J S Schoonees

CONFIDENTIAL

THE EFFECT OF THE MVUMASE PROJECT ON THE TUGELA ESTUARY AND ADJACENT COASTLINE

submitted to

DEPARTMENT OF ENVIRONMENT AFFAIRS

SEDIMENT DYNAMICS DIVISION
COASTAL ENGINEERING AND HYDRAULICS
NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY
COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

CSIR REPORT C/SEA 8251

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SCOPE

The proposed Mvumase Project consists of two dams which are to be constructed on the lower Tugela River.

The determination of the effect of the Project on the Tugela estuary was based on the river hydrology, the river sediment load and the longshore sediment load. The latter, in turn, was derived from the local wave climate in conjunction with a set of refraction diagrams. The findings of this aspect of the study then led to recommendations regarding the discharge of compensation water through the two dams.

The determination of the effect of the Project on the Tugela coastline was based on available bathymetric charts, aerial photographs and the fluvial and littoral sediment transport rates.

This report was written by Mr J Nicholson and Mr J de V Serdyn under the supervision of Dr D H Swart.

F P ANDERSON
DIRECTOR

Stellenbosch, South Africa
February 1983

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1 INTRODUCTION

The Mvumase Project consists of the Mvumase and Sunbury Dams which are to be constructed on the lower Tugela River 56 km and 32 km, respectively, from the river mouth. These two dams are the main components of a pumped-storage scheme required by the Electricity Supply Commission for power balancing and also for power output. The location of the Project is given in Figure 1.

The Project is being planned jointly by the Department of Environment Affairs (DEA) and the Electricity Supply Commission (ESCOM). In a letter dated 8 October 1981 and referenced B1/1920 B1/2050, the DEA requested that the then Coastal Engineering and Hydraulics Division (since renamed the Sediment Dynamics Division) of this Institute undertake an environmental impact study, the aims of which were to be as follows:

(i) to determine the effect of the dams on the Tugela Estuary;
(ii) to determine the effect of the dams on the adjacent coastline;
(iii) to recommend a management policy for the dams for freshwater releases.

2 HYDROLOGICAL DATA

2.1 General

The pre-dam hydrology of the lower Tugela River was examined with the aid of computer print-outs of monthly flow rates and flow charts of monthly peak events for the hydrological years 1960/61 to 1980/81 (a hydrological year runs from October to September). These data were recorded at monitoring station V5M02, located 23 km upstream of the Tugela mouth, and were supplied by the DEA. Also made available by the DEA were monthly evaporation data recorded at monitoring station W1E04 during the years 1966/67 to 1977/78. This station is situated 20 km due north of the Tugela mouth.

Discussions on the Tugela River runoff and evaporation rates are contained in this chapter.

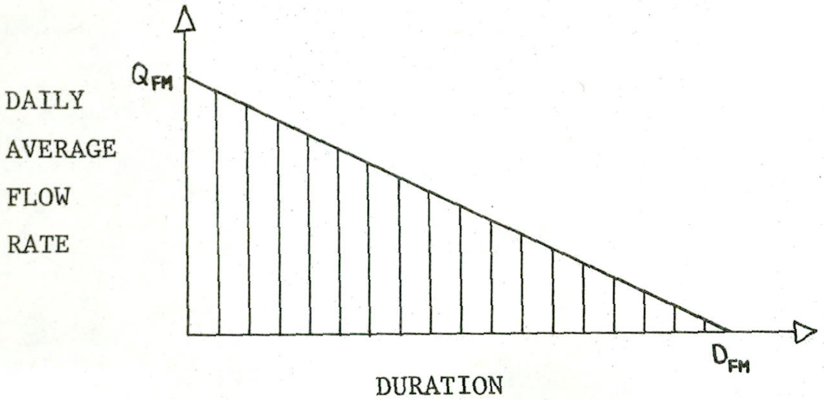
2.2 Runoff

Runoff has a major influence on the stability of an estuary mouth and on the management policy of a dam. For these reasons, it was necessary to analyse the available runoff data, the information extracted being as follows:

(i) peak monthly flood discharges;
(ii) annual flow rate.

Peak monthly flood discharges

The peak monthly floods were assumed to have a hydrograph of the following form:



It thus follows that the total runoff associated with a typical peak monthly flood is:

$$\Omega_{FM} = 24.3600.Q_{FM}.D_{FM}/2 \ (m^3)$$

where Q_{FM} = monthly maximum, daily average flow rate (m^3/s)

and D_{FM} = duration of peak monthly flood (days).

A survey of the available data yielded the average, monthly maximum, daily average flow rates, 'Q_{FM}', and their corresponding standard deviations, listed in Table I and plotted in Figure 2. The value for the average monthly maximum, daily average flow rate ranges from a minimum value of 34 m^3/s in June to a maximum of 1 176 m^3/s in February. In addition, the duration of a typical, peak monthly flood, 'D_{FM}' was estimated to have a value of approximately 4 days. The resulting peak monthly flood discharges derived with the aid of the above equation have also been included in Table I.

Annual flow rate

The average annual flow rate during the recording period was 3 $300.10^6 m^3/yr$, with a standard deviation of 1 $461.10^6 m^3/yr$. The minimum value for this flow rate was 1 $217.10^6 m^3/yr$ and the maximum 5 $891.10^6 m^3/yr$.

2.3 Evaporation

The rate of evaporation determines the minimum flow rate that must be maintained downstream of the dams. Monthly and annual evaporation rates were therefore calculated from the available evaporation data and an estimate was made of the area of water from which evaporation takes place.

The average monthly nett evaporation rates for the hydrological years 1966/67 to 1977/78, together with their standard deviations, are listed in Table II and plotted in Figure 3. These show that the average evaporation rate ranges from a minimum value of 28 mm/month in March to a maximum value of 129 mm/month in December; the average evaporation rate is 912 mm/year.

The area of water from which evaporation takes place consists of the plan area of the estuary and the plan area of the 32 km reach of river between the Sunbury Dam and the estuary. It is estimated that the estuary and river areas are $0{,}5.10^6 m^2$ [1] and $4{,}0.10^6 m^2$, respectively; the latter value is based on an average river width of between 100 and 150 m which was obtained from aerial photographs.

The volumetric evaporation rate corresponding to the above annual linear evaporation rate of 912 mm/year and water area of $4{,}5.10^6 m^2$ is $4{,}1.10^6 m^3$/year.

3 WAVE DATA

3.1 General

The frequencies of occurrence of wave heights, periods and directions at the breaker line were required for the computation of the longshore transport rates at the mouth of the Tugela. This breaker line wave climate was derived from the deep-sea wave climate with the aid of refraction diagrams.

The available deep-sea wave data, the refraction study and the resulting breaker line wave data are discussed below in this chapter.

3.2 Deep-sea wave data

Appropriate deep-sea wave data have been collected by Voluntary Observing Ships (VOS) while deep-sea data derived from the nearby Richards Bay and Port Zimbali clinometers were also available. However, the VOS distribution of wave directions did not match the corresponding distributions derived from the clinometers; in the event, the VOS data alone were used. The choice of the latter rested on the fact that they were measured in deep water, unlike the clinometer values, which had to be corrected for the effects of shoaling and refraction and were thus considered to be less accurate.

The relevant VOS deep-sea wave data [12] consisted of a series of monthly height versus period occurrence tables for 30° direction sectors. The total number of available readings was 5 181, a breakdown of which is as follows:

Directions undefined = 890
Directions defined = 4 291

Of the latter,

Heights and/or periods undefined = 572
Heights and periods defined = 3 719

It thus followed that 3 719 observations were suitable for use in the longshore transport computations. Of these, 700 observations had directions in the sectors 240° to 30° and were treated as 'calms' because the waves were moving away from the coastline.

The wave variables actually used in the longshore transport computations were the so-called 'instrument' values, namely, the deep-sea significant wave height, 'H_{OS}', and the period corresponding to the peak of the energy spectrum, 'T_P'. The relationships between these two values and their VOS counterparts are derived in Appendix A and are as follows:

$$H_{OS} = 1{,}0 + 0{,}55 \cdot H_{VOS}$$

$$T_P = 4{,}1 \cdot T_{VOS}^{0{,}55}$$

The resulting annual and monthly occurrences of wave periods as functions of deep-sea direction and the corresponding representative wave heights are given in Appendix B for the VOS data and in Table III for the 'instrument' data. The representative significant wave heights, in each case, were taken to be root-mean-square values because the longshore transport rate is a function of the wave height squared.

3.3 Refraction study

The conversion of the deep-sea wave data to breaker line data was achieved with the aid of refraction diagrams. A refraction diagram shows the paths taken by adjacent sections of a wave front as it advances towards the shoreline, and thus consists of a series of lines which are orthogonal to the wave front. At points where the orthogonals converge, the wave height increases and vice versa, this change in the wave height being quantified by means of a refraction coefficient. A given refraction diagram is valid for only one particular wave period and one particular deep-sea wave direction.

All wave orthogonals were terminated at the breaker line. Various criteria can be used to establish the break point of a wave, the one used in this case being a fixed depth of 3 m. This particular value was chosen because it was considered to be a realistic estimate for the mean breaker depth for all wave conditions.

A set of 30 refraction diagrams was prepared for the five wave periods and six deep-sea wave directions listed in Table III. The necessary computations were carried out with the aid of a Fortran computer program which incorporated a focusing technique. The latter involved three separate grids, which covered the offshore, nearshore and inshore areas, details of which are as follows:

Offshore grid : mesh size = 1 517,8 m square;
mesh number = 22*52;
Nearshore grid: mesh size = 505,9 m square;
mesh number = 11*51;
Inshore grid : mesh size = 168,6 m square;
mesh number = 13*153

The positions of the various grids and the results of the refraction computation are given in Figures 4a to 4ad.

3.4 Breaker line wave data

The breaker line wave data yielded by the refraction study are summarised in Table IV.

The breaker angle was defined as the angle between the wave crest at breaking and the 3 m depth contour, where breaking was assumed to occur. The mean breaker angles and refraction coefficients quoted in Table IV were derived from the refraction diagrams by averaging over a section of coastline which extended 5 km to the north and 3 km to the south of the Tugela mouth. This particular section of coastline was chosen because it included the 4 km-wide offshore bar plus a further 2 km on either side of the bar and was therefore considered to be long enough to yield representative values for the breaker line characteristics.

8km.

4 SEDIMENT TRANSPORT

4.1 General

Waves approaching a coastline obliquely produce a flux of momentum in a direction parallel to the coastline. This, in turn, generates a longshore current which transports sediment stirred up by breakers. Because the wave direction is a variable, this longshore transport may take place in an upcoast or in a downcoast direction. The sum of these two quantities, the gross longshore transport rate, is of primary importance in determining the stability of an estuary mouth and adjacent coastline. Of equal importance, in the case of the Tugela estuary and coastline, is the fluvial sediment transport, the material carried by the river itself. Both the coastal and the fluvial sediment transport rates are assumed to refer to sand (diameter $>60\mu$) only.

This chapter consists of a derivation of the longshore and fluvial sediment transport rates in the vicinity of the Tugela estuary mouth. Because the estuary analysis was carried out on a monthly basis, the two transport rates were also computed on a monthly basis, although they were expressed in terms of an equivalent annual rate.

4.2 Longshore sediment transport

The longshore sediment transport rates were computed by means of the SPM formula [5] as modified by Swart [11]. This formula was applied to each wave condition in turn and the results then summed to give the total transport rate. Details of the formula are as follows:

$$S_X = K(D) \cdot f_I \cdot T_P \cdot H_{OS}^2 \cdot K_{RB}^2 \cdot \sin 2\Theta_B$$

where S_X = longshore sediment transport rate (m^3/yr);
$K(D)$ = grain size parameter
= $91.10^4.\log(0{,}00146/D_{50})$ (m/(yr.s));
D_{50} = median grain size (m);
f_I = fractional occurrence of a given wave condition;

T_P = wave period corresponding to the peak of the energy spectrum (s);
H_{OS} = significant deep-water wave height (m);
K_{RB} = refraction coefficient at the breaker line;
Θ_B = angle between the wave crest and the local bed contour at the breaker line.

The deep-water wave variables (f_I; T_P; H_{OS}) are given in Table III and the breaker line wave variables (K_{RB}; Θ_B) in Table IV. The median grain size of the beach sediment (D_{50}) was taken to be 300 μ. This value is based on the analysis of 52 samples collected between the high water line and the 15 m depth contour on the southern side of the Tugela mouth [4]. The resulting value for the grain size parameter, K(D), is 63.10^4m/(yr.s).

The potential longshore transport rates predicted by the above equation are listed in Table V. Aerial photographs of the Tugela coastline indicate that a plentiful supply of sand is available for transport and thus it was concluded that the actual and the potential transport rates are identical. The value for the gross longshore transport rate was found to range from a minimum of $0{,}9.10^6$m^3/yr in March to a maximum of $1{,}6.10^6$m^3/yr in May; the average nett longshore transport rate has a value of $1{,}1.10^6$m^3/yr.

4.3 Fluvial sediment transport

According to Rooseboom [9], the average mass of solids transported by the river is between 7,6 . 10^6 and 9,5 . 10^6 tonne/yr. Thus, using the higher, and therefore the more conservative, of these two values and converting it into a volume discharge, assuming a voids ratio of 40 per cent, the volumetric rate is 5,0 . 10^6m^3/yr. It was also concluded by Rooseboom [10] that 12]2 per cent of this load consists of sand. The resulting fluvial sediment transport rate is therefore 0,6 . 10^6m^3=yr. m^3/yr

The average monthly fluvial sediment loads were derived by assuming that this parameter is a function of the maximum monthly flow rate, the relationship being

$$S_{FM} \alpha Q_{FM}^{1,8}$$

$$= kQ^{1,8}$$ (k se waarde is nie hier van belang nie, aangesien slegs die relatiewe grootte v.d. S_{FM}-waarde gebruik word)

where 'S_{FM}' is fluvial monthly sediment transport rate, 'Q_{FM}' is the maximum monthly flow rate and the value of 1,8 for the exponent was obtained by Oliff [7]. The maximum monthly flow rates are given in Table I and, when these are raised to the power 1,8 and used as weighting factors, the resulting fluvial sediment transport rates for each month are as given in Table VI. This quantity ranged from a minimum of zero between May and September to a maximum of $3,3.10^6 m^3/yr$ in February.

5 STABILITY OF THE ESTUARY MOUTH

5.1 General

The stability of an estuary mouth is dependent on factors which tend to flush the mouth out and factors which tend to block it. There are two flushing factors, namely, tidal flow and fluvial flow, and two blocking factors, namely longshore sediment transport and fluvial sediment transport. It is, moreover, the peak values of these factors which have most influence on the estuary stability.

Bruun and Gerritsen [3] have proposed that the stability of an estuary mouth be expressed in terms of the ratio between the flushing factors and the blocking factors. However, fluvial flow and fluvial sediment transport were neglected with the result that the total flushing factor, 'Ω_{TOT}', comprised the spring tidal prism in m^3, 'Ω_T', and the total blocking factor, 'S_{TOT}', comprised the gross longshore transport rate in m^3/yr., 'S_{XG}'. In a field study, Bruun [2] then came to the following conclusions regarding the significance of various 'Ω_{TOT}/S_{TOT}' values:

(i) $\Omega_{TOT}/S_{TOT} > 150$: conditions are relatively good with a small offshore bar and good flushing;

(ii) $100 < \Omega_{TOT}/S_{TOT} \leq 150$: conditions are less satisfactory and offshore bar is more pronounced;

(iii) $50 < \Omega_{TOT}/S_{TOT} \leq 100$: offshore bar can be large but it is usually intersected by a channel;

(iv) $20 < \Omega_{TOT}/S_{TOT} \leq 50$: offshore bar is large and inlet is kept open, if at all, by fluvial flood discharges;

(v) $\Omega_{TOT}/S_{TOT} \leq 20$: estuary mouth is closed and acts only as an overflow channel for fluvial discharges

In the case of the Tugela estuary, the fluvial flow and the fluvial sediment transport cannot be neglected. 'Ω_{TOT}' was therefore taken to be the peak monthly flood discharge, the 'fluvial spring tidal prism', plus the actual spring tidal prism and 'S_{TOT}' was taken to be the sum of the gross longshore transport rate and the fluvial sediment transport rate. The stability analysis was undertaken on a monthly basis but the latter two quantities were expressed in m^3/yr even though they were based on the transport rates occurring during a particular calendar month.

5.2 Computations

The peak monthly flood discharges or 'fluvial spring tidal prisms', the gross longshore transport rates and the fluvial transport rates were taken from Tables I, V and VI respectively. The spring tidal prism was estimated to have a value of $5.10^5 m^3$ based on an estuary plan area of approximately $5.10^5 m^2$ [1] and an average estuarine spring tidal range of 1 m. The spring tidal prism was assumed to remain constant throughout the year.

The resulting 'Ω_{TOT}/S_{TOT}' values are set out in Table VII which shows that this parameter has a minimum value of 6 in August and a maximum value of 55 in March.

5.3 Discussion

The 'Ω_{TOT}/S_{TOT}' values given in Table VII indicate that the estuary mouth is stable during the summer months when the large river flows flush out the sand deposits. However, during the winter months the river flows are low and most material arriving at the estuary mouth remains there, thus reducing its cross-sectional area. During the latter period, the mouth is kept open by the relatively weak tidal flushing action supplemented by the small river flows. The estuary only closes during periods of severe drought.

The maximum (summer) and minimum (winter) values for the cross-sectional area of the estuary mouth are estimated to be as follows:

Maximum (summer)

According to Bruun and Gerritsen [3], the cross-sectionally averaged maximum spring tidal velocity in an estuary mouth is approximately 1,0 m/s. Neglecting the small tidal flow and assuming that the maximum, monthly, fluvial flood discharge of 1 176 m^3/s, which occurs in February (see Table I), is equivalent to the maximum spring tidal discharge, this criterion yields:

$$A_{MAX} \approx 1\ 200\ m^2$$

where A_{MAX} = maximum cross-sectional area of the estuary mouth below mean sea level.

In addition, Begg [1] quotes a value of 1 000 m for the maximum width of the estuary mouth, although this is probably associated with extreme floods. Hence, assuming a typical, maximum width of 600 m, say, the corresponding average depth of the estuary mouth below mean sea level is approximately 2 m.

Minimum (winter)

Application of the Bruun and Gerritsen criterion to the minimum estuary mouth conditions involves the tidal flow, as well as the fluvial flood discharge, because the former quantity cannot be neglected. The tidal flow is estimated to generate a maximum, spring tidal discharge of 36 m^3/s, based on a spring tidal prism of $0{,}5.10^6 m^3$ discharging sinusoidally, and the minimum, monthly, fluvial flood discharge, which occurs in June (see Table I), is 34 m^3/s. The effective minimum monthly spring tidal discharge is therefore 70 m^3/s and hence the Bruun and Gerritsen criterion gives

$$A_{MIN} \approx 70\ m^2$$

where A_{MIN} = minimum cross-sectional area of the estuary mouth below mean sea level.

A minimum value of 50 m for the width of the estuary mouth is given by Orme [8], which was confirmed during a site visit by the writer in June 1982. The corresponding average depth of the estuary mouth below mean sea level is therefore approximately 1,5 m.

To summarise, the cross-sectional area of the estuary mouth attains a maximum value of approximately 1 200 m^2 after the February floods and then, during the winter when the river discharges are low, it is reduced to about 70 m^2 by the longshore drift.

6 STABILITY OF THE ADJACENT COASTLINE

6.1 Pre-dam conditions

It is estimated that the volume of sand arriving at the mouth of the Tugela during a typical year is $1{,}1.10^6 m^3$ due to nett northbound longshore transport (see Section 4.2) and $0{,}6.10^6 m^3$ due to fluvial transport (see Section 4.3). Thus, the total quantity of sand supplied to this area is $1{,}7.10^6 m^3$/yr.

Offshore surveys carried out on the Tugela coastline [4] indicate that the bar at the mouth of the river grew at a rate of approximately $1{,}1.10^6 m^3$/yr between 1913 and 1978. This accumulation, however, consisted of sediment with a wide spectrum of grain sizes, and it is therefore necessary to separate out the sand fraction. That portion of the fluvial sand load which accumulates on the bar does so on the landward side of this structure, the seaward limit of deposition being dependent on the fall velocity of the smallest grains (60 μ diameter), the river flow velocity and the local bathymetry. The fall velocity of the smallest grains is 0,003 m/s [6] and an estimated value for the flow velocity is 1 m/s. These two velocities, in conjunction with the available bathymetric survey [4], indicate that the fluvial sand load is deposited landwards of the 15 m depth contour. As this is also the limiting depth for most of the longshore sand transport, it can therefore be concluded that the section of the bar landwards of the 15 m depth contour consists mainly of sand. On this basis, the sand deposition rate on the bar is approximately $0{,}4.10^6 m^3$/yr. This deposition rate, in combination with the supply rate of $1{,}7.10^6 m^3$/yr, thus indicates that the longshore transport rate immediately to the north of the river mouth is $1{,}3.10^6 m^3$/yr in a northerly direction.

A study of aerial photographs of shoreline movement at the Siaya River mouth, the position of which is given in Figure 1, shows that the variations in the local beach width between 1937 and 1977 were as follows:

1937/53	1953/57	1957/65	1965/69	1969/77
+1,8 m/yr	-0,6 m/yr	+3,6 m/yr	-1,3 m/yr	+8,1 m/yr

(die ander riviere lewer 'n baie klein bydrae tot die sedimenttoevoer)

The average growth rate over this forty-year period was thus +2,9 m/yr. A similar study of the beach width at the Nyoni and Mlalazi estuaries (see Figure 1) suggests that the Siaya growth rates are representative of the whole stretch of coastline between the Tugela and Durnford Point. Taken in conjunction with the length of the coastline, this information thus points to a mean volumetric growth rate of $0{,}6.10^{6}m^{3}/yr$ between the Tugela and the Siaya and $0{,}4.10^{6}m^{3}/yr$ between the Siaya and Durnford Point. Furthermore, it also follows that the nett northerly longshore transport rate of $1{,}3.10^{6}m^{3}/yr$ immediately to the north of the Tugela has decreased to $(1{,}3-0{,}6).10^{6}$ or $0{,}7.10^{6}m^{3}/yr$ at the Siaya and is $(0{,}7-0{,}4).10^{6}$ or $0{,}3.10^{6}m^{3}/yr$ at Durnford Point.

It should be noted, however, that the above findings are for a so-called typical year and during any given year the following factors can cause fluctuations in the fluvial and longshore sediment transport capacities;

(a) variations in the total rainfall in the Tugela catchment;
(b) variations in the rainfall distribution in the Tugela catchment;
(c) variations in the land-use pattern in the Tugela catchment;
(d) variations in the wave climate.

In addition, it has been observed [7] that most of the fluvial sediment transport can take place within a very short period (28 per cent of the annual transport occurred within a period of two days in one particular year), during which time the longshore current may be unidirectional. The bar formed by the deposition of material opposite the river mouth may therefore be skewed in a northerly or southerly direction. This skewness, in turn, influences a blocking effect which the bar has on the longshore transport rate and hence affects the growth rate of the northern coastline.

The pre-dam conditions, which are also set out graphically in Figure 5, can therefore be summarised as follows:

(i) fluvial sand load arriving at the Tugela mouth is $0{,}6.10^{6}m^{3}/yr$;
(ii) longshore sand load arriving at the Tugela mouth from the south is $1{,}1.10^{6}m^{3}/yr$;
(iii) sand deposition rate at the Tugela mouth is $0{,}4.10^{6}m^{3}/yr$;

(iv) longshore sand transport rate immediately to the north of the Tugela mouth is 1,3.10^6m^3/yr;

(v) volume of sand deposited between the Tugela and the Siaya is 0,6.10^6m^3/yr. equivalent to a coastline progression rate of 3 m/yr;

(vi) volume of sand deposited between the Siaya and Durnford Point is 0,4.10^6m^3/yr. equivalent to a coastline progression rate of 3 m/yr;

(vii) contribution of the Tugela sand load to the accretion between the Tugela and the Siaya is effectively (0,6-0,4)/0,6 or 33 per cent.

6.2 Post-dam conditions

Assuming that the Mvumase and Sunbury dams trap all the fluvial sand load [9], then the total quantity of sand arriving at the mouth of the Tugela will be the 1,1.10^6m^3/yr due to longshore transport from the south. However, during the early part of the post-dam period the longshore transport rate immediately to the north of the estuary will remain at 1,3.10^6m^3/yr and therefore the bar opposite the estuary mouth will be eroded. The resulting conditions along the Tugela coastline, which are also shown in Figure 5, will therefore be as follows:

(i) the bar opposite the Tugela mouth will be eroded;

(ii) the longshore sand transport rate immediately to the north of the Tugela mouth will decrease until it eventually equals the rate immediately to the south of the Tugela mouth, namely, 1,1.10^6m^3/yr;

(iii) the progression rate for the Tugela-Siaya coastline will ultimately fall by approximately 33 per cent to 2 m/yr;

(iv) annual fluctuations in the Tugela-Siaya coastline progression rate will be less marked due to the removal of the highly variable Tugela sand load;

(v) the first kilometre or so of coastline immediately to the south of the bar will become more stable due to the removal of fluctuations in the blocking effect caused by the variations in the shape of the bar;

(vi) little change will take place along the section of coastline further to the south of the Tugela mouth;

(vii) the change from the pre-dam to the post-dam conditions will be gradual (over decades).

If it is assumed that the Tugela catchment reverts to its so-called virgin condition and the Mvumase Project is not carried out, then the fluvial sediment load will be reduced by a factor of three [10]. Hence, assuming that the voids ratio and the sand content remain unchanged at 40 and 12 per cent, respectively, then the fluvial sand transport rate will fall to 0,2.10^{6}m^3/yr. The quantity of sand arriving at the estuary mouth will therefore be 1,1.10^{6}m^3/yr due to longshore transport from the south plus 0,2.10^{6}m^3/yr due to fluvial transport giving a total of 1,3.10^{6}m^3/yr. This, however, exactly balances the northbound longshore transport rate of 1,3.10^{6}m^3/yr immediately to the north of the estuary, which indicates that the bar opposite the Tugela mouth will be in a state of equilibrium. In these circumstances, the expected conditions along the Tugela coastline, which are also given in Figure 5, will be as follows:

(i) the bar opposite the Tugela mouth will cease growing and will remain at its present size;

(ii) the longshore sand transport rate immediately to the north of the Tugela mouth will remain at its pre-dam value of 1,3.10^{6}m^3/yr;

(iii) the progression rate for the Tugela-Siaya coastline will remain at its pre-dam value of approximately 3 m/yr and will continue indefinitely;

(iv) annual fluctuations in the Tugela-Siaya coastline progression rate will be less marked due to the partial removal of the highly variable Tugela sand load; (blokeffek v.d. rivierdelta ("bar"))

(v) the first kilometre of so of coastline immediately to the south of the bar will become more stable due to the partial removal of fluctuations in the blocking effect caused by the variations in the shape of the bar;

(vi) little change will take place along the section of coastline further to the south of the estuary mouth.

7 OPERATING POLICY FOR THE PROPOSED DAMS

7.1 General

The primary aim of the operating policy for the proposed dams, from an engineering standpoint, is to maintain the existing morphology of the Tugela River mouth. Ideally, therefore, compensation water should be released from the dams so that the cross-sectional area of the estuary mouth varies between a minimum value of approximately 70 m^2 relative to mean sea level during the dry winter (June) and a maximum value of approximately 1 200 m^2 relative to mean sea level during the wet summer (February). It is also desirable, from an aesthetic standpoint, that there should be a small, perennial river flow downstream of the lower dam site.

In order to achieve the objectives set out above, the operating policy for the dams should consist of two separate parts, namely:

(i) the release of a minimum, perennial flow;
(ii) the release of one or more "floods" during each wet season.

7.2 Minimum perennial flow

The minimum perennial flow must be large enough to counteract losses due to evaporation; in addition it is recommended that an extra 50 per cent allowance be made for seepage losses. According to Table II, the evaporation rate is lowest between February and May, when it has a mean value of 45 mm/month, and is highest between June and January, when it has a mean value of 92 mm/month. Using the evaporation area of $4,5.10^6 m^2$ derived in Section 2.3, the resulting minimum perennial flows are as follows:

February to May : 0,1 m^3/s;
June to January : 0,2 m^3/s.

The total quantity of water involved in the maintenance of these discharges is $5,2.10^6 m^3$/year or less than 0,2 per cent of the total annual runoff.

7.3 Simulated floods

The simulated floods should be large enough to ensure that the estuary mouth remains open throughout the year. Ideally, therefore, the dam should not be built at all, although a close approximation to this ideal is obtained by releasing the peak flood discharges during each of the seven wettest months (October to April). This latter policy, however, involves the discharge of 19 per cent of the mean annual runoff and is therefore impractical. Two, more realistic, operating procedures are therefore proposed and are discussed below in order of preference.

Operating Procedure A

This operating procedure involves the annual release of flood discharges during each of the seven wettest months (October to April). In each case, the pre-dam peak discharge rate is released but its duration is reduced so that the resulting value for 'Ω_{TOT}/S_{TOT}' is approximately 20. This particular value was chosen because Bruun (see Section 5.1) established that it corresponded to the limiting condition for a stable (open) estuary mouth. When computing the duration of the monthly releases, it was assumed that the fluvial sediment loads were as given in Table VII. Details of operating procedure 'A' are as follows:

Month	Discharge Rate (m^3/s)	Duration (days)	Quantity ($10^6 m^3$)
Oct.	200	2,0	35
Nov.	300	1,2	31
Dec.	400	0,9	31
Jan.	900	0,8	62
Feb.	1 200	0,8	83
Mar.	500	0,7	30
Apr.	200	1,6	28

The total volume of water released is $300.10^6 m^3$ which is equivalent to 9 per cent of the mean total annual runoff.

It is recommended that the timing of each release be so arranged that the front of the flood wave reaches the estuary mouth at about mean water level during a falling spring tide. This ensures that appreciable scour takes place before the occurrence of the following high tide when the tidal currents, in combination with wave action, will tend to move sediment back into the estuary mouth again.

Operating procedure B

This operating procedure involves the release each year of the October and April pre-dam peak flood discharges only, but with the duration of the latter adjusted so that 'Ω_{TOT}/S_{TOT}' attains a value of 50. This ensures that on two equally spaced occasions during a year the estuary mouth is scoured out to a 'stable' configuration.

Details of operating procedure 'B' are as follows:

Month	Discharge Rate (m^3/s)	Duration (days)	Quantity ($10^6 m^3$)
Oct.	200	4,9	85
Apr.	200	4,1	71

The total quantity of water involved in this operating procedure is $156.10^6 m^3$ or 5 per cent of the mean total annual runoff.

It may, however, be decided that this operating procedure be adopted but that different discharge rates be used from those quoted in the above table. In that case, not only must the duration of each release be adjusted so that the value of the ratio 'Ω_{TOT}/S_{TOT}' is maintained at 50 but allowance must also be made for the fact that the fluvial sediment load is a function of the discharge rate (see Section 4.3). The effect of varying the discharge rate is given in the following table:

Month	Discharge Rate (m^3/s)	Duration (days)	Quantity ($10^6 m^3$)	Prop. of Mean Total Annual Runoff (%)
Oct.	300	3,7	96	5
Apr.	300	3,1	80	
Oct.	400	3,2	111	6
Apr.	400	2,7	93	
Oct.	500	2,9	125	7
Apr.	500	2,5	108	
Oct.	600	2,8	145	8
Apr.	600	2,5	130	

As can be seen from the contents of this table, the quantity of water released increases as the discharge rate increases, in spite of the reduced flow duration.

8 CONCLUSIONS

The main effects of the Mvumase Project on the coastline adjacent to the Tugela estuary mouth will be as follows:

(i) the bar opposite the Tugela mouth will be eroded;

(ii) the progression rate for the Tugela-Siaya coastline will decrease from its pre-dam value of 3 m/year to 2 m/year;

(iii) annual fluctuations in the Tugela-Siaya coastline progression rate will be reduced;

(iv) the section of coastline immediately to the south of the Tugela mouth will become more stable.

If the Mvumase Project is not carried out and the Tugela catchment reverts to its so-called 'virgin' state, the effects on the coastline adjacent to the Tugela mouth will be as follows:

(a) the bar opposite the Tugela mouth will stop growing and remain at its present size;

(b) the progression rate for the Tugela-Siaya coastline will remain at its present value of 3 m/year;

(c) annual fluctuations in the Tugela-Siaya coastline progression rate will be less marked;

(d) the section of coastline immediately to the south of the Tugela mouth will become more stable.

The recommended operating policy for the release of compensation water from the Mvumase Project dams is as follows:

(I) a perennial flow of 0,1 m^3/s should be released between February and May and a perennial flow of 0,2 m^3/s should be released between June and January of each year;

(II) an annual flood release procedure should be adopted which, in order of preference, can take one of the following forms:

  (A) the release of 7 monthly flood discharges involving in total 9 per cent of the total annual runoff;

  (B) the release of 2 monthly flood discharges involving in total 5 per cent of the total annual runoff.

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TABLE I: AVERAGE MONTHLY MAXIMUM DAILY AVERAGE FLOW RATES AND AVERAGE PEAK MONTHLY FLOOD DISCHARGES

Month	Average Monthly Max. Daily Av. Flow Rate Q_{FM} (m^3/s)	Standard Deviation (m^3/s)	Average Peak Monthly Flood Discharge Ω_{FM} ($10^6 m^3$)
Oct.	225	259	38,9
Nov.	329	302	56,9
Dec.	429	261	74,1
Jan.	879	708	151,9
Feb.	1 176	1 089	203,2
Mar.	503	376	86,9
Apr.	247	204	42,7
May	102	185	17,6
Jun.	34	27	5,9
Jul.	54	161	9,3
Aug.	44	61	7,6
Sep.	99	179	17,1

TABLE II: AVERAGE MONTHLY EVAPORATION RATES

Month	Av. Monthly Evaporation Rate (mm/month)	Standard Deviation (mm/month)
Oct.	93,7	71,9
Nov.	96,6	37,8
Dec.	128,7	69,7
Jan.	84,2	88,0
Feb.	48,1	108,2
Mar.	27,7	73,7
Apr.	61,7	50,8
May	40,9	105,2
Jun.	84,2	34,1
Jul.	71,1	44,9
Aug.	97,9	63,3
Sep.	77,3	91,1
Total	912,1	--

TABLE III/1: DEEP SEA WAVE OCCURRENCES

Source : VOS [12] converted to "instrument" values
No. of obs. : 3 719
Peak energy wave periods

Year

Sector Period T_p(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
11,5	0,043	0,031	0,021	0,032	0,068	0,056	--	0,251
13,3	0,021	0,019	0,012	0,020	0,053	0,049	--	0,174
14,9	0,005	0,004	0,006	0,011	0,032	0,022	--	0,080
16,4	0,002	0,003	0,002	0,005	0,011	0,010	--	0,033
17,8	0,001	0,001	0	0,001	0,004	0,004	--	0,011
Calm	0,067	0,037	0,019	0,031	0,045	0,064	0,188	0,451
Total	0,139	0,095	0,060	0,100	0,213	0,205	0,188	1,000

TABLE III/1: DEEP SEA WAVE OCCURRENCES (cont'd)

January

Sector / Period T_p(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
11,5	0,0056	0,0043	0,0022	0,0051	0,0060	0,0035	--	0,0267
13,3	0,0011	0,0021	0,0005	0,0027	0,0038	0,0016	--	0,0118
14,9	0,0003	0,0005	0,0003	0,0011	0,0029	0,0032	--	0,0083
16,4	0	0,0003	0	0 0003	0,0013	0,0011	--	0,0030
17,8	0	0,0003	0	0	0,0003	0	--	0,0006
Calm	0,0075	0,0027	0,0021	0,0024	0,0062	0,0038	0,0167	0,0414
Total	0,0145	0,0102	0,0051	0,0116	0,0205	0,0132	0,0167	0,0918

February

Sector / Period T_p(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
11,5	0,0035	0,0040	0,0032	0,0043	0,0038	0,0043	--	0,0231
13,3	0,0024	0,0030	0,0011	0,0024	0,0051	0,0016	--	0,0156
14,9	0	0,0005	0,0005	0,0011	0,0024	0,0005	--	0,0050
16,4	0,0003	0,0008	0,0003	0,0005	0,0005	0,0003	--	0,0027
17,8	0,0003	0	0	0	0	0	--	0,0003
Calm	0,0048	0,0030	0,0027	0,0038	0,0016	0,0043	0,0092	0,0294
Total	0,0113	0,0113	0,0078	0,0121	0,0134	0,0110	0,0092	0,0761

TABLE III/1: DEEP SEA WAVE OCCURRENCES (cont'd)

March

Sector / Period T_p(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
11,5	0,0030	0,0032	0,0025	0,0028	0,0048	0,0038	--	0,0201
13,3	0,0013	0,0040	0,0005	0,0019	0,0022	0,0029	--	0,0128
14,9	0,0003	0,0003	0,0005	0,0016	0,0027	0,0005	--	0,0059
16,4	0,0005	0,0005	0,0003	0,0005	0,0005	0,0003	--	0,0026
17,8	0	0	0	0	0	0,0003	--	0,0003
Calm	0,0067	0,0044	0,0016	0,0013	0,0027	0,0048	0,0118	0,0333
Total	0,0118	0,0124	0,0054	0,0081	0,0129	0,0126	0,0118	0,0750

April

Sector / Period T_p(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
11,5	0,0016	0,0016	0,0027	0,0027	0,0060	0,0034	--	0,0180
13,3	0,0005	0,0008	0,0013	0,0016	0,0051	0,0022	--	0,0115
14,9	0	0,0003	0,0008	0,0008	0,0027	0,0019	--	0,0065
16,4	0,0005	0	0,0003	0,0005	0,0013	0,0005	--	0,0031
17,8	0	0	0	0	0,0005	0,0003	--	0,0008
Calm	0,0049	0,0043	0,0011	0,0030	0,0030	0,0070	0,0180	0,0413
Total	0,0075	0,0070	0,0062	0,0086	0,0186	0,0153	0,0180	0,0812

TABLE III/1: DEEP SEA WAVE OCCURRENCES (cont'd)

May

Sector / Period T_p(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
11,5	0,0032	0,0024	0,0005	0,0021	0,0059	0,0038	--	0,0179
13,3	0,0022	0,0019	0,0017	0,0016	0,0065	0,0043	--	0,0182
14,9	0,0005	0,0003	0,0005	0,0003	0,0030	0,0019	--	0,0065
16,4	0,0003	0	0	0,0003	0,0008	0,0008	--	0,0022
17,8	0	0	0	0,0003	0,0005	0,0005	--	0,0013
Calm	0,0046	0,0029	0,0011	0,0013	0,0046	0,0164	0,0135	0,0344
Total	0,0108	0,0075	0,0038	0,0059	0,0213	0,0177	0,0135	0,0805

June

Sector / Period T_p(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
11,5	0,0030	0,0016	0,0011	0,0038	0,0043	0,0051	--	0,0189
13,3	0,0016	0,0005	0,0011	0,0022	0,0054	0,0056	--	0,0164
14,9	0,0008	0	0,0008	0,0013	0,0035	0,0027	--	0,0091
16,4	0	0	0,0008	0	0,0016	0,0011	--	0,0035
17,8	0	0	0	0	0,0003	0,0003	--	0,0006
Calm	0,0072	0,0038	0,0016	0,0013	0,0035	0,0027	0,0231	0,0432
Total	0,0126	0,0059	0,0054	0,0086	0,0186	0,0175	0,0231	0,0917

TABLE III/1: DEEP SEA WAVE OCCURRENCES (cont'd)

July

Sector Period T_p(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
11,5	0,0032	0,0027	0,0017	0,0016	0,0061	0,0070	--	0,0223
13,3	0,0008	0,0011	0,0013	0,0010	0,0046	0,0059	--	0,0147
14,9	0,0003	0	0,0003	0,0003	0,0046	0,0019	--	0,0074
16,4	0	0,0005	0	0	0,0011	0,0011	--	0,0027
17,8	0	0	0	0,0003	0,0003	0	--	0,0006
Calm	0,0043	0,0022	0,0005	0,0016	0,0032	0,0048	0,0145	0,0311
Total	0,0086	0,0065	0,0038	0,0048	0,0199	0,0207	0,0145	0,0788

August

Sector Period T_p(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
11,5	0,0040	0,0016	0,0019	0,0021	0,0043	0,0051	--	0,0190
13,3	0,0019	0,0016	0,0016	0,0008	0,0054	0,0056	--	0,0169
14,9	0,0005	0,0008	0	0,0008	0,0024	0,0011	--	0,0056
16,4	0	0,0005	0,0003	0,0003	0,0011	0,0013	--	0,0035
17,8	0	0	0	0	0,0003	0,0008	--	0,0011
Calm	0,0062	0,0025	0,0013	0,0019	0,0040	0,0060	0,0196	0,0415
Total	0,0126	0,0070	0,0051	0,0059	0,0175	0,0199	0,0196	0,0876

TABLE III/1: DEEP SEA WAVE OCCURRENCES (cont'd)

September

Sector / Period T_p(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
11,5	0,0021	0,0024	0,0008	0,0030	0,0070	0,0051	--	0,0204
13,3	0,0011	0,0005	0,0013	0,0013	0,0040	0,0073	--	0,0155
14,9	0,0003	0	0	0,0008	0,0019	0,0029	--	0,0059
16,4	0	0	0	0,0005	0,0005	0,0008	--	0,0018
17,8	0	0	0	0,0003	0,0003	0,0003	--	0,0009
Calm	0,0064	0,0033	0,0025	0,0024	0,0038	0,0073	0,0204	0,0461
Total	0,0099	0,0062	0,0046	0,0083	0,0175	0,0237	0,0204	0,0906

October

Sector / Period T_p(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
11,5	0,0051	0,0035	0,0019	0,0011	0,0079	0,0040	--	0,0235
13,3	0,0027	0,0013	0,0013	0,0016	0,0043	0,0038	--	0,0150
14,9	0,0008	0,0003	0,0008	0,0005	0,0016	0,0013	--	0,0053
16,4	0,0003	0	0	0,0005	0,0008	0,0011	--	0,0027
17,8	0,0005	0	0	0	0,0005	0,0003	--	0,0013
Calm	0,0051	0,0035	0,0011	0,0052	0,0048	0,0048	0,0148	0,0393
Total	0,0145	0,0086	0,0051	0,0089	0,0199	0,0153	0,0148	0,0871

TABLE III/1: DEEP SEA WAVE OCCURRENCES (cont'd)

November

Sector / Period T_p(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
11,5	0,0040	0,0026	0,0013	0,0027	0,0064	0,0054	--	0,0224
13,3	0,0038	0,0013	0,0006	0,0013	0,0035	0,0043	--	0,0148
14,9	0,0005	0,0008	0,0008	0,0019	0,0027	0,0016	--	0,0083
16,4	0	0,0003	0,0003	0,0005	0,0003	0,0011	--	0,0025
17,8	0	0,0003	0	0,0003	0,0003	0,0005	--	0,0014
Calm	0,0035	0,0022	0,0013	0,0038	0,0029	0,0070	0,0132	0,0339
Total	0,0118	0,0075	0,0043	0,0105	0,0161	0,0199	0,0132	0,0833

December

Sector / Period T_p(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
11,5	0,0051	0,0013	0,0011	0,0008	0,0059	0,0059	--	0,0201
13,3	0,0013	0,0008	0	0,0016	0,0035	0,0038	--	0,0110
14,9	0,0003	0,0003	0,0003	0,0005	0,0022	0,0019	--	0,0055
16,4	0,0003	0,0003	0	0,0005	0,0008	0,0005	--	0,0024
17,8	0,0003	0	0	0	0,0005	0,0005	--	0,0013
Calm	0,0056	0,0027	0,0018	0,0031	0,0043	0,0051	0,0134	0,0360
Total	0,0129	0,0054	0,0032	0,0065	0,0172	0,0177	0,0134	0,0763

TABLE III/2 : DEEP SEA WAVE HEIGHTS

Source : VOS [12] converted to "instrument" values

No.of obs. : 3 719

Significant wave heights and peak energy wave periods

Year

Sector / Period T_P(s)	Significant Wave Height H_{OS} (m)					
	60°	90°	120°	150°	180°	210°
11,5	2,2	2,0	2,2	2,2	2,4	2,5
13,3	2,5	2,0	2,7	2,5	2,5	3,0
14,9	2,5	2,2	2,5	2,5	2,8	3,4
16,4	3,0	2,2	2,5	2,6	2,8	3,6
17,8	2,9	2,5	-	2,9	2,9	4,1

TABLE III/2: DEEP SEA WAVE HEIGHTS (cont'd)

January

Sector / Period T_P(s)	Significant Wave Height H_{OS} (m)					
	60°	90°	120°	150°	180°	210°
11,5	2,2	1,8	1,8	2,3	2,4	2,3
13,3	2,7	2,1	1,8	2,3	2,6	2,8
14,9	2,1	2,1	2,1	2,4	2,7	3,6
16,4	–	1,8	–	2,4	2,7	2,8
17,8	–	2,4	–	–	2,9	–

February

Sector / Period T_P(s)	Significant Wave Height H_{OS} (m)					
	60°	90°	120°	150°	180°	210°
11,5	2,0	2,0	2,5	2,2	2,2	2,4
13,3	2,3	2,2	1,8	2,7	2,5	3,1
14,9	–	2,2	2,5	2,8	2,5	2,6
16,4	4,3	2,4	3,2	3,2	3,4	2,1
17,8	2,7	–	–	–	–	–

March

Sector / Period T_P(s)	Significant Wave Height H_{OS} (m)					
	60°	90°	120°	150°	180°	210°
11,5	2,4	1,8	2,1	2,4	2,5	2,8
13,3	2,6	2,0	2,3	2,6	2,2	2,9
14,9	1,8	1,8	2,4	2,5	2,2	3,6
16,4	3,0	1,8	2,4	2,9	2,0	2,1
17,8	–	–	–	–	–	3,5

TABLE III/2: DEEP SEA WAVE HEIGHTS (cont'd)

April

Sector Period T_P(s)	Significant Wave Height H_{OS}(m)					
	60°	90°	120°	150°	180°	210°
11,5	2,0	2,2	2,2	1,9	2,6	2,5
13,3	2,3	2,0	2,2	2,4	2,3	2,8
14,9	–	2,1	1,8	2,5	2,7	3,8
16,4	2,7	–	2,4	2,5	2,7	2,1
17,8	–	–	–	–	2,8	2,4

May

Sector Period T_P(s)	Significant Wave Height H_{OS}(m)					
	60°	90°	120°	150°	180°	210°
11,5	2,2	1,9	2,0	2,4	2,4	2,2
13,3	2,5	2,2	3,1	2,5	2,4	2,8
14,9	1,9	2,1	2,7	2,7	3,0	3,7
16,4	2,7	–	–	3,2	2,7	4,2
17,8	–	–	–	3,8	4,0	5,1

June

Sector Period T_P(s)	Significant Wave Height H_{OS}(m)					
	60°	90°	120°	150°	180°	210°
11,5	2,0	1,6	2,0	2,1	2,7	2,7
13,3	2,7	2,0	4,5	2,3	2,7	2,9
14,9	2,1	–	1,7	2,6	2,8	3,2
16,4	–	–	2,8	–	2,8	2,9
17,8	–	–	–	–	2,7	2,4

TABLE III/2: DEEP SEA WAVE HEIGHTS (cont'd)

July

Sector / Period T_P(s)	Significant Wave Height H_{OS}(m)					
	60°	90°	120°	150°	180°	210°
11,5	1,9	1,9	1,7	2,1	2,4	2,4
13,3	2,5	2,0	1,9	1,7	2,6	3,2
14,9	2,4	-	4,0	1,3	3,1	3,5
16,4	-	2,0	-	-	3,1	2,8
17,8	-	-	-	2,7	2,7	-

August

Sector / Period T_P(s)	Significant Wave Height H_{OS}(m)					
	60°	90°	120°	150°	180°	210°
11,5	2,0	2,3	1,9	2,5	2,3	2,6
13,3	2,3	1,9	2,3	2,3	2,3	3,5
14,9	2,8	2,6	-	1,9	3,2	4,7
16,4	-	2,5	1,8	2,1	2,5	4,3
17,8	-	-	-	-	2,4	3,8

September

Sector / Period T_P(s)	Significant Wave Height H_{OS}(m)					
	60°	90°	120°	150°	180°	210°
11,5	2,2	2,1	2,6	1,9	2,3	2,5
13,3	2,3	2,3	2,1	2,7	2,8	3,0
14,9	1,8	-	-	2,7	3,0	3,2
16,4	-	-	-	2,1	2,9	3,1
17,8	-	-	-	2,7	2,7	7,9

TABLE III/2: DEEP SEA WAVE HEIGHTS (cont'd)

October

Sector / Period T_P(s)	Significant Wave Height H_{OS}(m)					
	60°	90°	120°	150°	180°	210°
11,5	2,4	2,0	2,0	2,2	2,4	3,0
13.3	2,7	1,7	2,3	2,3	2,9	2,7
14,9	3,4	2,1	3,1	2,4	3,1	2,9
16,4	2,7	-	-	2,7	2,6	3,3
17,8	3,1	-	-	-	2,7	4,9

November

Sector / Period T_P(s)	Significant Wave Height H_{OS}(m)					
	60°	90°	120°	150°	180°	210°
11,5	2,3	2,1	2,2	2,3	2,4	2,4
13,3	2,4	1,8	2,7	2,5	2,3	2,7
14,9	2,3	2,8	2,3	2,6	2,9	2,6
16,4	-	2,1	1,8	2,1	2,4	5,0
17,8	-	2,7	-	2,4	3,2	2,4

December

Sector / Period T_P(s)	Significant Wave Height H_{OS}(m)					
	60°	90°	120°	150°	180°	210°
11,5	2,2	2,2	2,1	2,5	2,5	2,5
13,3	2,4	2,2	-	2,9	2,4	2,7
14,9	2,1	2,1	1,8	2,4	2,3	2,6
16,4	2,9	2,1	-	2,4	3,1	2,5
17,8	2,7	-	-	-	2,3	1,8

TABLE IV: BREAKER LINE WAVE DATA

Deep Sea Wave Direction θ_o(o)	Peak Energy Wave Period T_P(s)	Mean Breaker Angle θ_B(o)	Mean Breaker Refraction Coeff. K_{RB} f	Deep Sea Wave Direction θ_o(o)	Peak Energy Wave Period T_P(s)	Mean Breaker Angle θ_B(o)	Mean Breaker Refraction Coeff. K_{RB}
60	11,5	17,5N	0,34 0,043	150	11,5	5,3S	1,18
	13,3	12,6N	0,39		13,3	10,1S	1,08
	14,9	15,9N	1,40		14,9	7,9S	1,08
	16,4	6,0N	0,87		16,4	8,4S	1,59
	17,8	5,1N	1,19		17,8	6,6S	1,89
90	11,5	6,4N	0,68	180	11,5	21,0S	1,39
	13,3	8,2N	0,84		13,3	20,3S	1,30
	14,9	4,2S	0,71		14,9	19,6S	1,31
	16,4	4,3N	0,85		16,4	10,1S	1,56
	17,8	0	0,79		17,8	10,6S	0,96
120	11,5	0,6N	1,05	210	11,5	22,9S	0,70
	13,3	1,0S	0,98		13,3	14,6S	0,39
	14,9	0,9S	1,34		14,9	22,3S	0,68
	16,4	16,3S	1,47		16,4	25,8S	0,74
	17,8	12,7S	1,22		17,8	21,8S	1,07

TABLE V: PREDICTED LONGSHORE TRANSPORT RATES

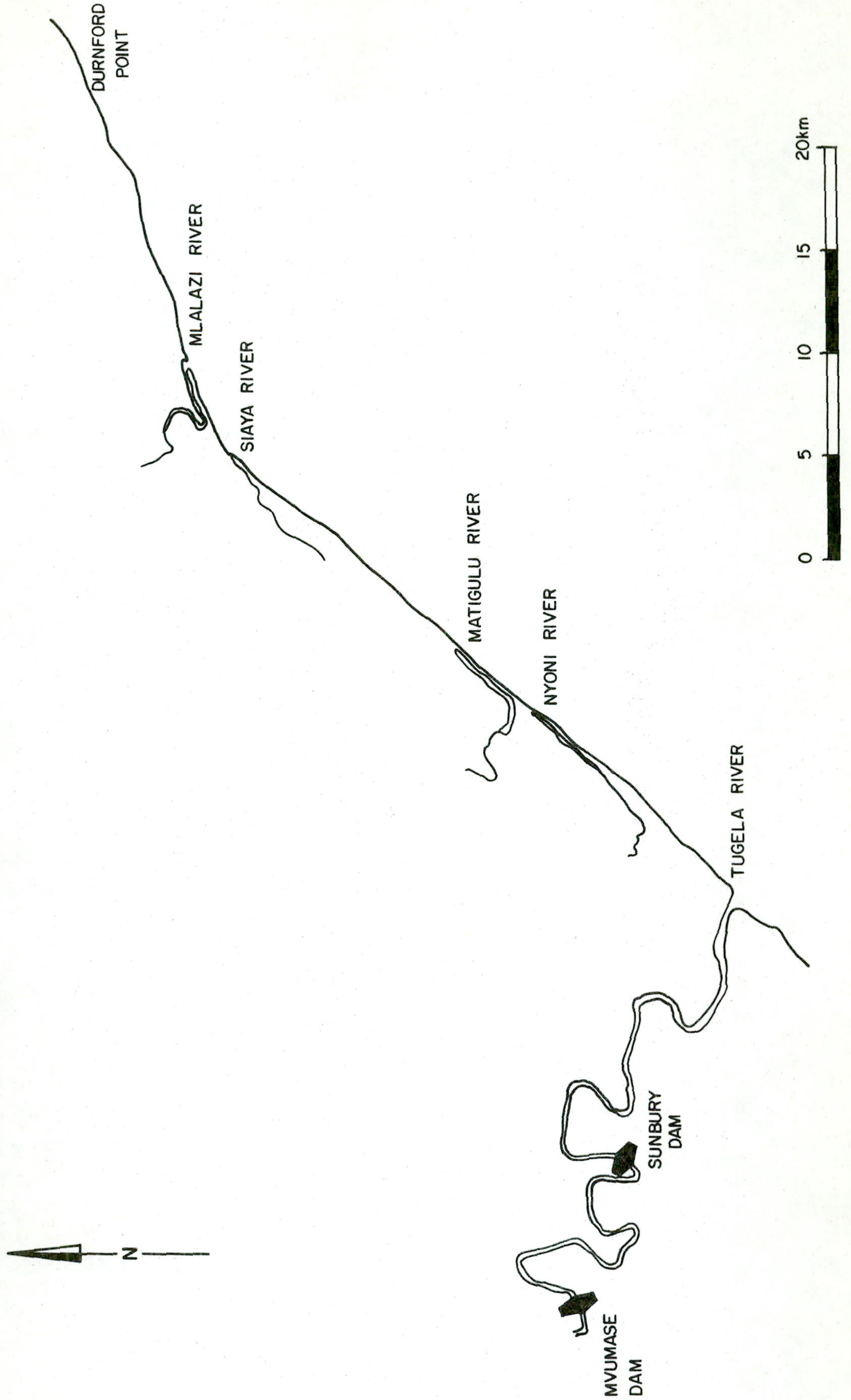
Month	Longshore Transport Rate S_x ($10^6 m^3/yr$)			
	Northbound	Southbound	Nett	Gross
Oct.	1,3	0,2	1,1	1,5
Nov.	1,2	0,1	1,1	1,3
Dec.	1,0	0,1	0,9	1,1
Jan.	1,2	0,1	1,1	1,3
Feb.	1,0	0,1	0,9	1,1
Mar.	0,8	0,1	0,7	0,9
Apr.	1,2	0	1,2	1,2
May	1,5	0,1	1,4	1,6
Jun.	0,9	0,1	0,8	1,0
Jul.	1,5	0	1,5	1,5
Aug.	1,3	0,1	1,2	1,4
Sep.	1,4	0	1,4	1,4
Mean	1,2	0,1	1,1	1,3

TABLE VI: MONTHLY FLUVIAL SEDIMENT TRANSPORT RATES

Month	Fluvial Sed. Transp. Rate S_{FM} ($10^6 m^3/yr$)
Oct.	0,2
Nov.	0,3
Dec.	0,5
Jan.	1,9
Feb.	3,3
Mar.	0,7
Apr.	0,2
May	0
Jun.	0
Jul.	0
Aug.	0
Sep.	0
Mean	0,6

TABLE VII: ESTUARY MOUTH STABILITY

Month	Ω_{TOT}		S_{TOT}		Ω_{TOT}/S_{TOT}
	Actual Spring Tidal Prism $\Omega_T(10^6 m^3)$	'Fluvial Spring Tidal Prism' $\Omega_{FM}(10^6 m^3)$	Gross Longshore Transport Rate $S_{XG}(10^6 m^3/yr)$	Monthly Fluvial Transport Rate $S_{FM}(10^6 m^3/yr)$	
Oct.	0,5	38,9	1,5	0,2	23
Nov.	0,5	56,9	1,3	0,3	36
Dec.	0,5	74,1	1,1	0,5	47
Jan.	0,5	151,9	1,3	1,9	48
Feb.	0,5	203,2	1,1	3,3	46
Mar.	0,5	86,9	0,9	0,7	55
Apr.	0,5	42,7	1,2	0,2	31
May	0,5	17,6	1,6	0	11
Jun.	0,5	5,9	0,9	0	7
Jul.	0,5	9,3	1,5	0	7
Aug.	0,5	7,6	1,4	0	6
Sep.	0,5	17,1	1,4	0	13



TRACED D.D. CHECKED DATE REF	**LOCATION**	**FIGURE** **1**

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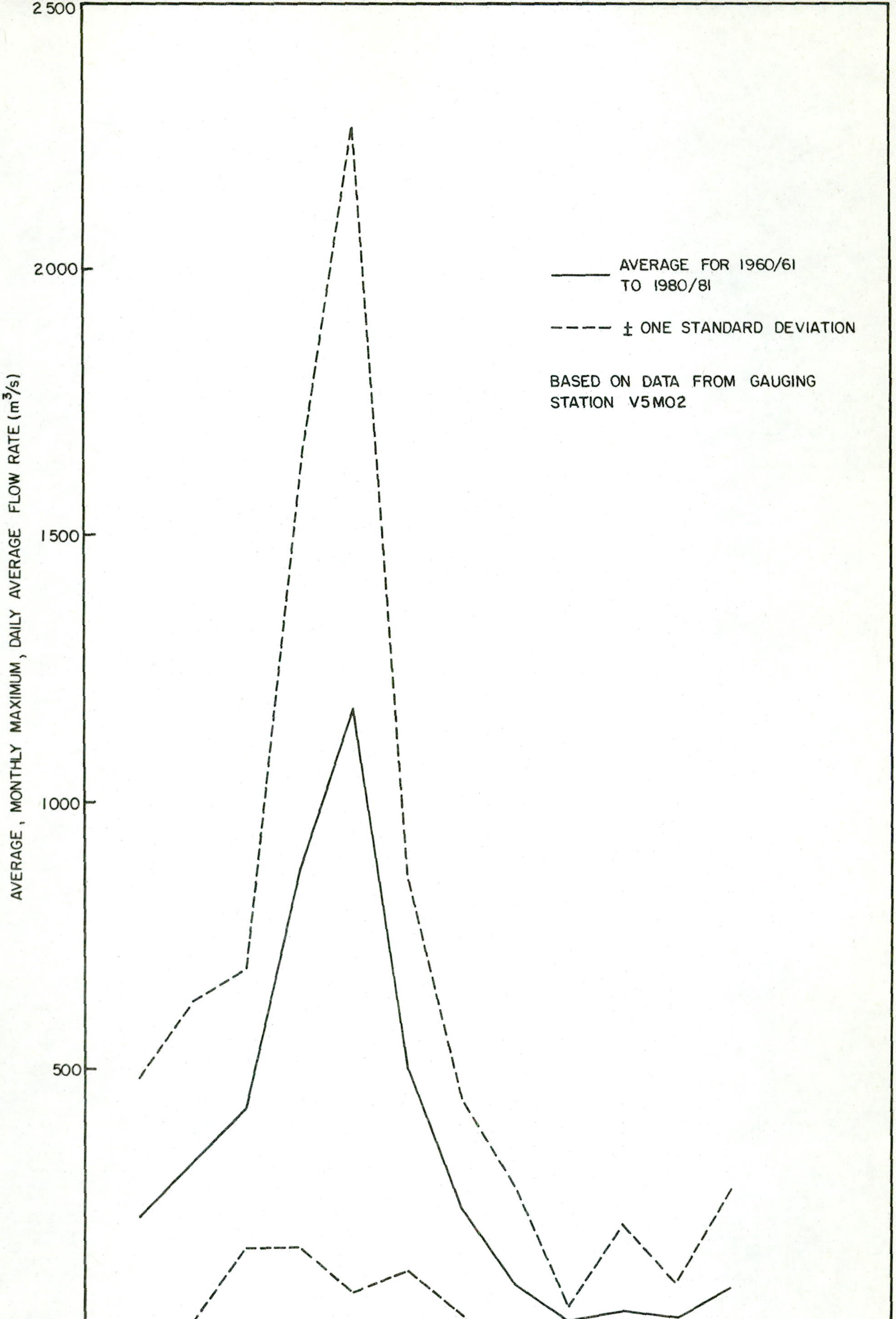

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AVERAGE, MONTHLY MAXIMUM, DAILY AVERAGE FLOW RATES

FIGURE 2

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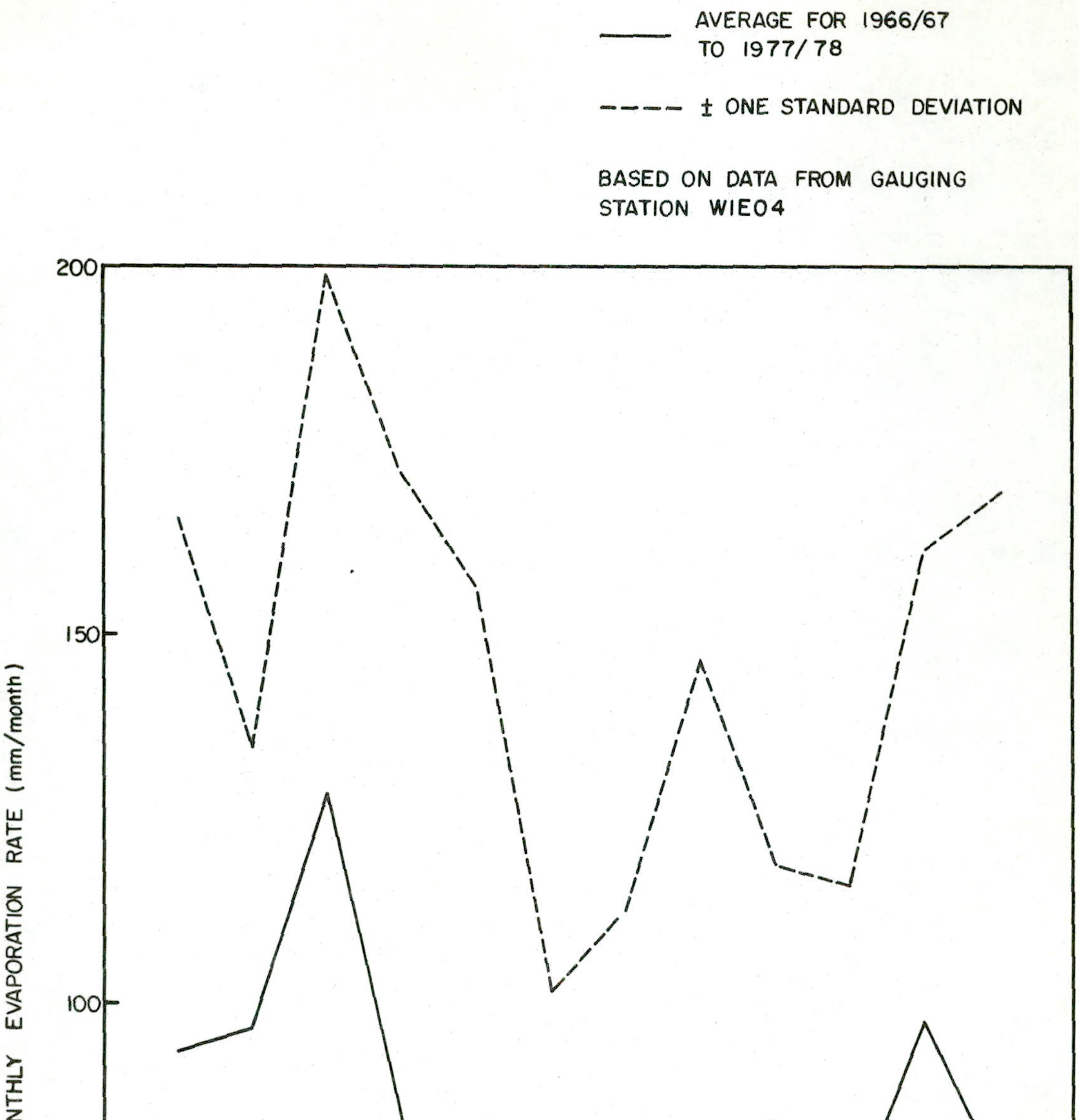

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AVERAGE, MONTHLY EVAPORATION RATES

FIGURE 3

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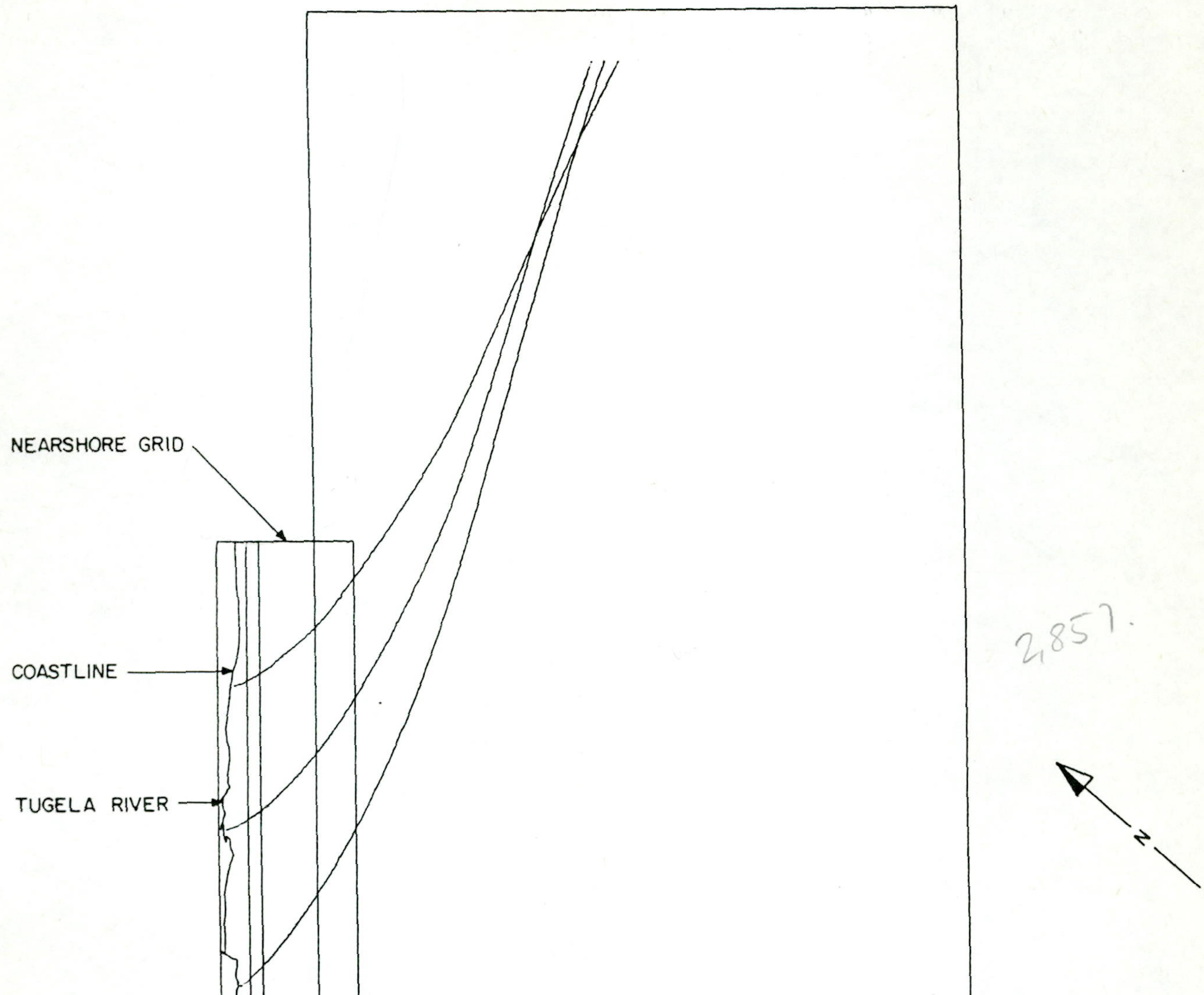

2857.

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 60.0

WAVE PERIOD: 11.5 SECS
SCALE : 1/350000

FIGURE
4a

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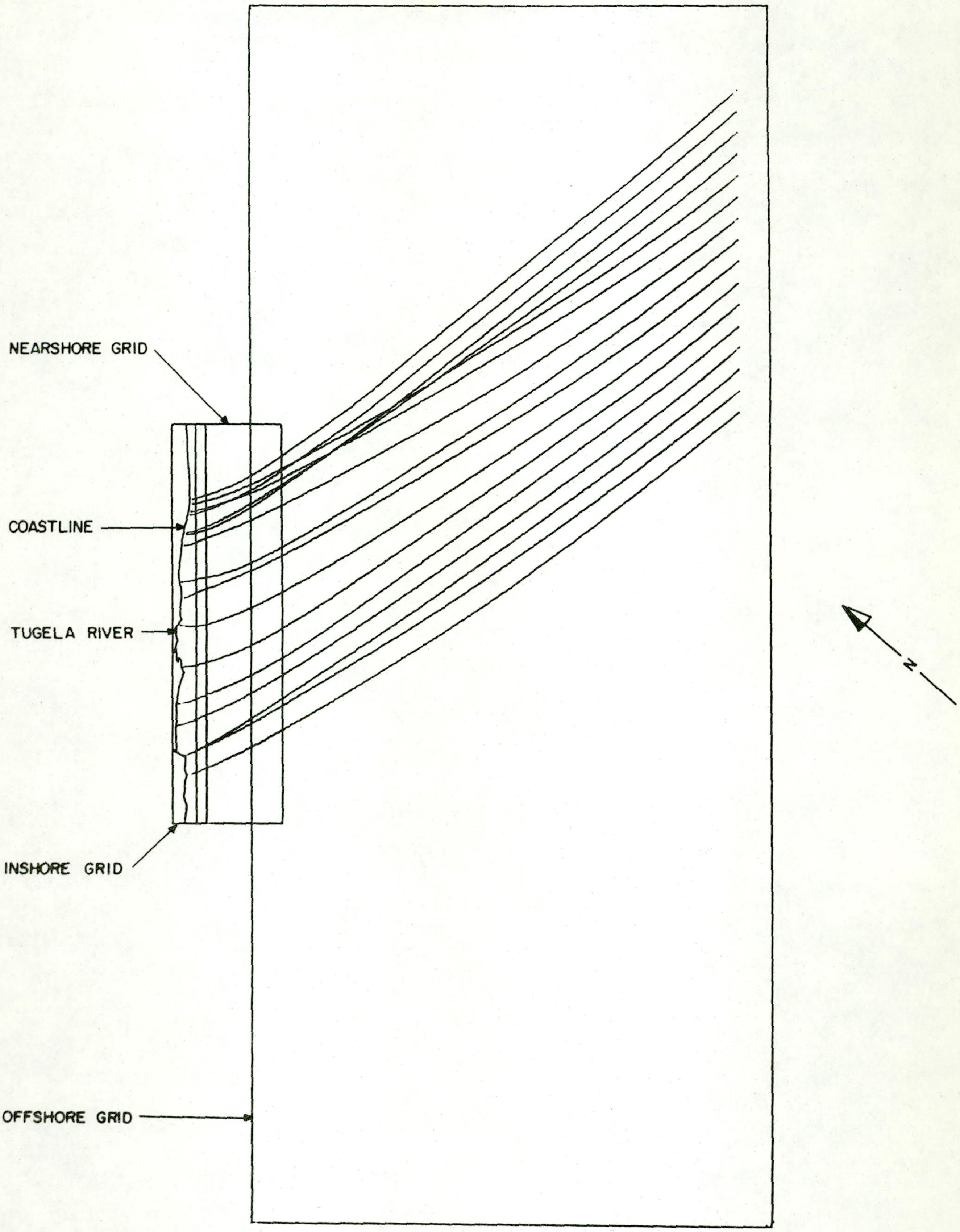

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 90.0

WAVE PERIOD: 11.5 SECS
SCALE :1/350000

FIGURE
4b

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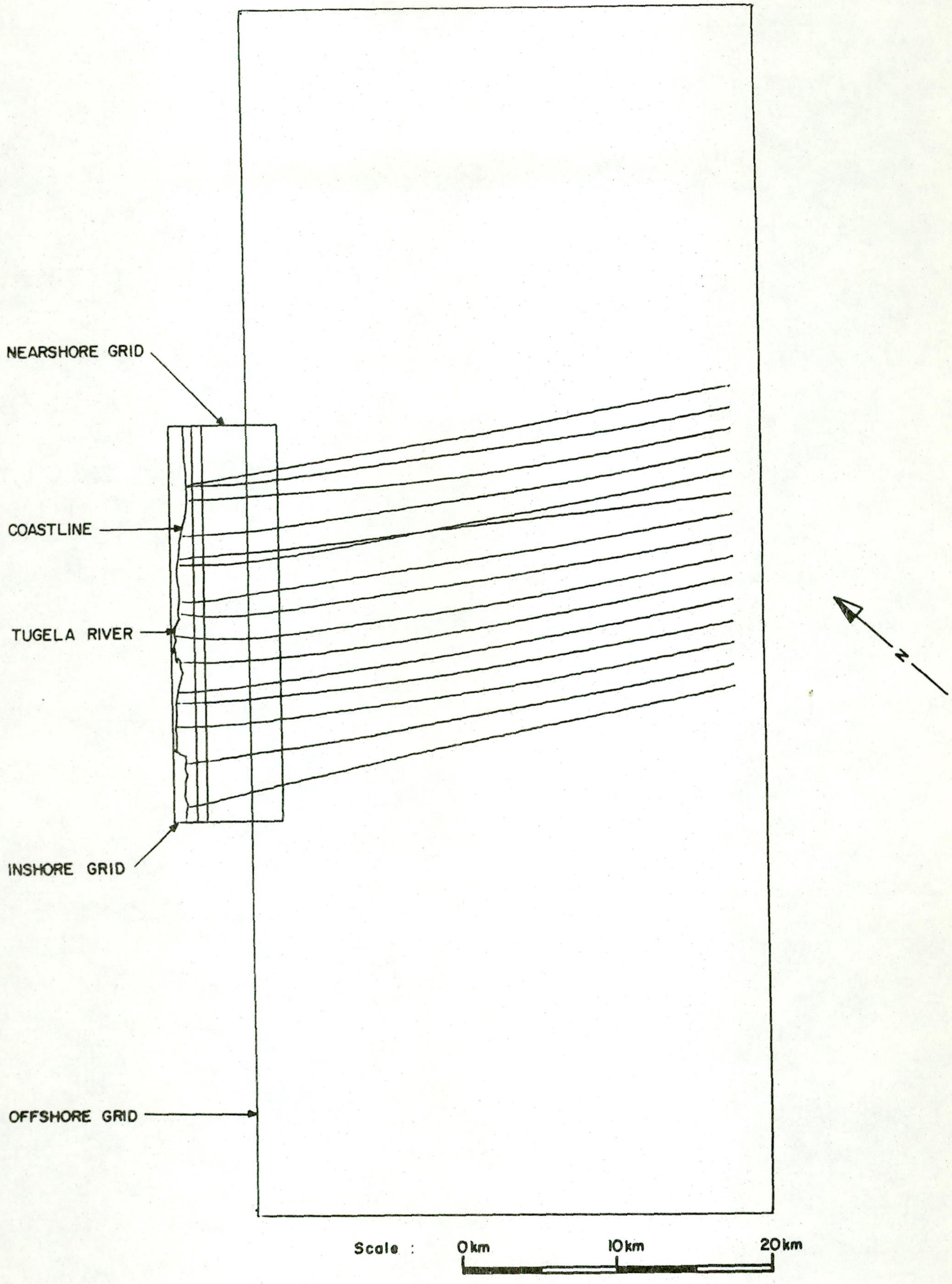

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 120.0

WAVE PERIOD: 11.5 SECS
SCALE :1/350000

FIGURE
4c

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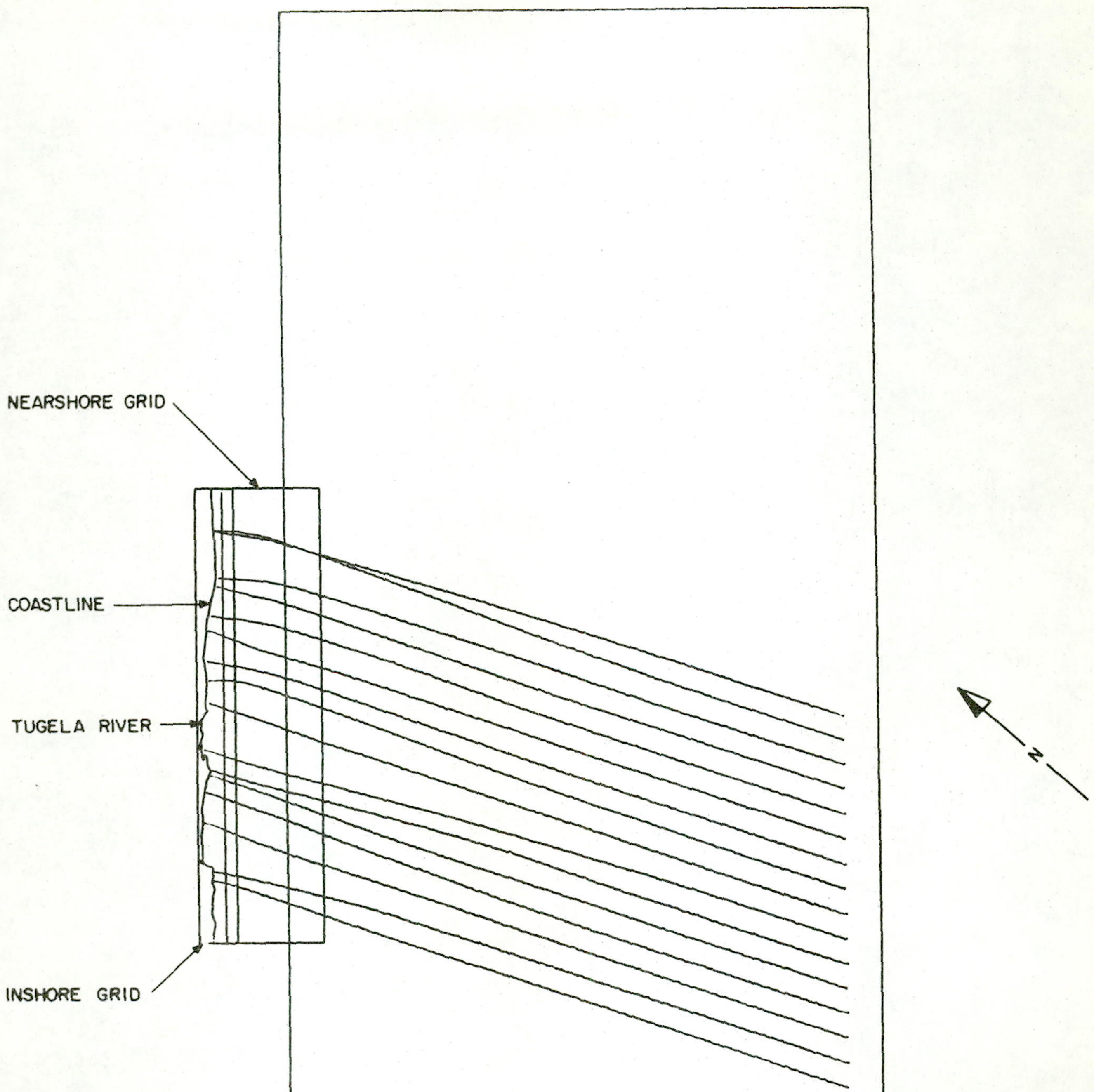

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 150.0

WAVE PERIOD: 11.5 SECS
SCALE :1/350000

FIGURE
4d

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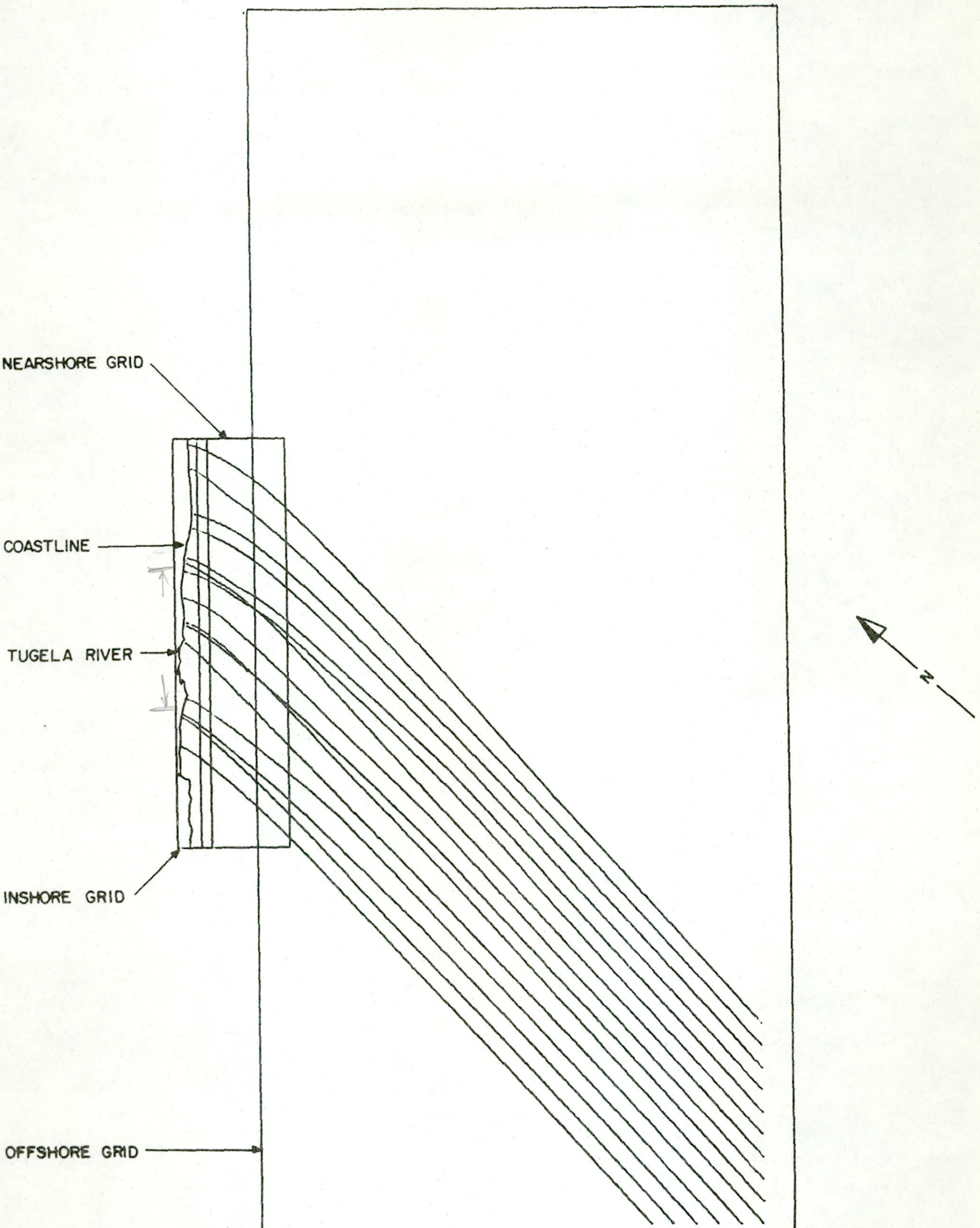

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 180.0

WAVE PERIOD: 11.5 SECS
SCALE :1/350000

FIGURE
4e

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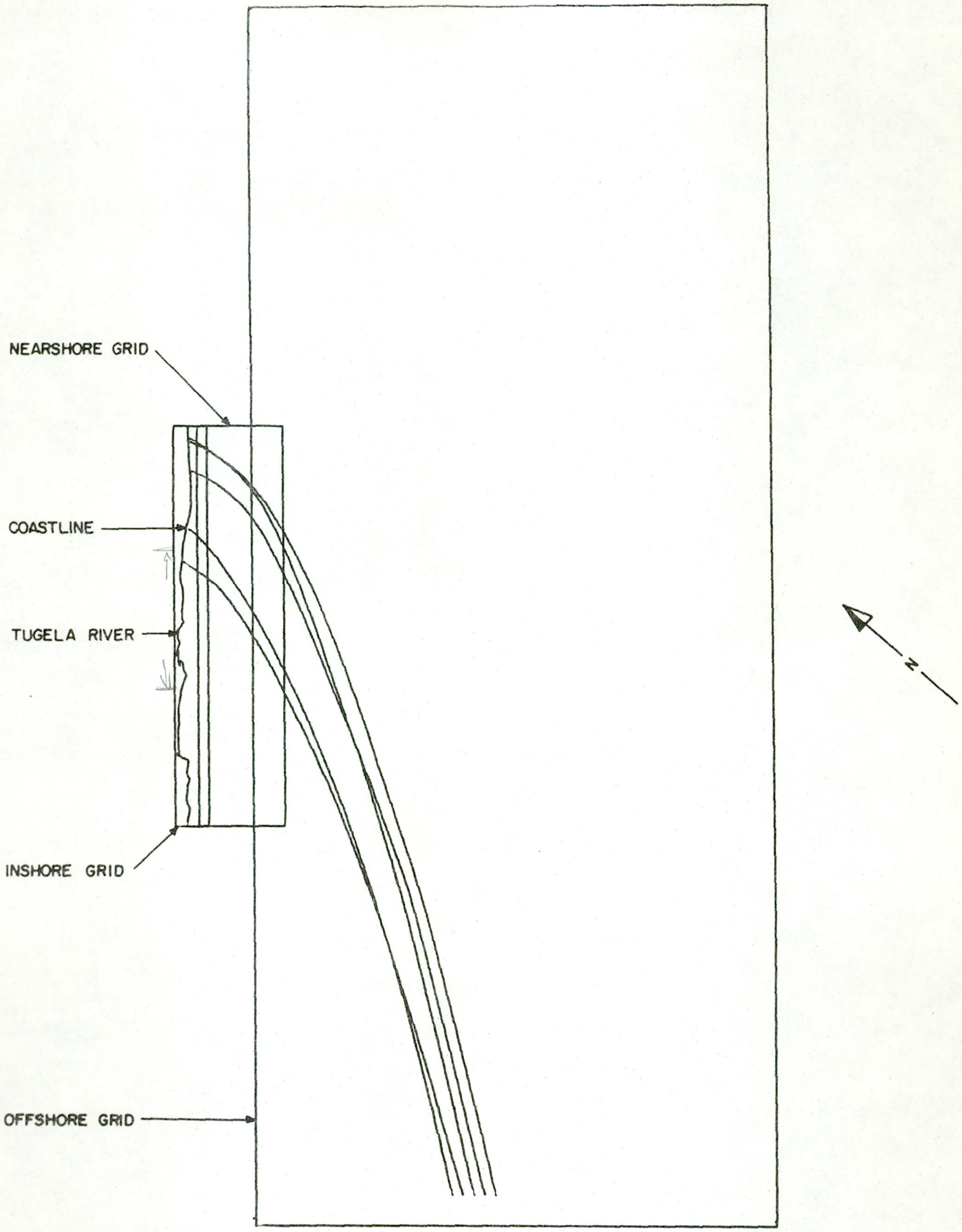

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 210.0

WAVE PERIOD: 11.5 SECS
SCALE :1/350000

FIGURE
4f

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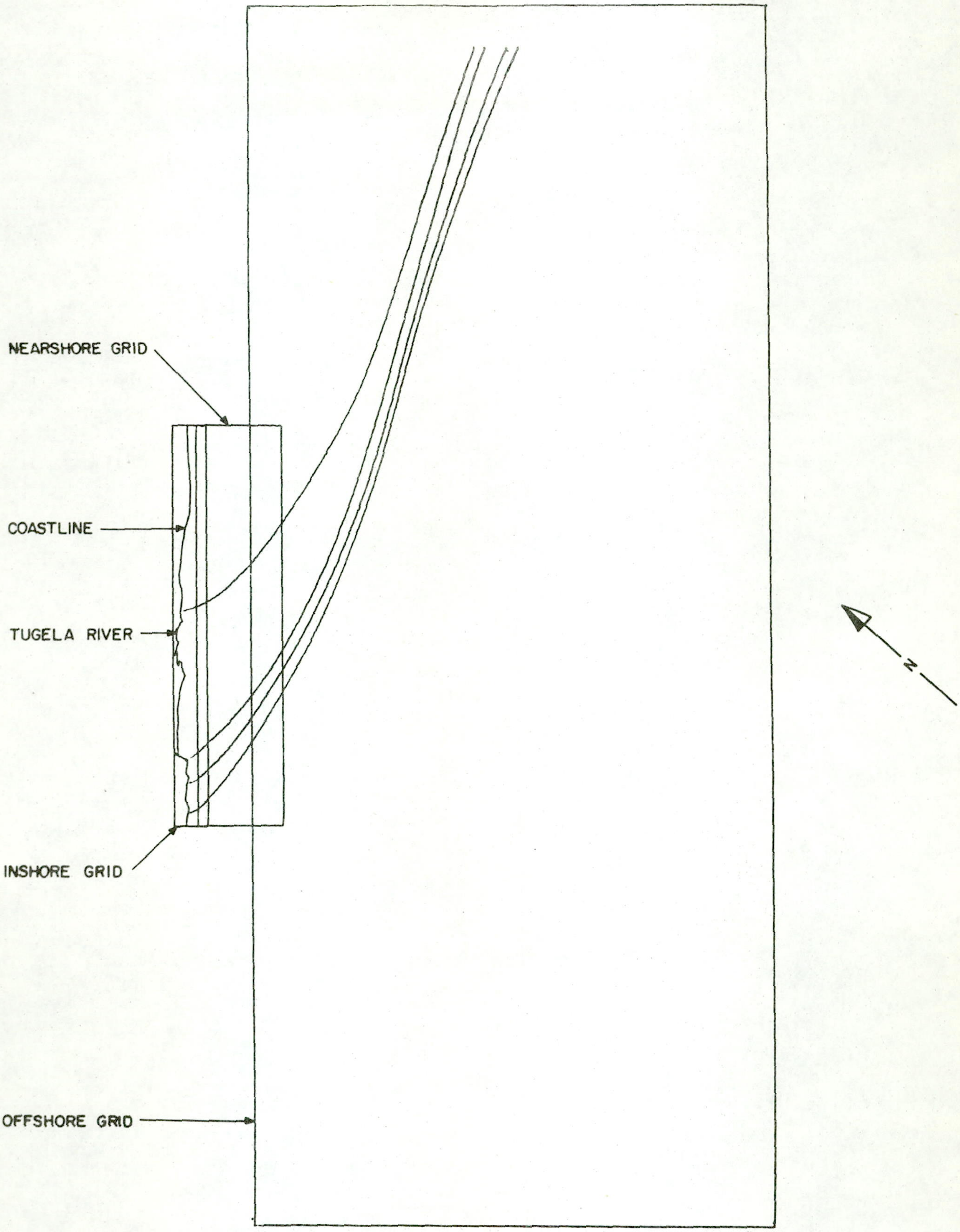

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 60.0

WAVE PERIOD: 13.3 SECS
SCALE :1/350000

FIGURE
4g

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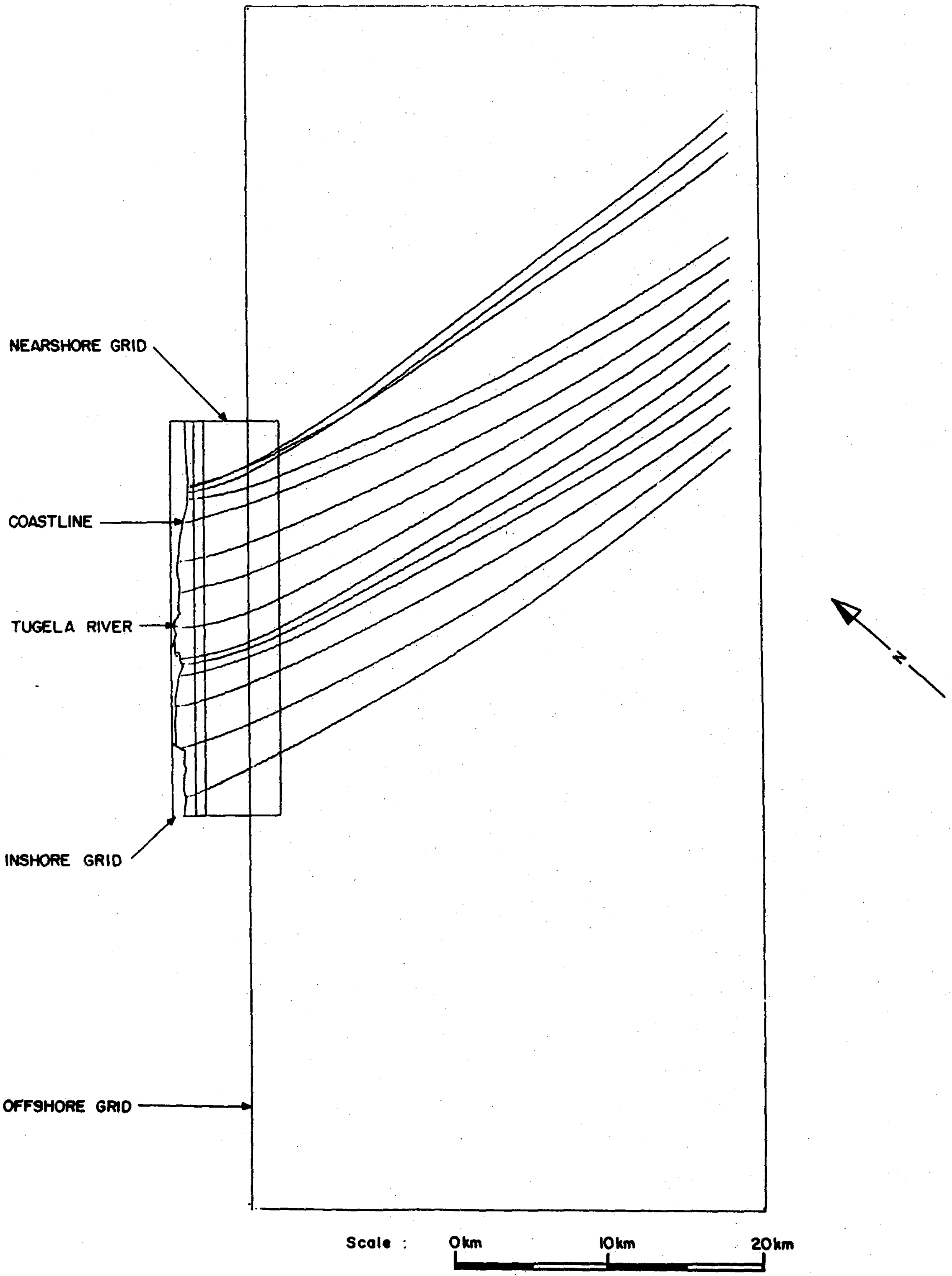

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 90.0

WAVE PERIOD: 13.3 SECS
SCALE :1/350000

FIGURE
4h

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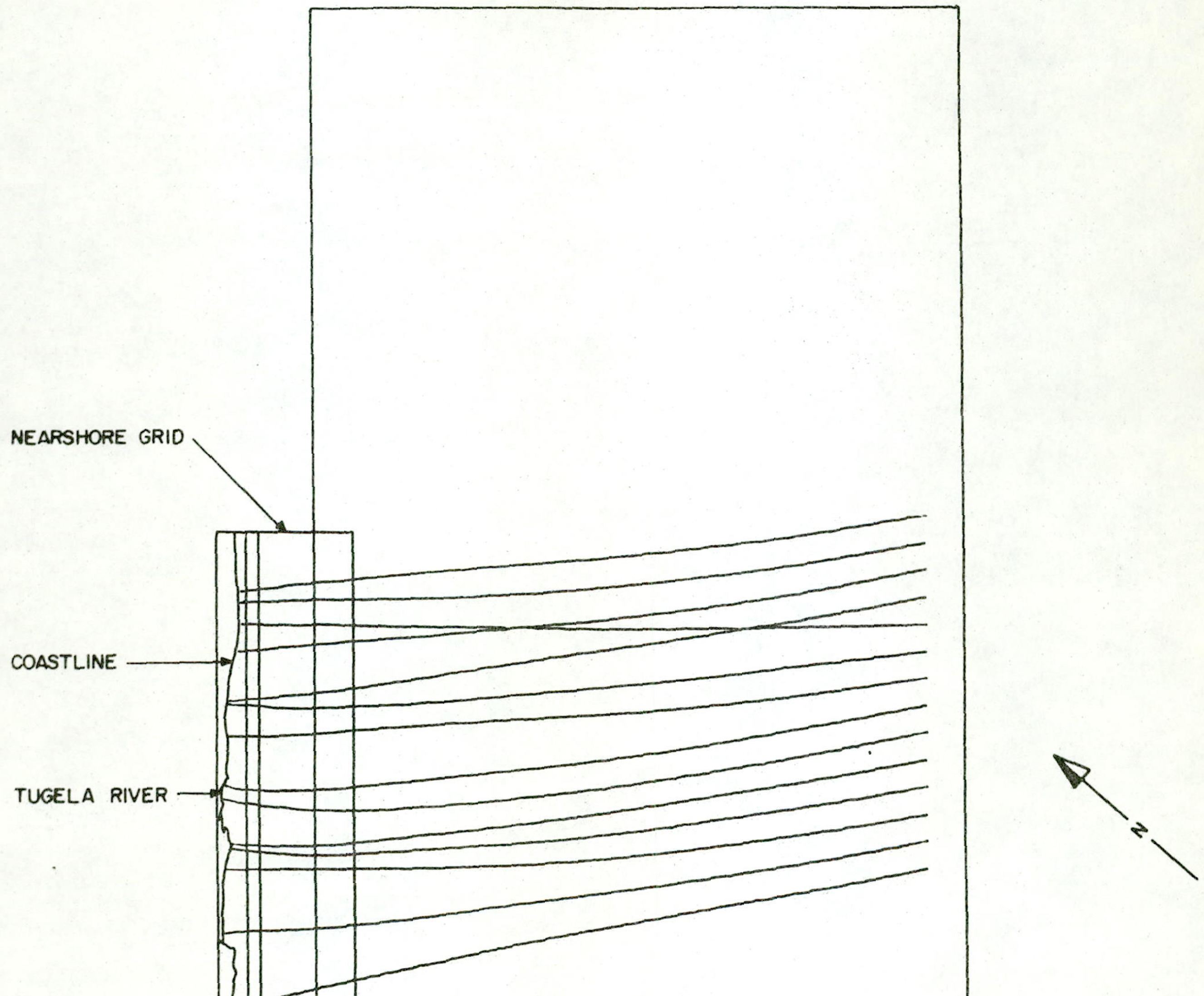

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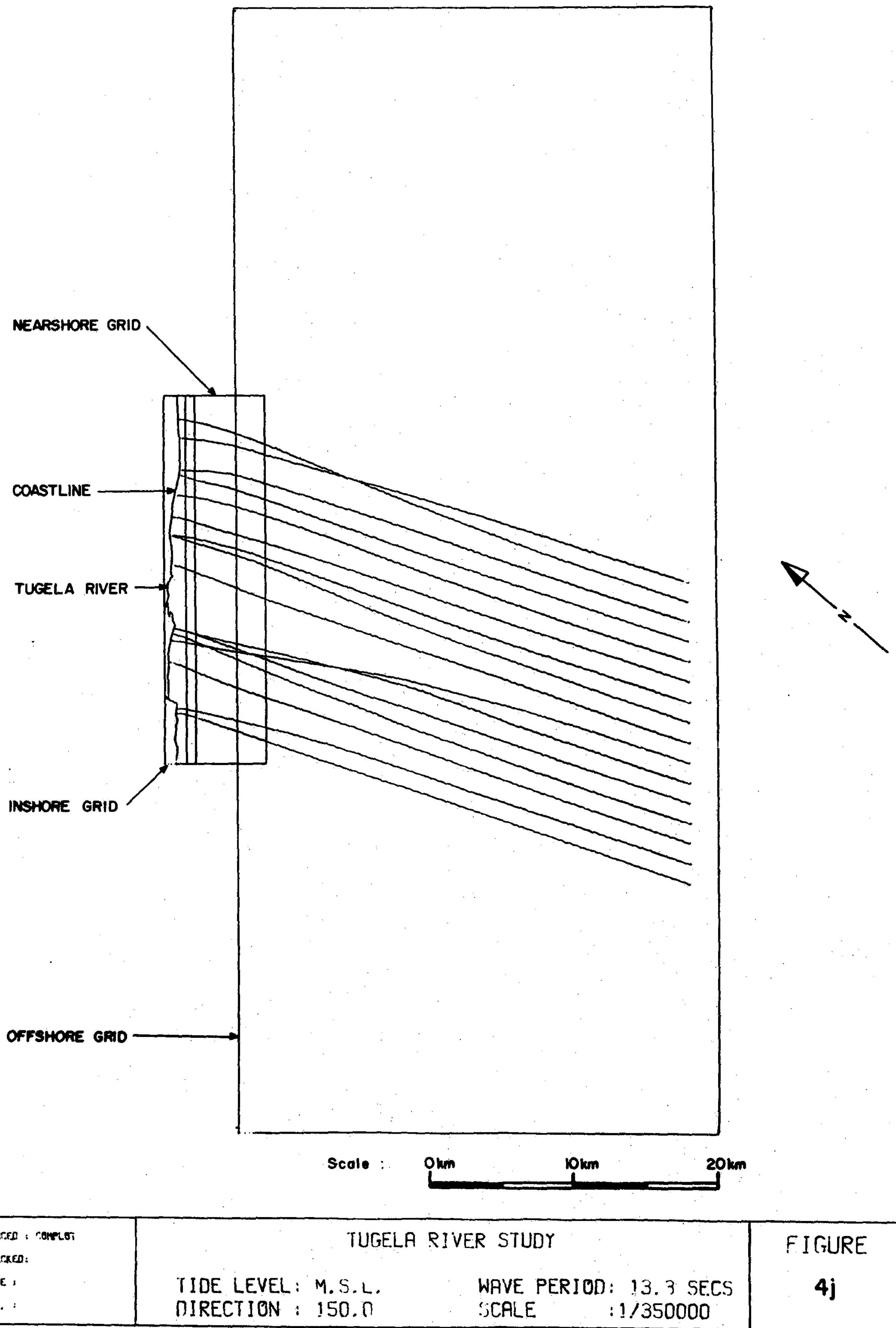

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 150.0

WAVE PERIOD: 13.3 SECS
SCALE :1/350000

FIGURE
4j

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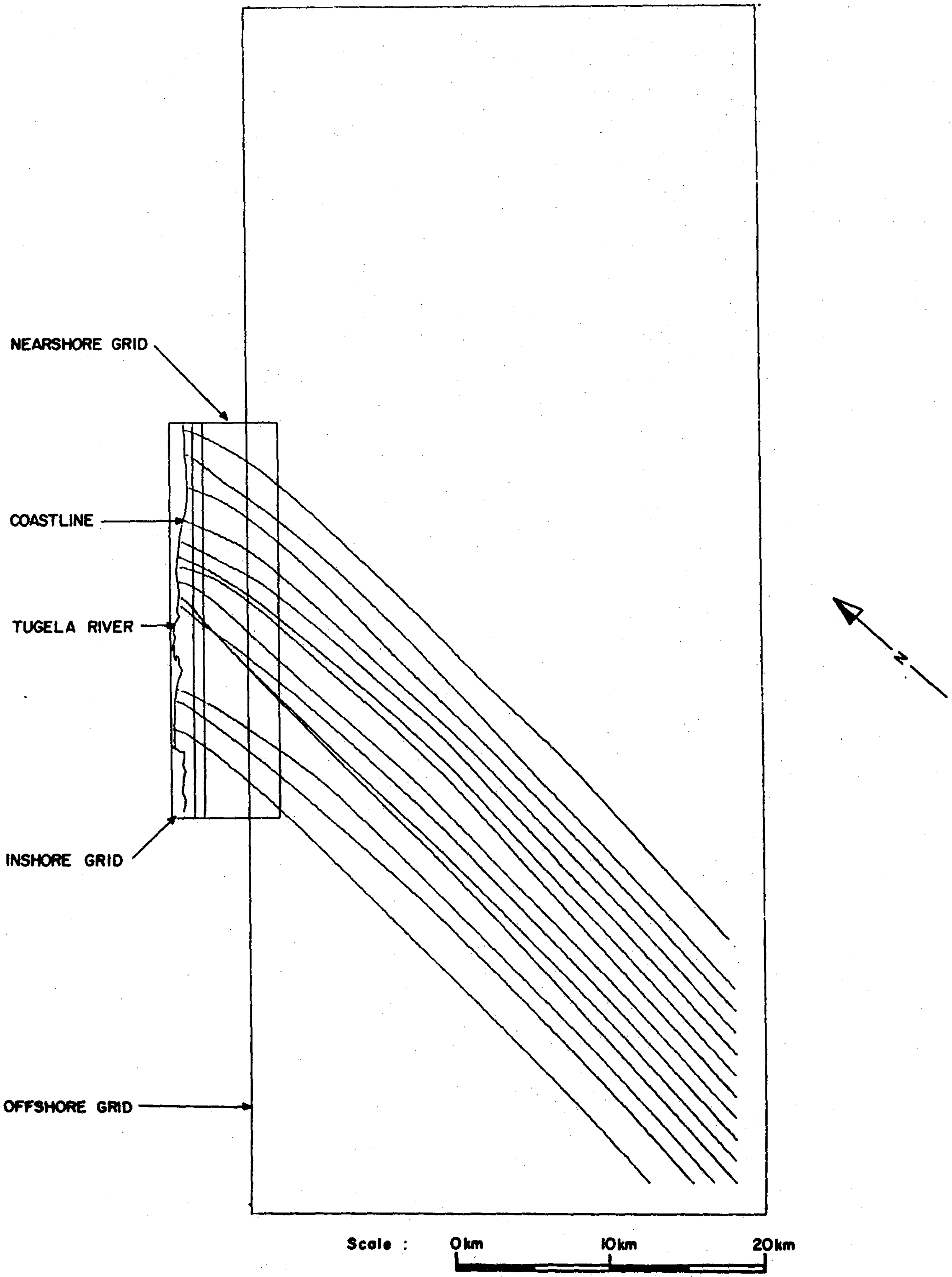

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 180.0

WAVE PERIOD: 13.3 SECS
SCALE :1/350000

FIGURE
4k

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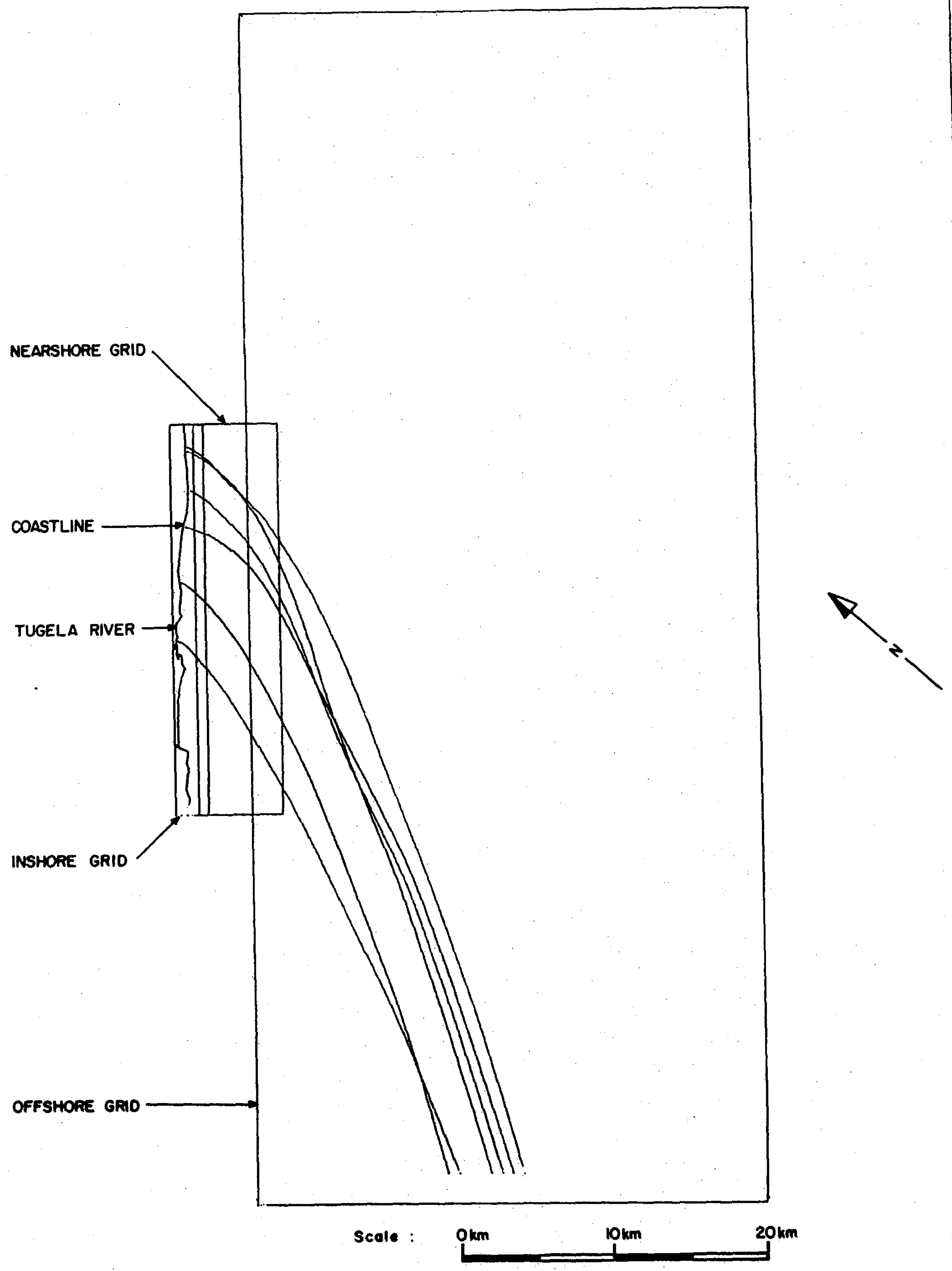

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 210.0

WAVE PERIOD: 15.3 SECS
SCALE :1/350000

FIGURE 41

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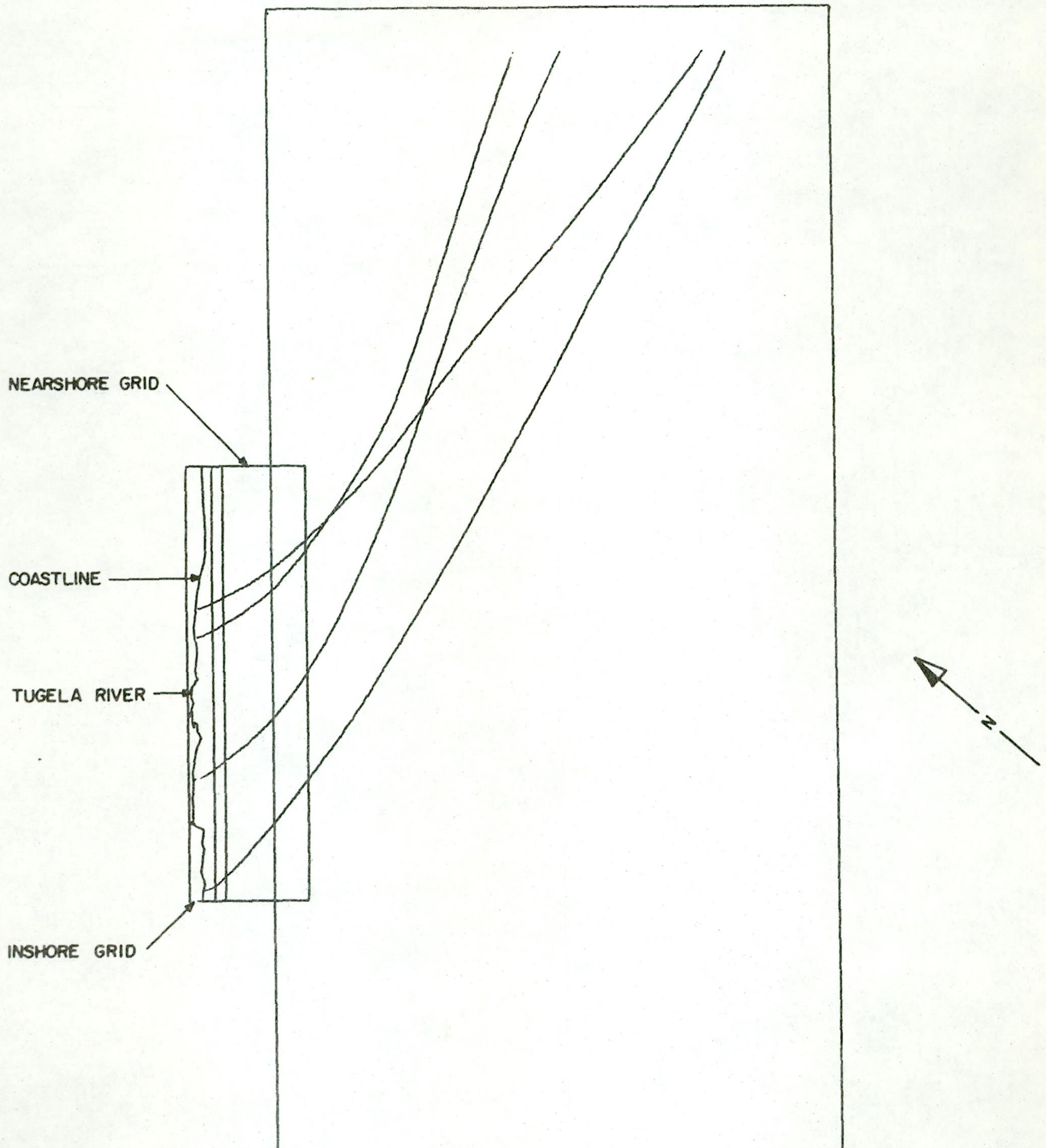

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 60.0

WAVE PERIOD: 14.9 SECS
SCALE :1/350000

FIGURE
4m

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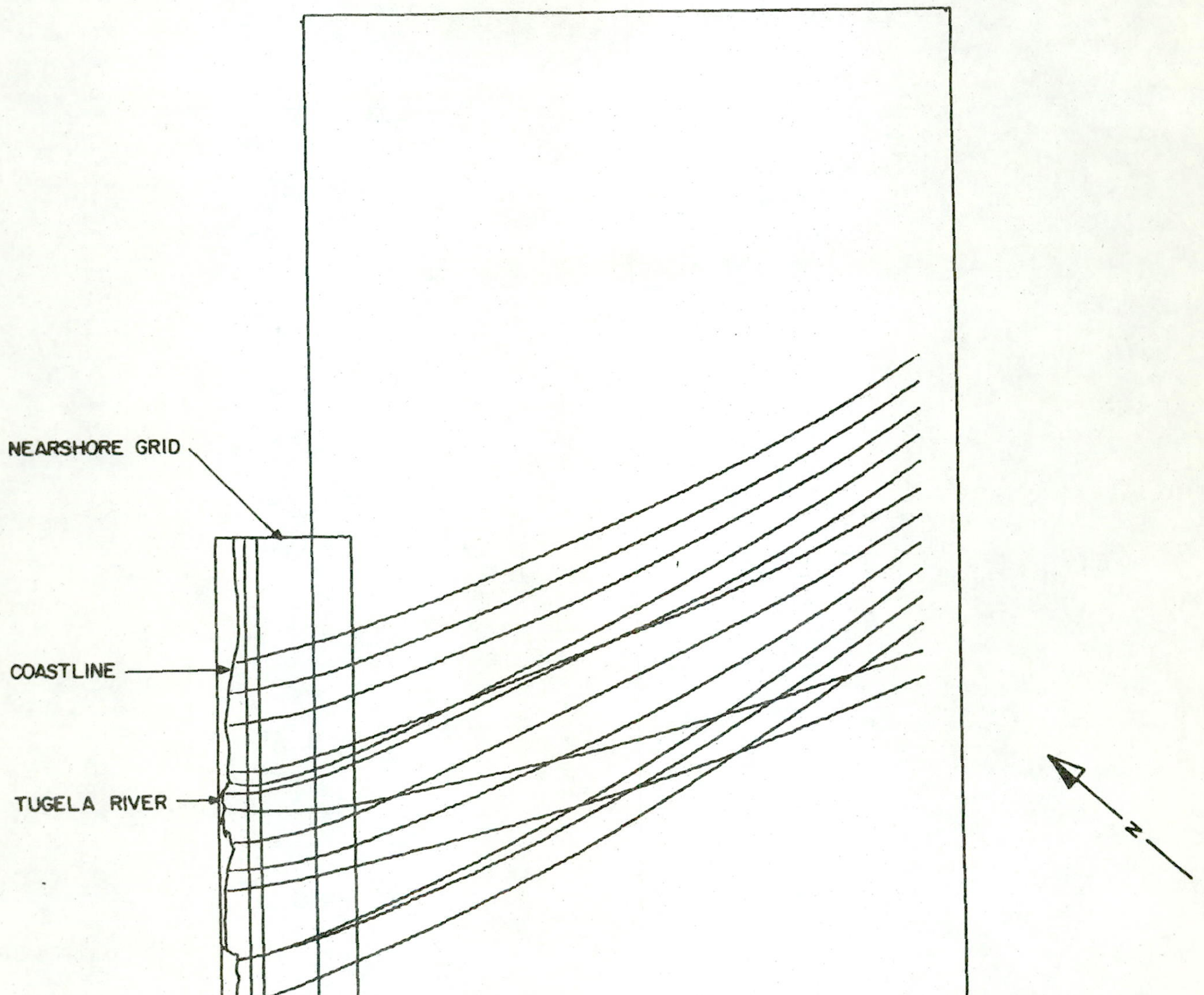

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 90.0

WAVE PERIOD: 14.9 SECS
SCALE :1/350000

FIGURE
4n

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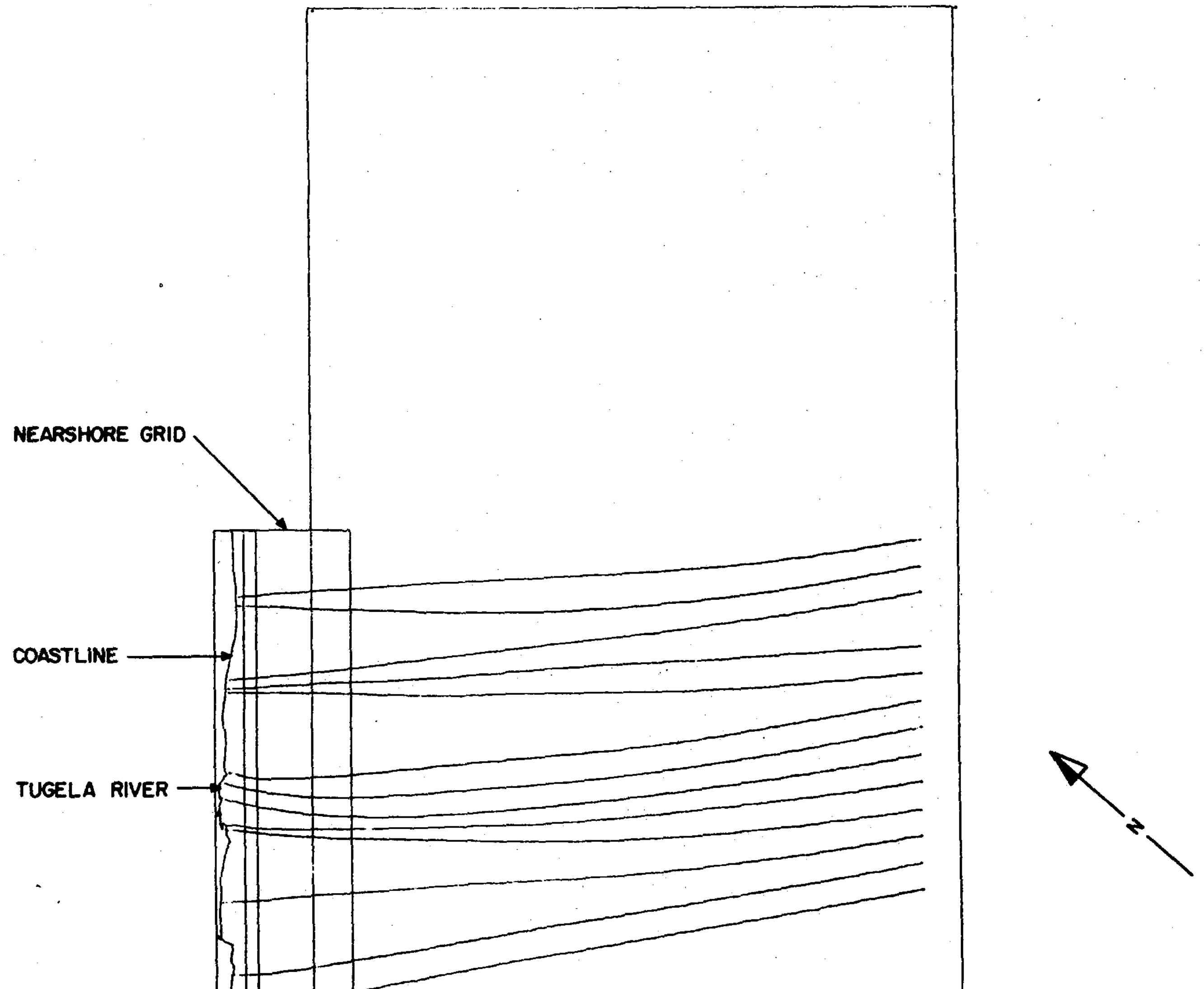

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 120.0

WAVE PERIOD: 14.9 SECS
SCALE :1/350000

FIGURE
40

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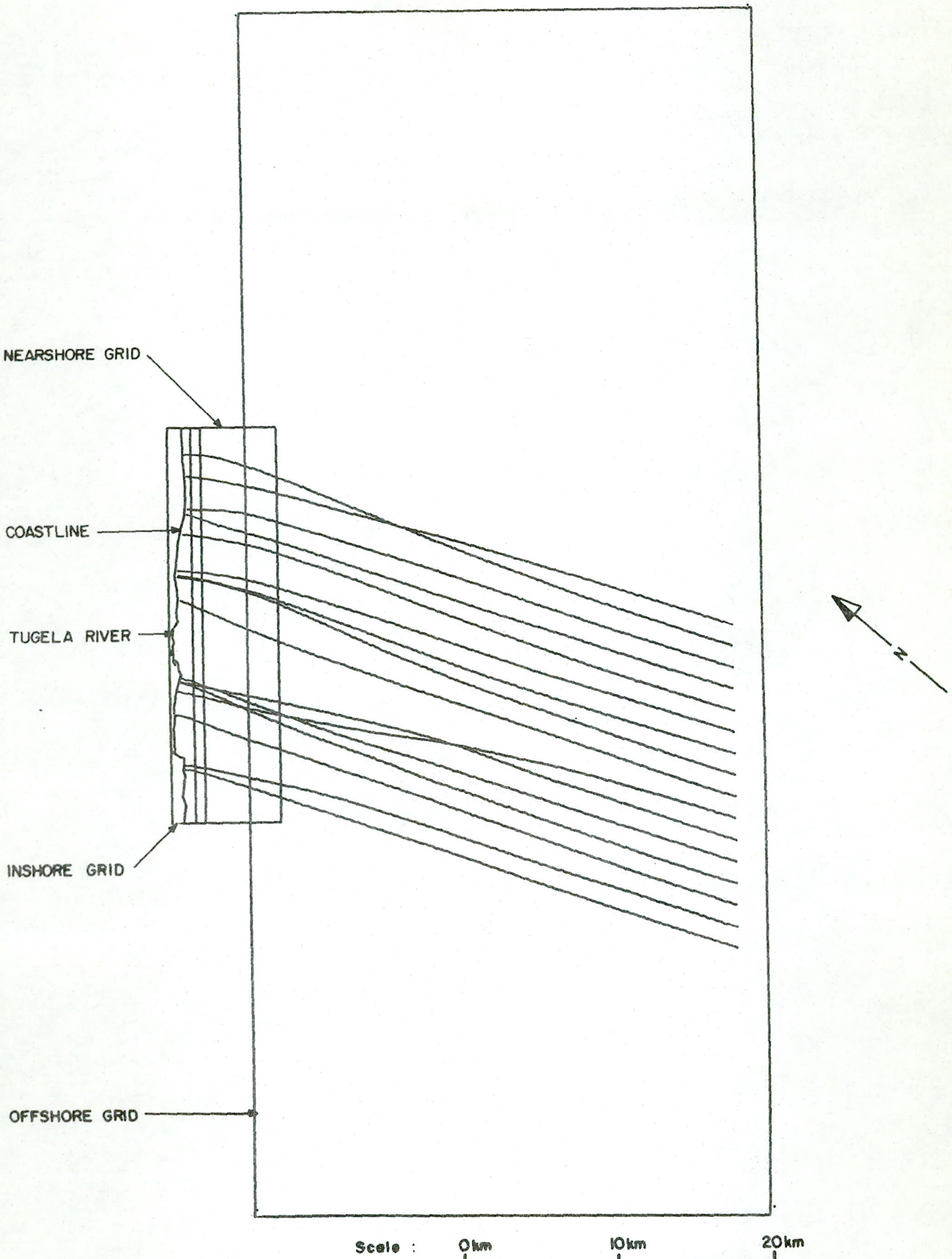

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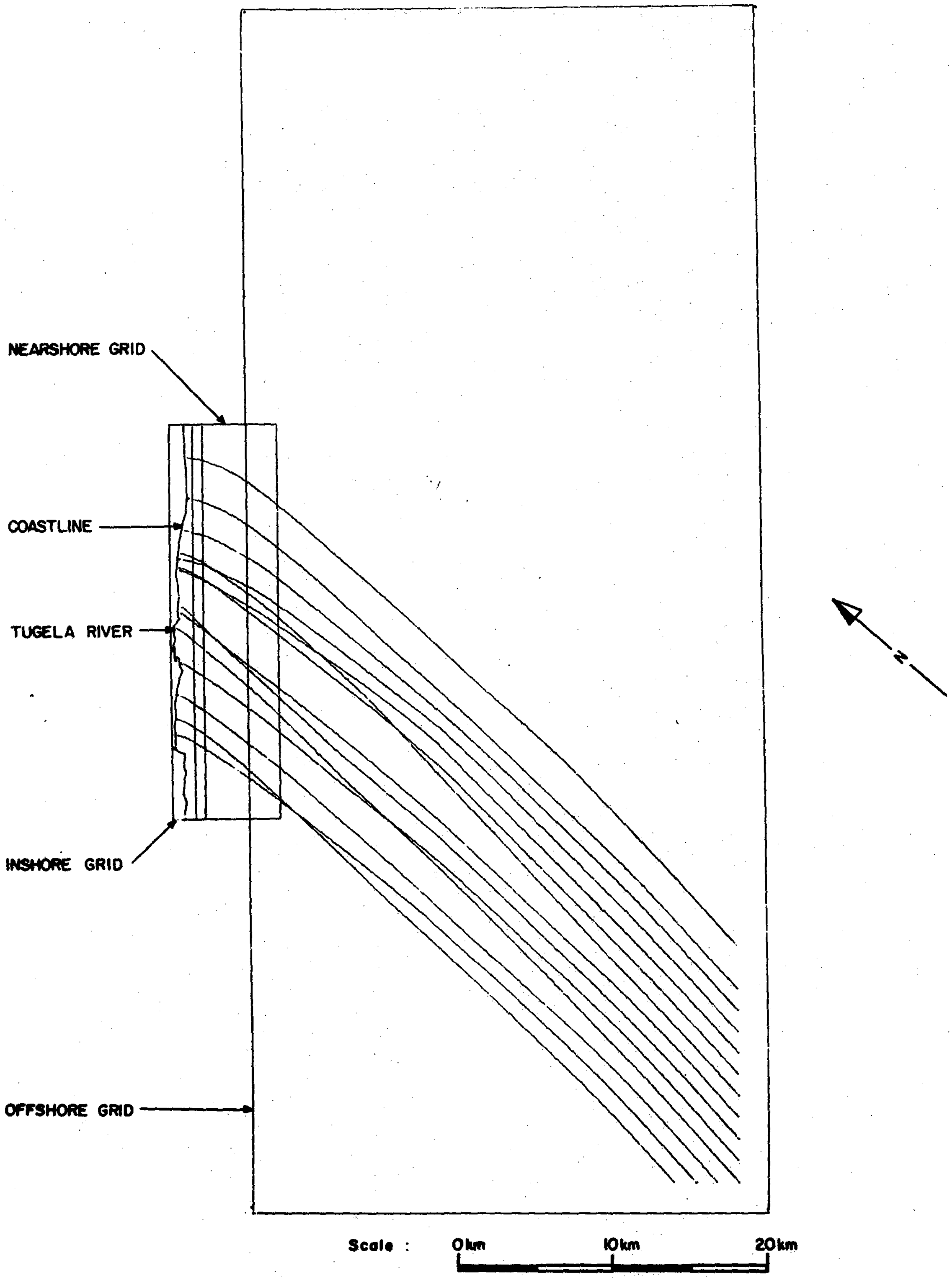

TRACED : COMPLD:	TUGELA RIVER STUDY	FIGURE
CHECKED:		
DATE :	TIDE LEVEL: M.S.L. WAVE PERIOD: 14.9 SECS	4q
REF. :	DIRECTION : 180.0 SCALE :1/350000	

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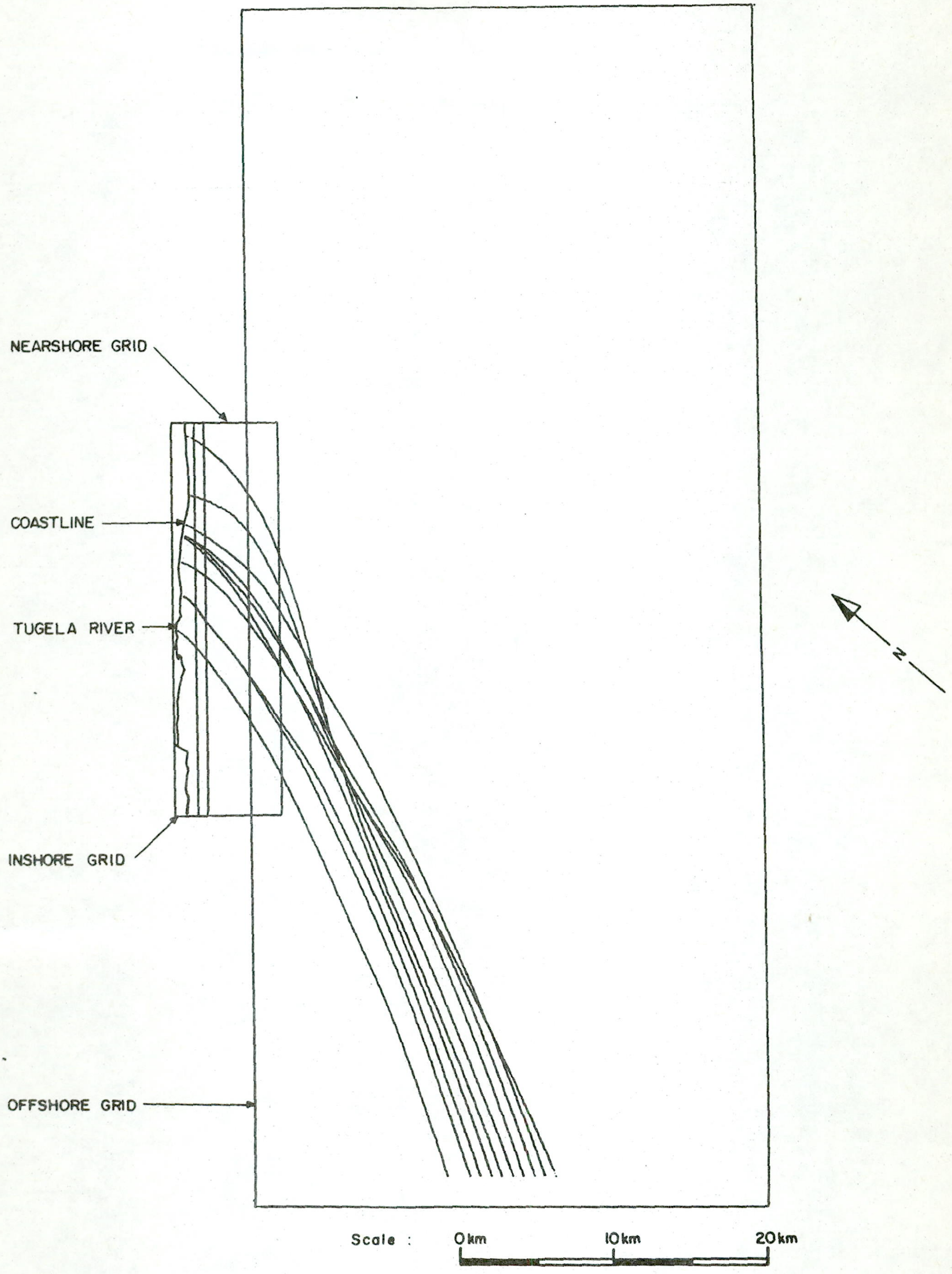

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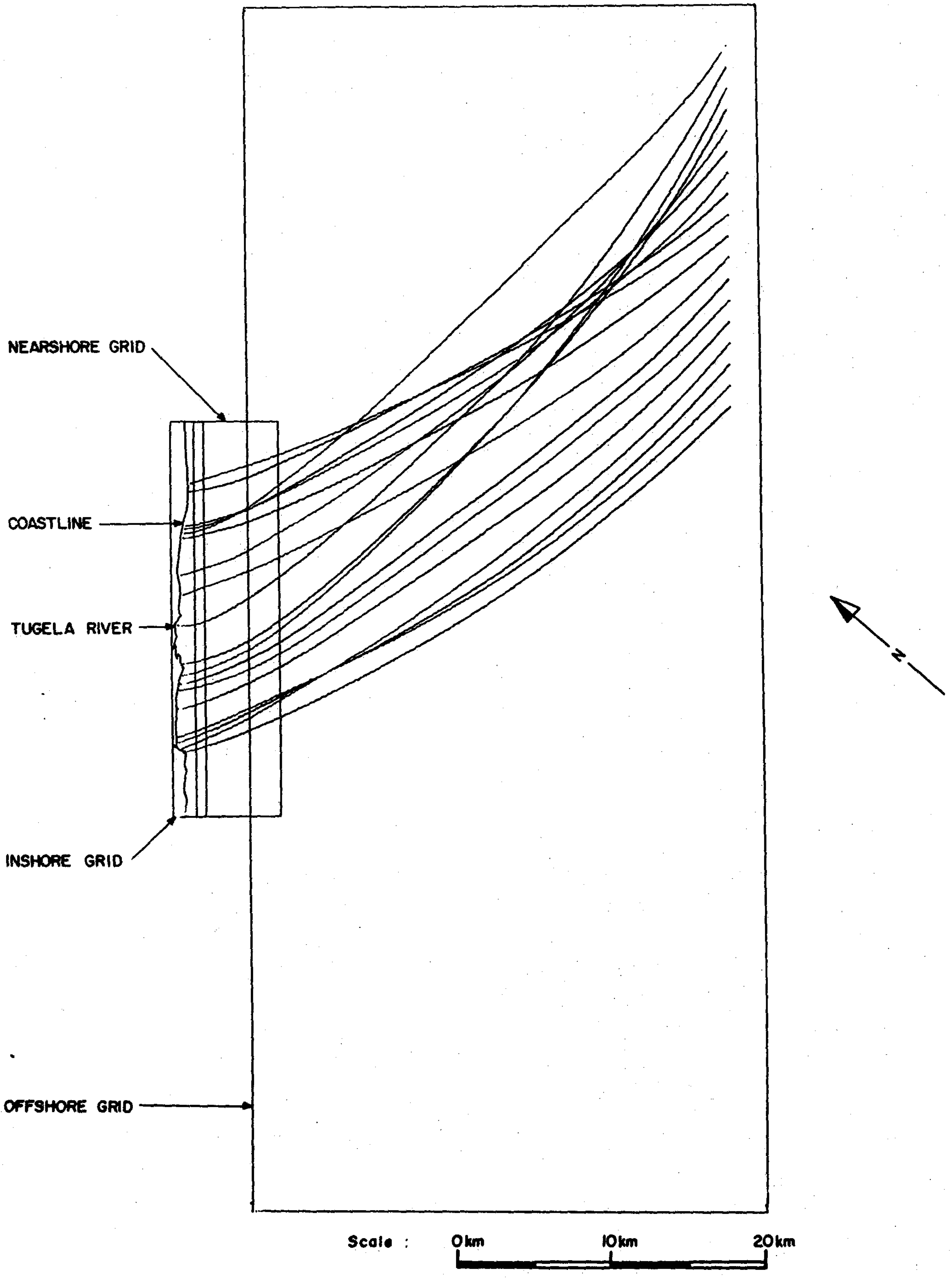

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 60.0

WAVE PERIOD: 16.4 SECS
SCALE :1/350000

FIGURE
4s

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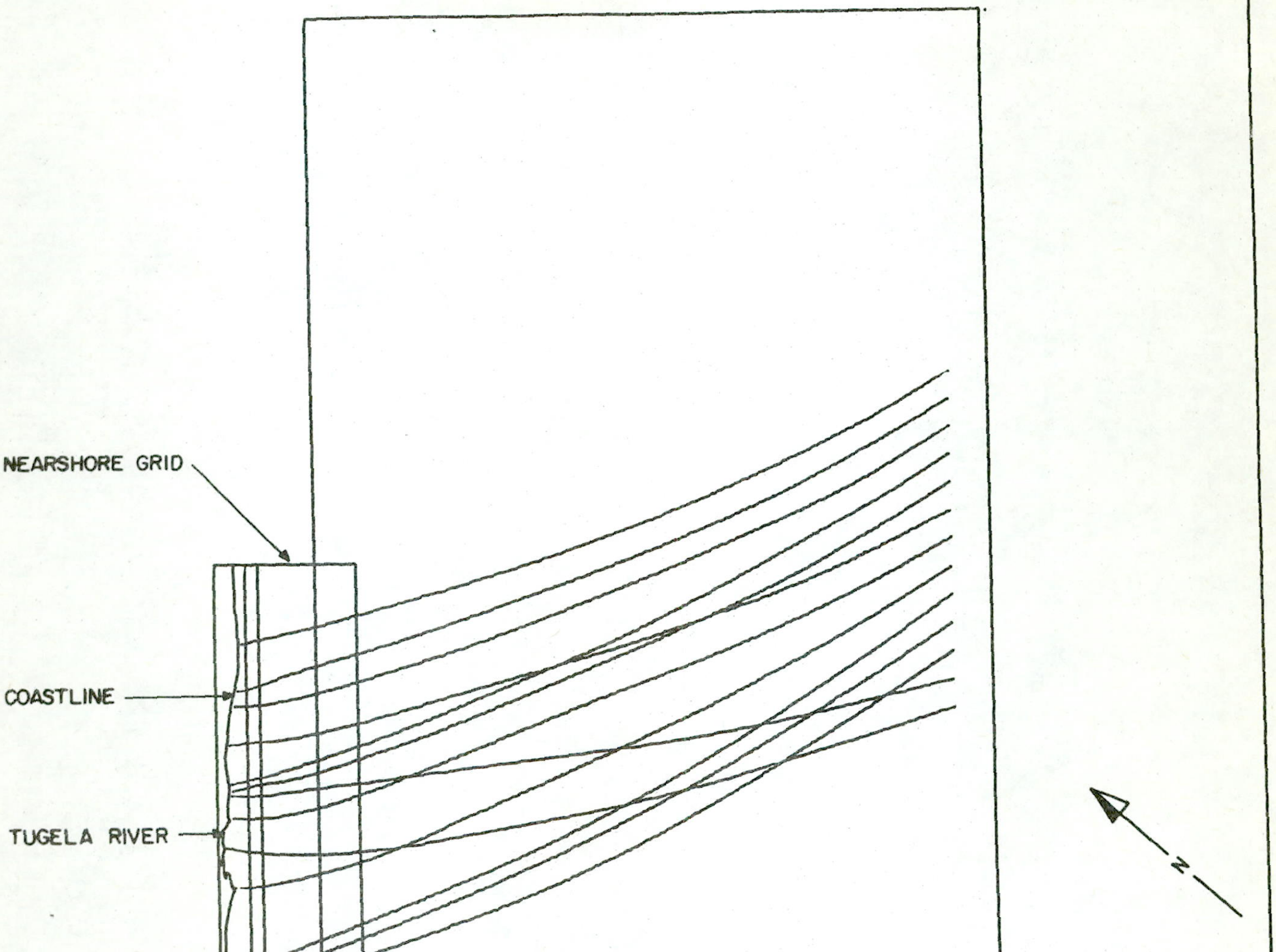

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 90.0

WAVE PERIOD: 16.4 SECS
SCALE :1/350000

FIGURE
4t

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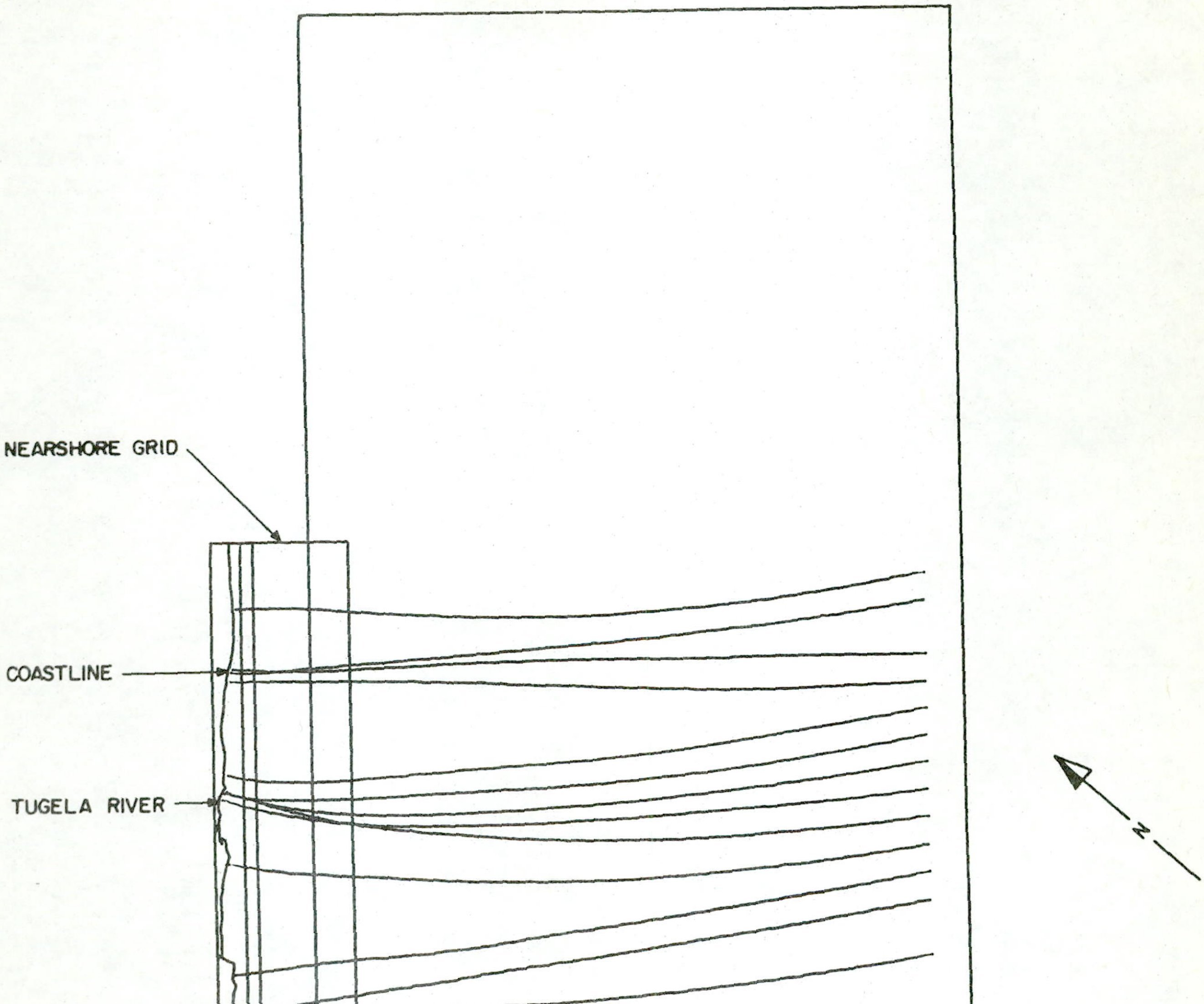

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 120.0

WAVE PERIOD: 16.4 SECS
SCALE :1/350000

FIGURE
4u

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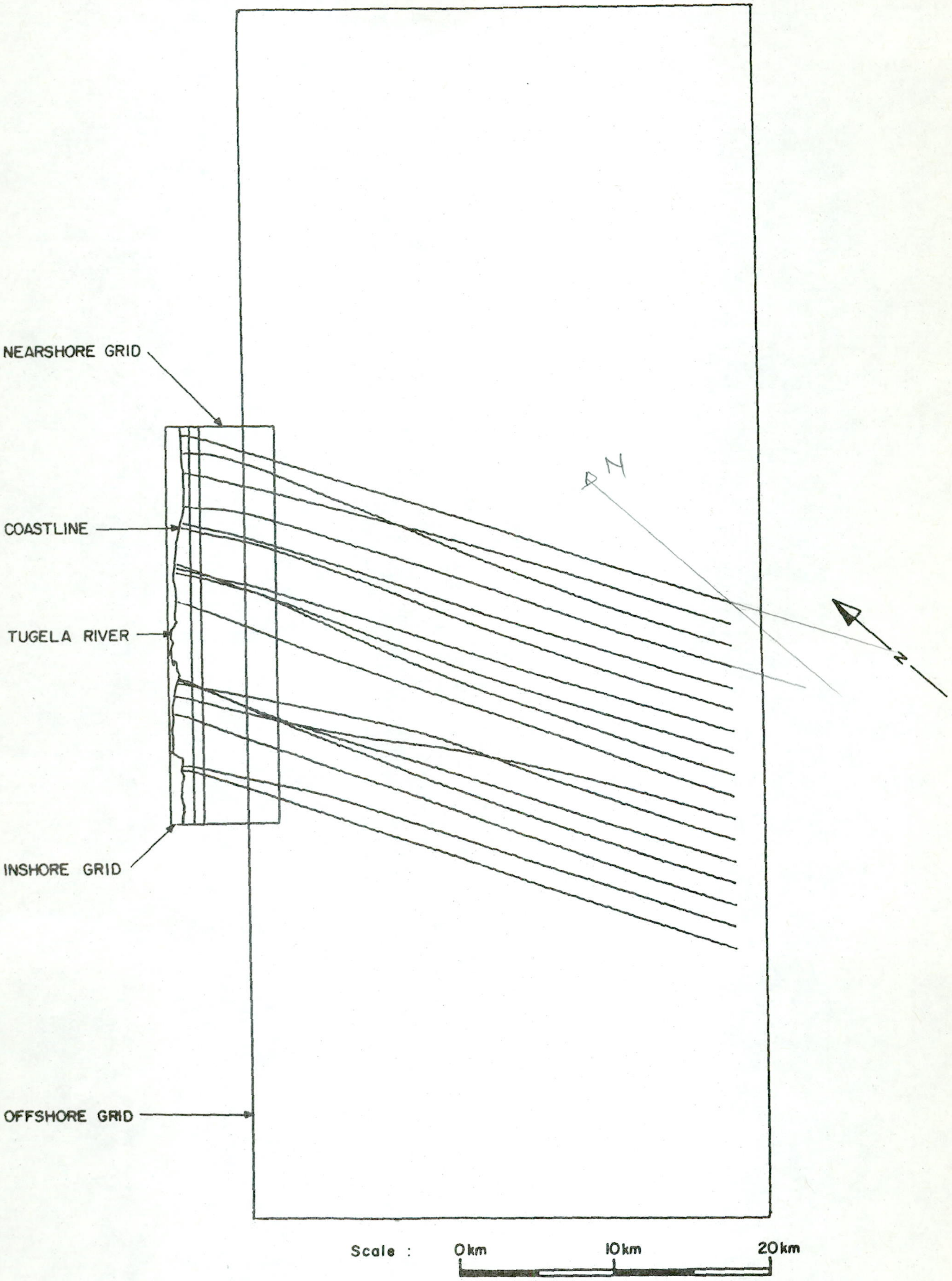

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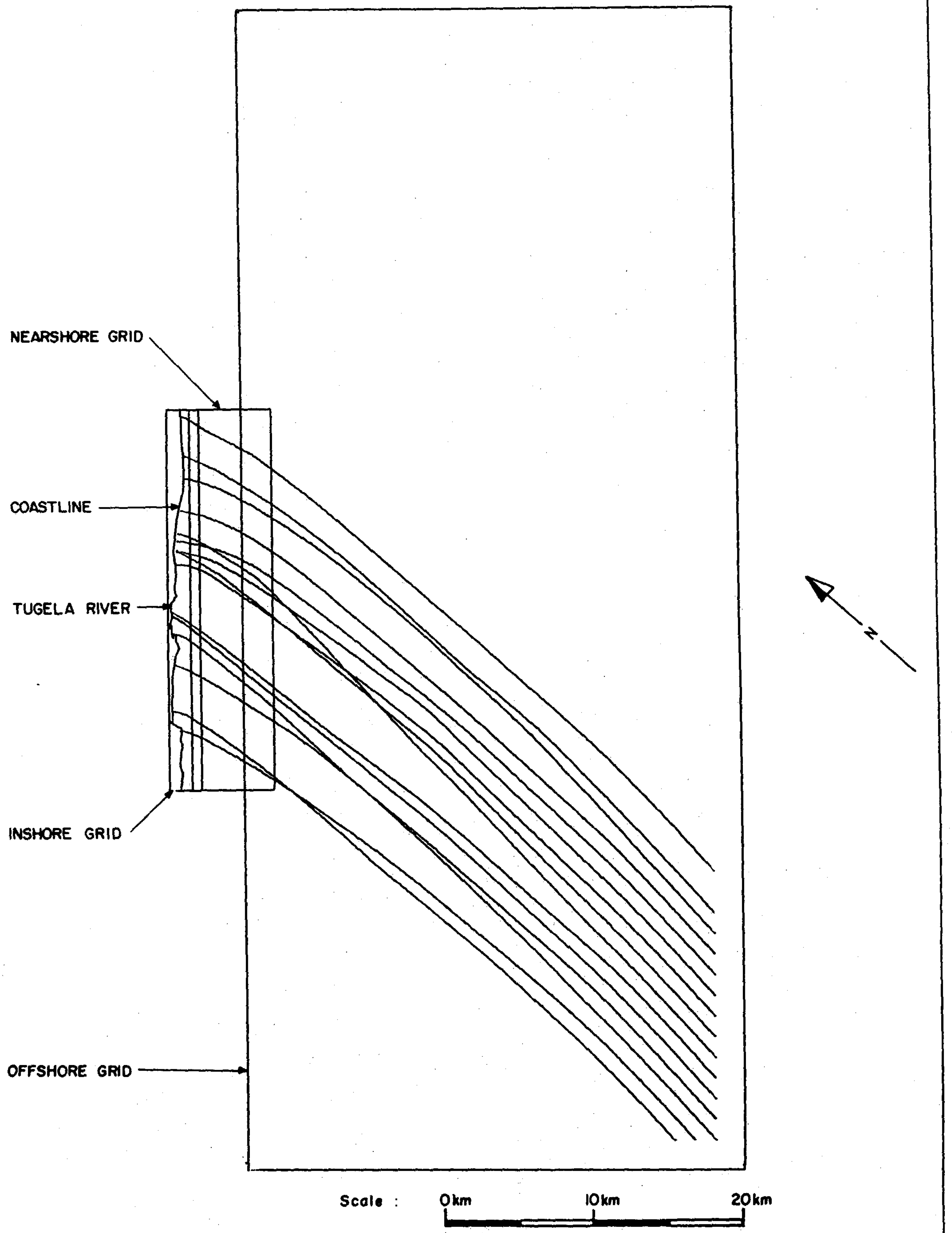

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 180.0

WAVE PERIOD: 16.4 SECS
SCALE :1/350000

FIGURE
4w

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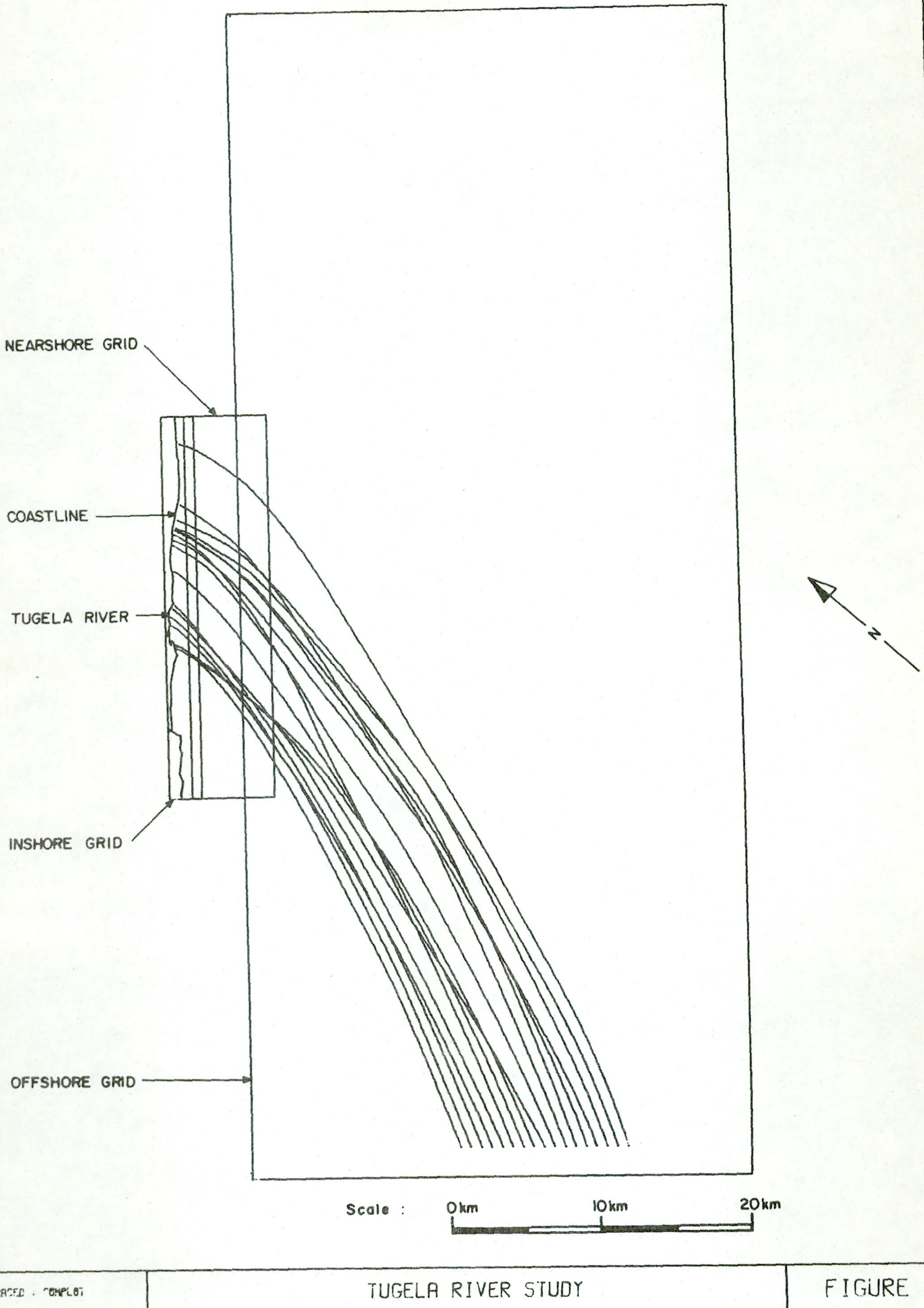

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 210.0
WAVE PERIOD: 16.4 SECS
SCALE :1/350000

FIGURE
4x

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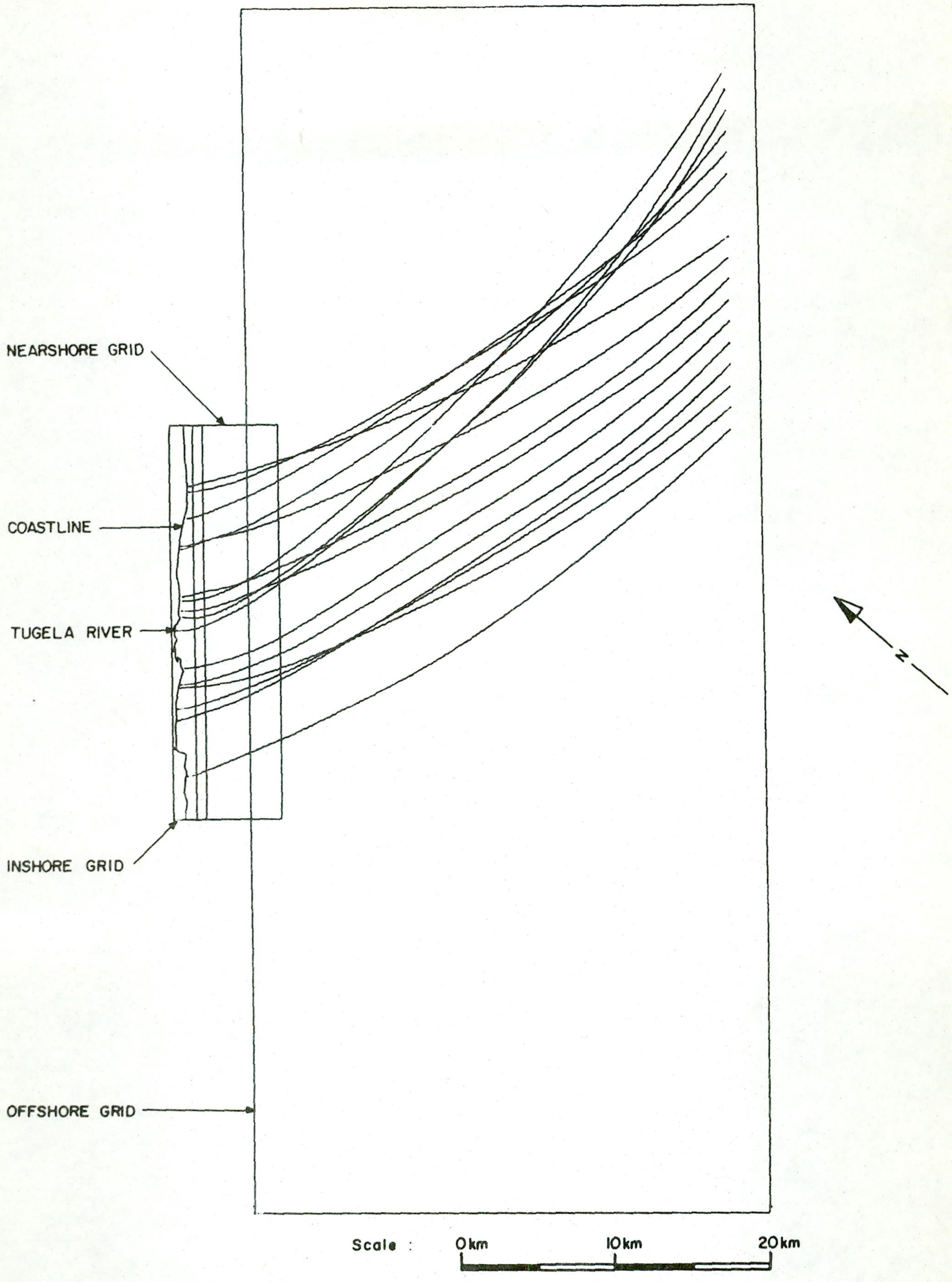

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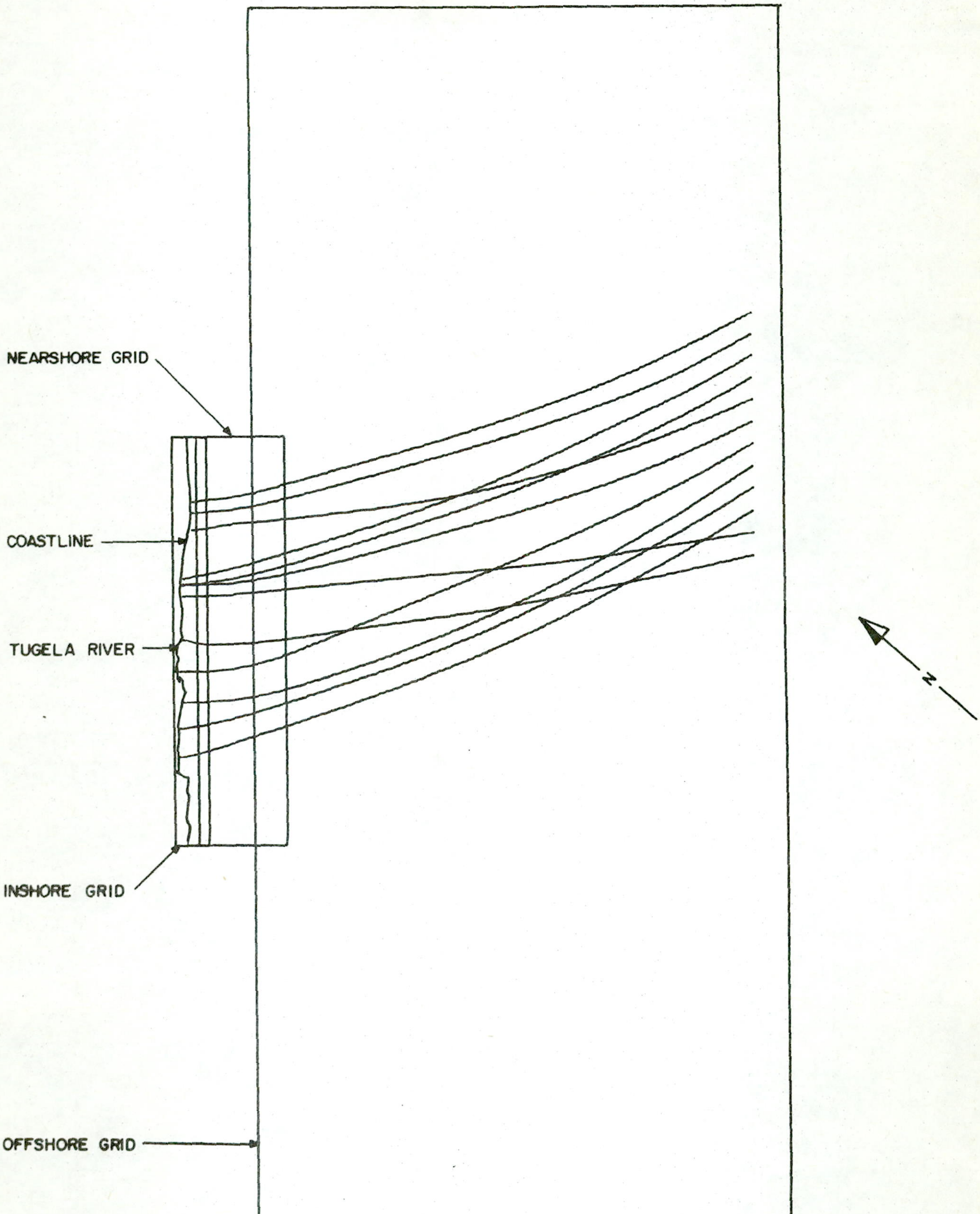

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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 90.0

WAVE PERIOD: 17.8 SECS
SCALE :1/350000

FIGURE
4z

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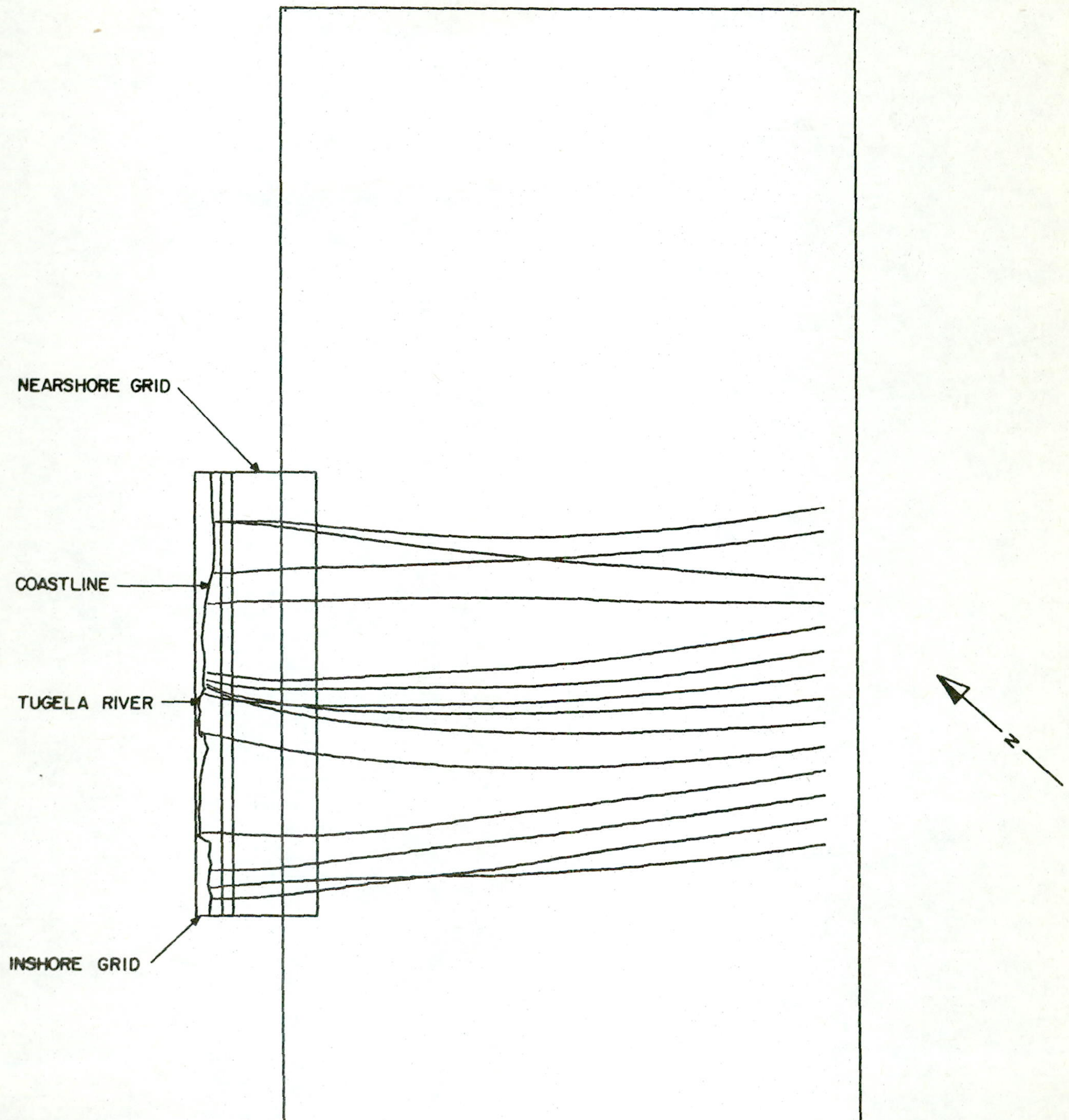

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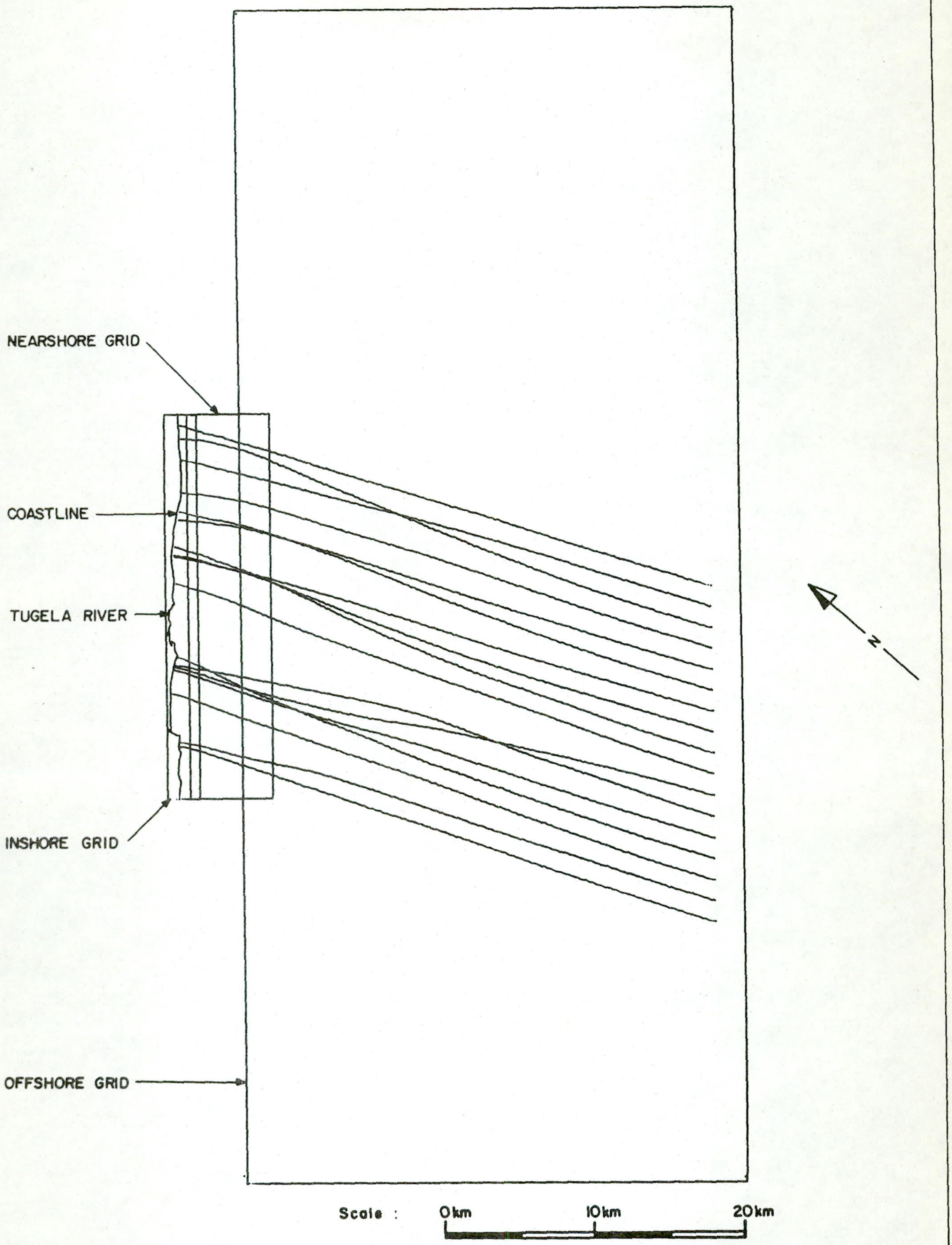

TRACED : COMPLOT
CHECKED:
DATE :
REF. :

TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 150.0

WAVE PERIOD: 17.8 SECS
SCALE :1/350000

FIGURE
4ab

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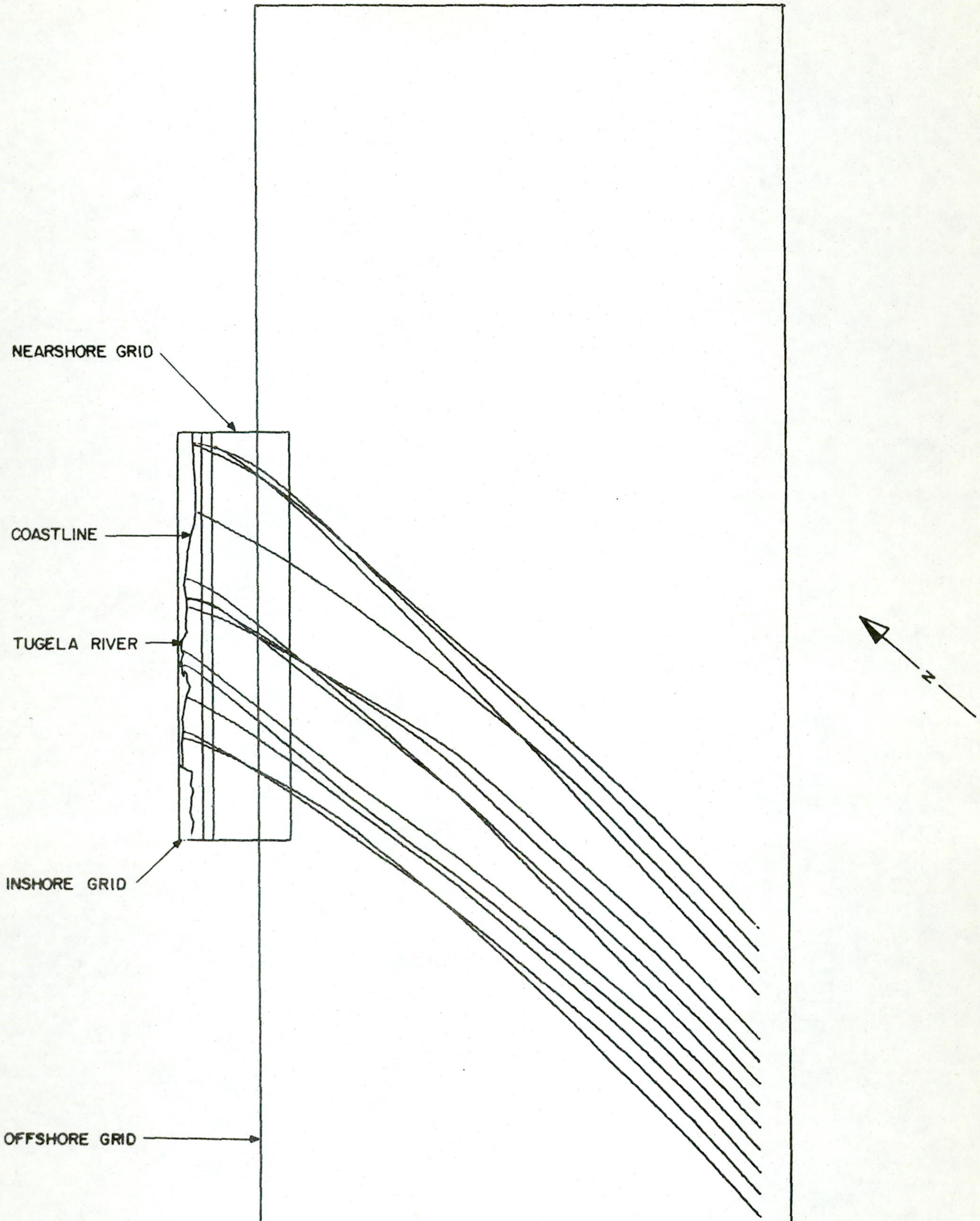
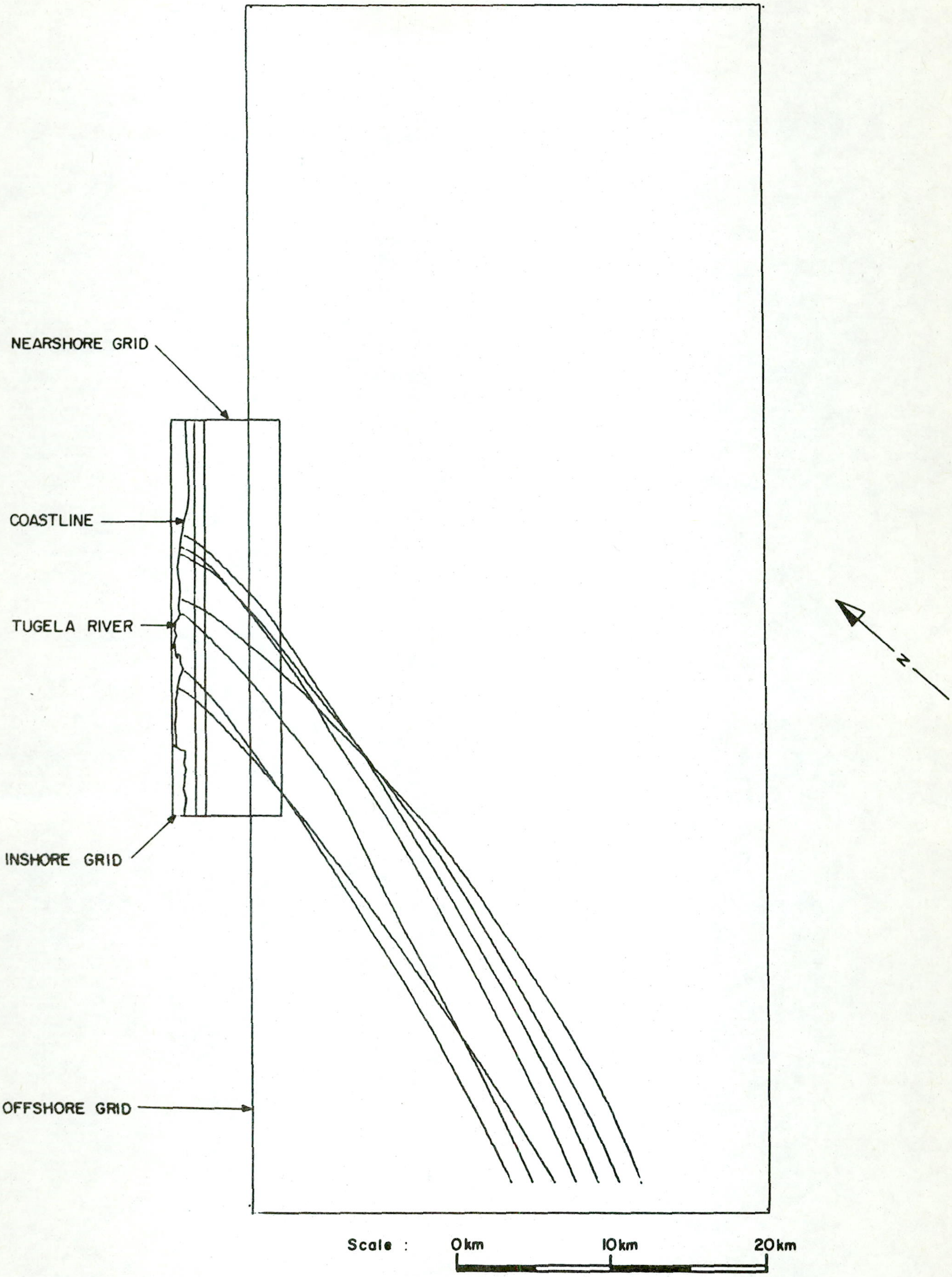


TRACED : COMPLOT CHECKED: DATE : REF. :	TUGELA RIVER STUDY TIDE LEVEL: M.S.L. WAVE PERIOD: 17.8 SECS DIRECTION : 180.0 SCALE :1/350000	FIGURE 4ac

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



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TUGELA RIVER STUDY

TIDE LEVEL: M.S.L.
DIRECTION : 210.0

WAVE PERIOD: 17.8 SECS
SCALE :1/350000

FIGURE
4ad

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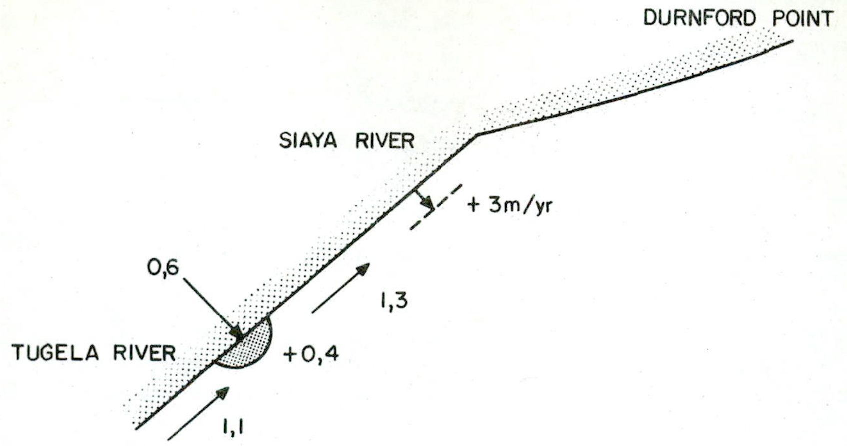
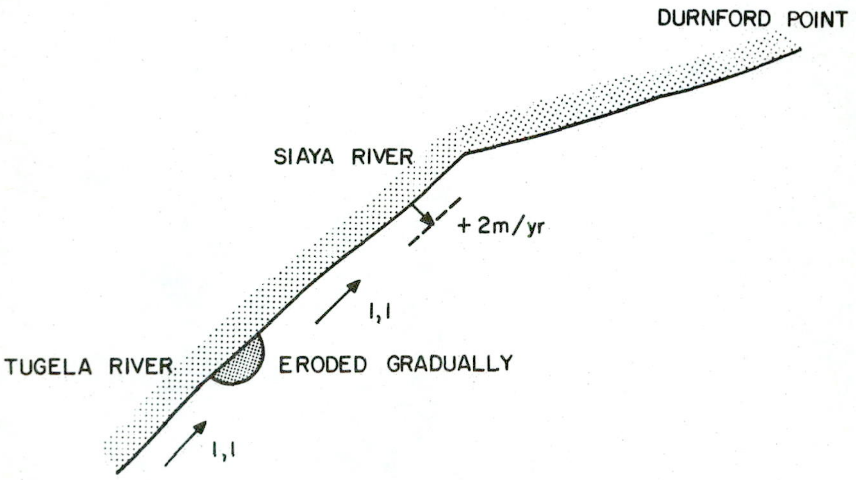
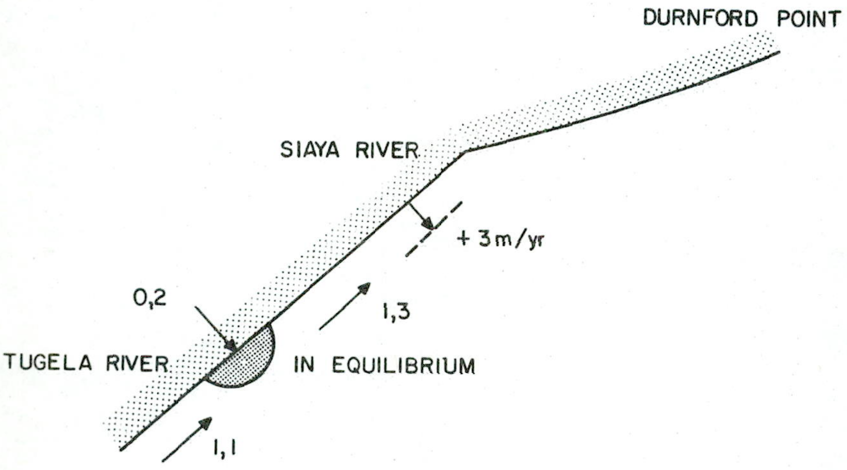


PRE-DAM CONDITIONS



POST-DAM CONDITIONS



VIRGIN CONDITIONS

Note: Unmarked quantities are in 10^6 m^3/yr

TRACED D.D. CHECKED DATE REF.	SEDIMENT TRANSPORT PATTERNS	FIGURE 5

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APPENDIX A: RELATIONSHIP BETWEEN 'INSTRUMENT' AND 'VOS' WAVE PARAMETERS

A.1 INTRODUCTION

The 'instrument' wave parameters used in the longshore transport calculations are the significant wave height in deep water, 'H_{OS}', and the peak energy wave period, 'T_P'. These two parameters are obtained from the energy spectrum of a wave record and are defined as follows:

$$H_{OS} = 4 \text{ (Area under spectrum)}^{\frac{1}{2}}$$
$$T_P = 1/\text{(Frequency of the spectral peak)}$$

The relationships between the 'instrument' wave parameters and the VOS wave parameters were derived from data which had been analysed by Rossouw [A1].

A.2 MEASURED AND VOS WAVE PARAMETER RELATIONSHIPS

The exceedence curves for 'H_{OS}' and 'H_{VOS}' values recorded in South African waters are given in Figures A1 and A2 respectively. The latter, when combined, yield Figure A3 which indicates that the relationship between 'H_{OS}' and 'H_{VOS}' is given by

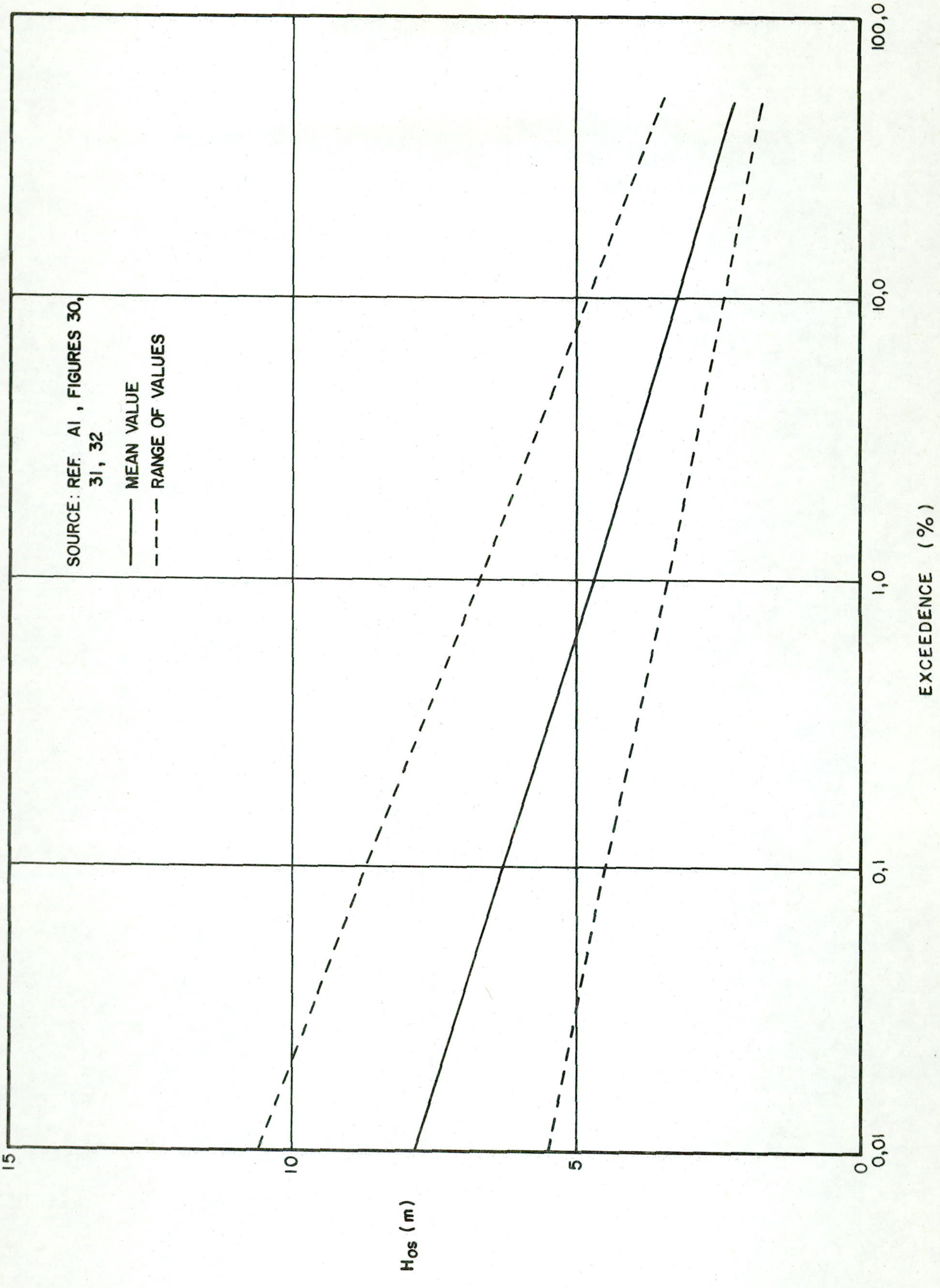
$$H_{OS} = 1{,}0 + 0{,}55 \, . \, H_{VOS}$$

Figures A4 and A5 contain the exceedence curves for 'T_P' and 'T_{VOS}' respectively. Based on these two curves, the relationship between 'T_P' and 'T_{VOS}' is set out in Figure A6. The latter yields the relationship

$$T_P = 4{,}1 \, . \, T_{VOS}^{0{,}55}$$

REFERENCE

A1 ROSSOUW J. Design wave conditions for South African and South West African coastal waters. CSIR REPORT (to be published).



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WAVERIDER SIGNIFICANT WAVE HEIGHT EXCEEDENCE CURVE

FIGURE A1

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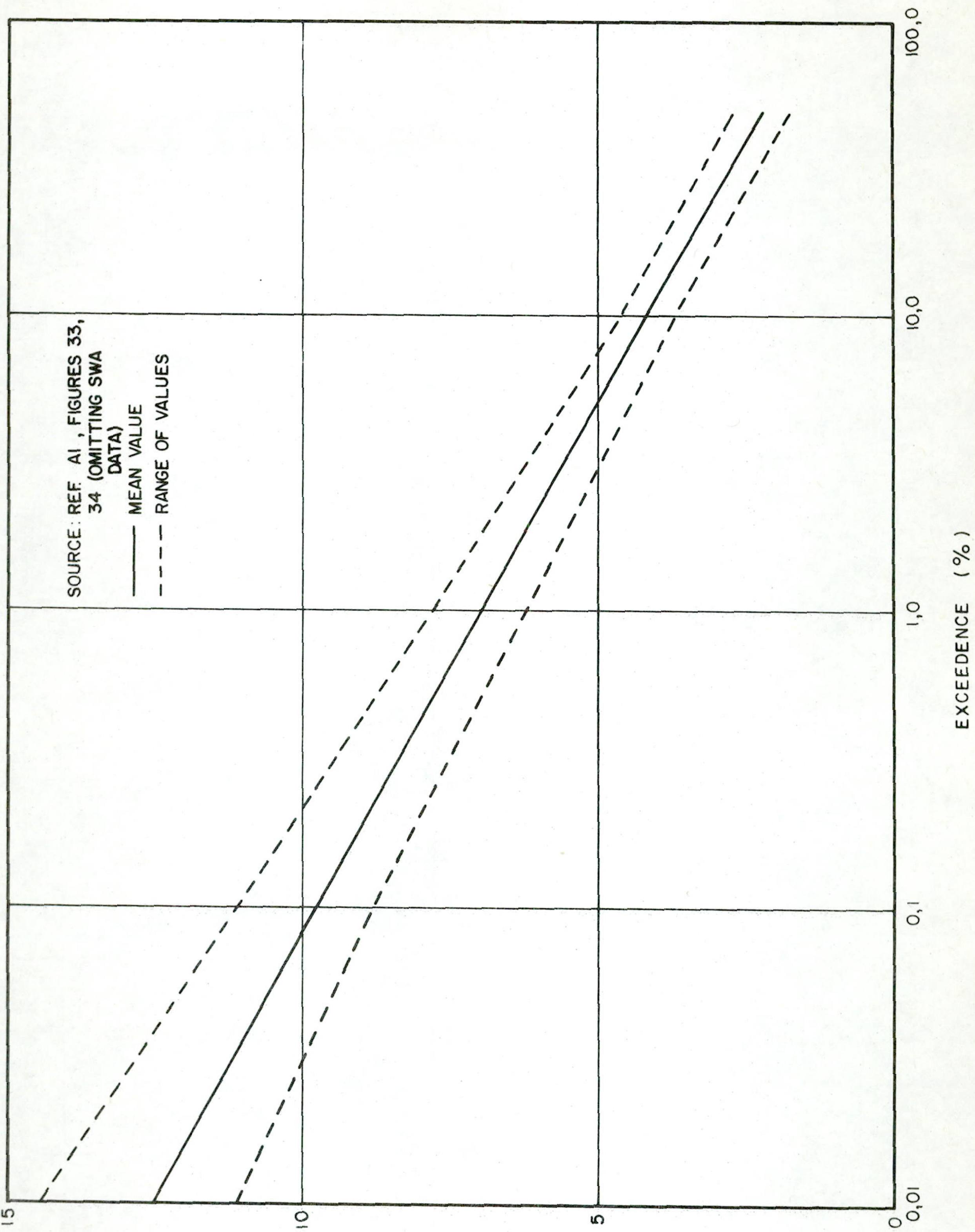

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VOS WAVE HEIGHT EXCEEDENCE CURVE

FIGURE A2

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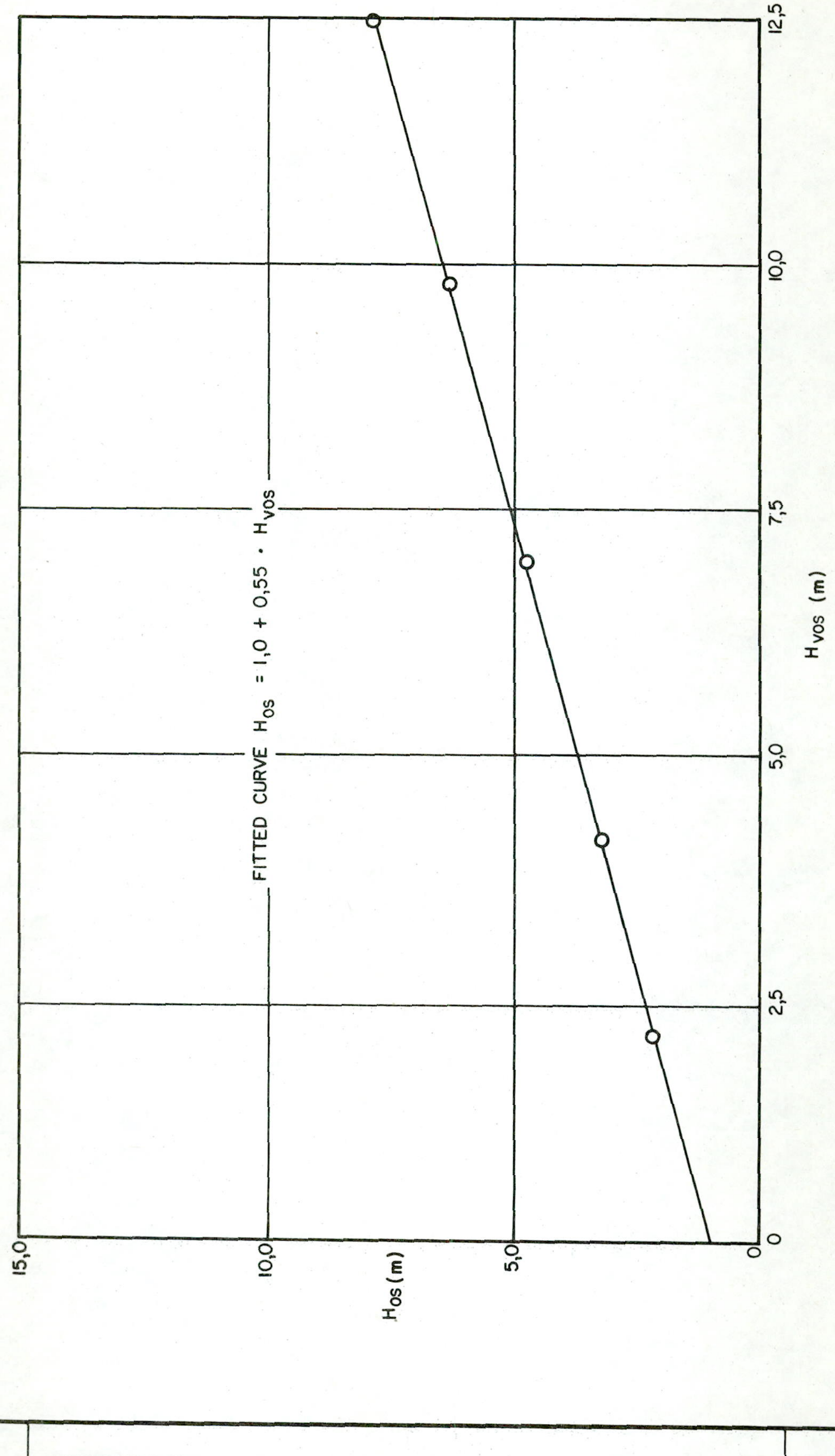

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WAVERIDER SIGNIFICANT WAVE HEIGHT VERSUS VOS WAVE HEIGHT

FIGURE
A3

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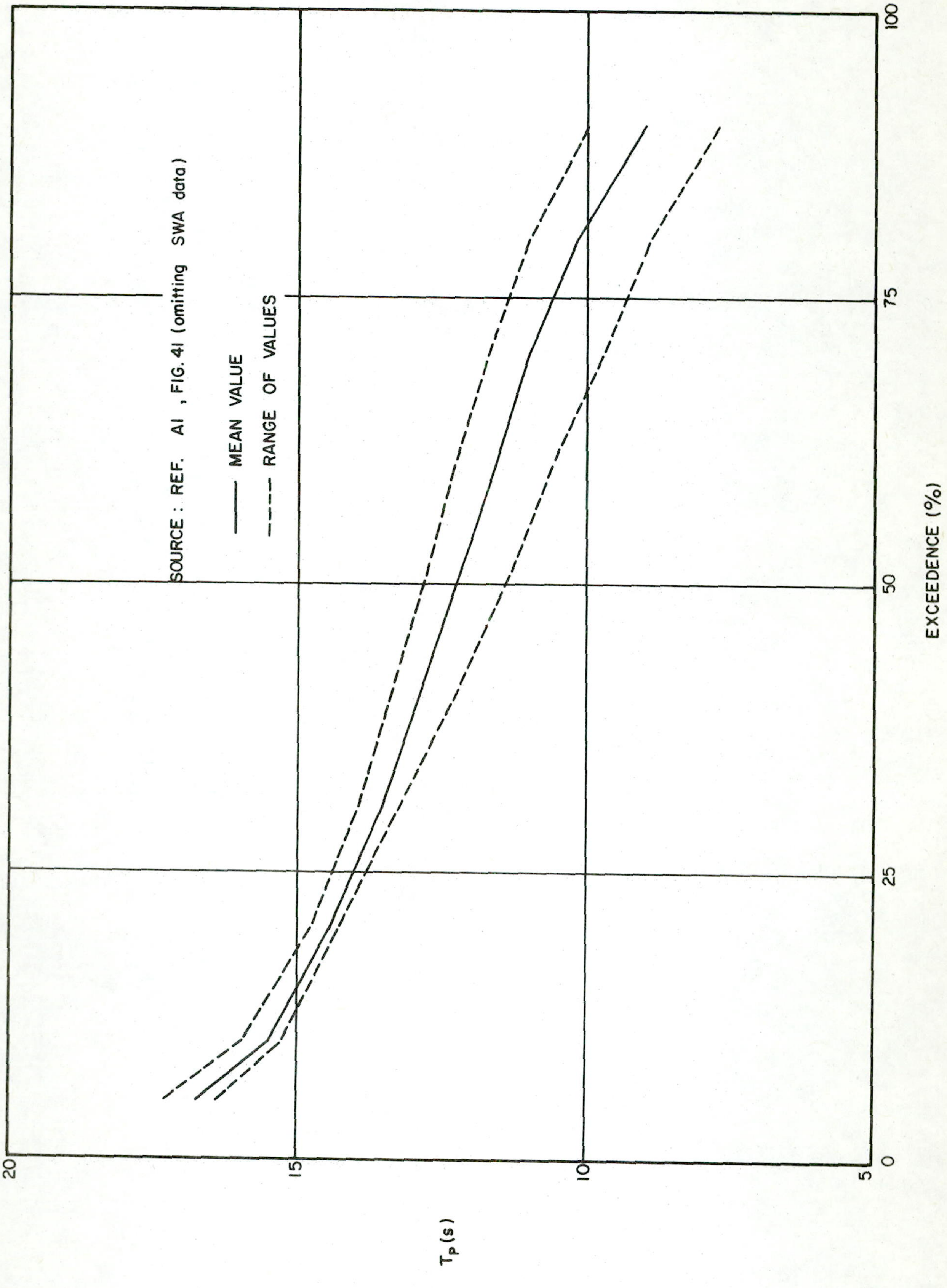

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WAVERIDER PEAK ENERGY WAVE PERIOD EXCEEDENCE CURVE

FIGURE A4

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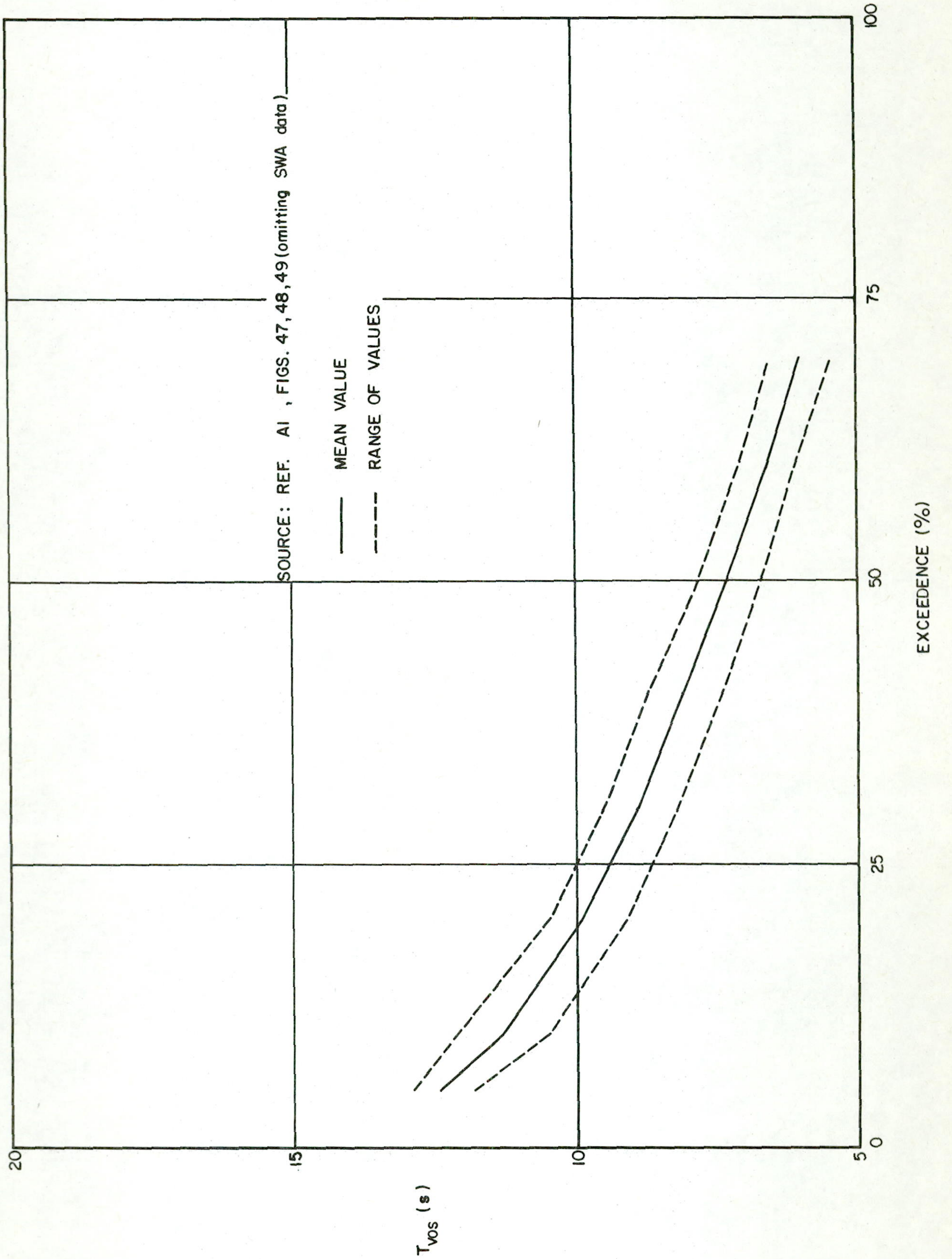

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VOS WAGE PERIOD EXCEEDENCE CURVE

FIGURE
A5

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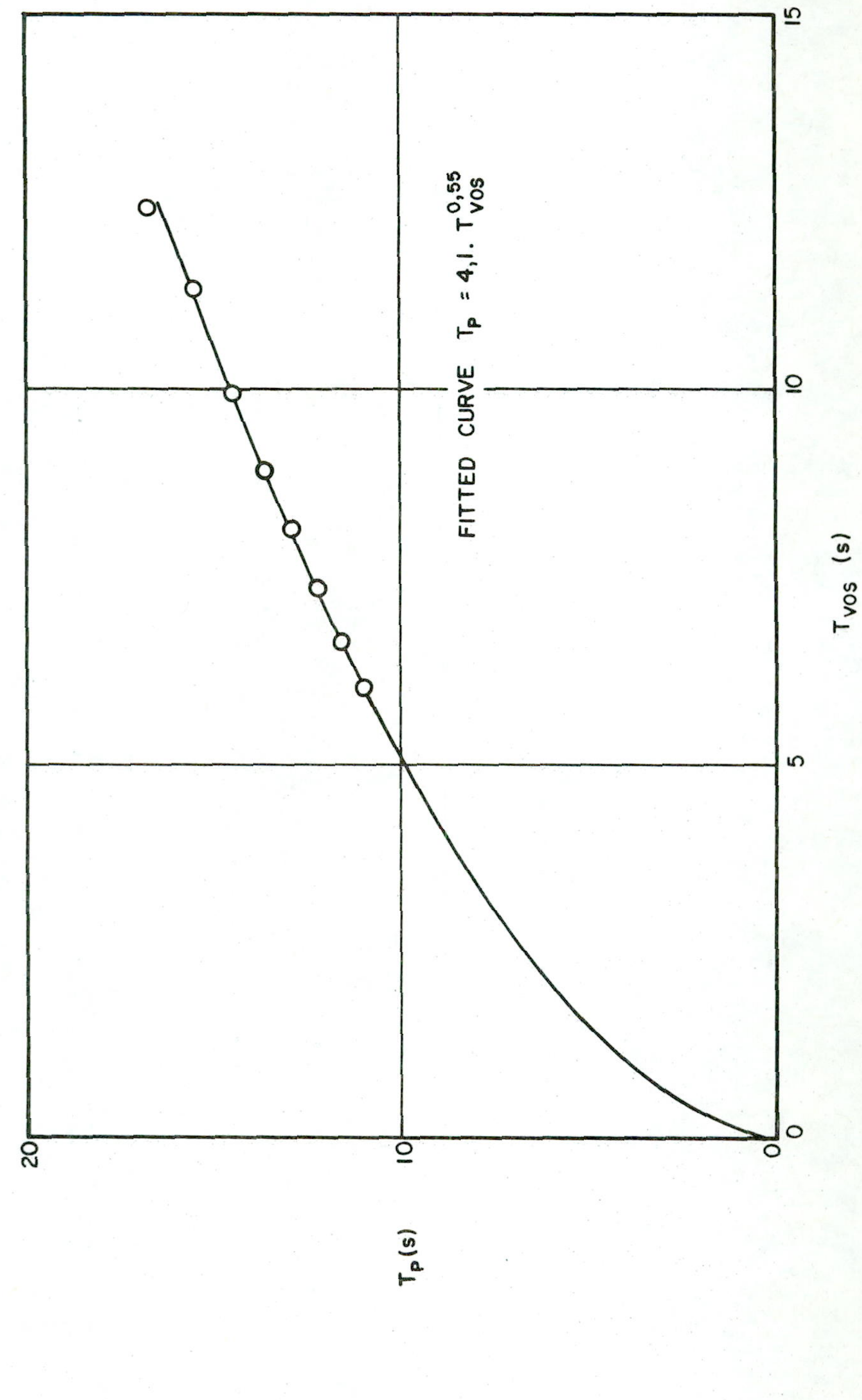

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WAVERIDER PEAK ENERGY WAVE PERIOD VERSUS VOS WAVE PERIOD

FIGURE
A6

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APPENDIX B: DEEP SEA WAVE CLIMATE

The deep sea wave climate was recorded by Voluntary Observing Ships (VOS). The results are contained in Tables BI and BII which show respectively wave occurrence and root-mean-square wave height as a function of period and direction; both the annual and the monthly values are given in each case.

TABLE BI: DEEP SEA WAVE OCCURRENCES

Source : VOS [12]

No. of obs. : 3 719

VOS wave periods

Year

Sector Period T_{VOS}(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
6,5	0,043	0,031	0,021	0,032	0,068	0,056	--	0,251
8,5	0,021	0,019	0,012	0,020	0,053	0,049	--	0,174
10,5	0,005	0,004	0,006	0,011	0,032	0,022	--	0,080
12,5	0,002	0,003	0,002	0,005	0,011	0,010	--	0,033
14,5	0,001	0,001	-	0,001	0,004	0,004	--	0,011
Calm	0,067	0,037	0,019	0,031	0,045	0,064	0,188	0,451
Total	0,139	0,095	0,060	0,100	0,213	0,205	0,188	1,000

TABLE BI: DEEP SEA WAVE OCCURRENCES (cont'd)

January

Sector Period T_{VOS}(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
6,5	0,0056	0,0043	0,0022	0,0051	0,0060	0,0035	--	0,0267
8,5	0,0011	0,0021	0,0005	0,0027	0,0038	0,0016	--	0,0118
10,5	0,0003	0,0005	0,0003	0,0011	0,0029	0,0032	--	0,0083
12,5	0	0,0003	0	0,0003	0,0013	0,0011	--	0,0030
14,5	0	0,0003	0	0	0,0003	0	--	0,0006
Calm	0,0075	0,0027	0,0021	0,0024	0,0062	0,0038	0,0167	0,0414
Total	0,0145	0,0102	0,0051	0,0116	0,0205	0,0132	0,0167	0,0918

February

Sector Period T_{VOS}(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
6,5	0,0035	0,0040	0,0032	0,0043	0,0038	0,0043	--	0,0231
8,5	0,0024	0,0030	0,0011	0,0024	0,0051	0,0016	--	0,0156
10,5	0	0,0005	0,0005	0,0011	0,0024	0,0005	--	0,0050
12,5	0,0003	0,0008	0,0003	0,0005	0,0005	0,0003	--	0,0027
14,5	0,0003	0	0	0	0	0	--	0,0003
Calm	0,0048	0,0030	0,0027	0,0038	0,0016	0,0043	0,0092	0,0294
Total	0,0113	0,0113	0,0078	0,0121	0,0134	0,0110	0,0092	0,0761

TABLE BI: DEEP SEA WAVE OCCURRENCES (cont'd)

March

Sector Period T_{VOS}(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
6,5	0,0030	0,0032	0,0025	0,0028	0,0048	0,0038	--	0,0201
8,5	0,0013	0,0040	0,0005	0,0019	0,0022	0,0029	--	0,0128
10,5	0,0003	0,0003	0,0005	0,0016	0,0027	0,0005	--	0,0059
12,5	0,0005	0,0005	0,0003	0,0005	0,0005	0,0003	--	0,0026
14,5	0	0	0	0	0	0,0003	--	0,0003
Calm	0,0067	0,0044	0,0016	0,0013	0,0027	0,0048	0,0118	0,0333
Total	0,0118	0,0124	0,0054	0,0081	0,0129	0,0126	0,0118	0,0750

April

Sector Period T_{VOS}(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
6,5	0,0016	0,0016	0,0027	0,0027	0,0060	0,0034	--	0,0180
8,5	0,0005	0,0008	0,0013	0,0016	0,0051	0,0022	--	0,0115
10,5	0	0,0003	0,0008	0,0008	0,0027	0,0019	--	0,0065
12,5	0,0005	0	0,0003	0,0005	0,0013	0,0005	--	0,0031
14,5	0	0	0	0	0,0005	0,0003	--	0,0008
Calm	0,0049	0,0043	0,0011	0,0030	0,0030	0,0070	0,0180	0,0413
Total	0,0075	0,0070	0,0062	0,0086	0,0186	0,0153	0,0180	0,0812

TABLE BI: DEEP SEA WAVE OCCURRENCES (cont'd)

May

Sector / Period T_{VOS}(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
6,5	0,0032	0,0024	0,0005	0,0021	0,0059	0,0038	--	0,0179
8,5	0,0022	0,0019	0,0017	0,0016	0,0065	0,0043	--	0,0182
10,5	0,0005	0,0003	0,0005	0,0003	0,0030	0,0019	--	0,0065
12,5	0,0003	0	0	0,0003	0,0008	0,0008	--	0,0022
14,5	0	0	0	0,0003	0,0005	0,0005	--	0,0013
Calm	0,0046	0,0029	0,0011	0,0013	0,0046	0,0064	0,0135	0,0344
Total	0,0108	0,0075	0,0038	0,0059	0,0213	0,0177	0,0135	0,0805

June

Sector / Period T_{VOS}(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
6,5	0,0030	0,0016	0,0011	0,0038	0,0043	0,0051	--	0,0189
8,5	0,0016	0,0005	0,0011	0,0022	0,0054	0,0056	--	0,0164
10,5	0,0008	0	0,0008	0,0013	0,0035	0,0027	--	0,0091
12,5	0	0	0,0008	0	0,0016	0,0011	--	0,0035
14,5	0	0	0	0	0,0003	0,0003	--	0,0006
Calm	0,0072	0,0038	0,0016	0,0013	0,0035	0,0027	0,0231	0,0432
Total	0,0126	0,0059	0,0054	0,0086	0,0186	0,0175	0,0231	0,0917

TABLE BI: DEEP SEA WAVE OCCURRENCES (cont'd)

July

Sector / Period T_{VOS}(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
6,5	0,0032	0,0027	0,0017	0,0016	0,0061	0,0070	--	0,0223
8,5	0,0008	0,0011	0,0013	0,0010	0,0046	0,0059	--	0,0147
10,5	0,0003	0	0,0003	0,0003	0,0046	0,0019	--	0,0074
12,5	0	0,0005	0	0	0,0011	0,0011	--	0,0027
14,5	0	0	0	0,0003	0,0003	0	--	0,0006
Calm	0,0043	0,0022	0,0005	0,0016	0,0032	0,0048	0,0145	0,0311
Total	0,0086	0,0065	0,0038	0,0048	0,0199	0,0207	0,0145	0,0788

August

Sector / Period T_{VOS}(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
6,5	0,0040	0,0016	0,0019	0,0021	0,0043	0,0051	--	0,0190
8,5	0,0019	0,0016	0,0016	0,0008	0,0054	0,0056	--	0,0169
10,5	0,0005	0,0008	0	0,0008	0,0024	0,0011	--	0,0056
12,5	0	0,0005	0,0003	0,0003	0,0011	0,0013	--	0,0035
14,5	0	0	0	0	0,0003	0,0008	--	0,0011
Calm	0,0062	0,0025	0,0013	0,0019	0,0040	0,0060	0,0196	0,0415
Total	0,0126	0,0070	0,0051	0,0059	0,0175	0,0199	0,0196	0,0876

TABLE BI: DEEP SEA WAVE OCCURRENCES (cont'd)

September

Sector	Frequency of Occurrence f_I							Total
Period T_{VOS}(s)	60°	90°	120°	150°	180°	210°	Calm	
6,5	0,0021	0,0024	0,0008	0,0030	0,0070	0,0051	--	0,0204
8,5	0,0011	0,0005	0,0013	0,0013	0,0040	0,0073	--	0,0155
10,5	0,0003	0	0	0,0008	0,0019	0,0029	--	0,0059
12,5	0	0	0	0,0005	0,0005	0,0008	--	0,0018
14,5	0	0	0	0,0003	0,0003	0,0003	--	0,0009
Calm	0,0064	0,0033	0,0025	0,0024	0,0038	0,0073	0,0204	0,0461
Total	0,0099	0,0062	0,0046	0,0083	0,0175	0,0237	0,0204	0,0906

October

Sector	Frequency of Occurrence f_I							Total
Period T_{VOS}(s)	60°	90°	120°	150°	180°	210°	Calm	
6,5	0,0051	0,0035	0,0019	0,0011	0,0079	0,0040	--	0,0235
8,5	0,0027	0,0013	0,0013	0,0016	0,0043	0,0038	--	0,0150
10,5	0,0008	0,0003	0,0008	0,0005	0,0016	0,0013	--	0,0053
12,5	0,0003	0	0	0,0005	0,0008	0,0011	--	0,0027
14,5	0,0005	0	0	0	0,0005	0,0003	--	0,0013
Calm	0,0051	0,0035	0,0011	0,0052	0,0048	0,0048	0,0148	0,0393
Total	0,0145	0,0086	0,0051	0,0089	0,0199	0,0153	0,0148	0,0871

TABLE BI: DEEP SEA WAVE OCCURRENCES (cont'd)

November

Sector / Period T_{VOS}(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
6,5	0,0040	0,0026	0,0013	0,0027	0,0064	0,0054	--	0,0224
8,5	0,0038	0,0013	0,0006	0,0013	0,0035	0,0043	--	0,0148
10,5	0,0005	0,0008	0,0008	0,0019	0,0027	0,0016	--	0,0083
12,5	0	0,0003	0,0003	0,0005	0,0003	0,0011	--	0,0025
14,5	0	0,0003	0	0,0003	0,0003	0,0005	--	0,0014
Calm	0,0035	0,0022	0,0013	0,0038	0,0029	0,0070	0,0132	0,0339
Total	0,0118	0,0075	0,0043	0,0105	0,0161	0,0199	0,0132	0,0833

December

Sector / Period T_{VOS}(s)	Frequency of Occurrence f_I							Total
	60°	90°	120°	150°	180°	210°	Calm	
6,5	0,0051	0,0013	0,0011	0,0008	0,0059	0,0059	--	0,0201
8,5	0,0013	0,0008	0	0,0016	0,0035	0,0038	--	0,0110
10,5	0,0003	0,0003	0,0003	0,0005	0,0022	0,0019	--	0,0055
12,5	0,0003	0,0003	0	0,0005	0,0008	0,0005	--	0,0024
14,5	0,0003	0	0	0	0,0005	0,0005	--	0,0013
Calm	0,0056	0,0027	0,0018	0,0031	0,0043	0,0051	0,0134	0,0360
Total	0,0129	0,0054	0,0032	0,0065	0,0172	0,0177	0,0134	0,0763

TABLE BII: DEEP SEA WAVE HEIGHTS

Source : VOS [12]

No. of obs. : 3 719

VOS wave heights and VOS wave periods

Year

Sector / Period T_{VOS}(s)	VOS Wave Height H_{VOS}(m)					
	60°	90°	120°	150°	180°	210°
6,5	2,2	1,8	2,1	2,2	2,6	2,8
8,5	2,7	1,9	3,0	2,7	2,8	3,6
10,5	2,7	2,1	2,7	2,7	3,3	4,3
12,5	3,7	2,1	2,8	2,9	3,3	4,7
14,5	3,4	2,8	-	3,5	3,5	5,6

TABLE BII: DEEP SEA WAVE HEIGHTS (cont'd)

January

Sector / Period T_{VOS}(s)	VOS Wave Height H_{VOS}(m)					
	60°	90°	120°	150°	180°	210°
6,5	2,2	1,5	1,5	2,3	2,5	2,4
8,5	3,1	2,0	1,5	2,4	2,9	3,2
10,5	2,0	2,0	2,0	2,6	3,0	4,5
12,5	-	1,5	-	2,5	3,1	3,3
14,5	-	2,5	-	-	3,5	-

February

Sector / Period T_{VOS}(s)	VOS Wave Height H_{VOS}(m)					
	60°	90°	120°	150°	180°	210°
6,5	1,9	1,8	2,7	2,2	2,1	2,5
8,5	2,3	2,1	1,4	3,1	2,7	3,8
10,5	-	2,1	2,8	3,2	2,8	2,9
12,5	6,0	2,5	4,0	4,0	4,3	2,0
14,5	3,0	-	-	-	-	-

March

Sector / Period T_{VOS}(s)	VOS Wave Height H_{VOS}(m)					
	60°	90°	120°	150°	180°	210°
6,5	2,6	1,5	2,0	2,5	2,7	3,2
8,5	2,9	1,9	2,4	2,9	2,1	3,5
10,5	1,5	1,5	2,5	2,7	2,2	4,7
12,5	3,7	1,5	2,5	3,5	1,8	2,0
14,5	-	-	-	-	-	4,5

TABLE BII: DEEP SEA WAVE HEIGHTS (cont'd)

April

Sector Period T_{VOS}(s)	VOS Wave Height H_{VOS}(m)					
	60°	90°	120°	150°	180°	210°
6,5	1,9	2,1	2,1	1,7	2,9	2,7
8,5	2,3	1,8	2,1	2,5	2,4	3,3
10,5	-	2,0	1,5	2,8	3,1	5,1
12,5	3,0	-	2,5	2,8	3,0	2,0
14,5	-	-	-	-	3,3	2,5

May

Sector Period T_{VOS}(s)	VOS Wave Height H_{VOS}(m)					
	60°	90°	120°	150°	180°	210°
6,5	2,1	1,7	1,9	2,5	2,6	2,1
8,5	2,8	2,2	3,8	2,7	2,6	3,3
10,5	1,6	2,0	3,0	3,0	3,6	4,9
12,5	3,0	-	-	4,0	3,1	5,8
14,5	-	-	-	5,0	5,4	7,5

June

Sector Period T_{VOS}(s)	VOS Wave Height H_{VOS}(m)					
	60°	90°	120°	150°	180°	210°
6,5	1,8	1,0	1,9	2,0	3,1	3,0
8,5	3,1	1,8	6,4	2,3	3,0	3,5
10,5	2,0	-	1,3	2,9	3,2	4,0
12,5	-	-	3,2	-	3,3	3,4
14,5	-	-	-	-	3,0	2,5

TABLE BII: DEEP SEA WAVE HEIGHTS (cont'd)

July

Sector Period T_{VOS}(s)	VOS Wave Height H_{VOS}(m)					
	60°	90°	120°	150°	180°	210°
6,5	1,7	1,7	1,3	2,0	2,6	2,5
8,5	2,7	1,8	1,7	1,3	2,9	4,0
10,5	2,5	-	5,5	0,5	3,8	4,6
12,5	-	1,8	-	-	3,9	3,2
14,5	-	-	-	3,0	3,0	-

August

Sector Period T_{VOS}(s)	VOS Wave Height H_{VOS}(m)					
	60°	90°	120°	150°	180°	210°
6,5	1,9	2,4	1,6	2,8	2,4	2,9
8,5	2,3	1,6	2,3	2,3	2,3	4,6
10,5	3,2	2,9	-	1,6	4,0	6,8
12,5	-	2,7	1,5	2,0	2,7	6,0
14,5	-	-	-	-	2,5	5,0

September

Sector Period T_{VOS}(s)	VOS Wave Height H_{VOS}(m)					
	60°	90°	120°	150°	180°	210°
6,5	2,2	2,0	2,9	1,7	2,4	2,8
8,5	2,4	2,3	2,0	3,0	3,2	3,6
10,5	1,5	-	-	3,1	3,7	4,0
12,5	-	-	-	2,0	3,5	3,9
14,5	-	-	-	3,0	3,0	12,5

TABLE BII: DEEP SEA WAVE HEIGHTS (cont'd)

October

Sector Period T_{VOS}(s)	VOS Wave Height H_{VOS}(m)					
	60°	90°	120°	150°	180°	210°
6,5	2,6	1,9	1,8	2,2	2,5	3,6
8,5	3,1	1,3	2,3	2,3	3,5	3,1
10,5	4,3	2,0	3,8	2,5	3,9	3,5
12,5	3,0	-	-	3,0	2,9	4,1
14,5	3,8	-	-	-	3,0	7,0

November

Sector Period T_{VOS}(s)	VOS Wave Height H_{VOS}(m)					
	60°	90°	120°	150°	180°	210°
6,5	2,4	2,0	2,1	2,4	2,6	2,5
8,5	2,6	1,4	3,0	2,7	2,4	3,1
10,5	2,3	3,2	2,4	2,9	3,4	2,9
12,5	-	2,0	1,5	2,0	2,5	7,3
14,5	-	3,0	-	2,5	4,0	2,5

December

Sector Period T_{VOS}(s)	VOS Wave Height H_{VOS}(m)					
	60°	90°	120°	150°	180°	210°
6,5	2,1	2,1	2,0	2,7	2,8	2,8
8,5	2,5	2,1	-	3,4	2,6	3,0
10,5	2,0	2,0	1,5	2,6	2,3	2,9
12,5	3,5	2,0	-	2,5	3,9	2,8
14,5	3,0	-	-	-	2,4	1,5

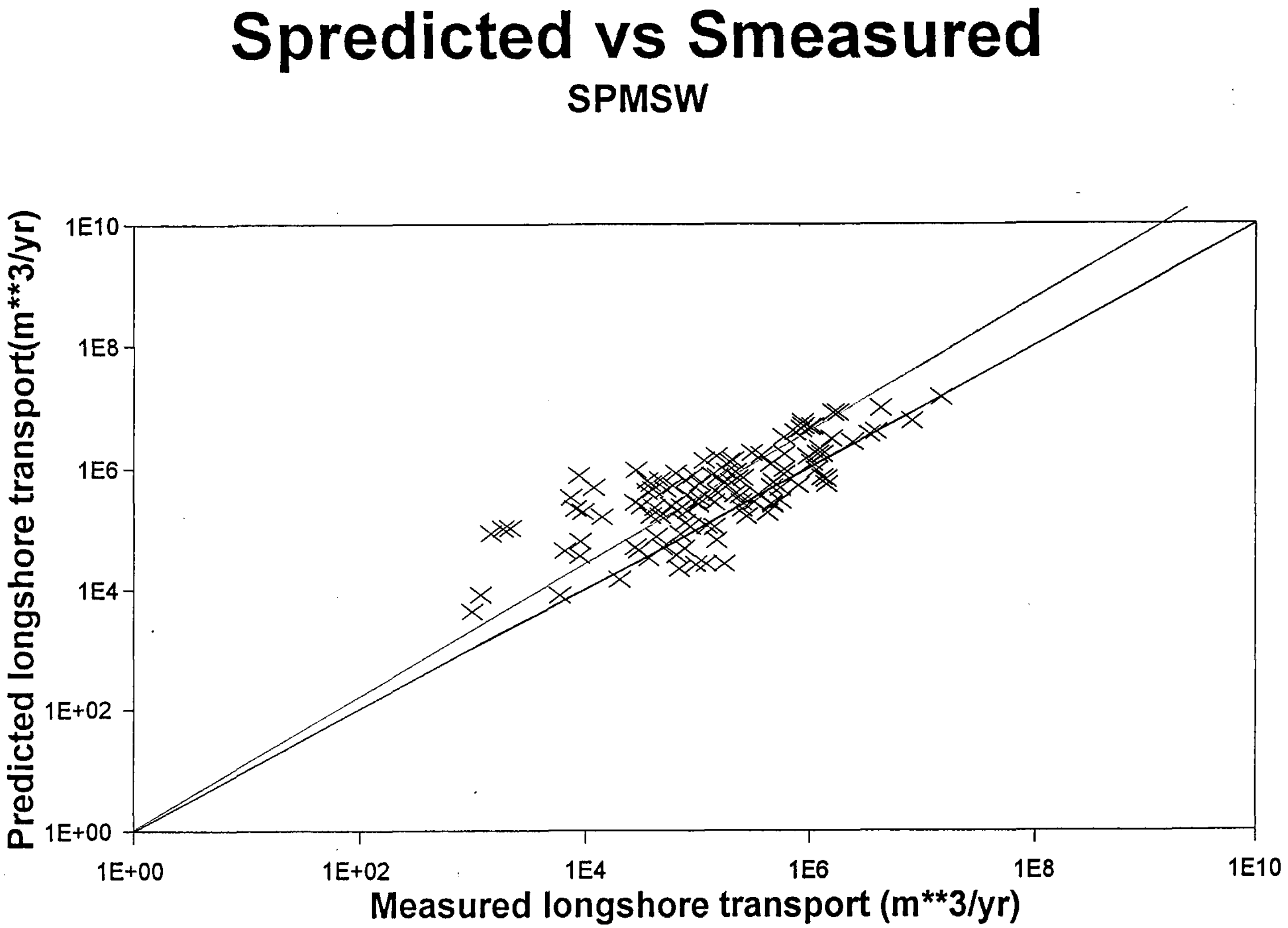

Figure E1a: Predicted versus measured longshore transport rates for the SPM and Swart formula

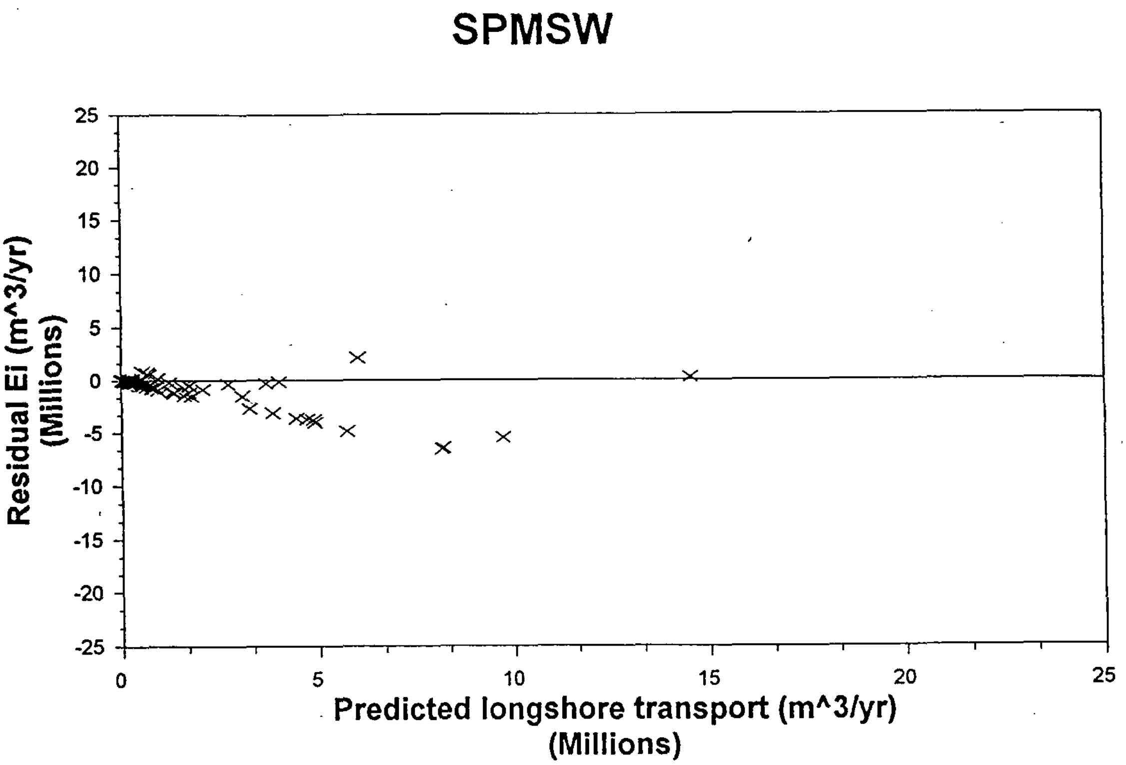

Figure E1b: Residuals versus the predicted longshore transport rates for the SPM and Swart formula

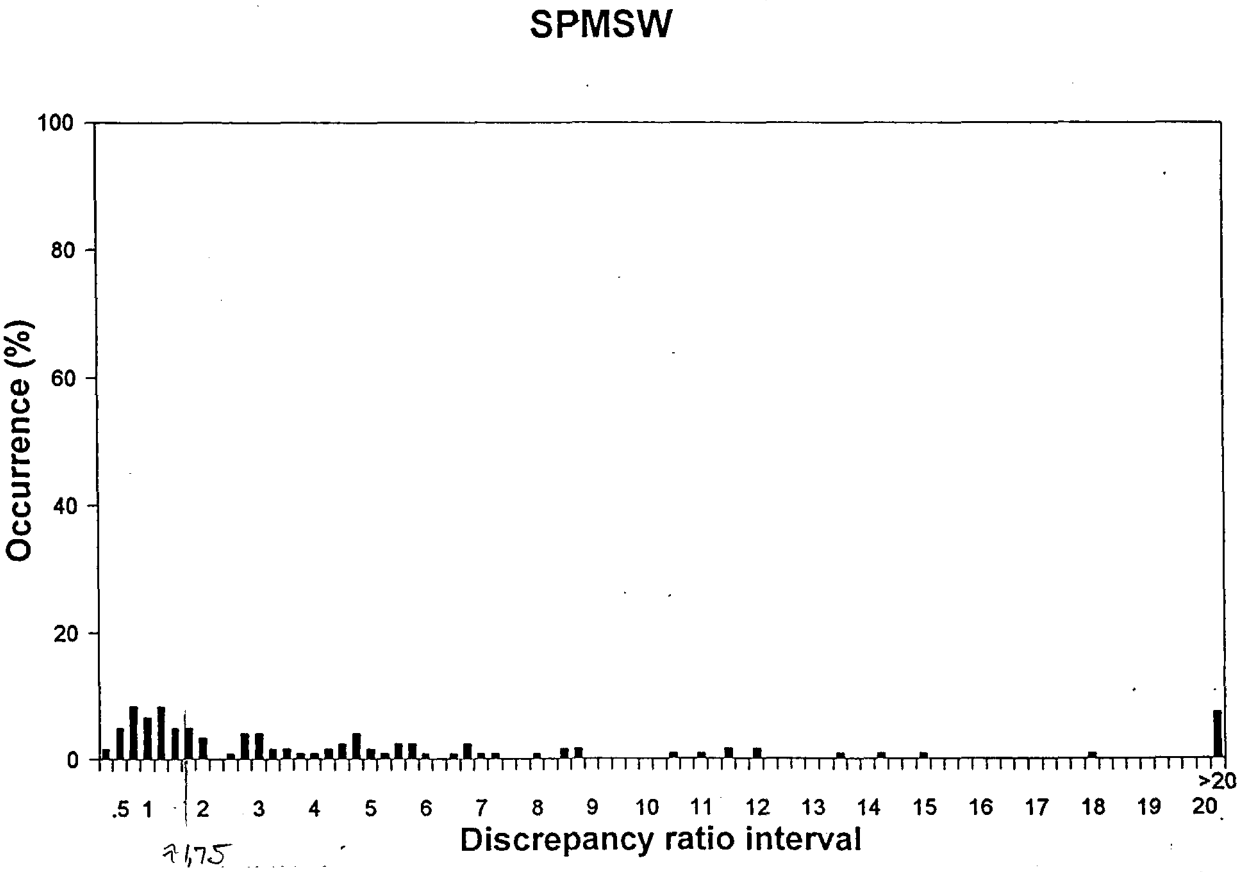

Figure E1c: Histogram of the discrepancy ratio for the SPM and Swart formula