°-26°E

FIGURE 2(v)

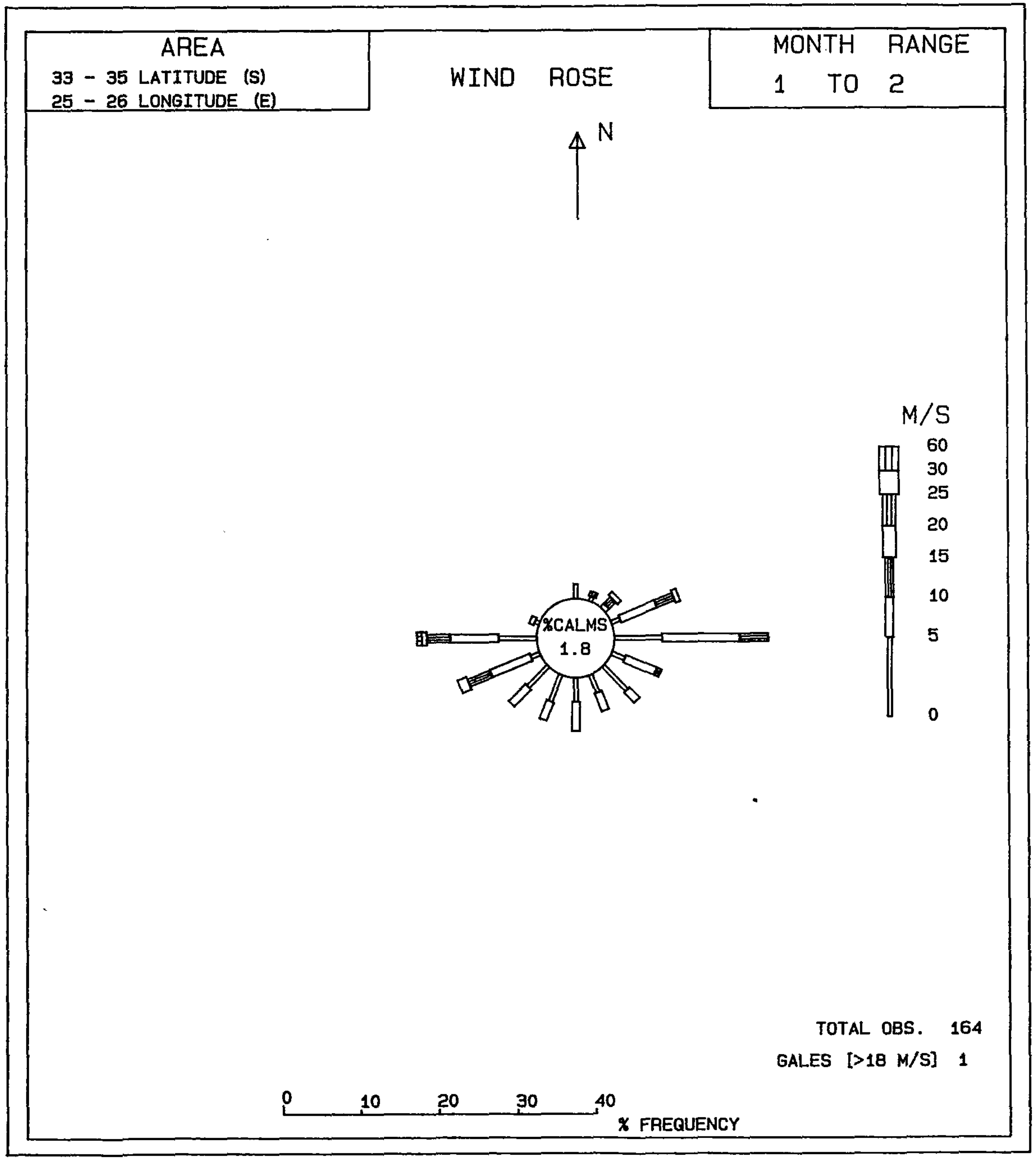

Figure 2(vi)

VOS Wind rose for Jan/Feb 1971

Area: 33°-35°S

25°-26°E

FIGURE 2(vi)

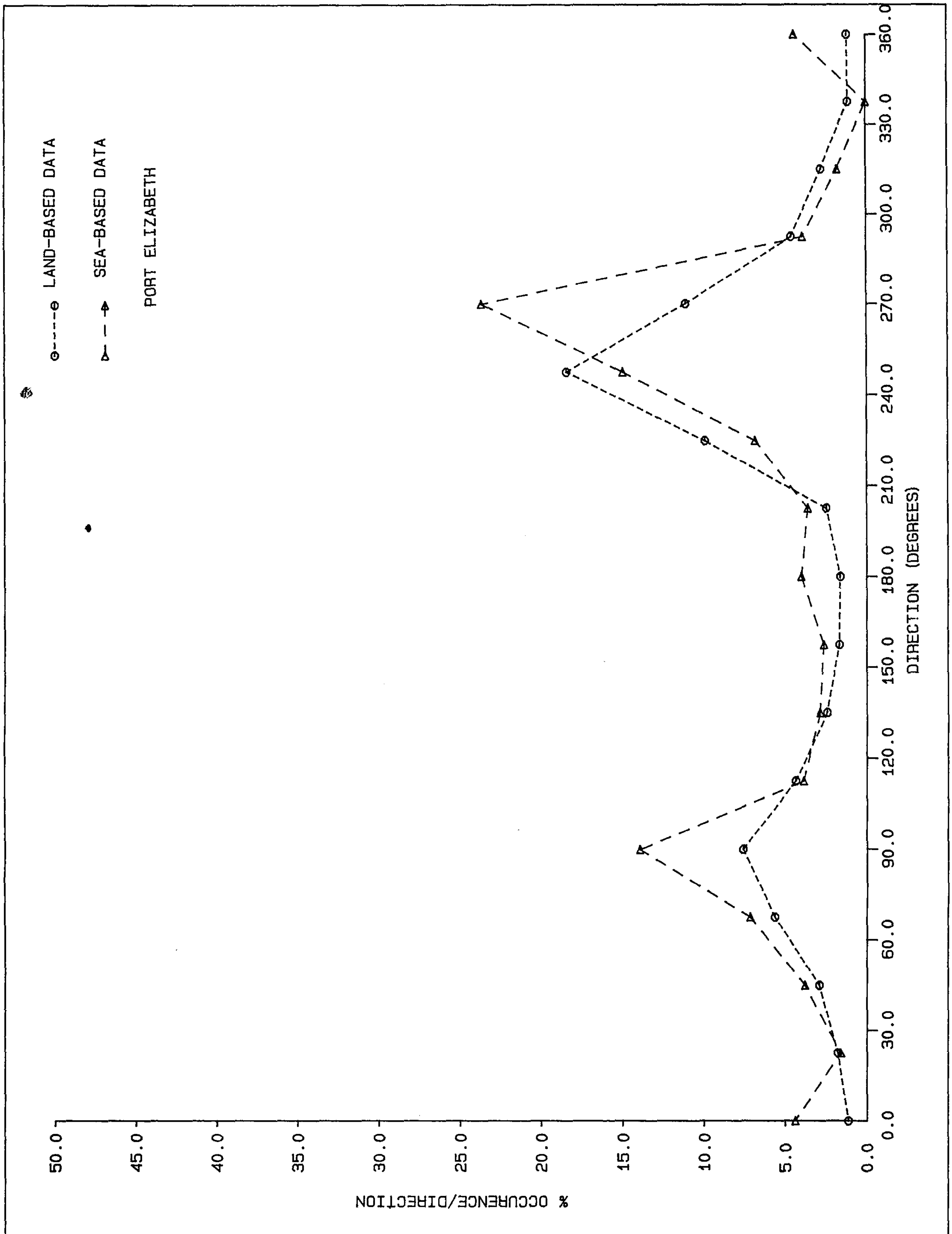

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Figure 3(i) Comparison of VOS and airport wind direction distributions for the whole year.

FIGURE 3(i)

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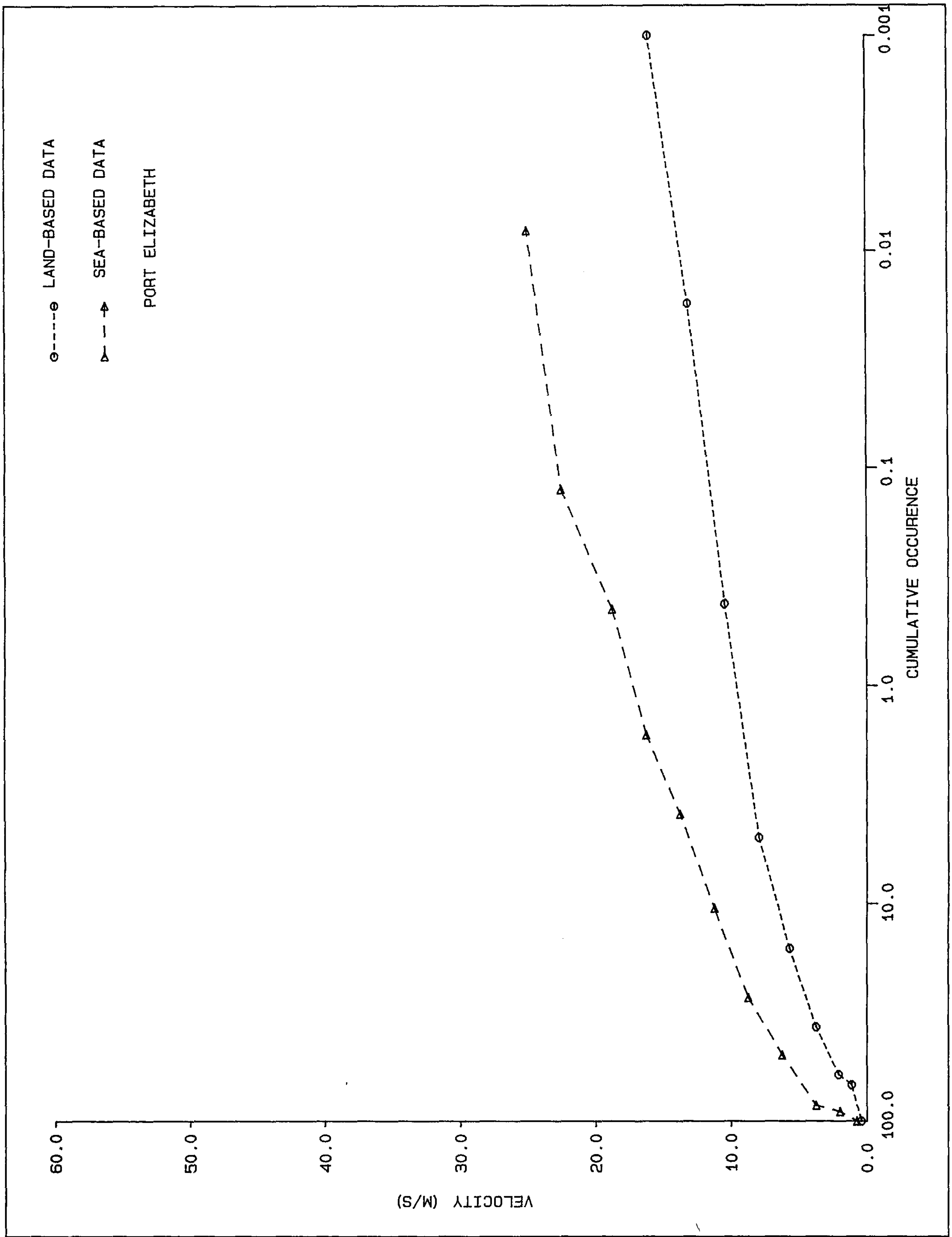

TRACED : COMPLOT CHECKED: DATE : REF. :	**Figure 3(ii)** Comparison of VOS and airport wind velocity exceedance curves for the whole year.	FIGURE 3(ii)

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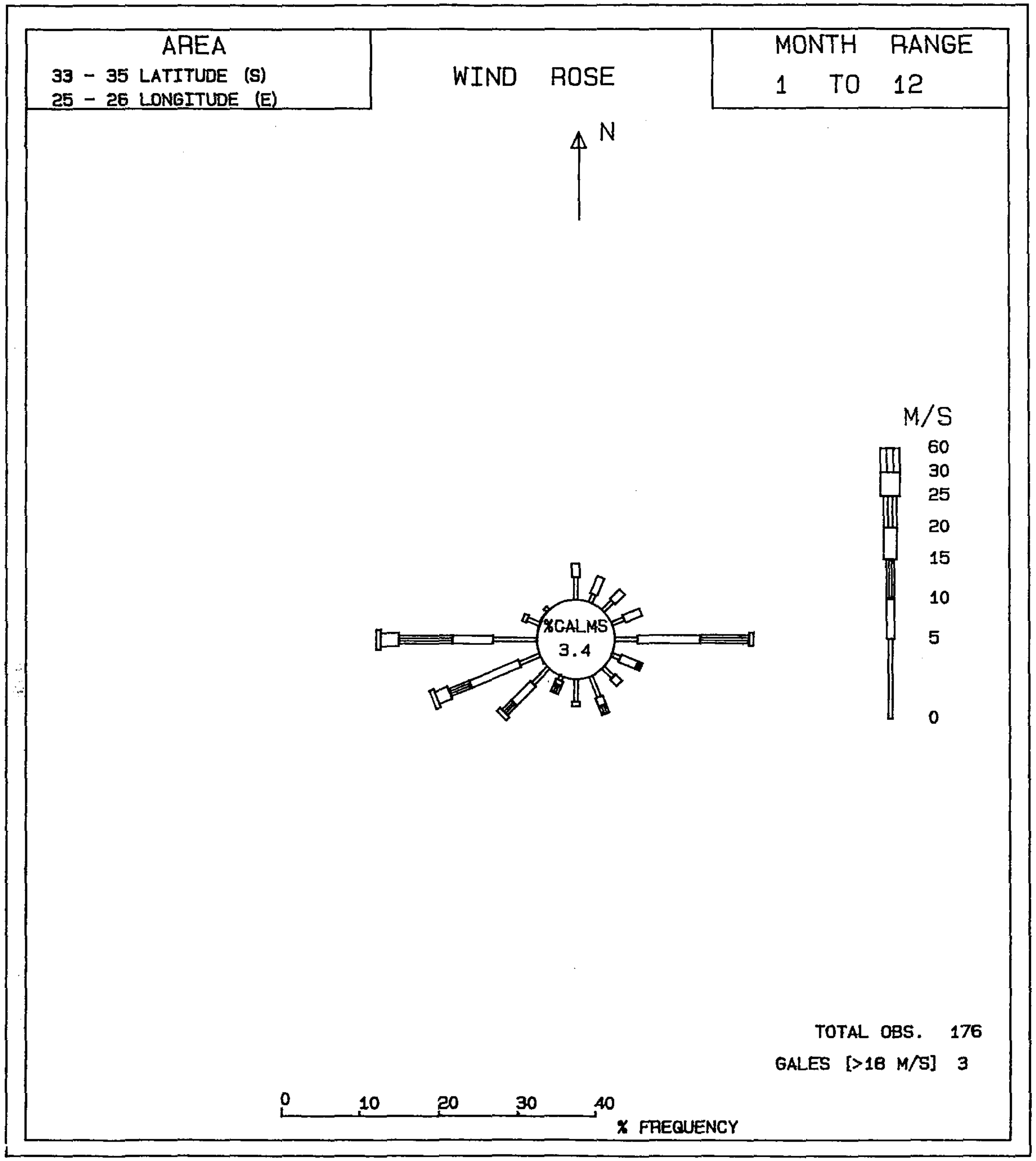


Figure 4(i) VOS wind rose for 1965. (33°-35° South, 25°-26° East).

FIGURE 4(i)

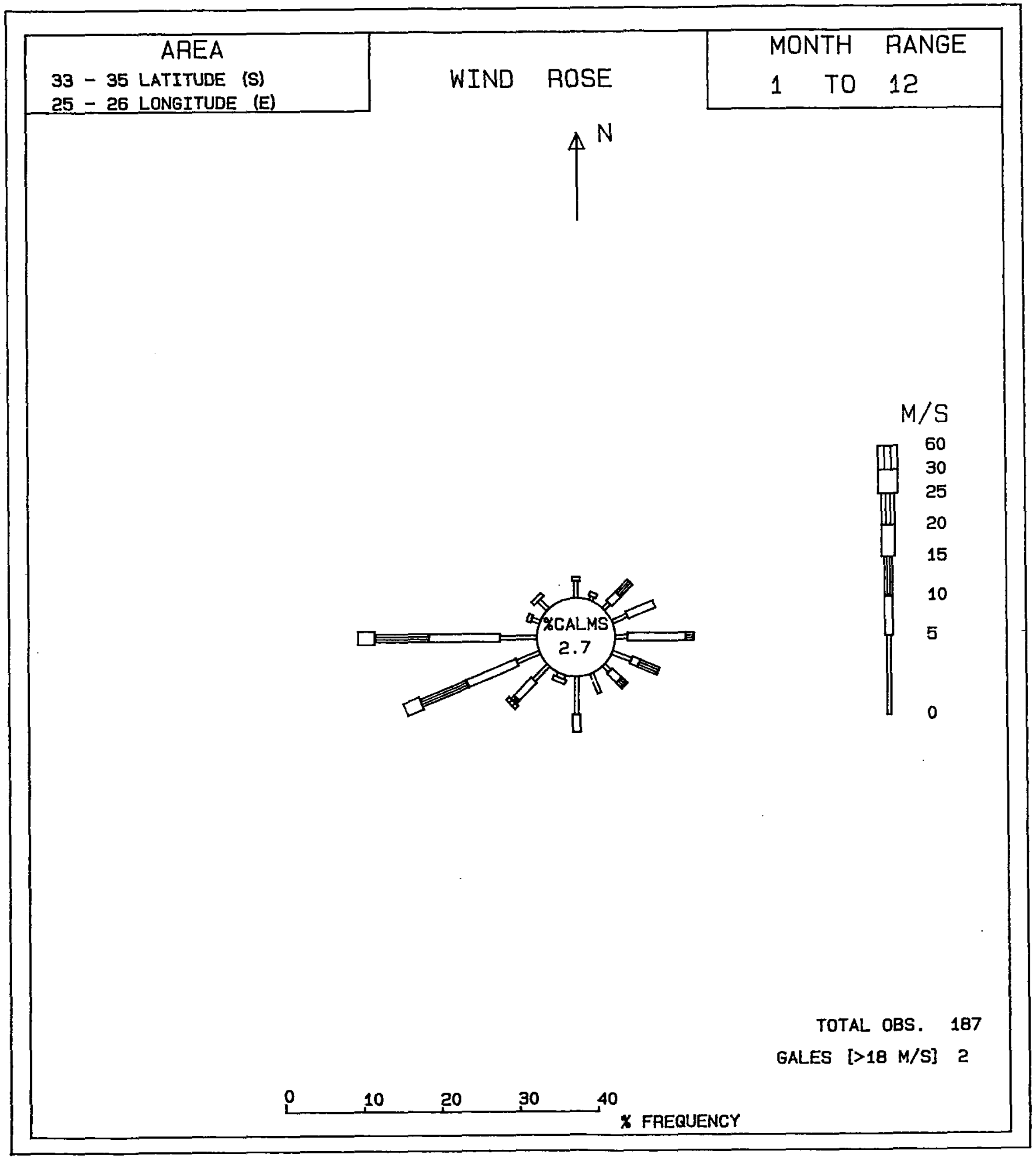


Figure 4(ii) VOS wind rose for 1966.
(33°-35° South, 25°-26° East).

FIGURE 4(ii)

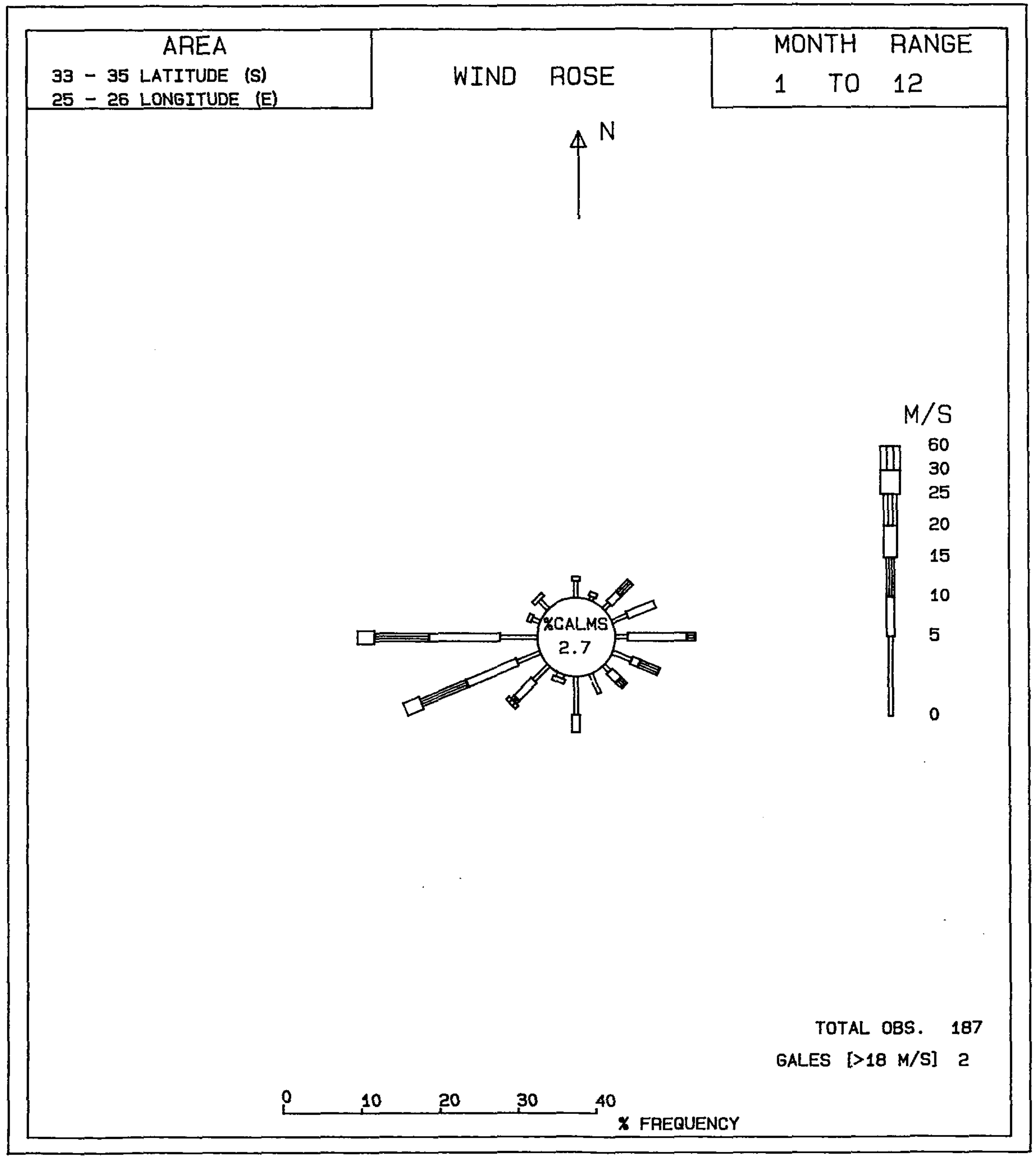


Figure 4(ii) VOS wind rose for 1966.
(33°-35° South, 25°-26° East).

FIGURE 4(ii)

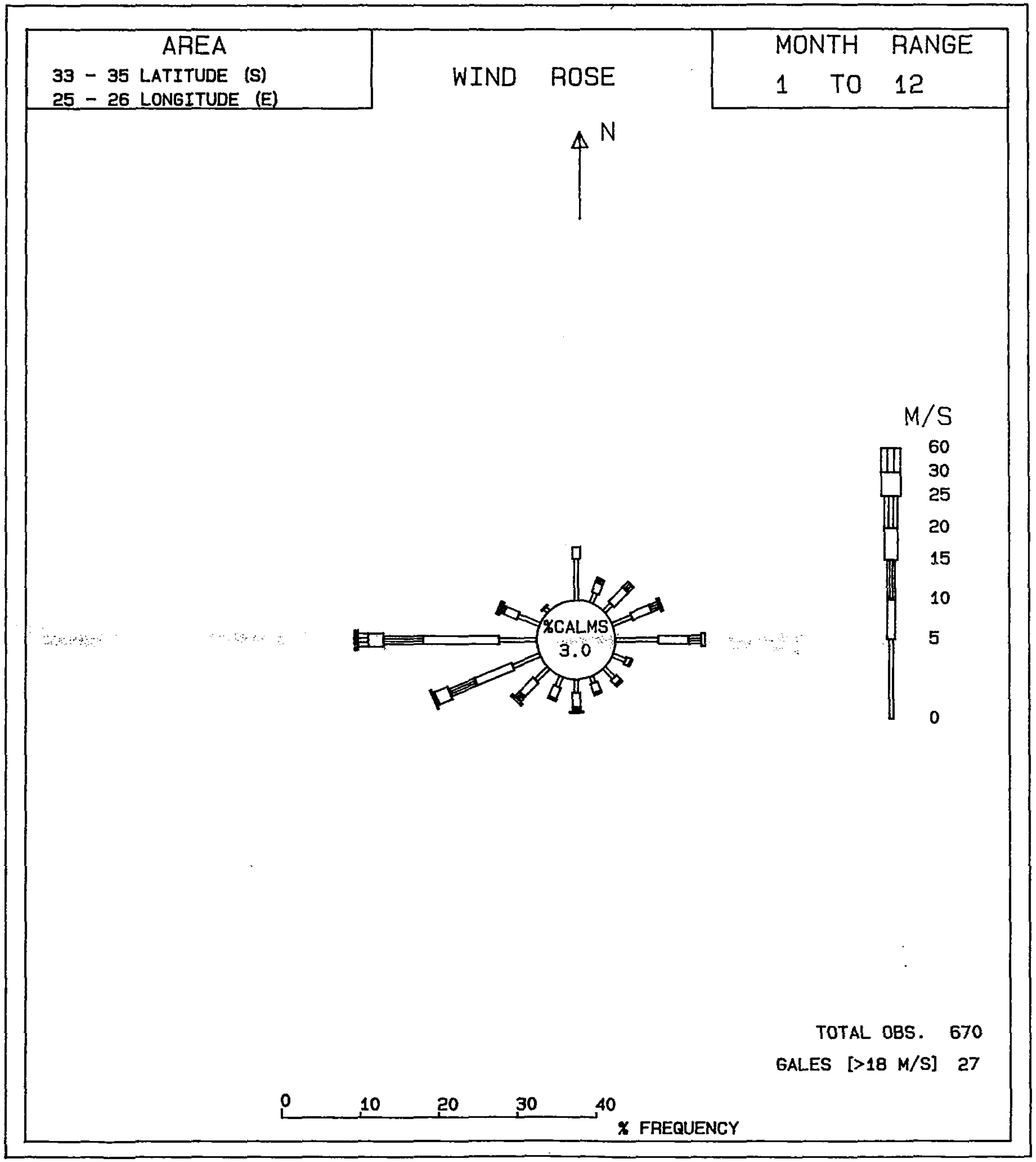


Figure 4(iii) VOS wind rose for 1967. (33°-35° South, 25°-26° East).

FIGURE 4(iii)

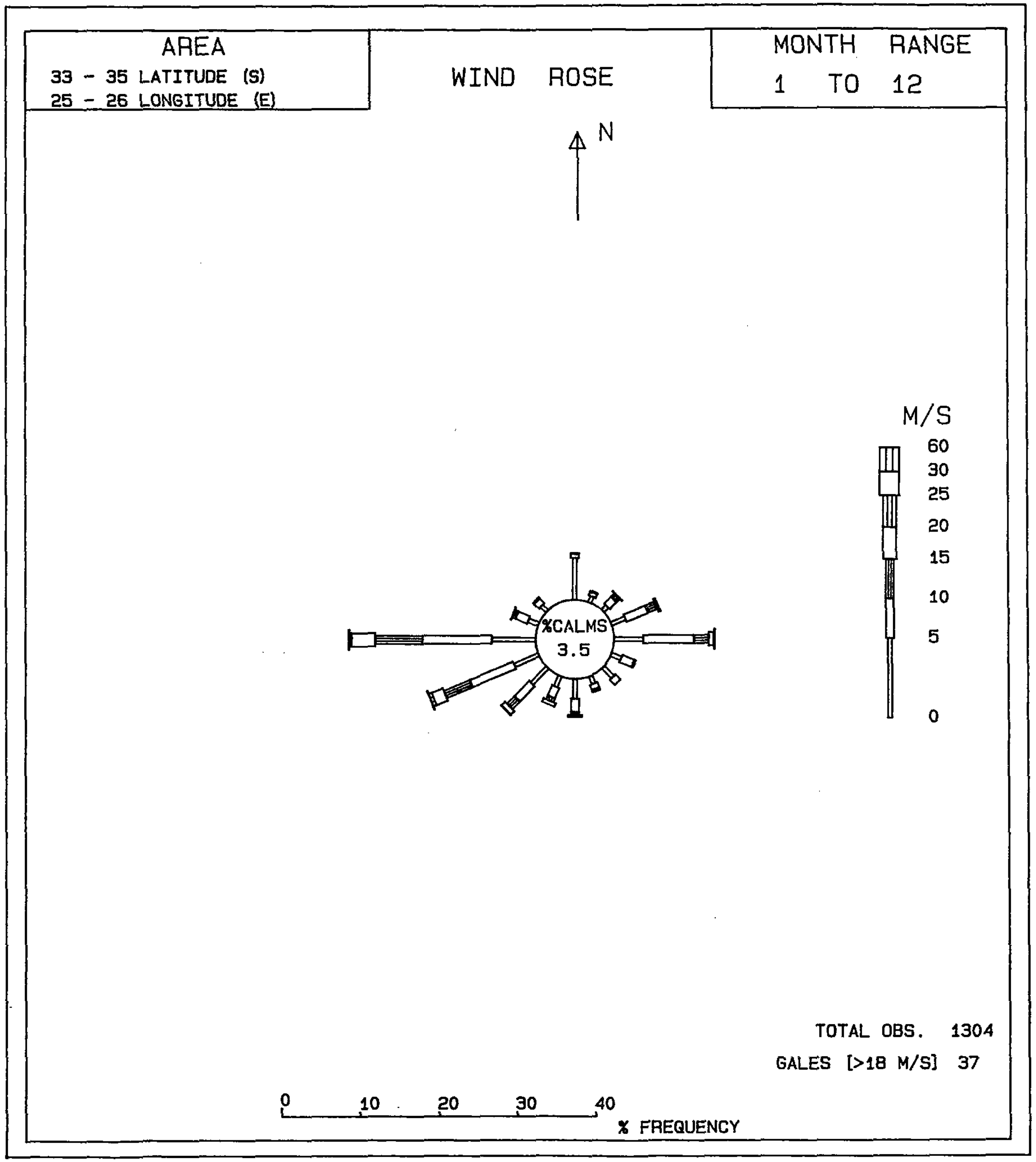


FIGURE 4(iv)

Figure 4(iv) VOS wind rose for 1968. (33°-35° South, 25°-26° East).

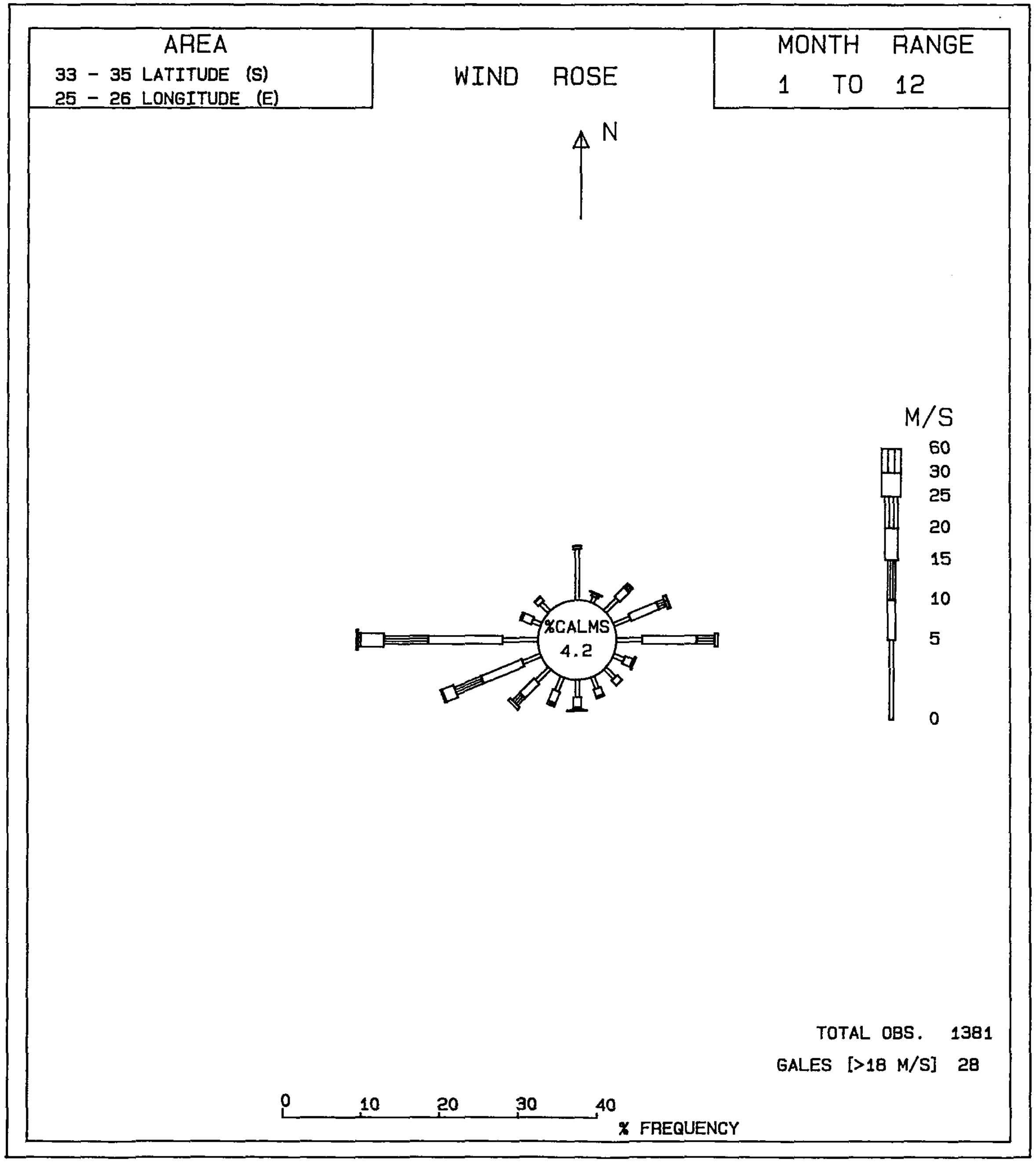


Figure 4(v) VOS wind rose for 1969. (33°-35° South, 25°-26° East).

FIGURE 4(v)

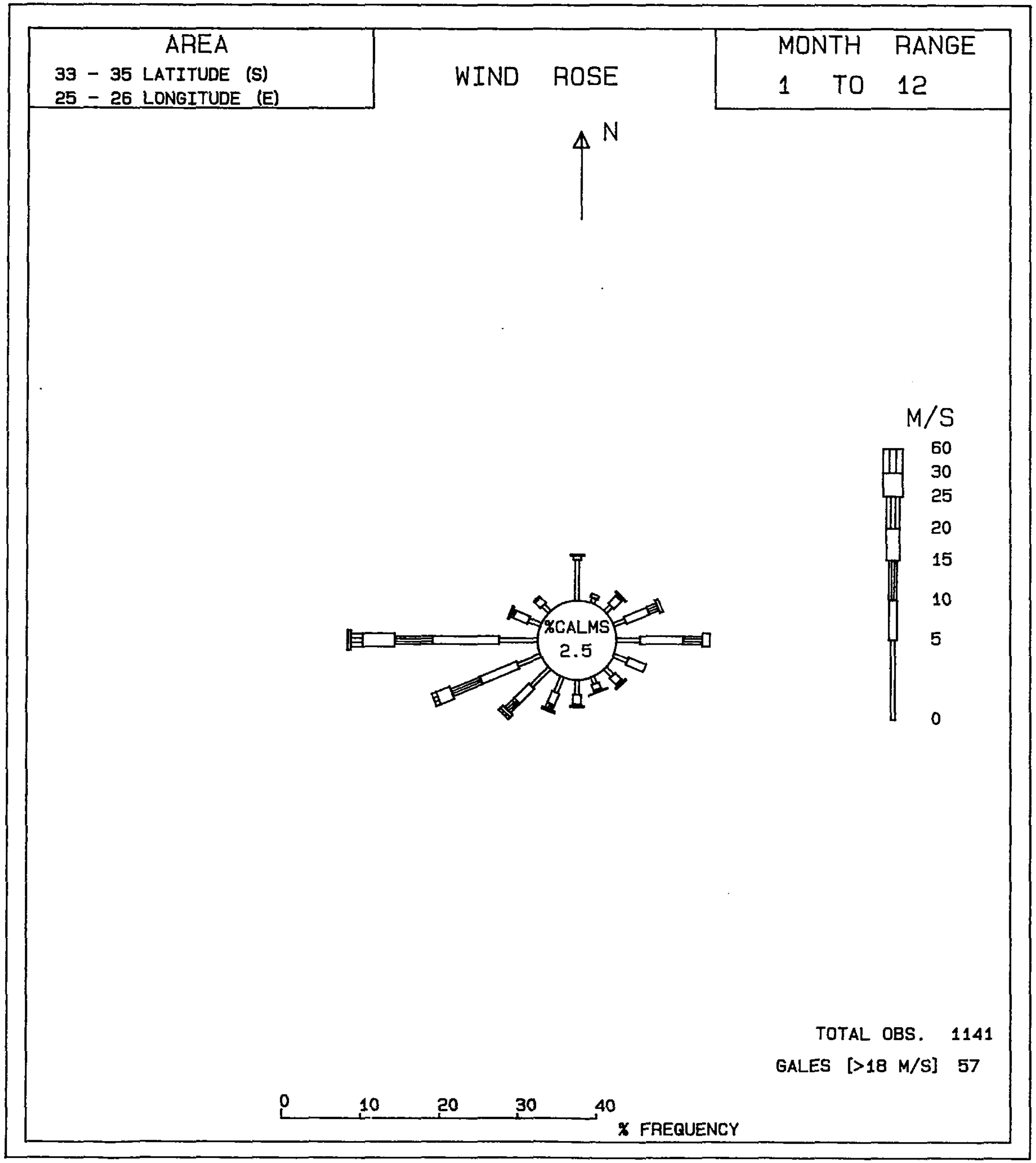


Figure 4 (vi) VOS wind rose for 1970. (33°-35° South, 25°-26° East).

FIGURE 4(vi)

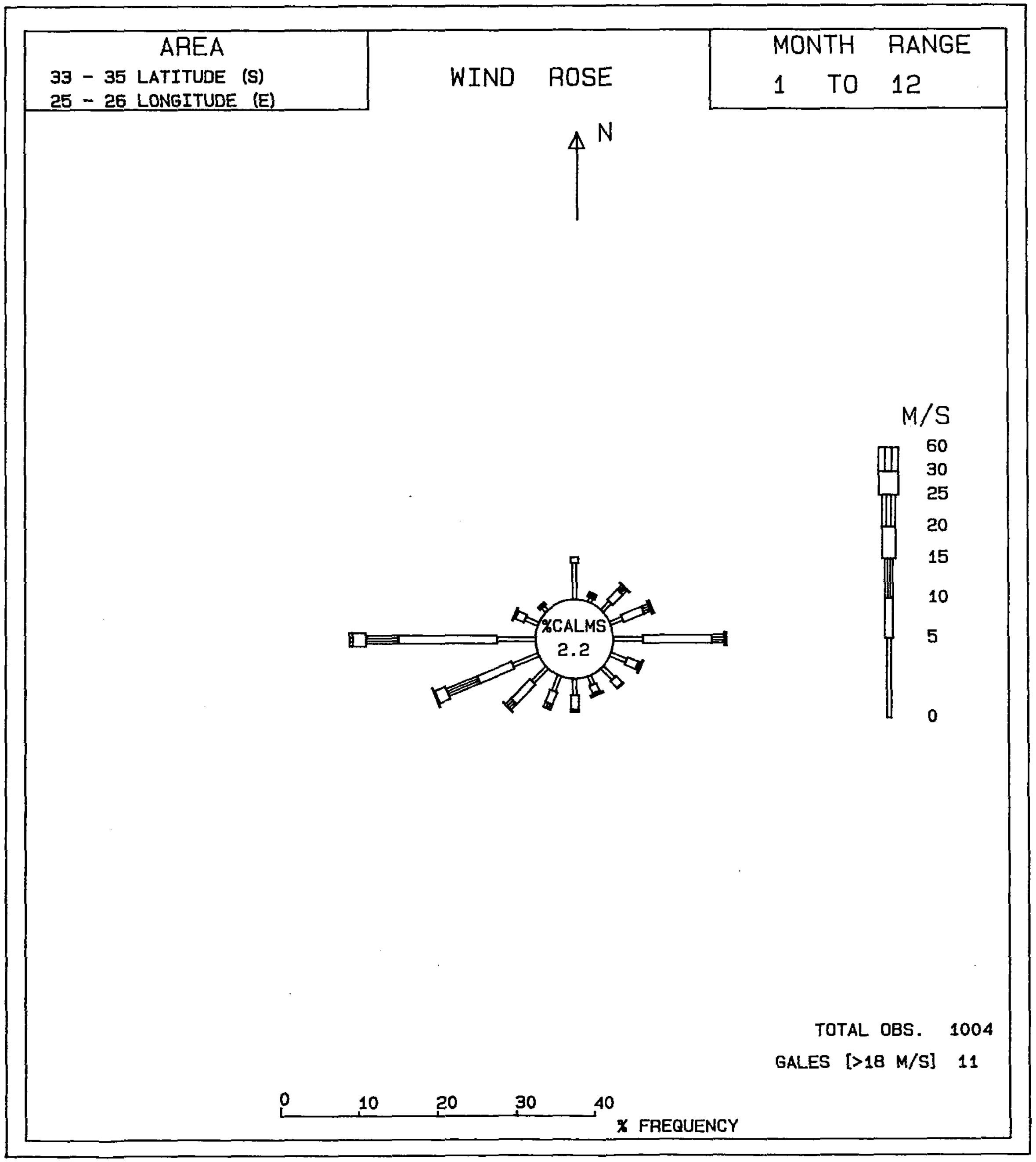


Figure 4(vii) VOS wind rose for 1971.
(33°-35° South, 25°-26° East).

FIGURE 4 (vii)

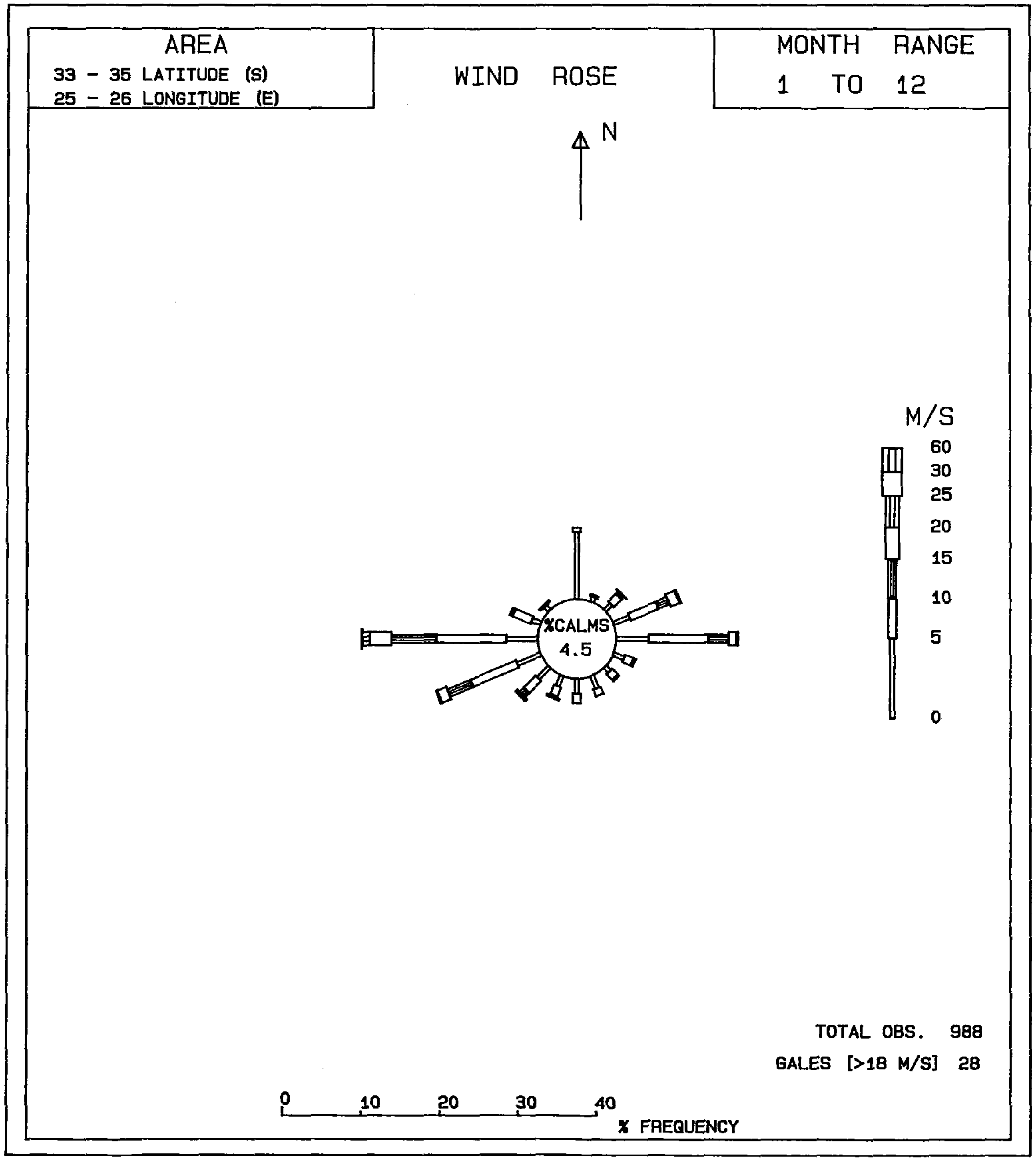


Figure 4(viii) VOS wind rose for 1972. (33°-35° South, 25°-26° East).

FIGURE 4(viii)

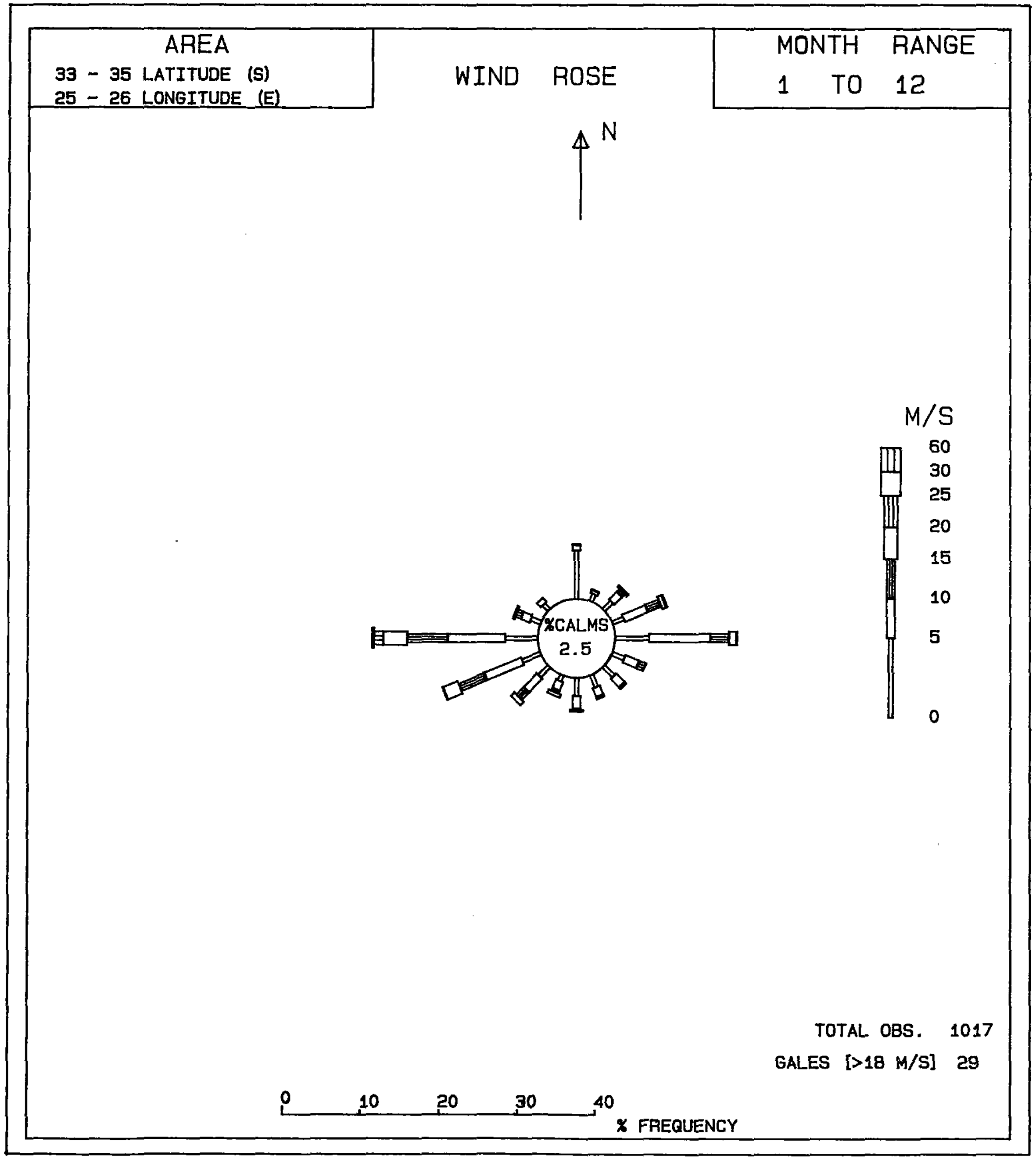


Figure 4(ix) VOS wind rose for 1973.
(33°-35° South, 25°-26° East).

FIGURE 4(ix)

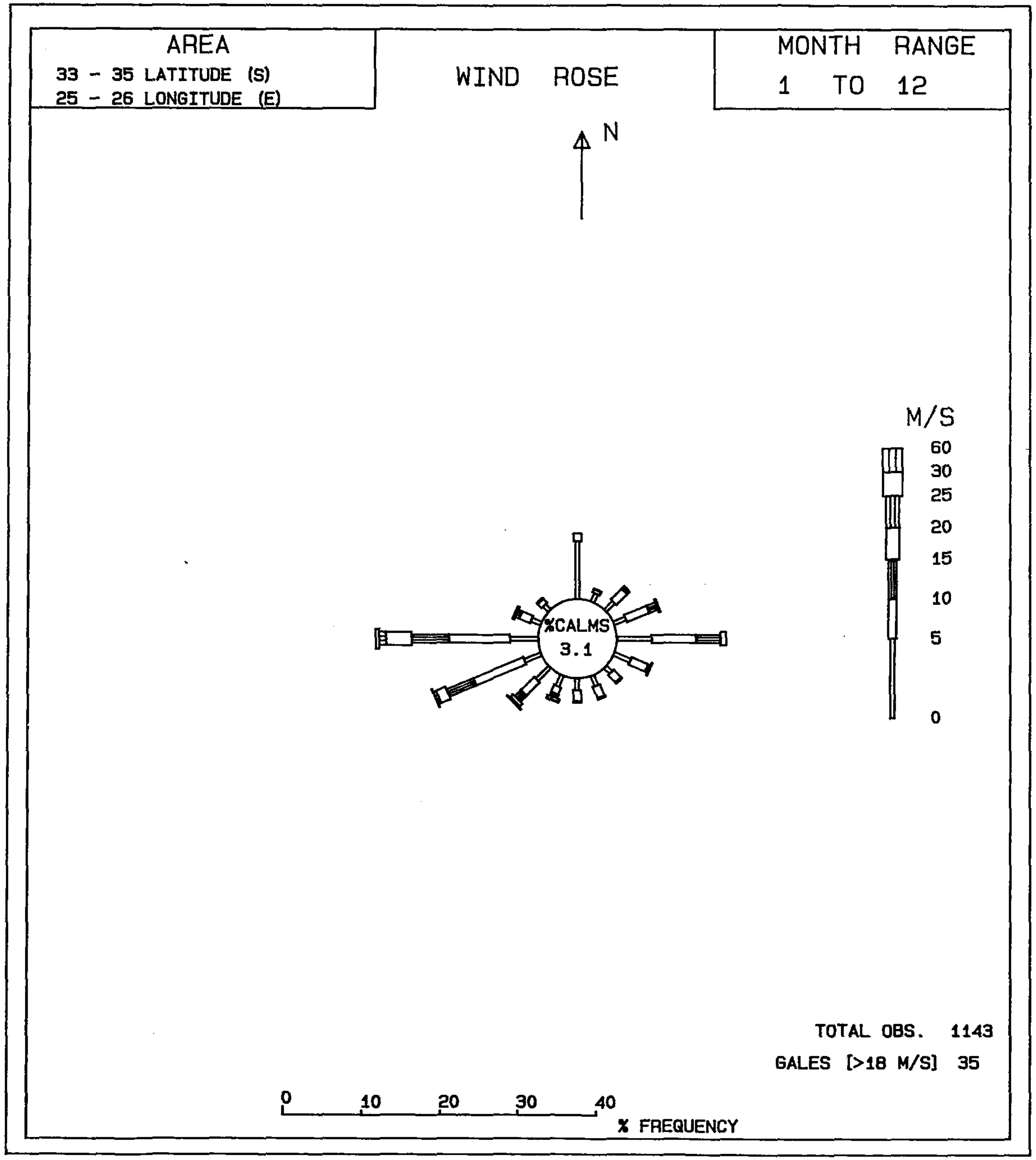


Figure 4(x) VOS wind rose for 1974.
(33°-35° South, 25°-26° East).

FIGURE 4(x)

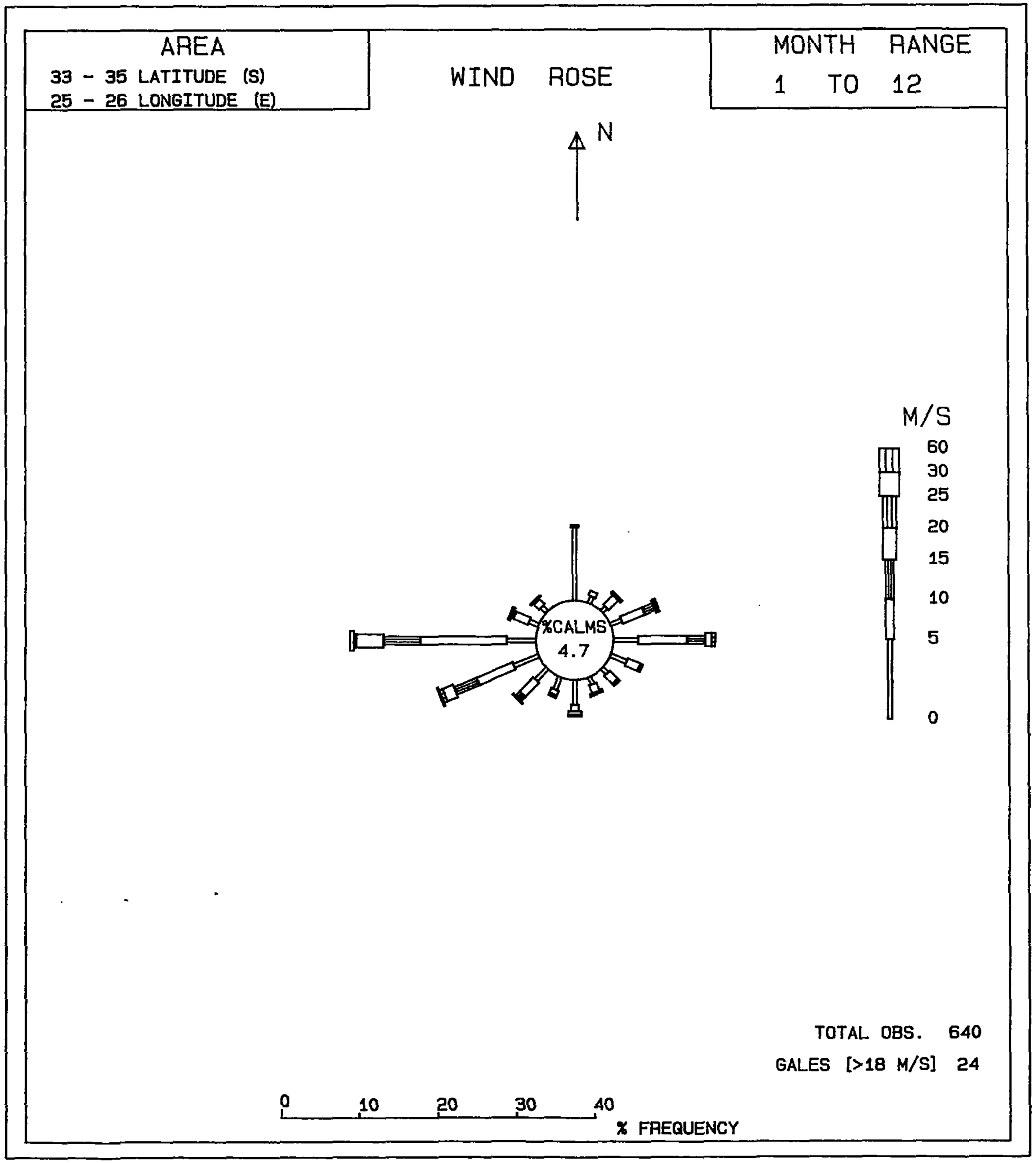


Figure 4(xi) VOS wind rose for 1975. (33°-35° South, 25°-26° East).

FIGURE 4(xi)

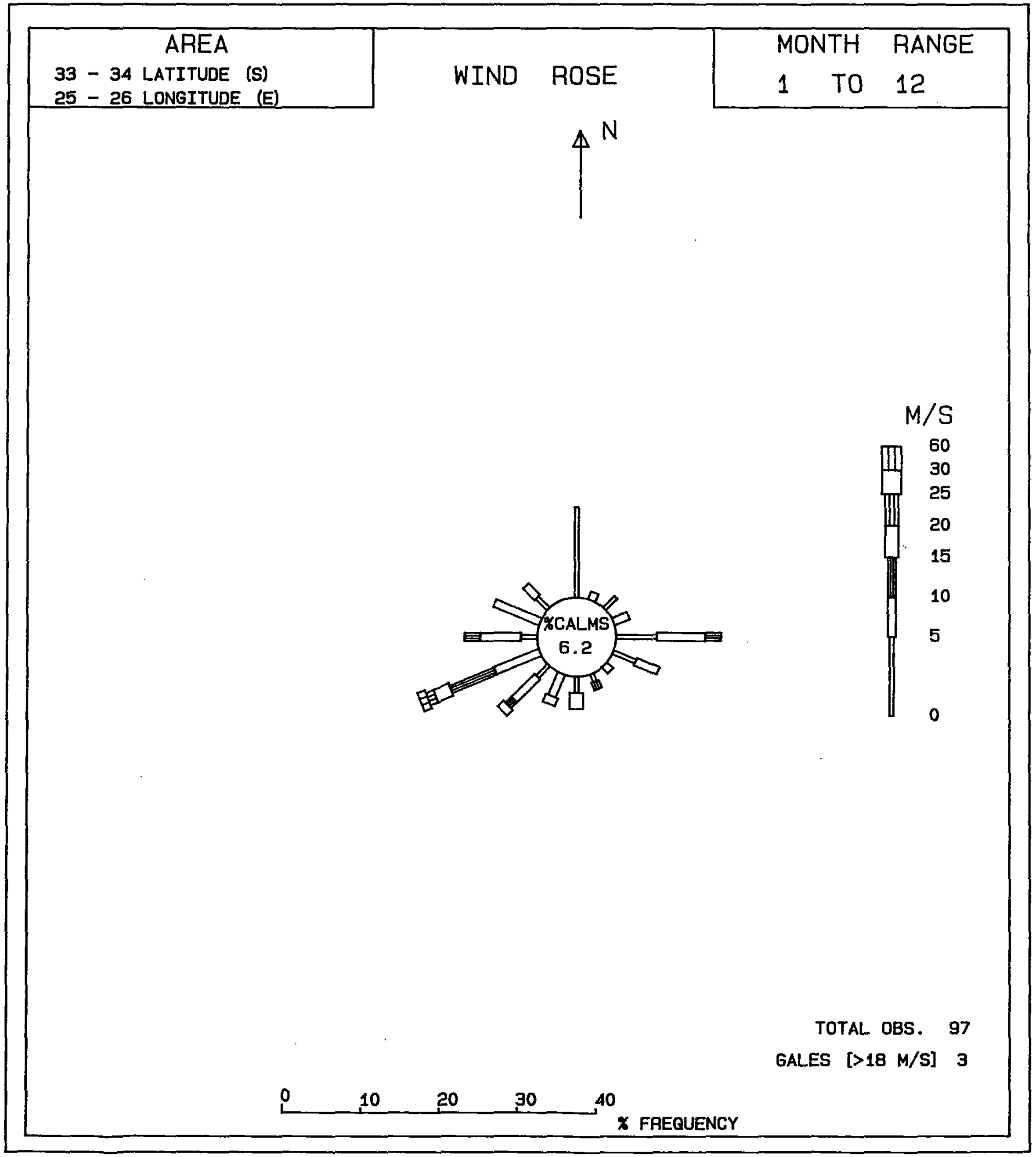


Figure 5(i)

VOS Wind rose for year (1961-1979)

Area: 33°40' - 34°S

25°40' - 26°E

FIGURE 5(i)

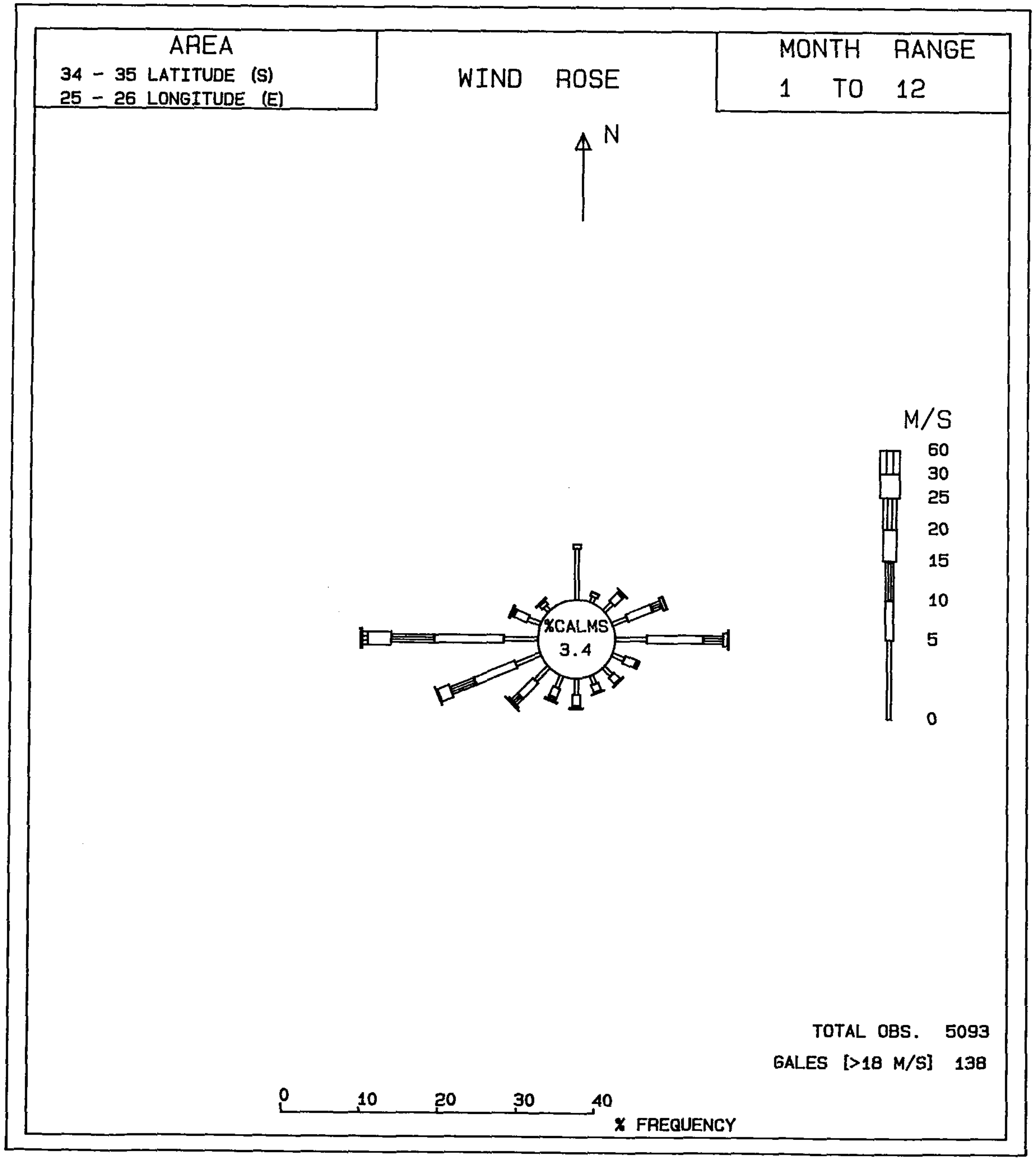


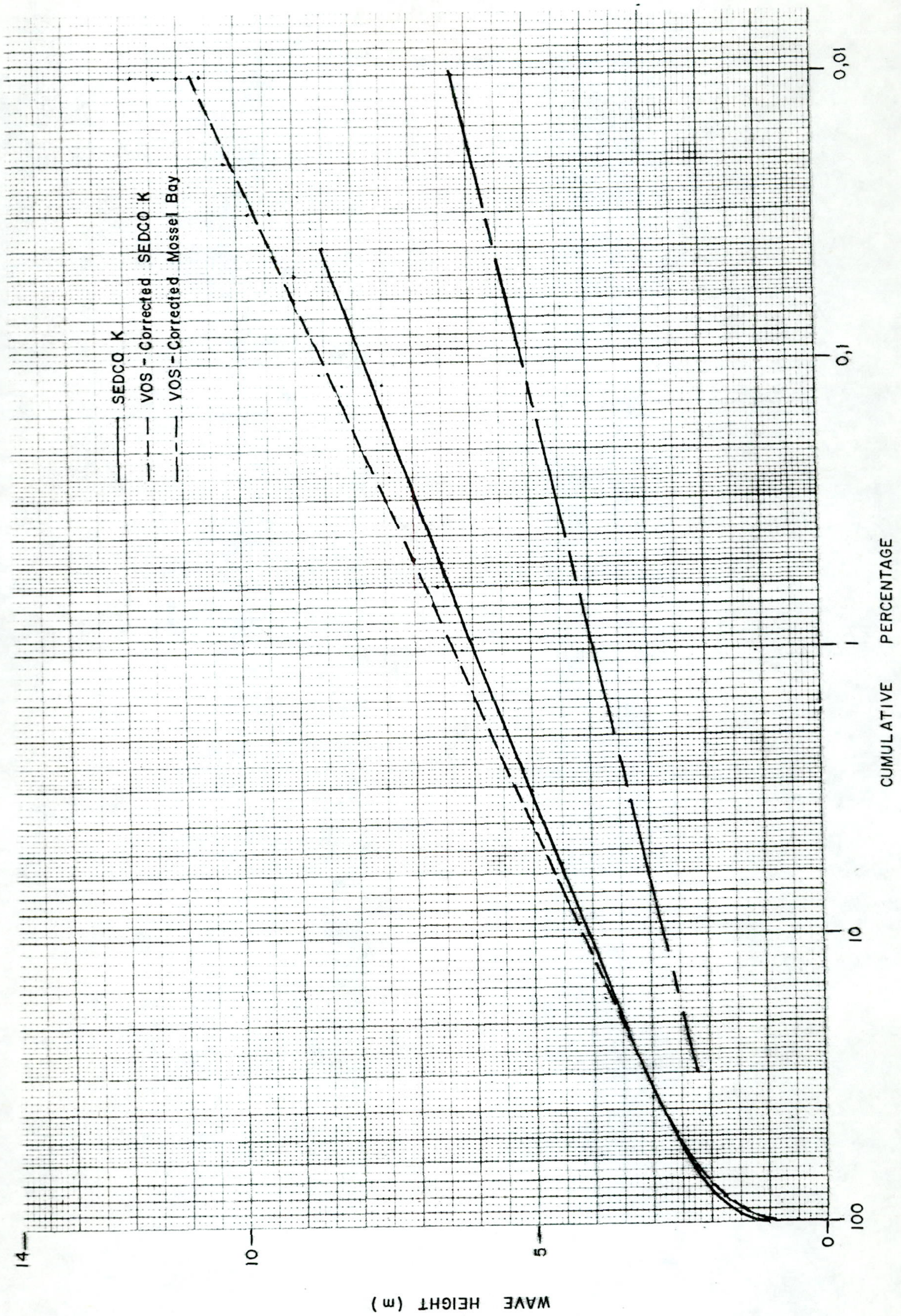
Figure 5(ii)

VOS Wind rose for year (1961-1979)

Area: 34° - 34°30'S

25°10' - 25°40'E

FIGURE 5(ii)



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SONDAGS RIVER / SCHELMHOEK

WAVE HEIGHT EXEEDANCE CURVES

FIGURE
6

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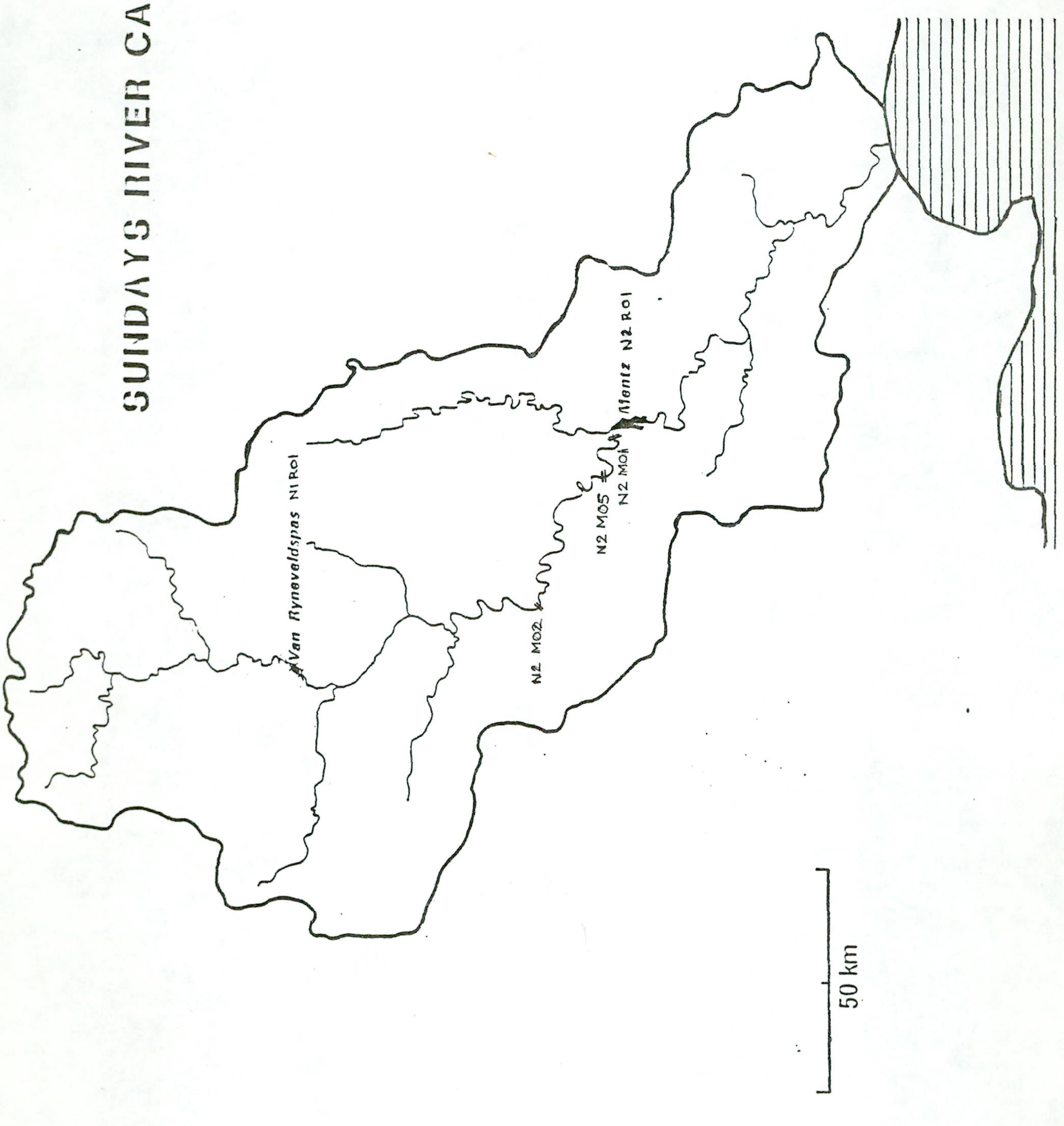
SUNDAYS RIVER CATCHMENT AREA



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SONDAGS RIVER / SCHELMHOEK

SONDAGS RIVER CATCHMENT AREA

FIGURE
7(i)

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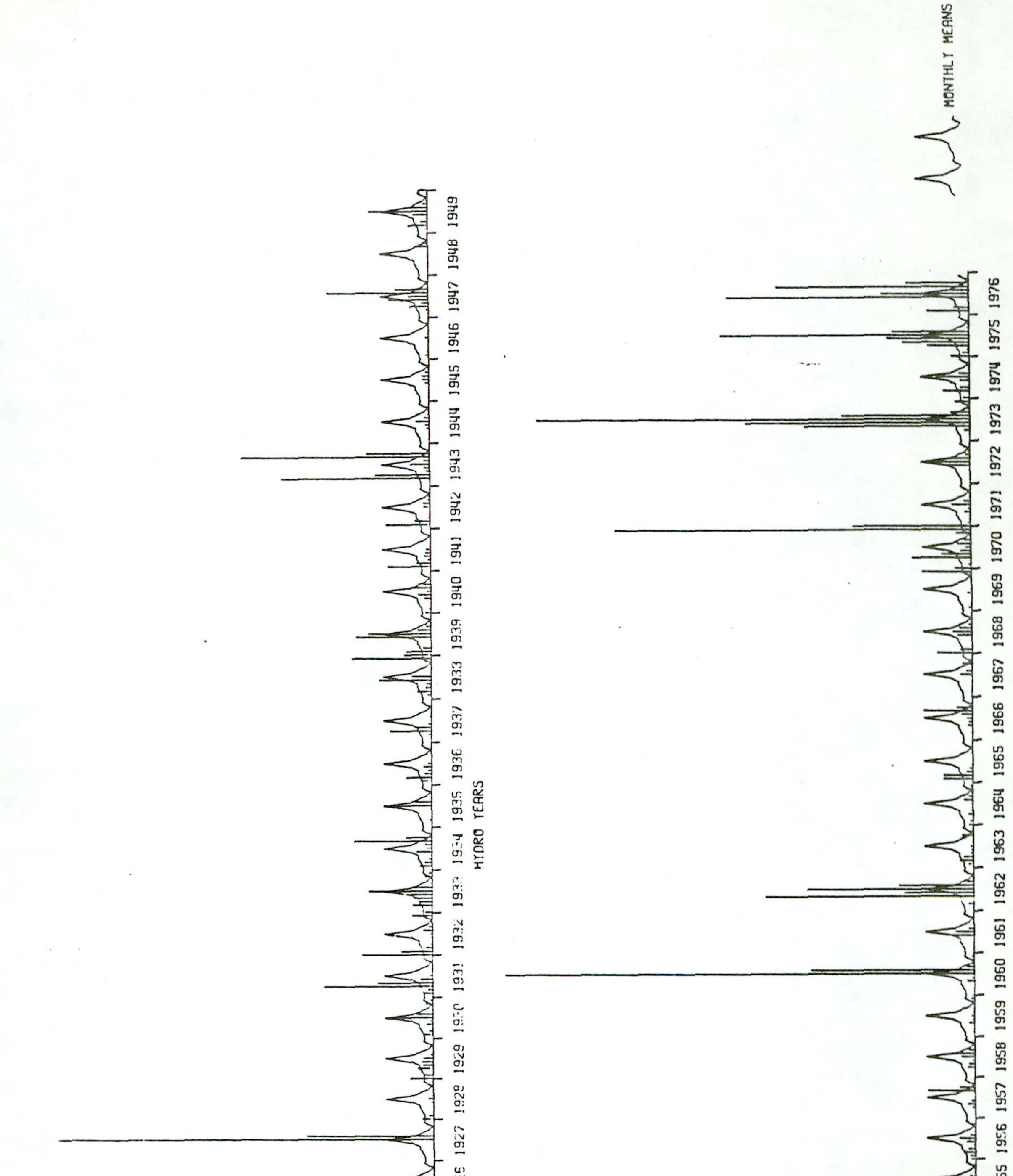

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CAPE ESTUARIES: SONDAGS

SIMULATED MONTHLY RUN-OFF

1921-1976

FIGURE

7(ii)

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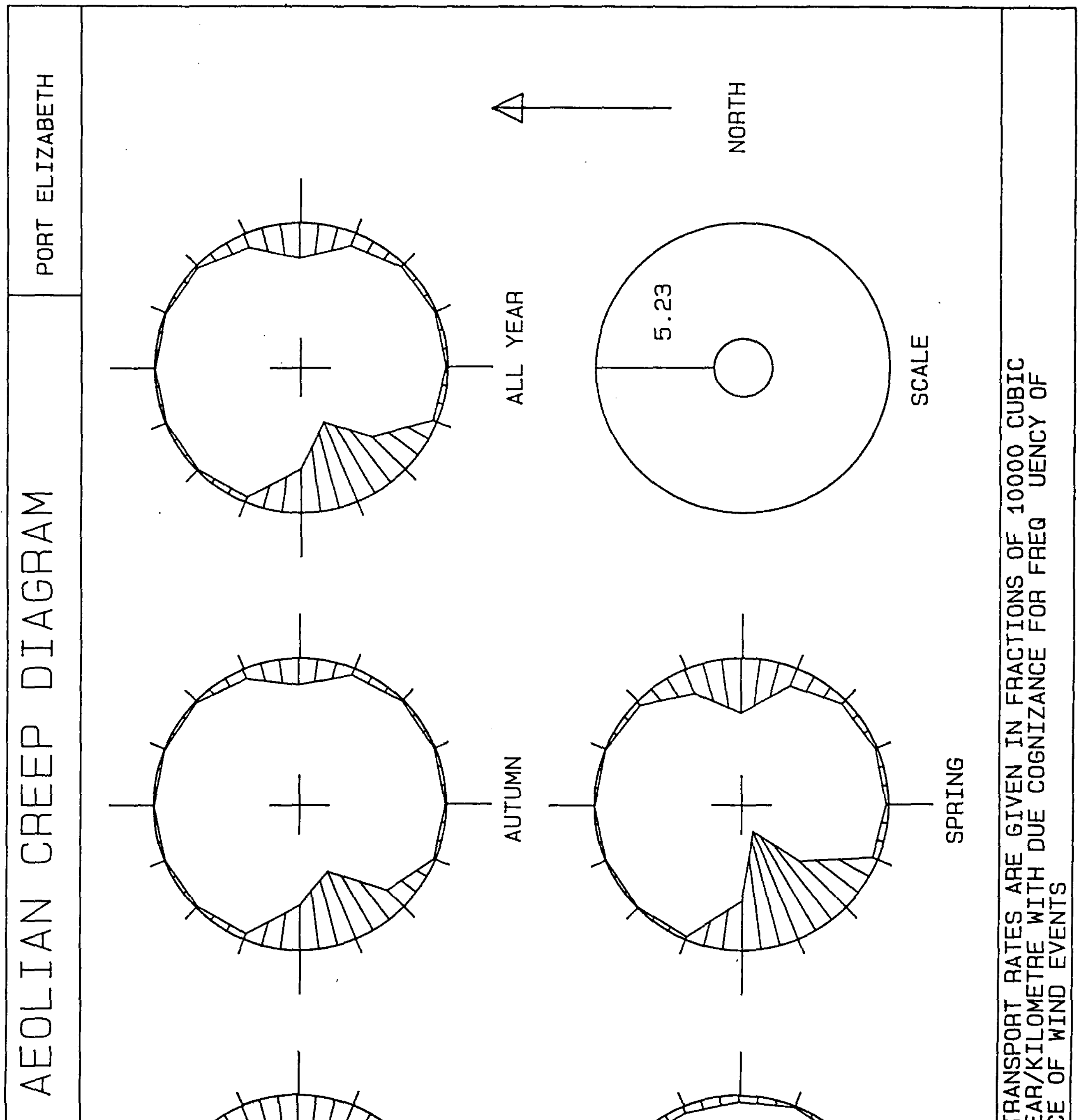


Figure 8(i) Aeolian Creep Diagram, Port Elizabeth airport.

FIGURE 8(i)

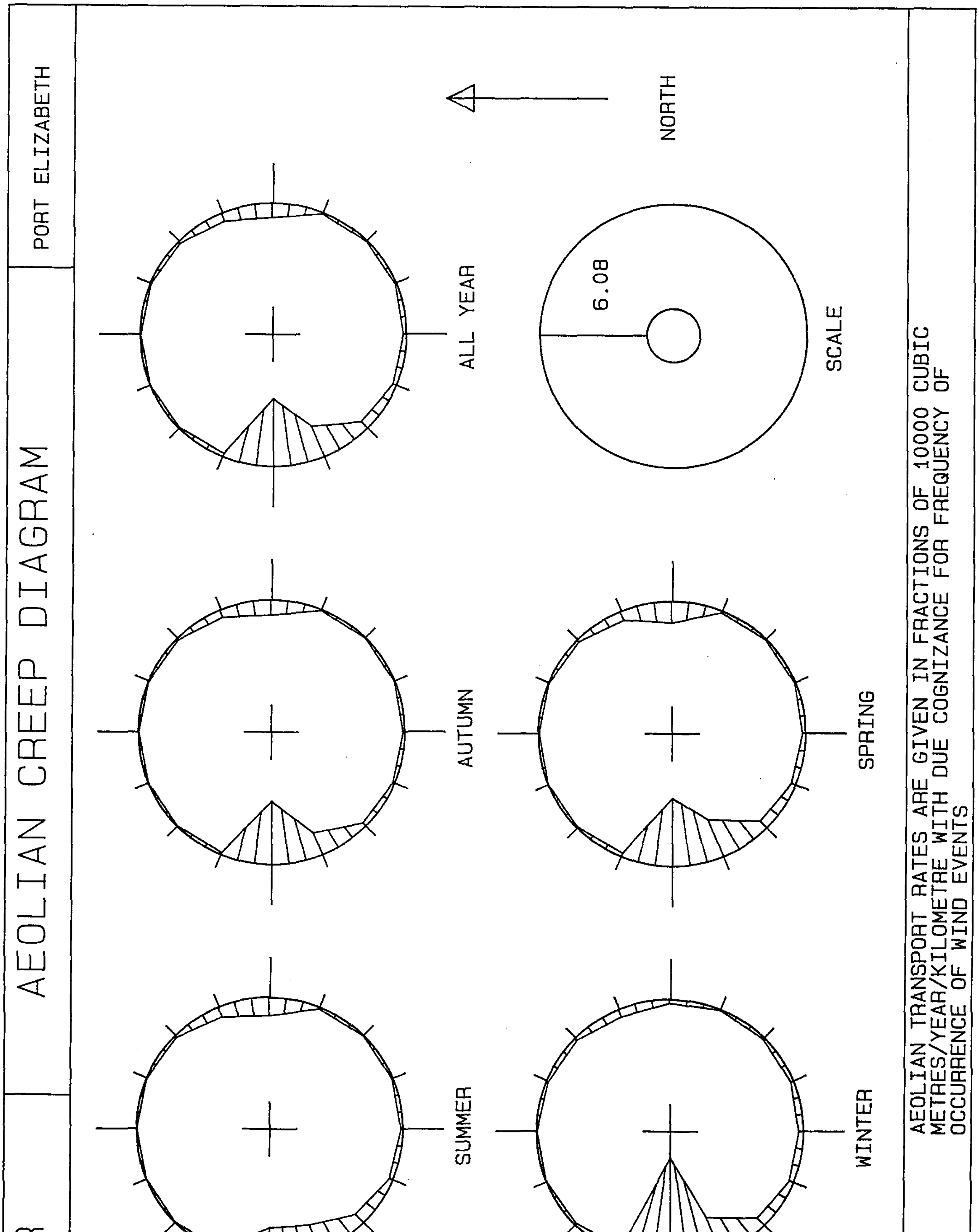
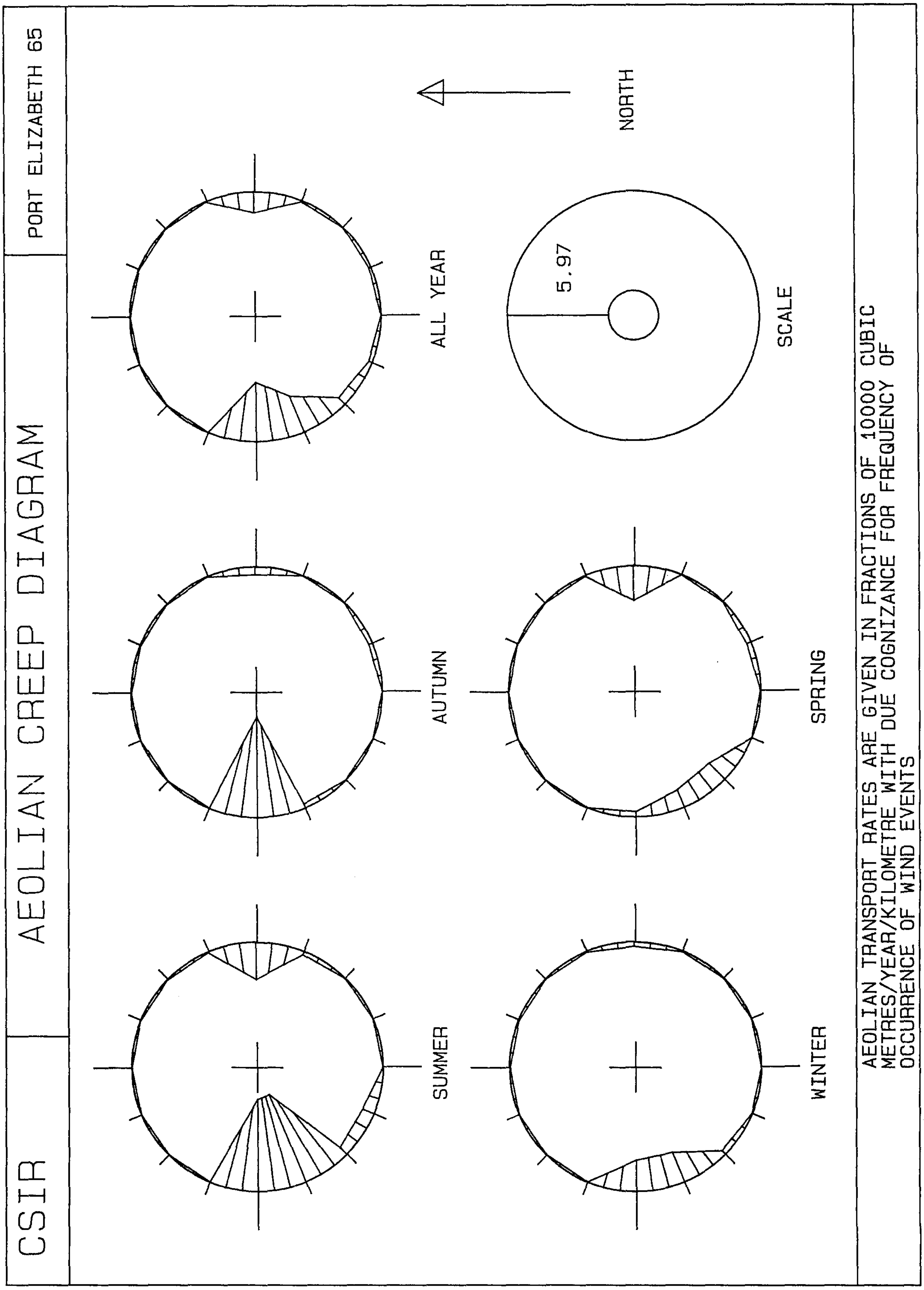


Figure 8(ii) Aeolian Creep Diagram, VOS data (33°-35° South, 25°-26° East).

FIGURE 8(ii)



AEOLIAN TRANSPORT RATES ARE GIVEN IN FRACTIONS OF 10000 CUBIC METRES/YEAR/KILOMETRE WITH DUE COGNIZANCE FOR FREQUENCY OF OCCURRENCE OF WIND EVENTS

Figure 9(i) Aeolian Creep Diagram for 1965. VOS data (33°-35° South, 25°-26° East).

FIGURE 9(i)

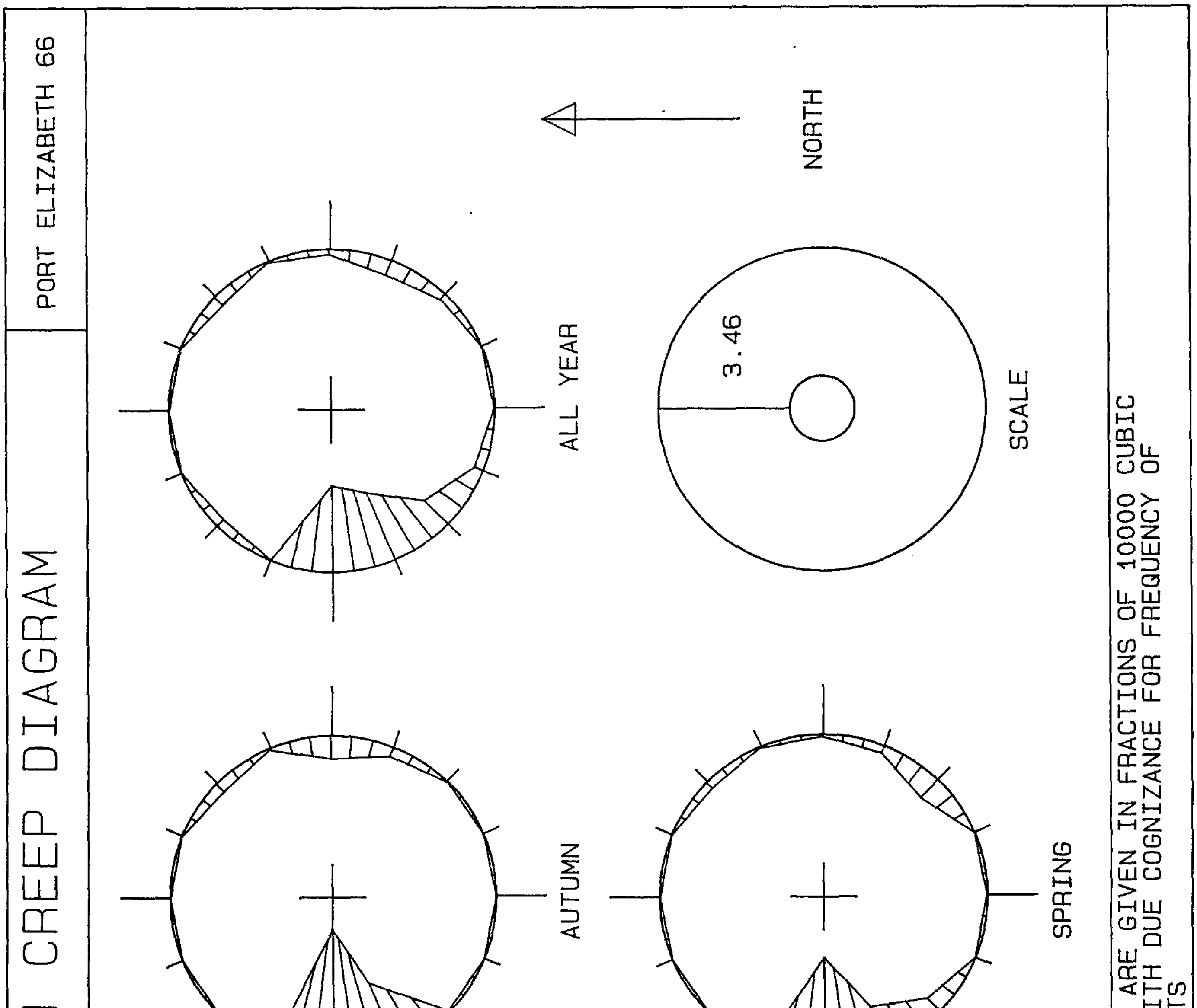


Figure 9(ii) Aeolian Creep Diagram for 1966 VOS data (33°-35° South, 25°-26° East).

FIGURE 9(ii)

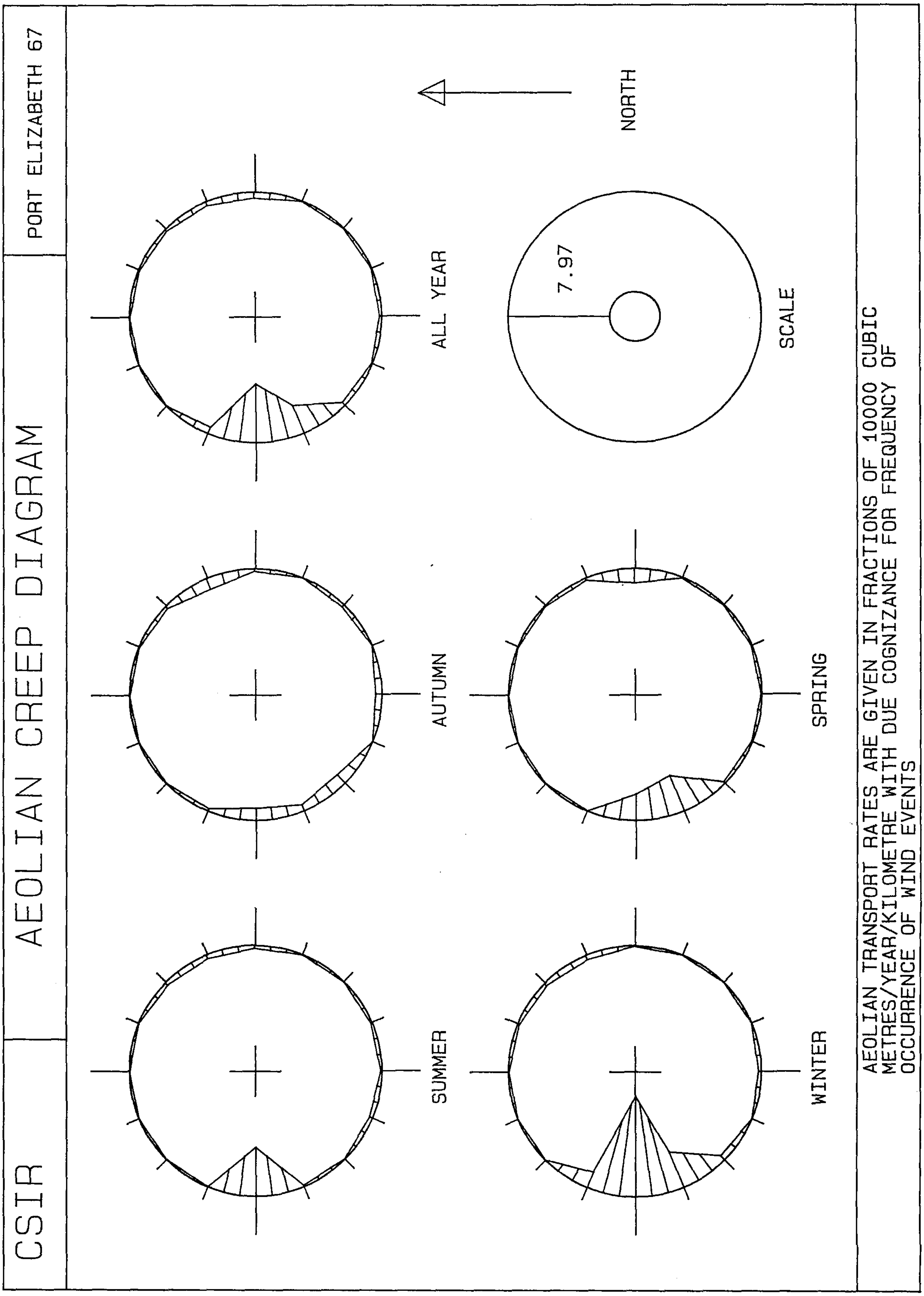
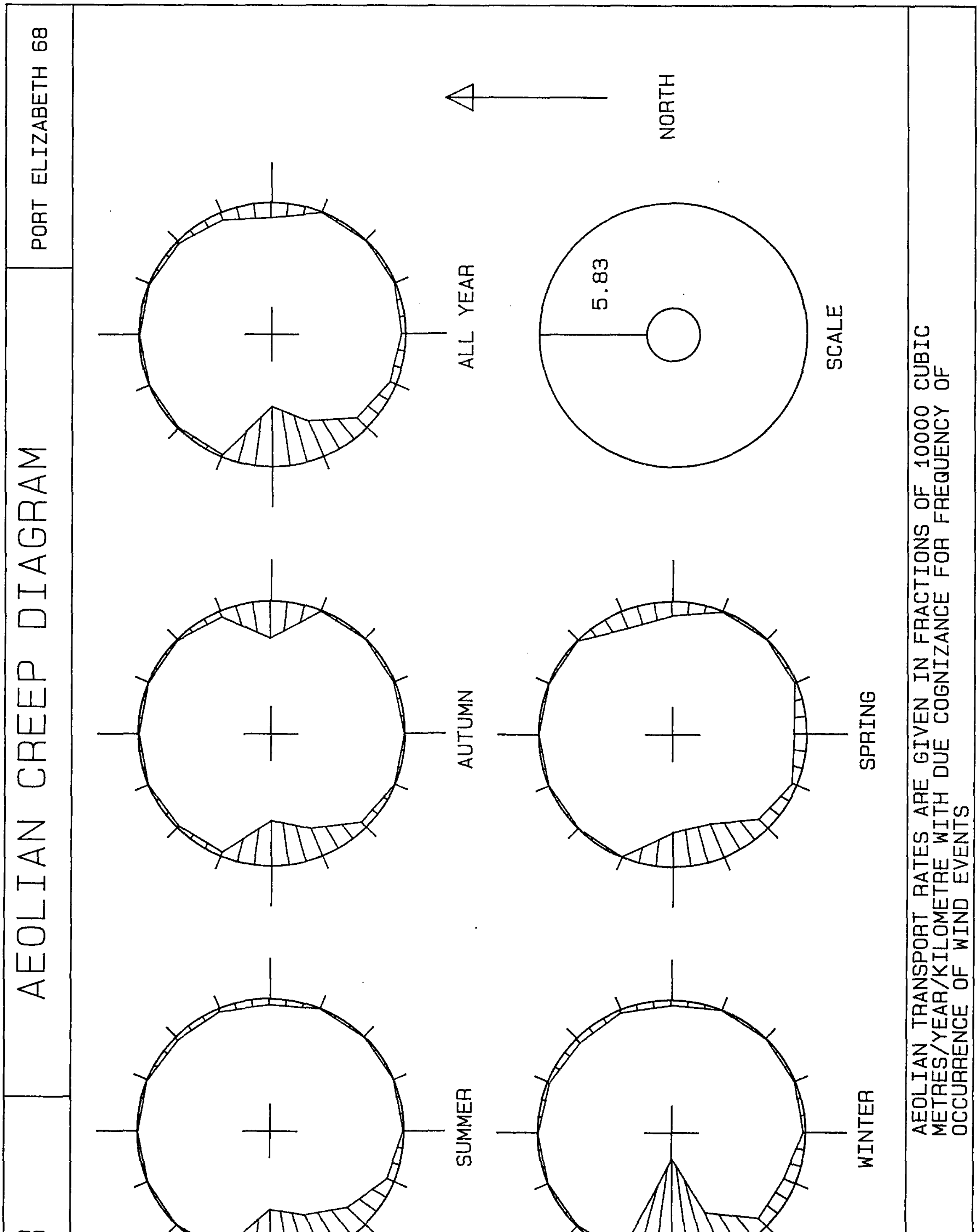


Figure 9(iii) Aeolian Creep Diagram for 1967. VOS data (33°-35° South, 25°-26° East).

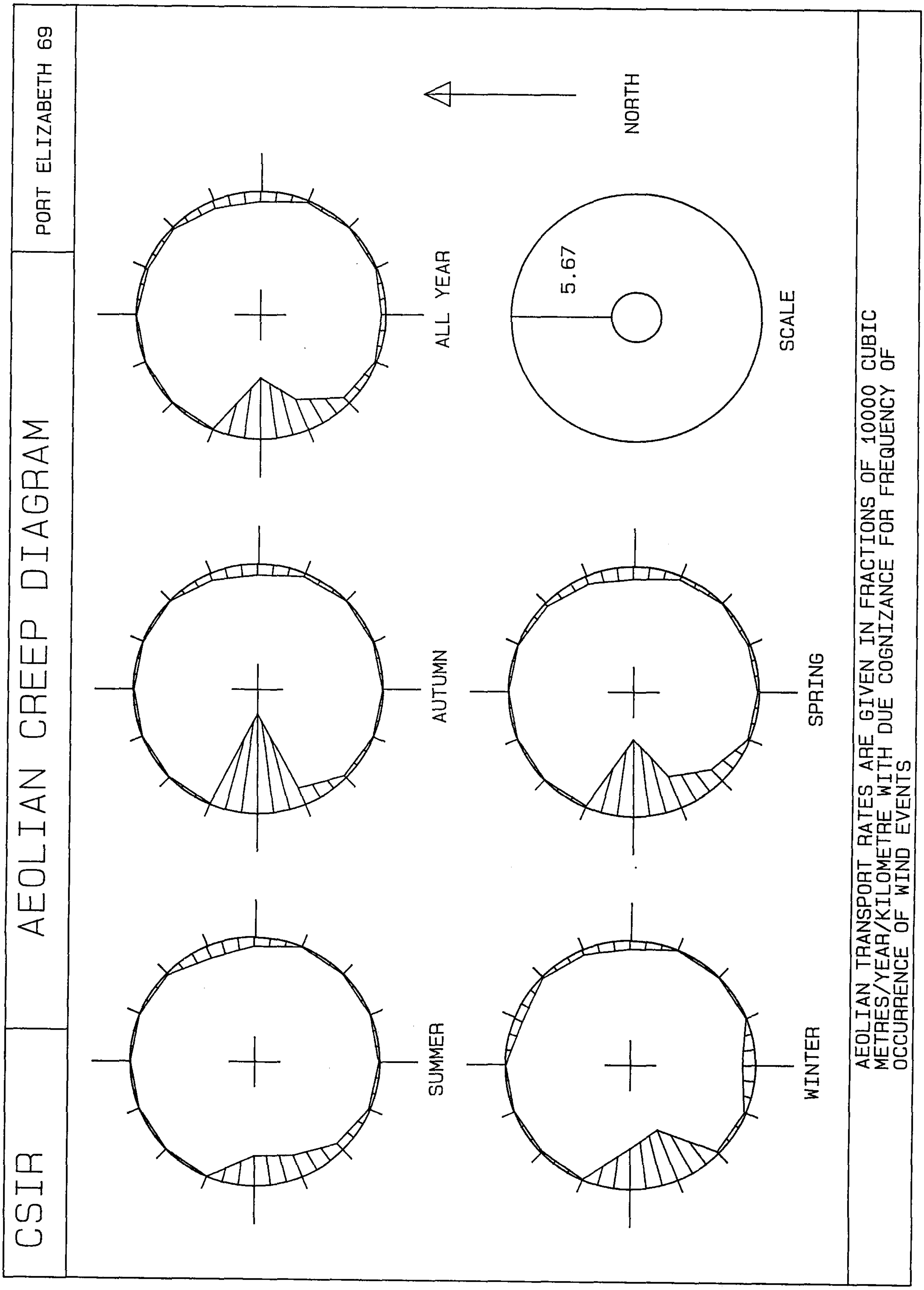
FIGURE 9(iii)



AEOLIAN TRANSPORT RATES ARE GIVEN IN FRACTIONS OF 10000 CUBIC METRES/YEAR/KILOMETRE WITH DUE COGNIZANCE FOR FREQUENCY OF OCCURRENCE OF WIND EVENTS

Figure 9(iv) Aeolian Creep Diagram for 1968. VOS data (33°-35° South, 25°-26° East).

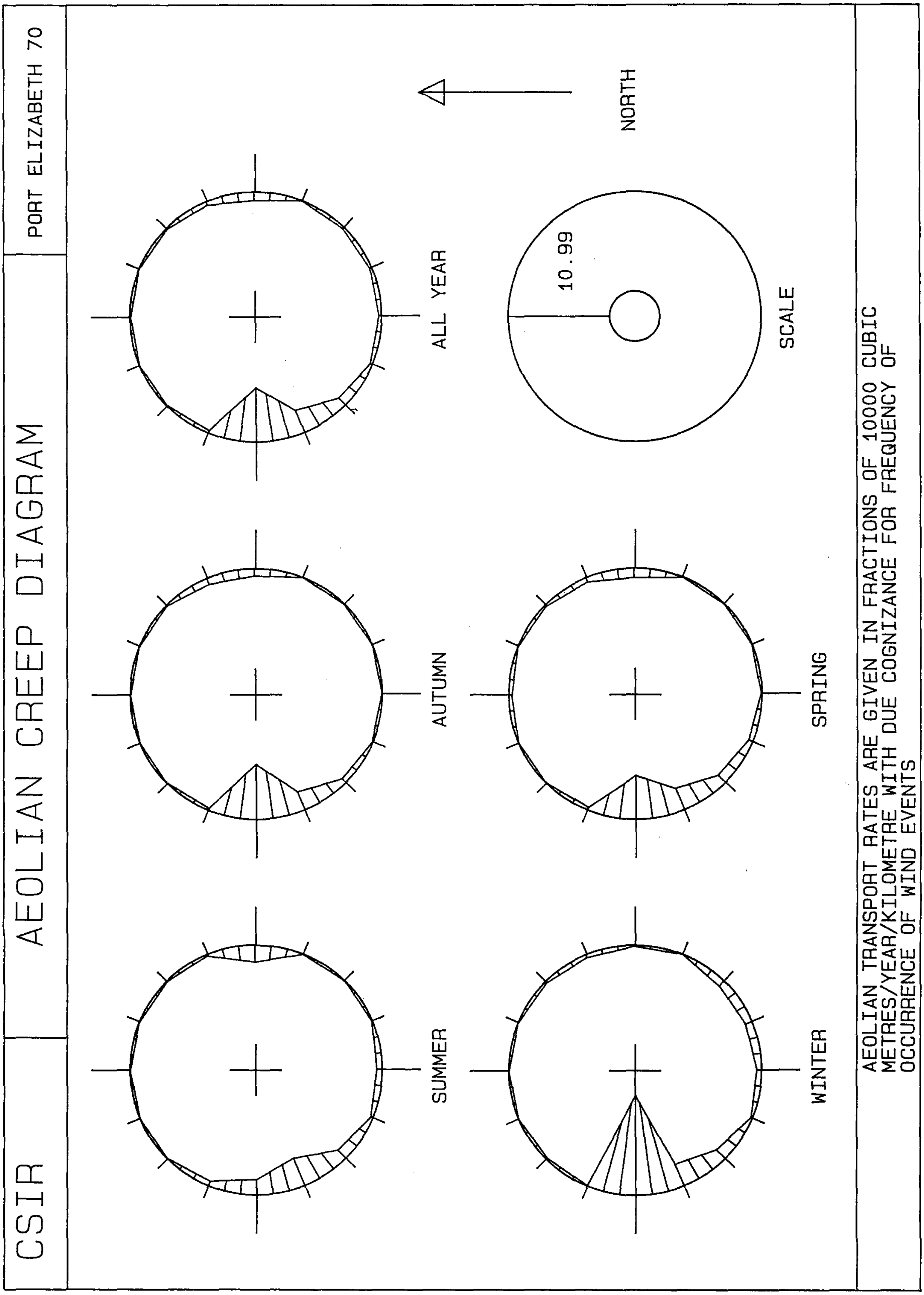
FIGURE 9(iv)



AEOLIAN TRANSPORT RATES ARE GIVEN IN FRACTIONS OF 10000 CUBIC METRES/YEAR/KILOMETRE WITH DUE COGNIZANCE FOR FREQUENCY OF OCCURRENCE OF WIND EVENTS

Figure 9(v) Aeolian Creep Diagram for 1969. VOS data (33°-35° South, 25°-26° East).

FIGURE 9(v)



AEOLIAN TRANSPORT RATES ARE GIVEN IN FRACTIONS OF 10000 CUBIC METRES/YEAR/KILOMETRE WITH DUE COGNIZANCE FOR FREQUENCY OF OCCURRENCE OF WIND EVENTS

Figure 9(vi) Aeolian Creep Diagram for 1970. VOS data (33°-35° South, 25°-26° East).

FIGURE 9(vi)

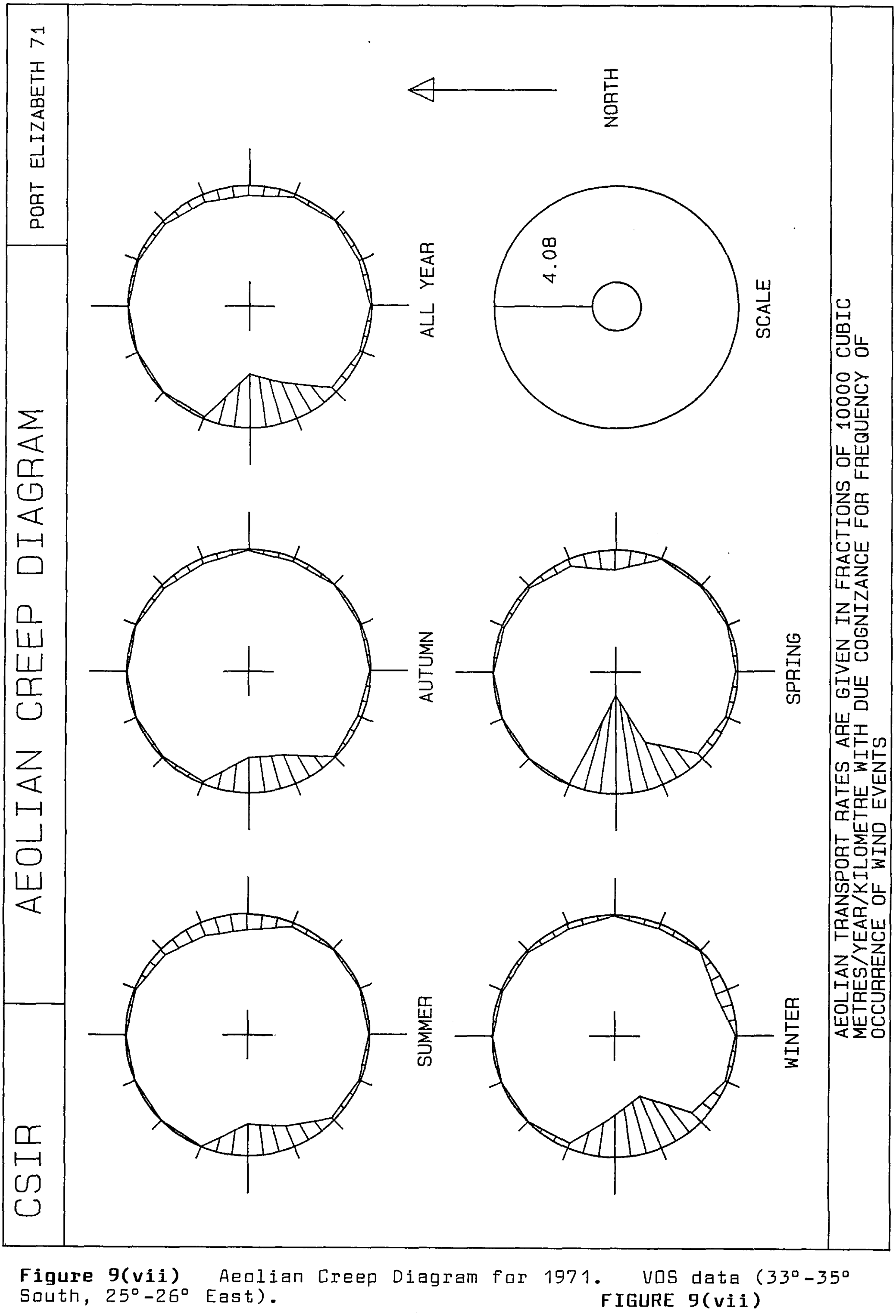
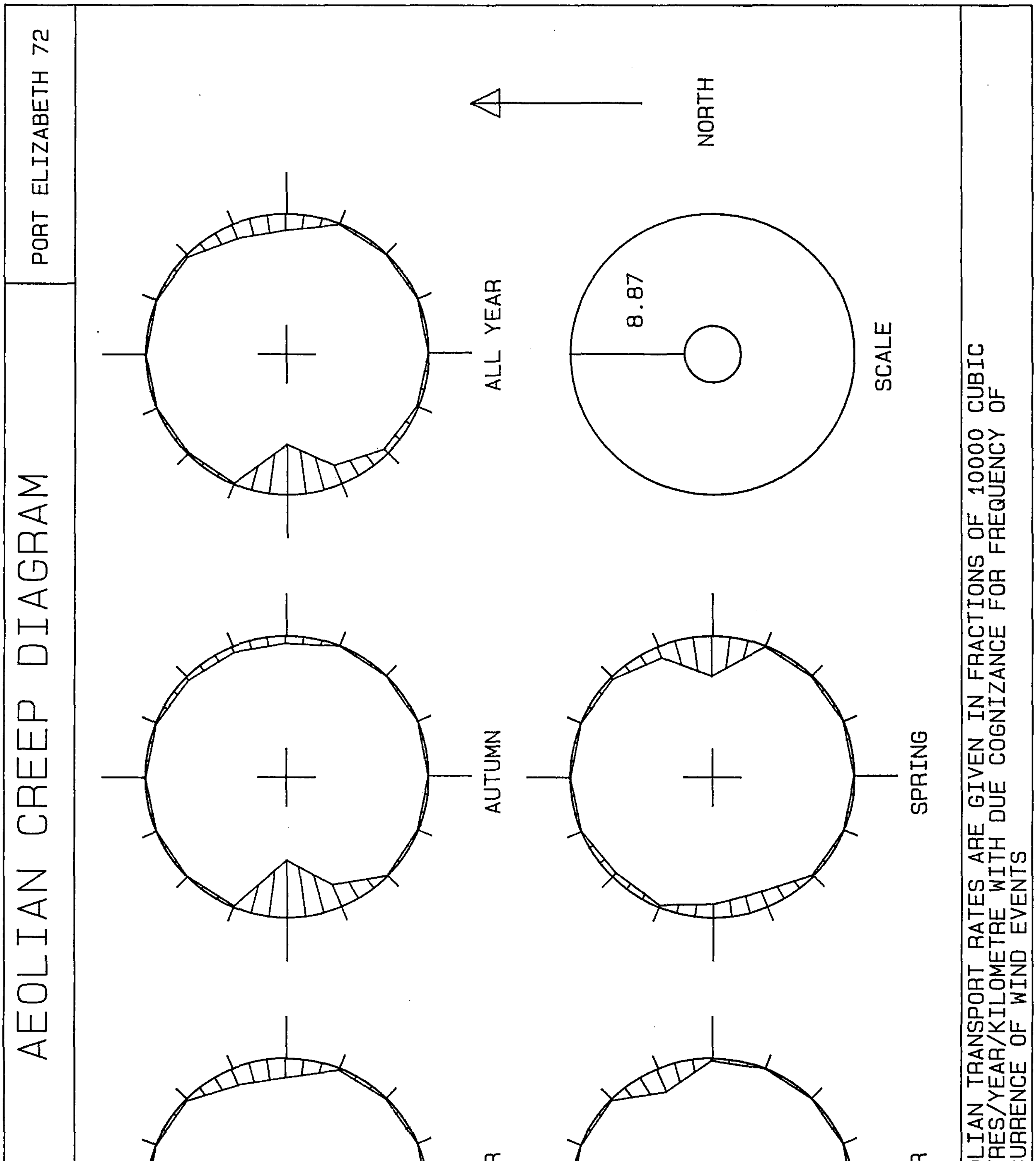


Figure 9(vii) Aeolian Creep Diagram for 1971. VOS data (33°-35° South, 25°-26° East).

FIGURE 9(vii)



AEOLIAN TRANSPORT RATES ARE GIVEN IN FRACTIONS OF 10000 CUBIC METRES/YEAR/KILOMETRE WITH DUE COGNIZANCE FOR FREQUENCY OF OCCURRENCE OF WIND EVENTS

Figure 9(viii) Aeolian Creep Diagram for 1972. VOS data (33°-35° South, 25°-26° East).

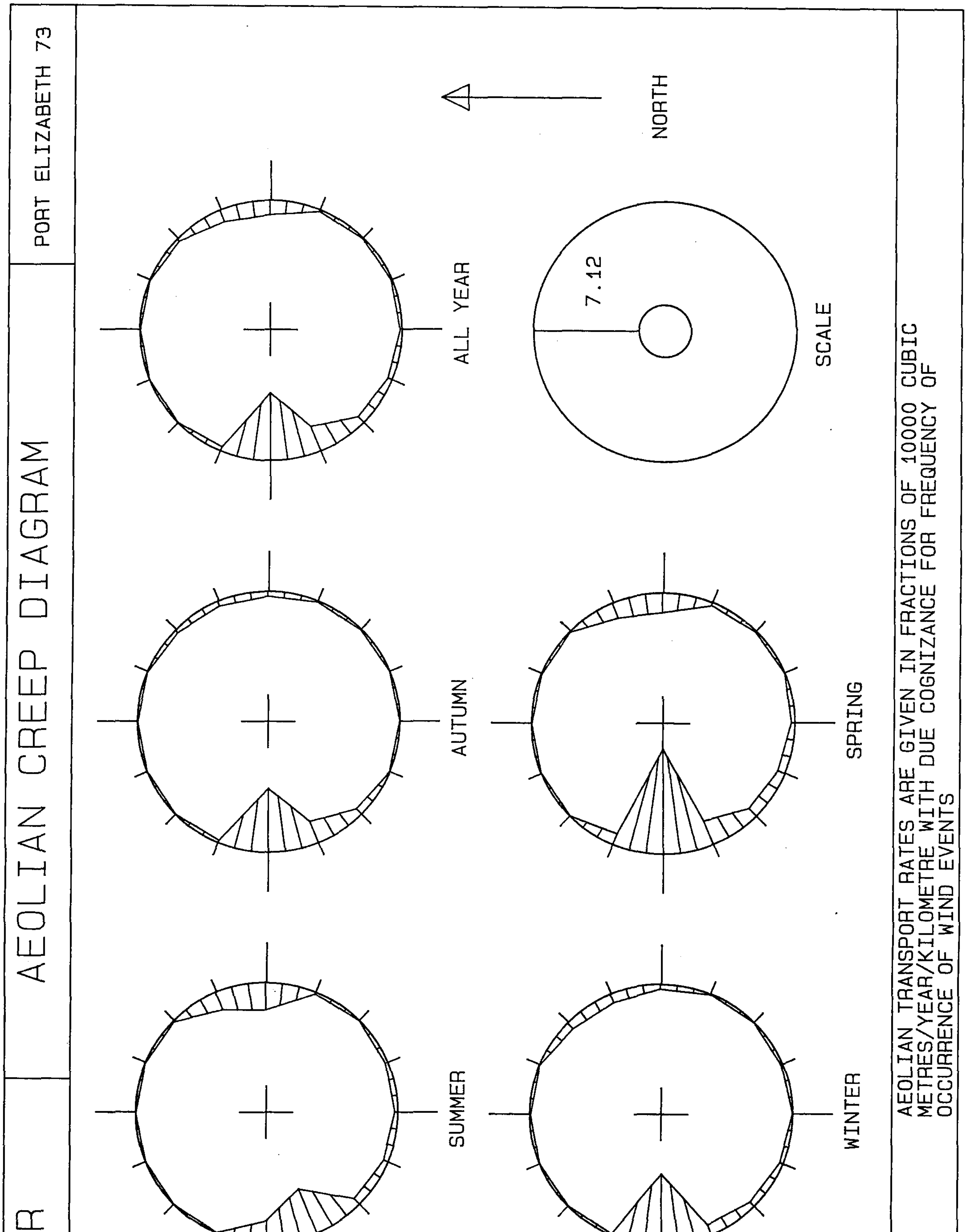


Figure 9(ix) Aeolian Creep Diagram for 1973. VOS data (33°-35° South, 25°-26° East).

FIGURE 9(ix)

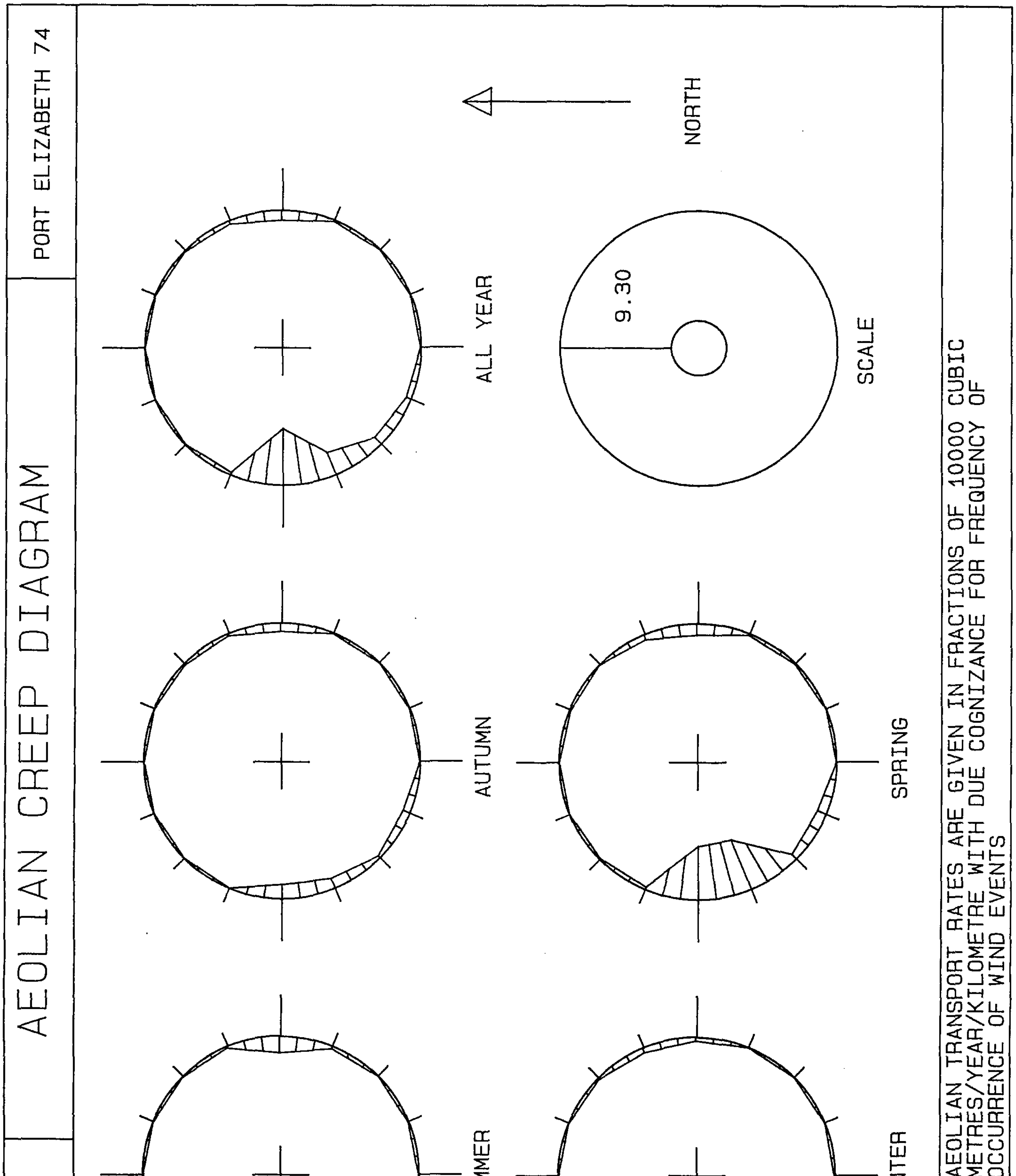


Figure 9(x) Aeolian Creep Diagram for 1974. VOS data (33°-35° South, 25°-26° East).

FIGURE 9(x)

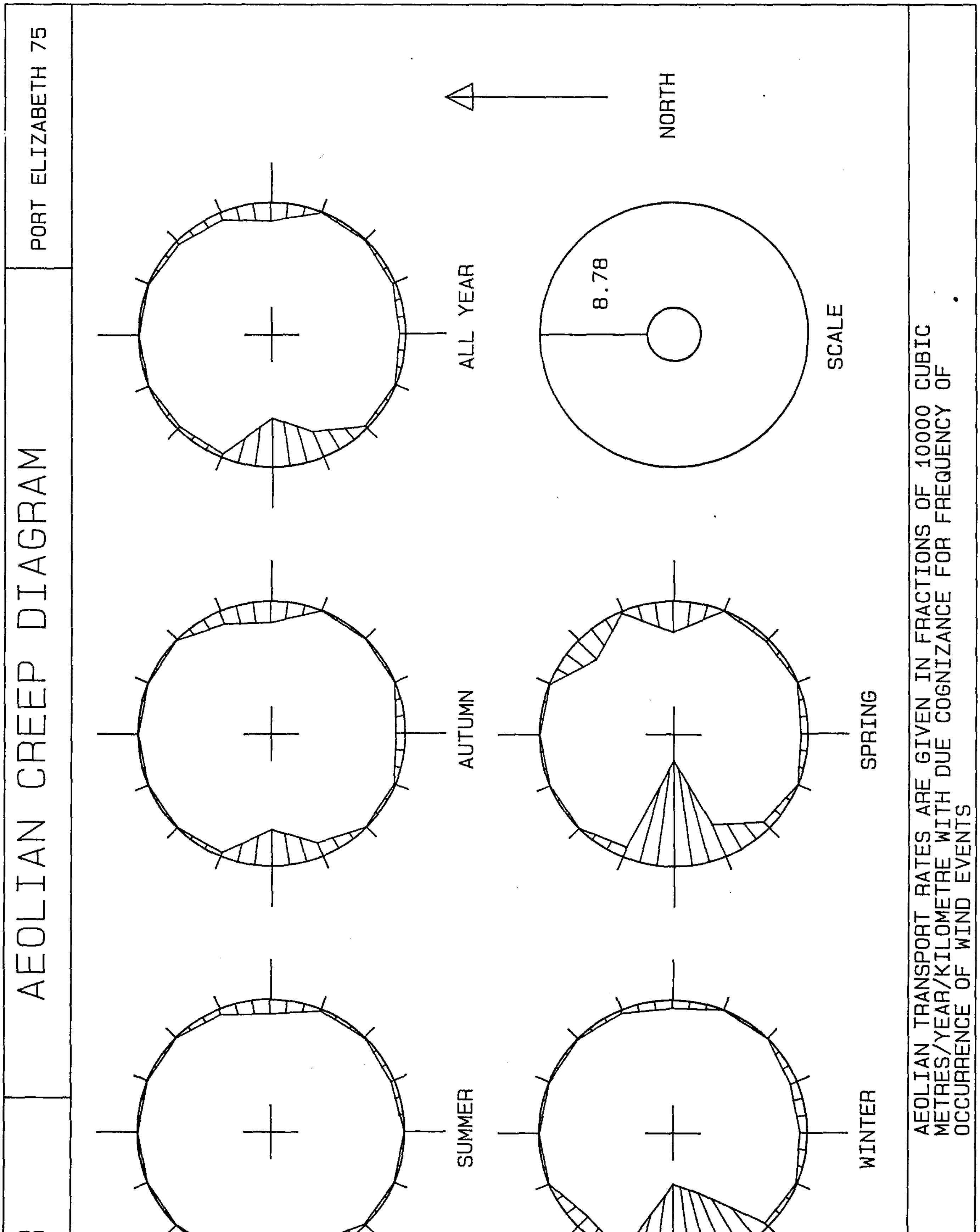
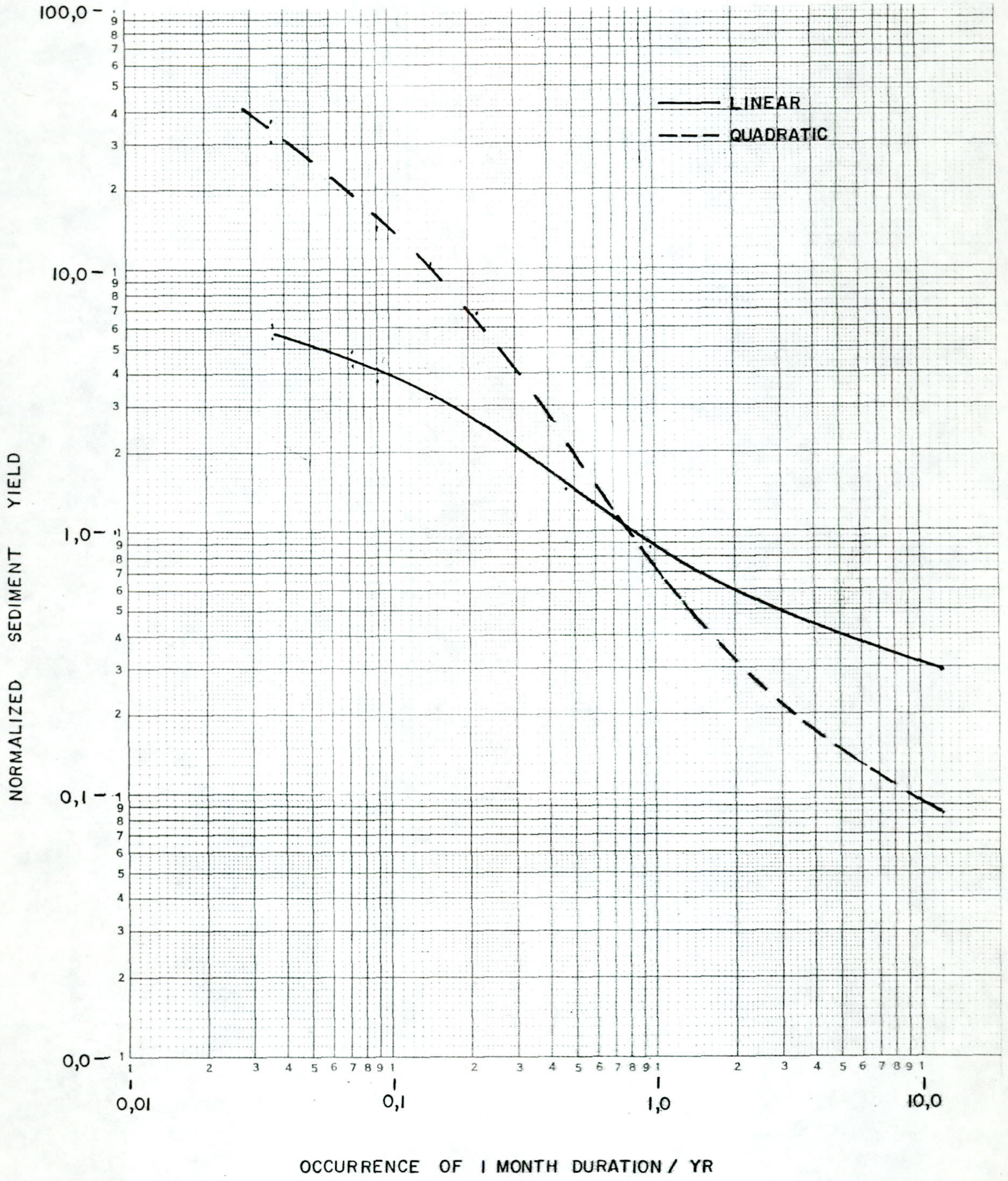


Figure 9(xi) Aeolian Creep Diagram for 1975. VOS data (33°-35° South, 25°-26° East).

FIGURE 9(xi)

COMMENT: Monthly sediment yields were normalized by the median sediment yield for the year.



TRACED: DD CHECKED: DATE: REF.:	SONDAGS RIVER / SCHELMHOEK **NORMALIZED SEDIMENT YIELD**	FIGURE 10

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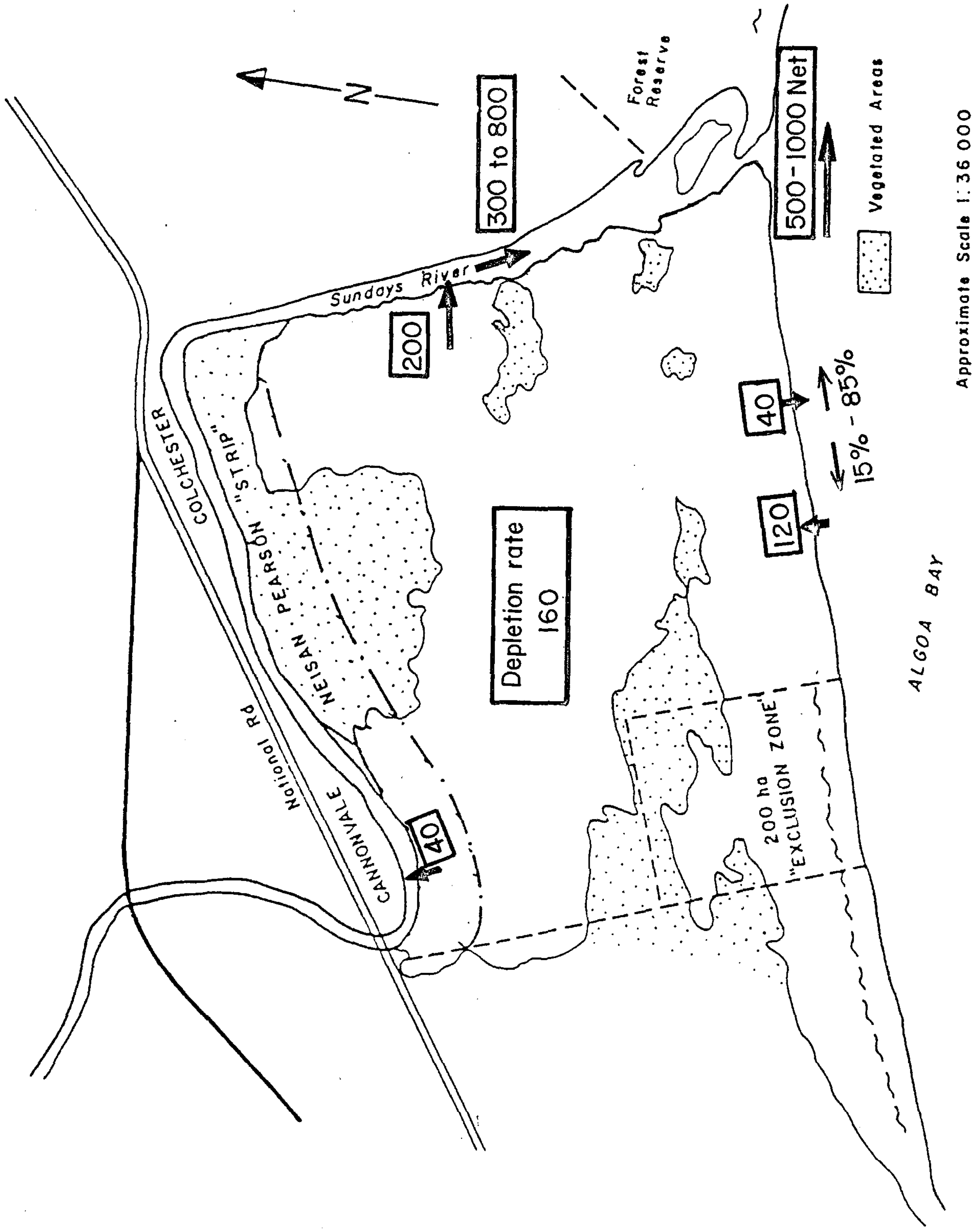
Comment : Transport rates are given in thousands of cubic metres/year.



TRACED: DD CHECKED: DATE: REF.:	SONDAGS RIVER / SCHELMHOEK SUMMARY OF LONG TERM-AVERAGE TRANSPORT RATES	FIGURE 11

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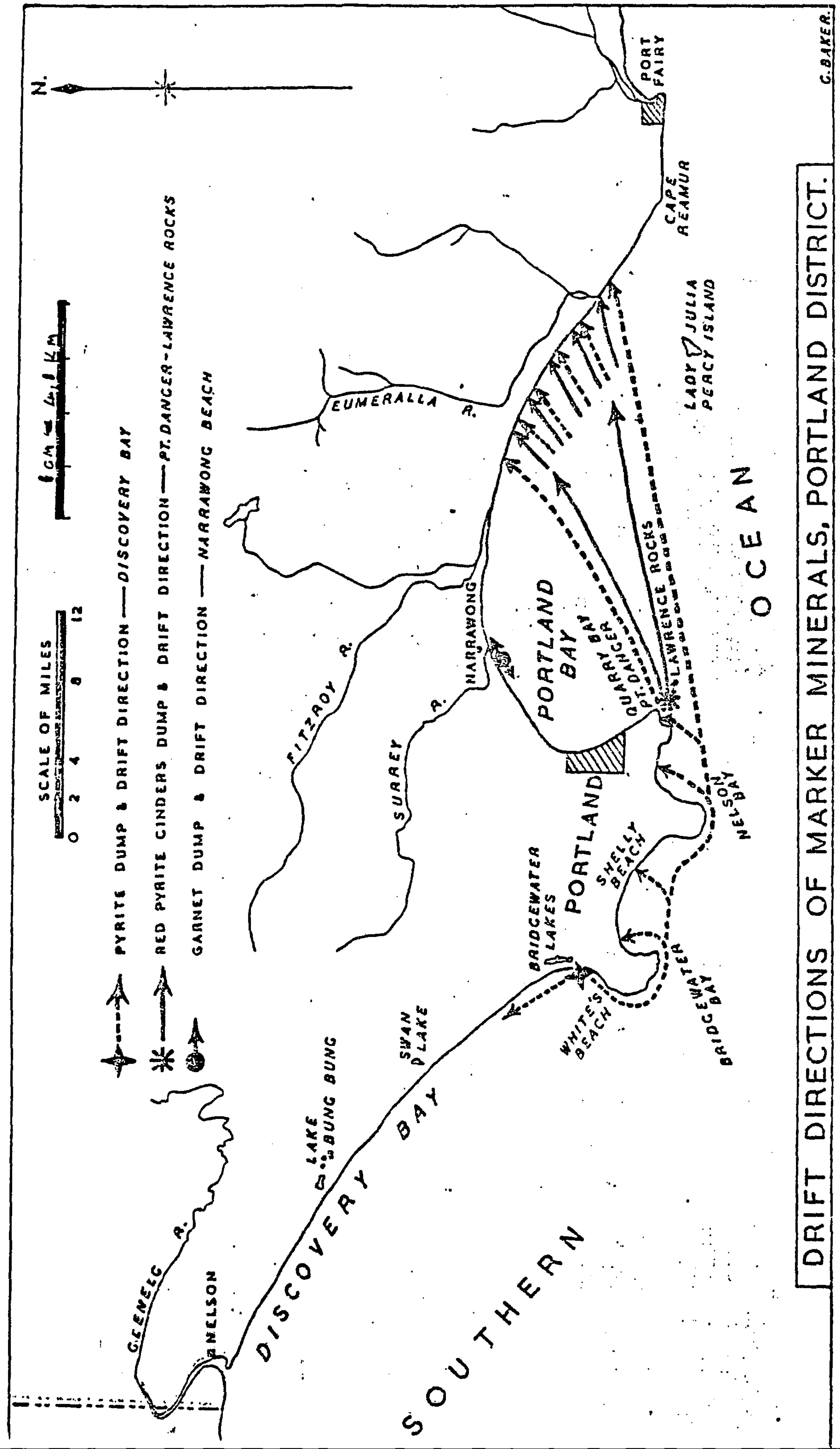
APPENDIX A: DRIFT DIRECTIONS OF MARKER MINERALS, PORTLAND DISTRICT (AFTER CSIRO, 1957)



DRIFT DIRECTIONS OF MARKER MINERALS, PORTLAND DISTRICT.

Fig. 1