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Annual variation in the net longshore sediment transport rate

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Abstract

The annual variation in the net longshore sediment transport rates at three South African and at one North African site is investigated. The net rates at these sites, given in the first table, show large variations. It was found that measurements of longshore transport rates should be conducted continuously for 5–8 years in order to obtain an accurate value (within 10%) of the true long-term mean net longshore transport rate. A second table was drawn up, which can be applied to determine the range in which the true mean rate will fall if measurements were done over a shorter period than the recommended 5–8 years. It is reasonable to expect that the conclusions are widely applicable, especially for exposed sites. It is recommended that an accurate assessment of the long-term mean net longshore transport rate at a site can best be made cost-effectively by doing limited site-specific measurements, calibrating the best longshore transport formula for the particular site, and predicting the transport rates using a representative wave climate. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Longshore sediment transport; Annual variations; Long-term mean transport rates; Richards Bay; Durban; Nouakchott

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1. Introduction

Longshore sediment transport forms an integral part of the input required for the determination of dredging requirements at a port entrance. Detailed knowledge of the longshore transport is also necessary for the assessment of the beach evolution caused

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by the construction of breakwaters at harbour entrances or beach improvement schemes incorporating groynes, detached breakwaters and beach-fill. Longshore transport also plays an important role in the stability of inlets and estuaries. Normally, an average net longshore transport rate is used to determine the dredging requirements or the beach evolution at a particular site. This is usually followed by a sensitivity analysis to see what the effect would be if the true net longshore transport is considerably higher or lower than the assumed average rate, or even if a reversal in the transport direction would occur. This average rate is an estimate of the true long-term net longshore transport rate at the site.

In order to obtain the true long-term mean net longshore transport rate at a site, it is necessary to assess the annual variation in the net transport rates. This annual variation can be determined either by computing the longshore transport rates with a reliable formula from wave data spanning a number of years, or by measuring continuously the longshore transport over a number of years. In both cases, it must be known over how many consecutive years either the computations or the measurements should be done. This aspect (the required measurement period) will be determined based on the data from three sites on the South African coast. However, sometimes, it may not be possible to take measurements for this required period (e.g., due to time and cost limitations). An alternative question that needs to be resolved is: Within what range can the long-term mean net transport rate vary if measurements are done over a shorter-than-recommended period? This issue will also be addressed in this paper. While comparing the two ways of obtaining the true long-term mean net transport rate (predictions or measurements), another question arises: What is the most cost-effective way of obtaining the true long-term mean net longshore transport rate? An answer to this question will be given, again based on data from the three sites.

Previous work on the variation in longshore transport rates focused mainly on daily to monthly transport rates and their temporal fluctuations. Seymour and Castel (1985) analysed the daily transport rates at seven sites and determined statistics from them. Raw (1993) presented weekly to monthly transport rates at the Port of Durban determined from volumetric differences (calculated from surveys). In addition, he investigated the annual variation in the net longshore transport rates over a period of 7 years. In a study by Shi-Leng and Teh-Fu (1987), a longshore sediment transport formula (the Bijker, 1967 method) was calibrated against short-term measurements at Nouakchott, Mauritania (Fig. 1) on the Atlantic coast. This formula was then used, based on wave data, to calculate the net longshore sediment transport rates for 7 consecutive years (the data are listed in Shi-Leng and Teh-Fu, 1987). They found a definite variation in the annual transport, such that the ratio of the maximum of the mean value of the annual transport is 1.31, and the ratio of maximum to minimum is 1.89. They also showed that the annual net longshore transport rate follows the Gumbel distribution for their site. However, from all available literature, it appears that very little has been done on the length of time for which measurements should be taken continuously to ensure an accurate long-term mean net transport rate.

The sites, where time series data are available, are briefly described below. This description is followed by an explanation of the analysis method. Thereafter, the results of the analysis of the time series will be presented and discussed. The paper concludes

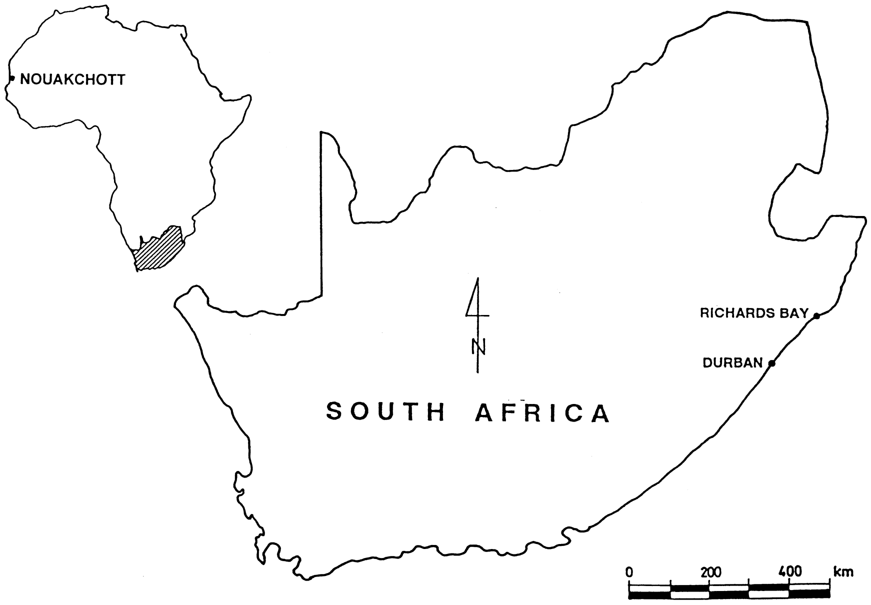

Fig. 1. Location map.

with a recommendation regarding the required period for determining the long-term net longshore transport rate. In addition, the range is given within which the true long-term mean net transport can vary if a shorter-than-recommended period has to suffice. The most cost-effective way of obtaining the true long-term mean net longshore transport rate is also determined.

2. Site characteristics and available data

2.1. General

The three sites, where time series data of the net longshore transport rates were available, are located on the east (Indian Ocean) coast of South Africa (Fig. 1). These are: Durban Bight, the sand trap of the Port of Durban, and the beaches around the Port of Richards Bay. For comparative purposes, the data for Nouakchott, Mauritania from Shi-Leng and Teh-Fu (1987) are also given.

2.2. Durban Bight

It is along the Durban Bight that the main bathing beaches of Durban are situated. The Durban Bight stretches from the entrance of the Port of Durban (between the south and north breakwaters) in the south up to the mouth of the Mgeni River in the north (Fig. 2). (The river mouth is located just north of Survey Station A shown in Fig. 2.)

The dominantly northbound net longshore transport is interrupted by the breakwaters and entrance channel of the Port of Durban, and virtually all of this transport accumulates in and around the sand trap immediately south of the breakwaters (Fig. 3a and b).

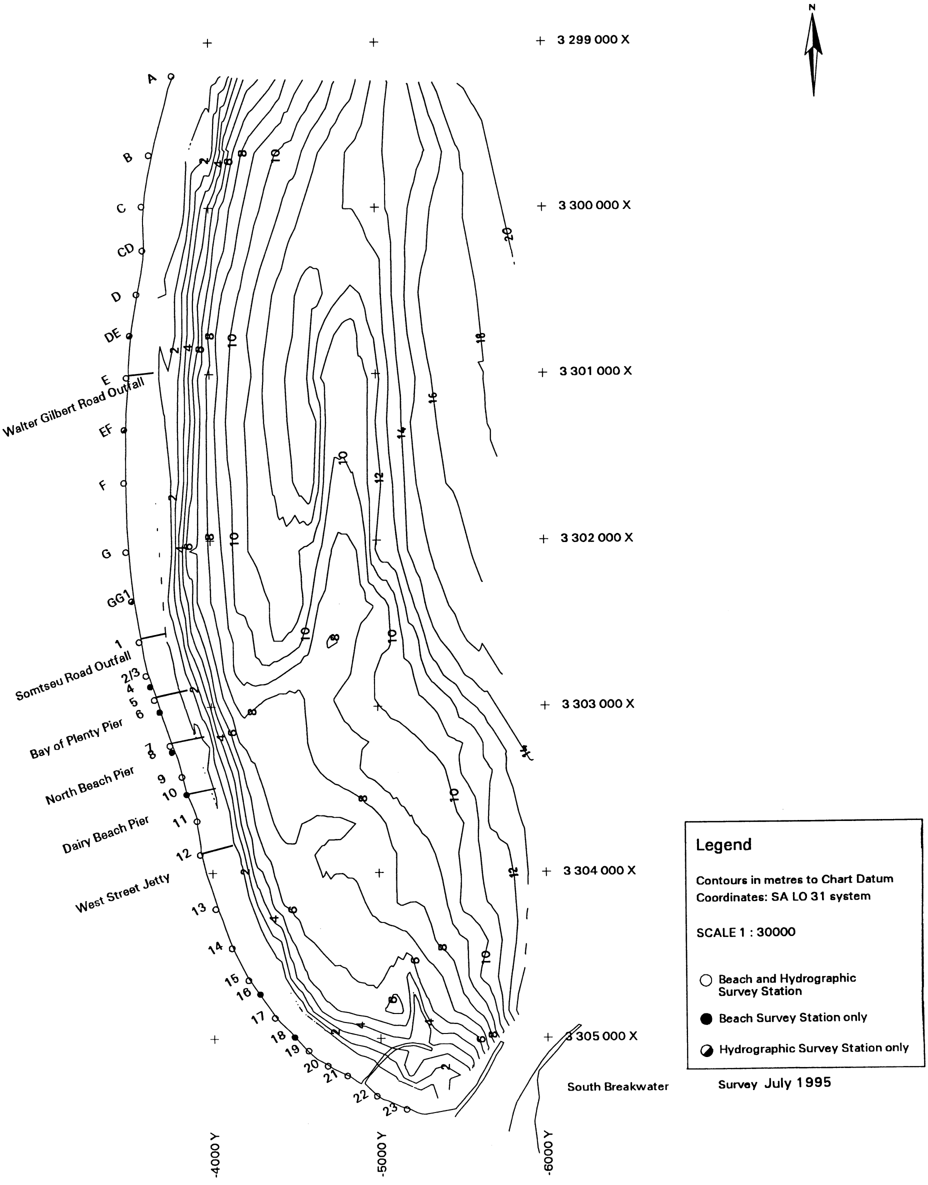

Fig. 2. Durban Bight reference map (from CSIR, 1996).

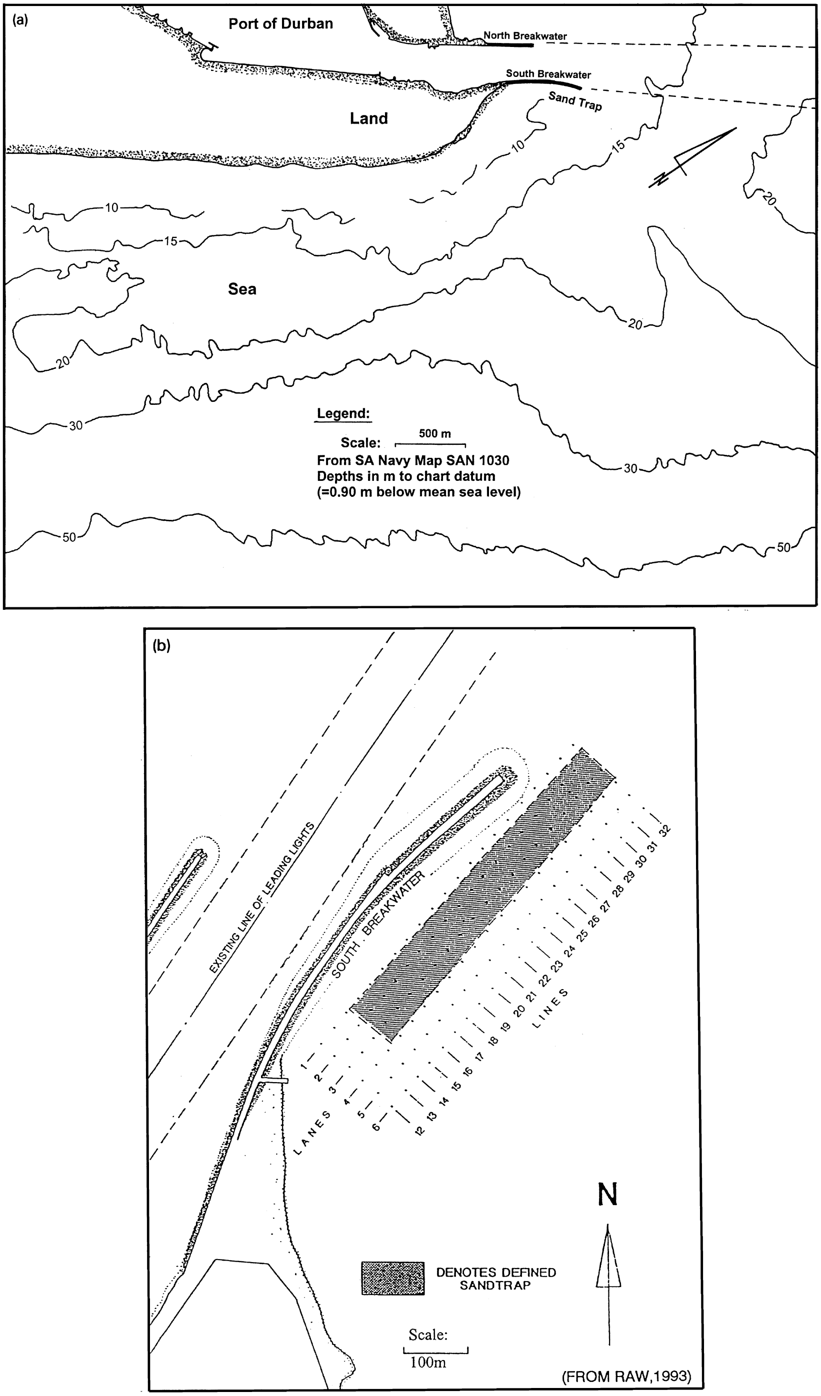

Fig. 3. (a) Bathymetry off the Port of Durban. (b) Sand trap at the Port of Durban.

Table 1
Annual net longshore transport rates

	Durban Bight		Durban sand trap		Richards Bay		Nouakchott (from Shi-Leng and Teh-Fu, 1987)	
	Period	Net loss rate (m^3/year)	Period	Net longshore transport rate (m^3/year)	Period	Net longshore transport rate (m^3/year)	Period	Net longshore transport rate (m^3/year)
	1985/1986	90,000	1986	420,000	1979/1980	1,020,000	1976	690,000
	1986/1987	120,000	1987	450,000	1980/1981	830,000	1977	970,000
	1987/1988	820,000	1988	360,000	1981/1982	850,000	1978	1,060,000
	1988/1989	210,000	1989	470,000	1982/1983	2,120,000	1979	780,000
	1989/1990	140,000	1990	590,000	1983/1984	1,880,000	1980	1,310,000
	1990/1991	430,000	1991	620,000	1984/1985	1,570,000	1981	1,140,000
	1991/1992	180,000	1992	560,000	1985/1986	−420,000	1982	1,040,000
	1992/1993	370,000			1986/1987	−260,000		
	1993/1994	270,000			1987/1988	720,000		
	1994/1995	380,000			1988/1989	1,010,000		
					1989/1990	−60,000		
					1990/1991	1,220,000		
					1991/1992	980,000		
					1992/1993	440,000		
Number of points		10		7		14		7
Mean		300,000		500,000		850,000		1,000,000
Standard deviation		220,000		100,000		750,000		210,000
Coefficient of variation		0.73		0.19		0.88		0.21

A trailing suction hopper dredger removes the sand from the sand trap and pumps the sand into a hopper just north of the north breakwater (the hopper is not shown in Fig. 2). Bypassing and beach nourishment are achieved by pumping the sand from the hopper along the beaches of the Durban Bight. The longshore transport potential along the Durban Bight is lower than the potential transport south of the harbour entrance, partially because of the protection against wave action offered by the breakwaters (the dominant deep-sea waves are from the south).

Monthly beach surveys have been done along the Durban Bight by using standard, accurate land surveying methods. Annual volumetric net loss rates were calculated from these surveys, representing the beach above chart datum. (Chart datum, which is approximately mean low-water spring tide level, is 0.90 m below mean sea level.) The volumes of sand bypassed are accurately determined in the hopper and are taken into account in assessing the net loss rates. These net loss rates are not equivalent to the net longshore transport rates. However, the loss rates are directly related to the longshore transport rates because longshore transport is the main mechanism for removing sand from the Durban Bight. It has been established that there is no major net long-term cross-shore transport of sand. Furthermore, it can be argued that the cross-shore losses are reasonably consistent from year to year because bypassing is conducted consistently. In any event, it is not the absolute values of the loss rates that are important in this analysis, but the variation in time of rates that were determined in a consistent manner.

The net loss rates that cover a 10-year period (Table 1) were taken from CSIR (1996). Fig. 4 illustrates the yearly variation in the net loss rates. Considerable variation

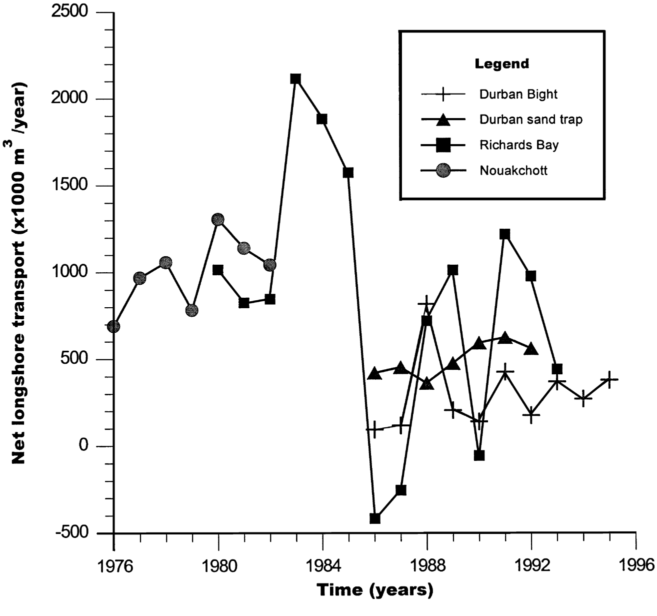

Fig. 4. Annual variation in the net longshore transport rate.

in these rates is apparent from this figure. The long-term mean rate is 300,000 $m^3/year$ with loss rates ranging between 90,000 and 820,000 $m^3/year$ (Table 1).

More information about the bypassing operation, wave and sediment characteristics, tidal information, etc., can be obtained from Laubscher et al. (1990) and CSIR (1996).

2.3. Sand trap at the Port of Durban

As mentioned above, the net northbound longshore transport accumulates in the sand trap just south of the south breakwater of the Port of Durban (Fig. 3a and b). A hydrographic survey of the sand trap is carried out roughly every 2 weeks (Raw, 1993). Fig. 3b shows the spacing of the survey lines. The vertical accuracy of the surveys is of the order of 30 cm (Raw, 1993). Volumetric differences between surveys were computed and summed to obtain the net longshore transport rates for each year between 1986 and 1992. The annual variations in these rates (Table 1) can be seen in Fig. 4. Less variation is apparent in the sand trap data compared with the values for the Durban Bight (Fig. 4). The long-term average longshore transport rate for the sand trap is 500,000 $m^3/year$ (minimum value = 360,000 $m^3/year$; maximum value = 620,000 $m^3/year$; Table 1). Raw (1993) presented more detailed information on sand accumulation in the sand trap.

2.4. Richards Bay

The Port of Richards Bay (Fig. 5) was constructed on a sandy coast. Comprehensive monitoring has been undertaken, such as beach and hydrographic surveys, wave recordings by means of a Waverider and a clinometer (graded telescope), tide recordings and sediment grain size analyses. Fig. 5 shows the main beaches adjacent to the harbour, namely:

Southern beach	From Survey Stations TS2–TS17
Near-northern beach	Between TN2 and TN10
Far-northern beach	From TN10 to beyond TN18

Sand is dredged by a trailing suction hopper dredger from south of the harbour entrance and pumped onto the near-northern beach. As at Durban, the net longshore transport is usually towards the northeast.

Volumetric differences were computed from the annual beach and hydrographic surveys. By taking into account the volumes of material dredged, it was possible to calibrate a few longshore transport formulae (Coppoolse and Schoonees, 1991; Laubscher et al., 1991). The measured wave characteristics were used in this calibration together with a detailed refraction analysis. The Kamphuis (1990) formula fared the best. Fig. 6 shows the calibration which was carried out for the southern beach. Note that the coefficient of determination (R^2) is equal to 0.86, which means that the formula accounts for 86% of the variation. This high percentage is very good for sediment transport predictions.

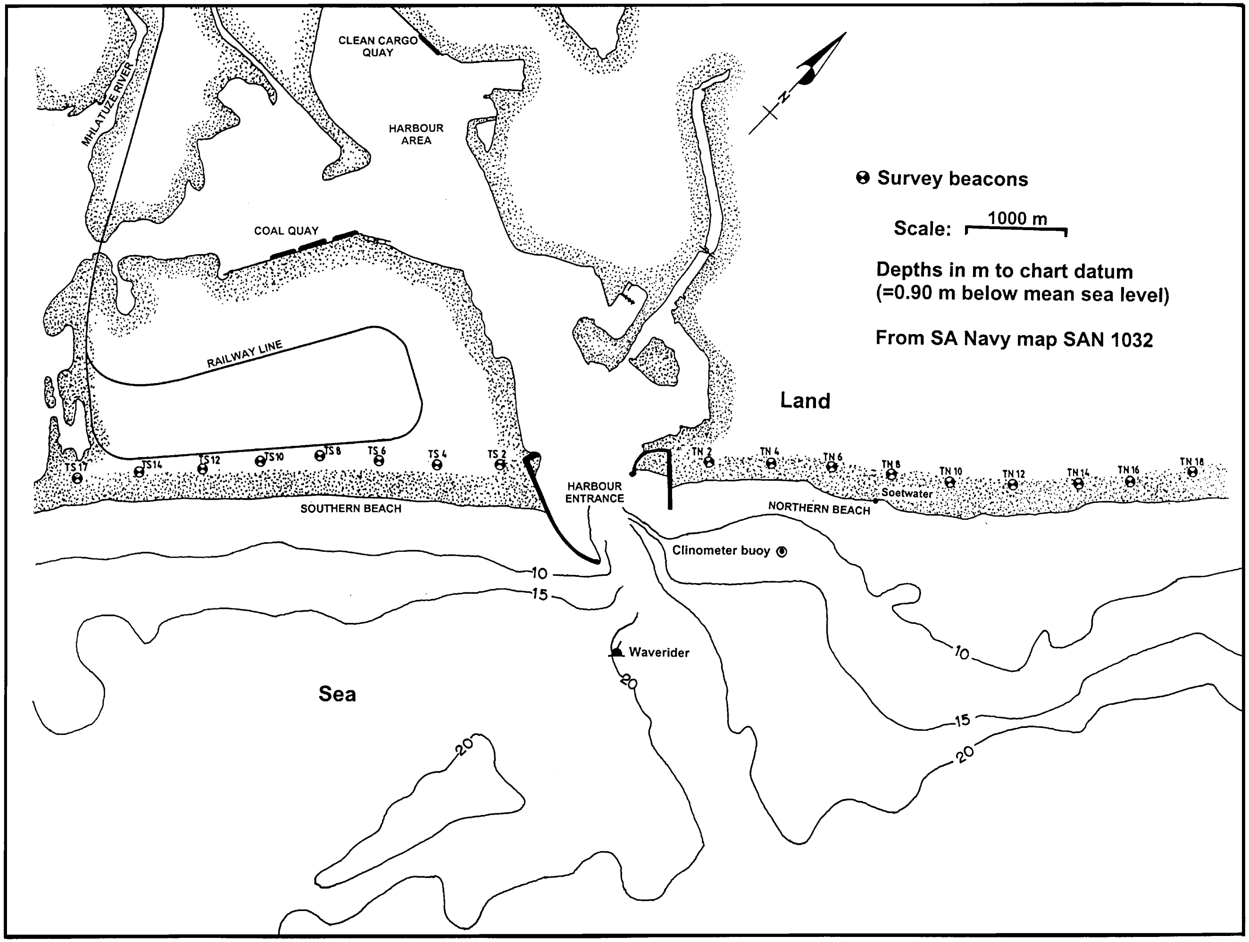

Fig. 5. Layout of the Port of Richards Bay (from CSIR, 1994).

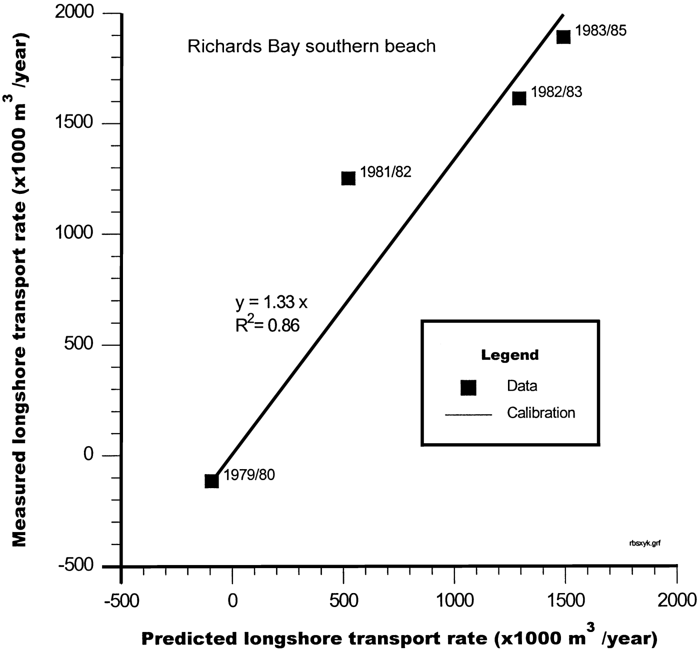

Fig. 6. Calibration of the Kamphuis formula using Richards Bay data.

Refraction results were also obtained for the near- and far-northern beaches and smoothened (averaged) for the specific beach, as was done for the southern beach. Each measured wave condition was then refracted out to deep sea, followed by refraction towards the particular beach. The calibrated Kamphuis formula was then employed to predict the longshore transport rate for each wave condition at each of the three beaches (CSIR, 1994). These rates were summed to obtain the net longshore transport rate for each year at each of the three beaches. Fig. 7 illustrates the variation in the net longshore transport rate over the 14 years from 1979/1980 to 1992/1993. Large differences in the net longshore transport rates are apparent from year to year in this figure. Reversals in the net longshore transport directions occurred a number of times on the southern beach and twice on the far-northern beach. The reasons for the frequent reversal in the net transport direction along the southern beach are the change in its orientation because of dredge spoil being pumped onto the beach (mostly in the 1970s) and shifts in the deep-sea wave direction. For the purpose of the analysis, the results for the three Richards Bay beaches were combined (Table 1), giving a long-term net north-eastbound longshore transport of 850,000 m^3/year. The net rates vary from −420,000 to 2,120,000 m^3/year (Table 1).

Detailed information about the site can be found in Swart (1981), CSIR (1989, 1994), Coppoolse and Schoonees (1991) and Laubscher et al. (1991). These references include descriptions of the wave recordings, tidal levels, refraction results, sediment grain sizes and the calibration of the longshore transport formula.

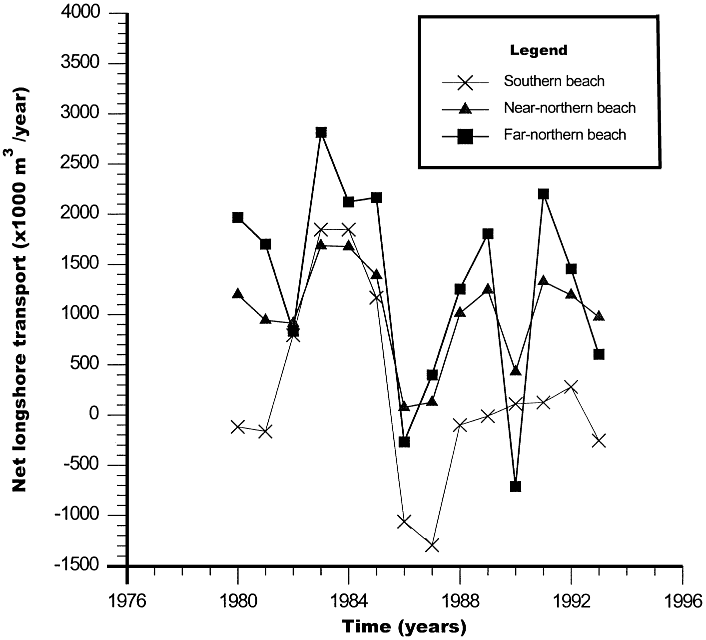

Fig. 7. Annual variation in the net longshore transport rate at Richards Bay.

2.5. Nouakchott

The data for Nouakchott from Shi-Leng and Teh-Fu (1987) are also contained in Table 1. The mean net longshore transport rate is 1,000,000 m^3/year with the rates varying between 690,000 and 1,310,000 m^3/year (Table 1).

3. Analysis method

The variation in the net longshore transport rate over time is characterised by two variables, namely, the standard deviation and the coefficient of variation. The coefficient of variation is defined as the standard deviation divided by the mean. These two variables are preferred above the ratio of the maximum rate to the minimum rate because they are the standard way in statistics of representing variation. In addition, if some of the net transport rates are negative (as for Richards Bay; Table 1), then the value of the abovementioned ratio is misleading. Both *running* and *floating* mean net longshore transport rates were used, as will be discussed below.

The running mean net transport rate is calculated as follows: the first point is the mean rate over 1 year; the second point is the mean rate of the first 2 years; the third point is average of the first 3 years; and so on. A factor (f_r), being the running mean rate divided by the long-term mean net longshore transport rate, was plotted against time for each of the three sites. The advantage of plotting this factor, instead of just the running mean rate against time, is that it is known that the factor will tend towards unity. It is then easy to see over how many years the running average needs to be taken to ensure a variation of say, 20%, above and below the net long-term average rate. In this example, the required number of years over which the mean should be computed (say t_1) will be when the value of this factor (f_r) is consistently between 0.8 and 1.2. Measurements should therefore be done for t_1 years in this example to ensure an accuracy of 20% in the long-term value of the net longshore transport rate.

Another area of inquiry is the sequence of years during which consecutive measurements are taken. If, e.g., measurements are taken for 3 years at a site for a new port, and these happen to be 3 years with low net transport rates, the answer (mean net rate) will be too low. This could have severe cost implications if the dredging requirements for the port are underpredicted. To address this problem, the effect of the sequence of years on the final answer was also investigated.

However, due to cost limitations, it is usually not possible also to measure the longshore transport over the required number of years. Guidance is therefore needed on how much a shorter-term average can deviate from the long-term average rate. A *floating* average was used for this purpose. The floating average is computed over a specified number of years. For example, the floating average over 3 years is calculated as follows: the first mean value is the average of the first, second and third net rates; the second mean value is the average of the second, third and fourth net rates; the third mean value is the average of the third, fourth and fifth net rates, etc. A characteristic of this method is the fewer data points obtained if averaging is done over longer periods. For example, if averaging is done over 10 years, and 14 years of data are available, five data points (floating mean rates) are obtained. As for the running mean, the floating mean is divided by the long-term mean rate to obtain a factor (f_f) that will tend towards unity. Confidence bands based on the data can then be drawn in on a plot of this factor vs. the period over which the floating mean was computed. Therefore, for a certain confidence level, the factors can be obtained within which the estimate of the long-term rate will fall if measurements are taken during a period shorter than the recommended period.

4. Results and discussion

4.1. Variation in the net longshore transport rates

Fig. 4 shows the variation in the net longshore transport rates at the four sites (Durban Bight, Durban sand trap, Richards Bay and Nouakchott). The largest variations occur at Richards Bay and the Durban Bight; however, significant annual variation is evident for the Durban sand trap. Since all three South African sites are situated within

300 km of each other along an exposed coastline subject to roughly the same weather systems, reasonably similar variations in the annual rates at the three sites are to be expected. The smaller variation for the Durban sand trap data can be attributed to the following causes:

- The survey area at the sand trap does not cover the beach and nearshore area to its south, i.e., the area between the sand trap and the beach (Fig. 3b). This means that appreciable accretion can, e.g., occur there without it being reflected in the volumetric differences calculated for the sand trap. This area is important because it is well-known that most longshore transports occur within the surf zone. Despite this, very little sand eventually bypasses the sand trap and the adjacent beach and nearshore area as maintenance dredging of the entrance channel is not normally required.
- The side slopes of the sand trap are also not included in the survey area (Raw, 1993). As with the above condition, all sand is not accounted for in the volume calculation.
- It is unlikely that sand in the sand trap and in the lee of the breakwaters of the port will be transported southwards in the case of southbound longshore transport. This is because of the protection offered by the breakwaters and because sand is not easily transported up the slope and out of the sand trap. In contrast, the breakwaters at Richards Bay virtually do not affect the results there because long stretches of beach are included in the volumetric computations and not only a strip in the lee of the breakwaters as at the Durban sand trap.
- It is expected that the variation in the longshore transport arriving at the sand trap will be more than the variation in the accumulated volumes of sand in the sand trap, which are recorded by surveys roughly every 2 weeks. This is mostly because it is not possible to dredge the exact rate of sand as it arrives at the sand trap because of storms. The trapping of sand and the dredging of it thus, in effect, smoothen out some of the variation in the longshore transport.

Because the Durban sand trap data cover a shorter period than the other two South African sites, it can be argued that only a period with smaller variation in the net longshore transport rates is covered. However, this is not the case. Investigating the same period, 1986–1992, for the Durban Bight data as for the Durban sand trap data, it is found that the coefficient of variation was between 0.77 and 0.93 for the Durban Bight compared with 0.19 for the Durban sand trap. (The value 0.77 is obtained for the period 1985/1986 to 1991/1992 while 0.93 is calculated from 1986/1987 to 1992/1993; Table 1. The calculation of the coefficient of variation for these two periods is done because the respective periods for the Durban Bight and Durban sand trap do not coincide exactly.) Therefore, it is clear that the Durban sand trap data do not cover a period with smaller-than-normal variations in the net longshore transport rate. On the other hand, it could be that the Durban Bight variation is somewhat too large because the loss rates are dependent on when the surveys were done. That is, if a survey were done immediately after a storm, the loss rate from the beach would be higher than if the survey was conducted before the storm.

Comparing the annual variation in the net longshore sediment transport rate for the three South African (Indian Ocean) sites with the variation at Nouakchott on the Atlantic coast (Shi-Leng and Teh-Fu, 1987), it is clear that the variation at Nouakchott is larger than the variation at the Durban sand trap, but lower than the variations found at the Durban Bight and at Richards Bay (Fig. 4 and Table 1). The values of the coefficient of variation are 0.19, 0.21, 0.73 and 0.88 for the Durban sand trap, Nouakchott, Durban Bight and Richards Bay, respectively. Although Shi-Leng and Teh-Fu (1987) give some information about the Nouakchott site, which is apparently along an exposed coastline on the west coast of north Africa, it is not possible to do a more detailed comparison.

4.2. Required measurement period

The factor (f_r) or ratio of the running mean net longshore transport divided by the long-term mean net longshore transport is plotted vs. time in Fig. 8 (S = longshore transport rate in this figure and in Figs. 9 and 10). Note that the long-term mean net longshore transport is the mean of the net longshore transport rates over the maximum number of years of data that are available, i.e., 10, 14 and 7 years, respectively, for the Durban Bight, Richards Bay and Durban sand trap data.

From Fig. 8, it can be seen that the factor f_r varies from about 0.3 to just over 1.6 for the data of the three sites. It is also clear that the Richards Bay and Durban Bight data exhibit the largest variations (as discussed above), while the Durban sand trap values show a slowly increasing trend towards unity.

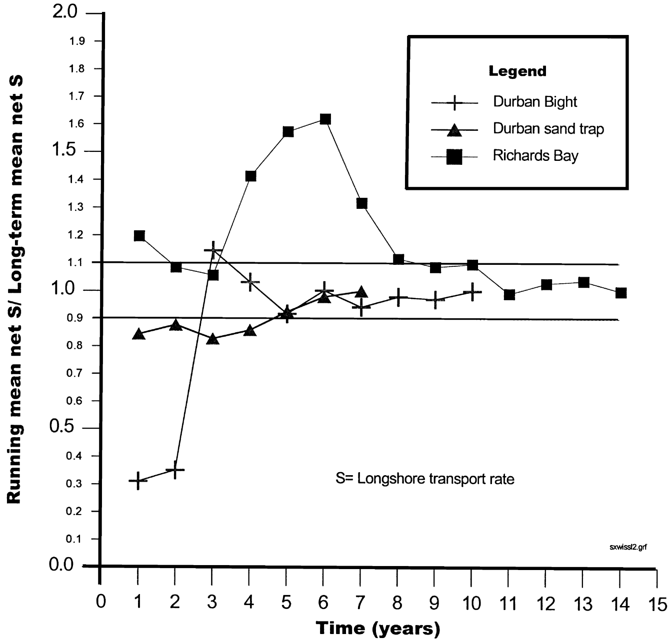

Fig. 8. Variation of the running mean net longshore transport rates over time.

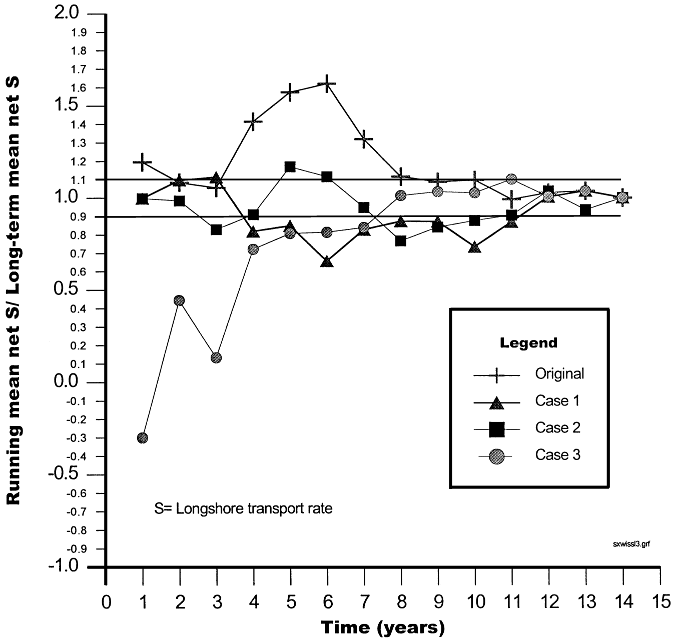

Fig. 9. Random variation of the net longshore transport rates at Richards Bay.

Fig. 8 also shows that the running mean needs to be computed, respectively, over 4, 5 and 8 years at the Durban Bight, Durban sand trap and Richards Bay for the running mean to be within 10% of the long-term mean net longshore transport rate. That is, the factor f_r will vary consistently between 0.9 and 1.1 in Fig. 8 after this number of years. A comparison of these periods (4–8 years) with the following corresponding periods in related fields is interesting. Rossouw (1989) found that wave measurements have to be done for 5 years or longer to be representative of the long-term wave climate. For fluvial sediment transport, Rooseboom (1992) concluded that a record of the sediment load of a river should be kept for 6 years or longer to yield a reliable estimate of the long-term mean load. This agreement of the required measurement period is interesting.

It is therefore recommended that the required measurement period to obtain an accurate long-term mean rate for exposed sites is from 5 to 8 years for a deviation of within 10% from the long-term mean. Although this recommendation is derived from three data sets only, it is believed to be more widely applicable because it agrees with the required recording period of 5 years for the wave climate. It is reasonable to expect that, for protected beaches, the required measurement period will also be 5–8 years or less because the wave attack is usually limited to a narrower range of wave directions compared with exposed sites.

The effect of the sequence in which the net longshore transport rates were obtained was also investigated. This is important because it is normally not known whether a cycle of high or low rates will be encountered during measurement.

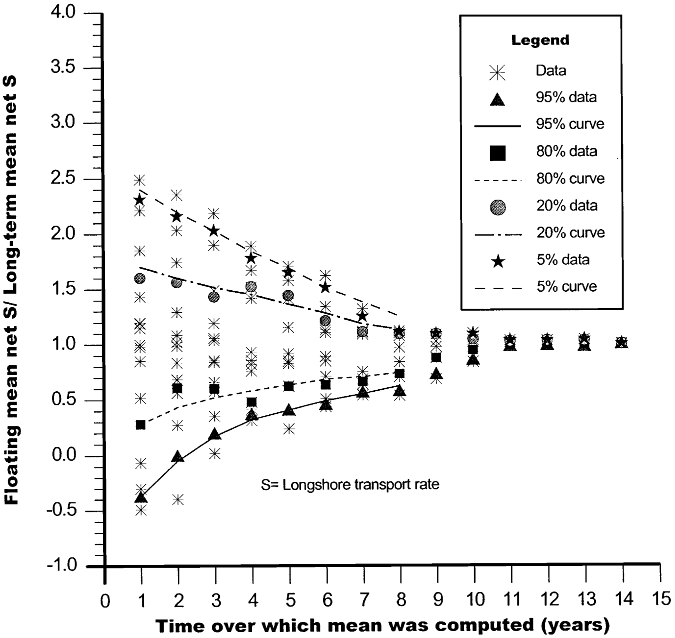

Fig. 10. Richards Bay: floating mean net longshore transport rate (S)/long-term mean net S.

The Richards Bay data were chosen for this investigation because the site yielded a data span over the longest period (14 years) and with large annual variations. A random number generator was used to alter the sequence in which the net transport rates occurred. The underlying assumption is therefore that the net transport rates are statistically independent. This is most probably not true, because weather patterns (and therefore wave patterns) can be distinguished over medium (5–10 years) and long terms (more than 10 years). However, maximum variations from year to year can be expected if independence is assumed. The effect on the required measurement period will therefore most probably be maximised.

Fig. 9 shows the factor (f_r, running mean rate/long-term mean rate) vs. time for the real (original) data for Richards Bay as in Fig. 8, together with three cases in which the order (sequence) of the net transport rates was varied in a random way. From Fig. 9, it can be seen that the required measurement period generally lies between 8 and 9 years in order to ensure that the deviation from the long-term mean is less than or equal to 10%. It can therefore be concluded that the sequence in which the net longshore transport rates at Richards Bay occur is not critical as long as the continuous required measurement period is adhered to. It is reasonable to assume that this finding is applicable to other sites as well (and/or that the finding is conservative) because of the large variations in net longshore transport rates found in Richards Bay.

4.3. Deviation of long-term mean transport rate from the short-term mean rate

Fig. 10 shows the variation in the factor (f_f) of the floating mean longshore transport divided by the long-term mean transport rate vs. the period over which the averaging was done. It should be recalled that the Richards Bay data set, which is the longest data set and shows the most variation, has been used. The data points fall within an approximately triangular area and are roughly symmetrical around 1.0. This is to be expected because the range of the values of the abovementioned factor should decrease as the period over which the averaging is done increases. Furthermore, because the net longshore transport rate can be negative, the data points will not be truncated where the factor is zero, as is the case for the sediment yield from river catchments (which cannot be less than zero; Rooseboom, 1992).

Four confidence bands (95%, 80%, 20% and 5%) were determined based on the occurrence of factor, f_f. The 95% limit indicates that 95% of the values of f_f will exceed the given value for the particular period over which the averaging was done. The data points showing the position of these four confidence limits (which were determined by means of linear interpolation) are also plotted in Fig. 10. Smooth lines were drawn through these points. Table 2, in which the values of f_f are tabulated, summarizes the confidence limits.

For example, if measurements, which were taken continuously over 2 years, yielded a mean net longshore transport rate of 300,000 m^3/year, it would mean that the long-term mean net rate can vary as follows by using Table 2:

> With a confidence of 90% (between 5% and 95%): from $-0.05 \times 300{,}000 = -15{,}000$ m^3/year to $2.20 \times 300{,}000 = 660{,}000$ m^3/year. This variation in the long-term net longshore transport rate will then have to be taken into account, as, e.g., in predicting accretion next to harbour breakwaters.

The values of the factor (f_f) tabulated in Table 2 are, strictly speaking, only applicable to the specific site. However, because Richards Bay lies on an exposed coast where large variations in the longshore transport regime occur (Fig. 7), it is believed that these values of f_f are more widely applicable. Engineering judgement is required to estimate how conservative these factors would be for protected coasts where the wave attack is usually limited to a narrower range of wave directions than that which occurs at Richards Bay. It is recommended that the above analysis be repeated for protected and partly protected coasts when data become available.

Table 2
Confidence bands of the factor, floating mean net longshore transport/true long-term mean net transport (Richards Bay data)

Confidence limit (%)	Period (years) over which the mean was computed							
	1	2	3	4	5	6	7	8
95	−0.37	−0.05	0.17	0.32	0.41	0.48	0.55	0.62
5	2.40	2.20	2.03	1.84	1.70	1.51	1.38	1.25
80	0.28	0.44	0.52	0.58	0.63	0.68	0.70	0.74
20	1.70	1.60	1.51	1.46	1.37	1.28	1.18	1.13

4.4. General discussion

An accurate assessment of the long-term mean net longshore transport rate at a site can be made in a number of ways (called options), as follows:

(1) The long-term mean net longshore transport rate may be known for nearby sites from long-term records. By inference, the long-term net rate at the new site can be determined. This can be done by comparing the wave climates, sand grain sizes, coastline orientations, beach and nearshore profiles, etc., of the particular site with the nearby sites.

(2) Measurements can be conducted over a 5–8 year period or over a shorter period and by using the values of f_{f} (floating mean rate/long-term mean rate) in Table 2 as explained above. Typical methods for doing these measurements are described in Schoonees and Theron (1993). Apart from the high costs involved in doing these measurements, such a long period is normally unacceptable for clients who commission this type of study.

(3) A representative wave climate can be used together with a well-calibrated longshore transport formula (Schoonees and Theron, 1996) to predict the long-term mean net transport rate.

(4) Limited site-specific measurements (e.g., by using short-term impoundment (Bodge, 1986) or other methods (Schoonees and Theron, 1993) can be made to calibrate a longshore transport formula (Schoonees and Theron, 1996) for the particular site. The calibrated formula can then be used with confidence in association with representative wave data to predict the long-term mean net rate.

In determining the average sediment yield of a river (or fluvial sediment transport), use has been made of almost continuous suspended sediment concentration measurements at a representative location (Rooseboom, 1992). In the sea, however, the cost of almost continuous concentration measurements is prohibitive. In addition, the zones of maximum concentration and transport shift all the time owing to changes in tidal levels, beach profiles, and wave heights. This means that the measuring point(s) (location) will have to shift continuously in order to measure within the zones where the maximum concentrations and transport occur. These zones are themselves difficult to determine before measurements are conducted.

It is recommended that the abovementioned option (4) (limited measurements, calibration and prediction) be carried out, possibly augmented by option (1) (inference of net rate from nearby sites). This is believed to be the most cost-effective method of determining the long-term mean net longshore transport rate.

The question may be asked: How many years of volume observations will it take to give a better estimate of the long-term mean transport rate than an estimate based on comprehensive wave data and the best longshore transport formula? Clearly, the answer will be the same number of years provided that the accuracies of the volume observations (the first method) and sediment transport predictions (the second method) are similar, assuming that the periods covered by both methods are equally representative of the long-term conditions. The factors that influence the accuracy of these methods include the accuracy of the following: the volume differences calculated from hydrographic surveys, the determination of dredged volumes, the measurement of wave characteristics (especially the wave direction), and the longshore sediment transport formula used. Either of the two methods may be significantly more accurate in a specific instance, but this will have to be assessed in each case. In any event, a larger database than contained in this paper would be required to reach a firm conclusion.

5. Conclusions and recommendations

Based on data from three sites on the South African east coast, it was found that measurements of the longshore transport rates should be conducted continuously for 5–8 years in order to obtain an accurate value (within 10%) of the long-term mean net longshore transport rate. It was also found that the order (sequence) in which the net longshore transport rates occur is not critical as long as the required measurement period is adhered to. In other words, it does not matter whether the measurements start at a time when the net longshore transport rates are low or high.

Four confidence bands (95%, 80%, 20% and 5%) were determined for the factor f_f, the floating mean net longshore transport/long-term mean net transport, for different measurement periods (Table 2). This table can be used to estimate the long-term net transport rate if measurements were done over a shorter period than the 5–8 years recommended above. That is, if measurements cover only, e.g., a 2-year period, the values of f_f in Table 2 can be applied to determine the range in which the true long-term mean net transport rate will fall for a given confidence band.

Although the above conclusions are derived from data originating from specific sites, it is reasonable to expect that the conclusions are more widely applicable, especially for exposed sites (such as the three South African sites considered here). For protected sites, the above results are most probably conservative. It is recommended that the above analysis be repeated for protected and partly protected coasts when data become available.

It is also recommended that an accurate assessment of the long-term mean net longshore transport rate at a site can best be made cost-effectively by doing limited site-specific measurements, calibrating the best longshore transport formula (Schoonees and Theron, 1996) for the particular site, and predicting the transport rates using a representative wave climate. Measurements can be made using a variety of methods as described in Schoonees and Theron (1993). If possible, these predictions should be augmented by comparing the net rate with the net rates from nearby sites.

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