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Development of an accurate longshore sediment transport model

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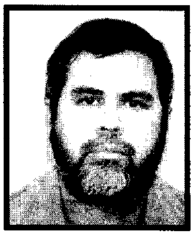

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Longshore sediment transport usually determines the dredging requirements of harbours, navigation channels and tidal inlets, and needs to be quantified for the design of, for example, beach nourishment. An accurate longshore transport model was developed and is described below. An overview is given of the comprehensive studies on which this model is based. The model is robust and well verified. The layout, input data, output and computer requirements of the model are discussed. Different applications are presented showing how the results of this model are used: for the design of groynes, breakwaters and sand bypassing systems at ports, and to complement three-dimensional computational morphological models. The model provides, per wave condition, the cross-shore distributions of the wave height, mean water levels and the longshore transport. In addition, the longshore transport climate at the particular site is summarised, and weighted, mean longshore transport distributions for both upcoast and downcoast transports are supplied.

INTRODUCTION

The process whereby sediment is moved parallel to the coastline by wave and current action is called longshore sediment transport, or longshore transport. The bottom material or sediment is stirred up (suspended) by wave action. In the nearshore zone, breaking waves suspend most of the transported sediment. Considerably less sediment is suspended outside the surf zone. Waves approaching the coastline obliquely generate longshore currents. In addition, other mechanisms such as tidal variation, wind and a longshore variation in (wave) breaker height can also generate longshore currents. These currents transport the sediment that has been stirred up by the waves, alongshore. The longshore transport rate, or littoral drift, is the rate at which sediment is moved parallel to the coast in the littoral zone. The rate is usually expressed as a volume per time, that is, in m^3/s or m^3/year.

Knowledge of longshore sediment transport is essential for the design of breakwaters at harbour and marina entrances, for navigation channels and their dredging requirements, for beach improvement schemes incorporating groynes, for detached breakwaters and beach-fill, as well as for the determination of the stability of inlets and estuaries. Sometimes the economic viability of these projects depends primarily on the siltation and therefore the longshore transport rate. It is therefore of paramount importance that this quantity can be determined accurately. Figure 1 shows longshore sediment transport problems at a small craft harbour where little or no maintenance dredging had been done. The longshore transport accumulated against the breakwater, eventually bypassed the harbour and filled the entrance channel, thereby cutting the harbour off from the sea.

How are longshore transport rates usually determined? Normally a wave refraction study is conducted covering a number of locations in the particular study area in order to calculate the nearshore wave climate. This climate is then used to compute the longshore transport for each wave condition at a specific location in the study area. Waves

Figure 1 Longshore sediment transport problems at a harbour (photo taken by D Phelp along the Eastern Cape coastline on 28 September 2000)

and currents can cause longshore transport in either of two directions at a location: up- or downcoast. Therefore, a convention for the longshore transport direction is (arbitrarily) chosen. Positive and negative transport represent, for example, up- and downcoast transports respectively. By adding up all the transport rates caused by the different wave conditions in the upcoast direction, the total upcoast longshore transport rate (S_{up}) is obtained. The total downcoast transport rate (S_{down}) is determined in a similar way. The gross and net longshore transport rates at a specific location (S_{gross} and S_{net}) are then determined as follows:

$$S_{gross} = \left|S_{up}\right| + \left|S_{down}\right|$$

and

$$S_{net} = S_{up} + S_{down}$$

The sign of S_{net} indicates the net longshore transport direction. This process is then repeated for the other locations in the study area.

The aim of this paper is to discuss the development of a software package (the longshore transport model) for the simulation of longshore sediment transport. Comprehensive studies were undertaken of longshore transport formulae and data. These studies form the basis of this model.

ASPECTS REGARDING THE CALCULATION OF LONGSHORE TRANSPORT

Longshore transport formulae can be classified as either bulk or detailed formulae (Swart & Fleming 1980). For the bulk formulae, a single longshore transport rate is obtained for each wave condition. This means that all the sand (total load) that is moved per time parallel to the coastline at different depths past a line perpendicular to the beach (the location) is estimated. Although it is known that more sand is transported in the surf zone than outside it, no information about the distribution of the transport is given by bulk formulae. Detailed formulae (or predictors) provide information on the transport rate at different depths at each location. The local longshore transport rate is the transport rate at the particular depth. Each of these local transport rates is multiplied by the cross-shore (horizontal) distance that it represents to obtain the local transport product. These local transport products are then added up to acquire the total (integrated) transport rate at the specific location (or line perpendicular to the beach). By dividing the local transport product at each depth by the total transport rate, the so-called cross-shore distribution of the longshore transport is obtained. Normally a depth increment is chosen and calculations are done at depths which are multiples of this depth increment. These calculations usually involve the determination of the dimensions of bed forms (if any), the local bed roughness, the local shear stress on the bed, the local longshore current velocity, and the local longshore transport rate (s_i where i is the number of the point on the line perpendicular to the beach). The longshore (or total) transport rate is then acquired by integration normal to the shore, as described above. This rate can then be compared to the answers obtained with bulk formulae.

For southern African conditions, the net longshore transport rate typically varies between 100 000 m^3/year and 1 million m^3/year. Usually, longshore sediment transport occurs mainly in the vicinity of the surf zone, namely in water depths that vary from 0 m to 10 m (especially inside the surf zone) or up to depths of about 2 to 3 times the significant breaker height.

If at all possible, the transport rates computed in the study area should be compared with transport rates measured nearby; for example, accretion at an adjacent harbour as proposed by US Army, Corps of Engineers (1984). It is even better to calibrate the prediction method(s) with data at the same site, as was done by Laubscher *et al* (1991) and Coppoolse and Schoonees (1991). Where no measurements are available it is customary to calculate the longshore transport regime at a number of locations in the study area and to compare the transport pattern with trends obtained from beach surveys and aerial photographs. For example, if the net longshore transport increases from one location to the next and the direction remains the same, it means that erosion has to take place between the two locations in order to achieve a larger longshore transport rate. This erosion is usually either revealed as a retreating coastline or a denuded rocky beach. Schoonees and Barwell (1991) applied such an approach in analysing beach erosion at Waenhuiskrans.

Although numerous formulae which have been developed over the last sixty years, are available to compute longshore transport rates, experience has shown that predictions from different formulae can easily vary by orders of magnitude. This causes a problem for the design engineer, who usually requires an accurate assessment of the average annual longshore transport rates (including the upcoast, downcoast, net and gross transport rates) at a site. The engineer is faced with the following questions:

- Which formulae give the most accurate answers?
- Do the formulae have sound theoretical bases?
- Have the formulae been calibrated against a wide range of data, or for conditions similar to those at the particular site?
- How accurate are these calibration data?
- What is the most cost-effective way of obtaining the true long-term net longshore transport rate at the site?

These questions have been addressed in Schoonees (2001). Based on the findings of this study, a software package has been developed by programming the best formulae for computing the longshore transport. This software package is called a longshore transport model in this paper. As discussed below, the longshore transport model simulates wave transformation from deep to shallow water, water levels, bed roughness, and longshore current velocity and combines these with the longshore transport formulae.

Like any model, the longshore transport model should only be used for the applications for which it has been designed. Certain aspects need to be considered before the longshore transport model is applied:

- One important aspect in studying longshore transport at a site is the effect of rocky areas (Schoonees 2001). It has been assumed that no rocky areas are present and that an average annual long-term wave climate is known. It should be noted here that a sandy bed under wave action might change in form (profile) and develop different bed forms such as ripples and dunes, thereby also limiting the magnitude of sediment transport. This effect is taken into account in the longshore transport model.
- Only particulate (non-cohesive) sediment has been considered. The sediment is sand, that is, between about 0,100 mm and 1 mm. Guidance can also be obtained on the prediction of longshore transport of coarse material (pebbles and shingle) in terms of the applied wave power approach (Schoonees 2001).
- It has been assumed that wave action and wave-generated longshore currents dominate, as is predominantly the case around the southern African coastline. Currents not generated by waves can, however, be incorporated in the model.
- The purpose of the longshore transport model is also to predict the time-averaged longshore transport rate per wave condition and not to consider short-term (inter-wave period) fluctuations in the transport.

MODEL BASIS

To evaluate the accuracy of longshore sediment transport formulae, it is necessary to collect longshore transport data and test the predictions of the formulae against the measured longshore transport rates. The results of studies addressing the accuracy of the data and formulae are contained in Schoonees and Theron (1993, 1994, 1996) and in Schoonees (2001), on which this section is mainly based.

A comprehensive database has been compiled containing field data on longshore transport rates. Virtually all conditions encountered on natural beaches are covered as the data were collected on beaches from many different sites around the world. Specific conditions were identified for which data still need to be collected. A point rating system was devised and applied to evaluate objectively the quality of the available data.

Other authors have previously tested only a small number of longshore transport formulae against limited data. In the above studies (eg Schoonees 2001), virtually all (51) existing longshore transport formulae and a new method based on the applied wave power approach (= 52 formulae) have been tested against the comprehensive database. Of the four different measures used, two were found to be the best by which to judge the accuracy of a formula. These are (i) the plot of predicted transport rates versus the measured rate, combined with (ii) the standard error of estimate.

The Kamphuis formula (Kamphuis 1991), which is a bulk predictor derived by means of dimensional analysis, was found to perform the best of the 52 longshore transport formulae tested. This formula, which performed well over the full range of the data, was recalibrated and slightly improved (Schoonees 2001). Confidence intervals have been derived for the recalibrated Kamphuis formula (Schoonees 2001).

The Van Hijum, Pilarczyk and Chadwick formula (Chadwick 1989) and the Van der Meer (1990) formula were found to be the second and third best longshore transport formulae respectively. The Van Hijum, Pilarczyk and Chadwick formula is based mainly on the results of physical model tests. Van der Meer (1990) used energy flux (energetics) considerations (US Army, Corps of Engineers 1984) and combined them with the approach followed by Van Hijum, Pilarczyk and Chadwick.

It was found that the Engelund, Hansen and Swart method (EHS) (Swart & Fleming 1980) is the second most accurate of the detailed predictors. This method was derived from an energy balance: the energy required to elevate sediment over the bed-form height was assumed to be equal to the work done by the drag forces on the sediment. Schoonees (2001) developed a theory for the prediction of the longshore transport in terms of the applied wave power approach, based on the principles of wave phenomena such as breaking. This approach resulted in a detailed predictor that accounts for the different processes inside and outside the surf zone. The applied wave power approach has been successfully calibrated against the comprehensive database and was found to be the best detailed longshore transport predictor, and overall the fourth best transport predictor of the 52 formulae tested.

It is customary to use more than one prediction method and then compare their predictions. Different package deal approaches (eg using the mean or median of the predictions of the five best longshore transport formulae) were also investigated (Schoonees 2001). It was found that none of the package deal approaches consistently yield better answers than the best formula (the Kamphuis method).

An investigation (Schoonees 2000, 2001) into the annual variation in the net longshore transport rates at a site showed that, for exposed sites, those measurements of the longshore transport rates should be conducted continuously for 5 years to 8 years in order to obtain an accurate value (within 10%) of the true long-term mean net longshore transport rate. A table was compiled (Schoonees 2000) to estimate the range in which the true long-term mean net transport rate will fall for a given confidence band if measurements were done over a shorter period than the recommended 5 years to 8 years.

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 (the recalibrated Kamphuis formula) for the particular site, and predicting the transport rates using a representative wave climate (Schoonees 2001).

LONGSHORE SEDIMENT TRANSPORT MODEL

Model composition

The longshore transport model applies the best three bulk longshore sediment transport models: the Kamphuis formula; the Van Hijum, Pilarczyk and Chadwick formula, and the Van der Meer formula, as well as the two best detailed predictors: the applied wave power approach and the Engelund, Hansen and Swart formula.

Figure 2, which is a flow diagram, shows the layout of the model. As can be seen from this figure, the bulk longshore transport is directly computed from the input data for each wave condition, using in turn, the three best longshore transport predictors.

For the two detailed predictors, the following parameters are calculated at each still-water depth (figure 2):

- distance from the still-water shoreline (x)
- ratio x/x_b where x_b is the surf zone width
- water depth, incorporating wave set-up and set-down, which differs from the still-water depth (the effect of tides on water levels can be easily incorporated)
- local significant wave height using the Dally *et al* (1985) method
- dimensions of the bed forms (if any), bed roughness (taking into account the grain roughness, bed-form roughness and sheet flow, if present) and the wave friction factor by using the Van Rijn (1989) method
- bed shear stress and bottom shear velocity
- local longshore current velocity with the Swart and Fleming (1980) and other methods
- local longshore transport rate (s_i)

The local longshore transport rates are then integrated across the surf zone and beyond (up to three times the width of the surf zone) to obtain the total longshore transport for the particular wave condition. This integration enables the model to compute, for each of the two detailed predictors, the ratio at each depth of the local longshore transport divided by the total longshore transport rate for the particular wave condition. These ratios, for all the water depths, give the distribution of the longshore transport normal to the shore for the particular wave condition and for each detailed predictor.

For each detailed predictor, two weighted mean longshore transport distributions normal to the shore are calculated: (1) for all the upcoast transport rates combined, and (2) for all the downcoast transport rates combined. These distributions are of benefit in the design of, for example, coastal structures, as is shown below. For example, the calculation for all upcoast transport rates is as follows: at each depth, the ratio of s_i/ total transport for each upcoast wave condition is weighted according to the frequency of occurrence of the particular wave condition. Then the weighted mean ratio at the particular water depth is calculated. The process is repeated for downcoast transport and for both detailed predictors. These weighted mean longshore transport distributions are also added to obtain the accumulated ratio, which indicates what fraction of the total longshore transport occurs in depths smaller or equal to the depth up to which the ratio has been accumulated.

The model then adds the transport rates for all the wave conditions to determine the upcoast, downcoast, gross and net transport rates at the particular site (usually for a year). In addition, the Galvin (1972) method, which was recalibrated and improved, provides an independent, quick and easy estimate of the gross longshore transport rate at the site. This method requires only the mean annual significant breaker height at the site, the median sediment grain size and the coverage of the wave data.

Input

The following general input parameters are required for the longshore transport model: identification of the site (for example, location, date and number of the run), the grain size distribution of the sediment (D_{35}, D_{50} and D_{90}; where D_i is the grain size that exceeds i% of the sample by mass, with i being equal to 35%, 50% and 90%), the average slope of the beach

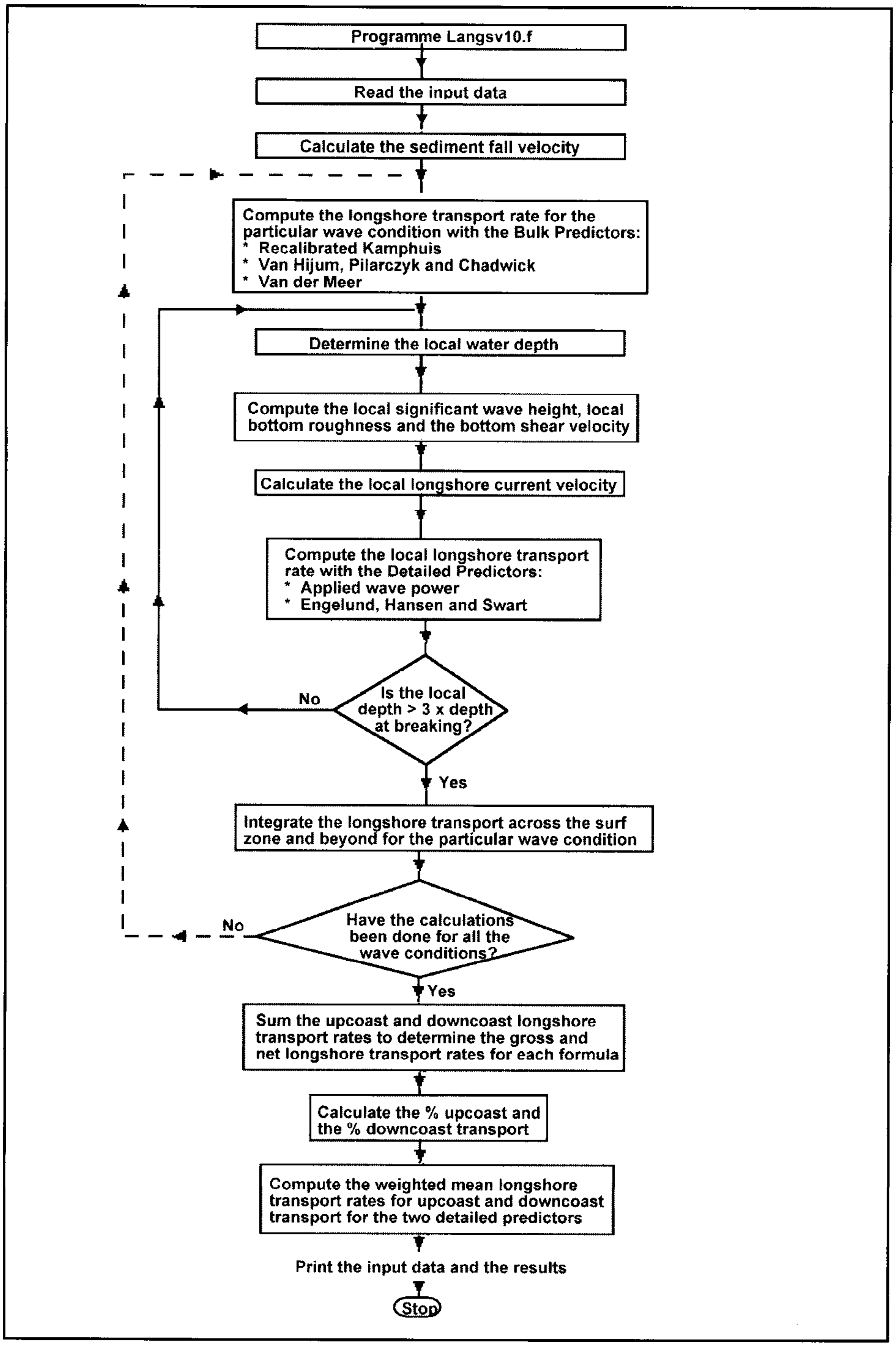

Figure 2 Flow diagram of the longshore transport model

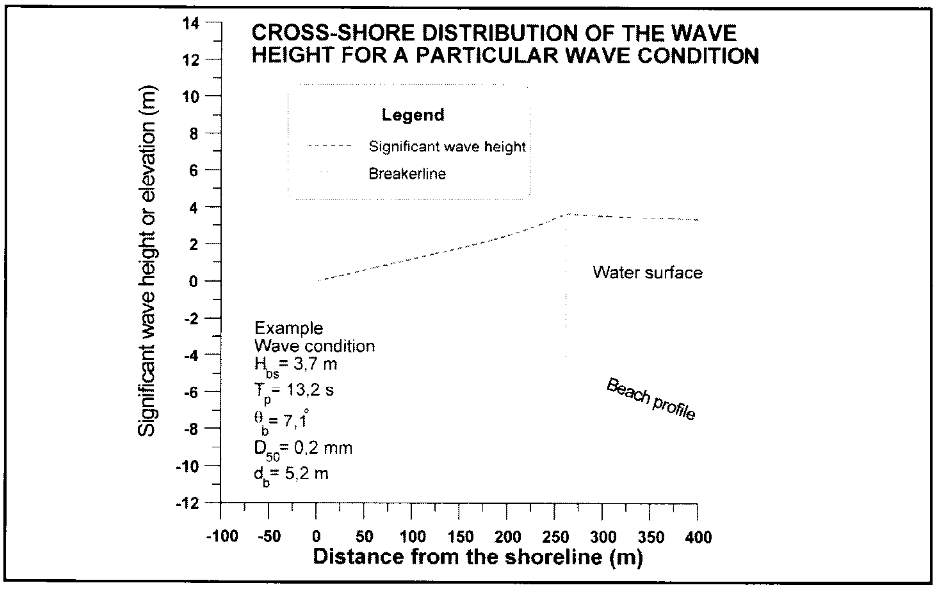

Figure 3 Cross-shore variation of the significant wave height

profile through the surf zone or the beach profile itself, and the number of wave conditions. For each wave condition it is necessary to supply the peak wave period (T_p), the zero up-crossing (significant) wave period (T_z), the significant breaker height (H_{bs}), the wave incidence angle at the breakerline (θ_b) and the frequency of occurrence of the wave condition.

Output

The model writes to output files both the general input data and the information supplied on each wave condition. In this way, it can be checked that the correct input has been used.

Simulation of wave transformation and water levels is also carried out. Figure 3 shows the cross-shore variation of the significant wave height for a specific example. It can be seen from this figure that there is a small increase in the wave height as the wave approaches the breakerline near the shore; thereafter wave breaking causes a sudden decrease in the wave height as the wave propagates towards the shore.

Figure 4 illustrates the distribution of the longshore transport perpendicular to the shoreline for a particular wave condition for each of the two detailed predictors. It can be seen that there is a difference in the distribution of the longshore transport predicted by the two methods. The Engelund, Hansen and Swart method predicts a gradual change from the surf zone to deeper water. The applied wave power approach predicts a rapid change from inside the surf zone to outside the surf zone. Measurements have clearly shown that there is a rapid change from inside to outside the surf zone because of the dominant effect of wave breaking inside the surf zone. The double peak predicted by the applied wave power approach has also been confirmed by measurements; it is well known that the major peak of sediment transport occurs just landwards of the breakerline and that, in many cases, a minor peak is found near the shoreline, as shown in figure 4. (Clearly, the shape of the beach and nearshore profile also influence the occurrence and magnitude of these peaks.) In this case (figure 4), the Engelund, Hansen and Swart method predicts that a more significant part of the longshore sediment transport will occur in deeper water (8 m to 11 m) compared with the results of the applied wave power approach.

The results of the five different longshore transport formulae compiled for all the wave conditions combined, are written to output files in tabular form. Table 1 presents the results for a realistic, yet hypothetical example. (Comparisons with measured data for South African sites are presented in the 'Applications' section.) From this table it can be seen that the upcoast transport, downcoast transport, gross transport and net transport are listed. In addition, the percentage of the

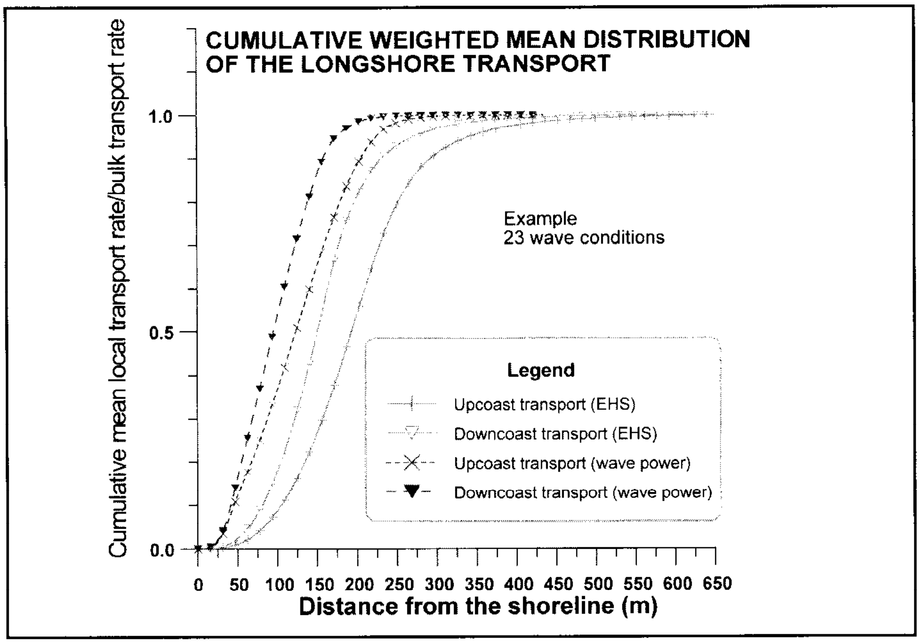

Figure 6 Cumulative weighted mean transport distributions

transport. Clearly, this is applicable only for the wave conditions modelled. This information is very important in simulating the shoreline evolution in the vicinity of a groyne or breakwater by means of one-line modelling. The percentage transport that will be trapped by a groyne or breakwater has a profound influence on the accretion updrift and erosion downdrift of the structure. The percentage of transport bypassing a breakwater is also important for estimating what volume of sediment will have to be dredged in the harbour entrance channel adjacent to the breakwater.

The weighted mean distributions of longshore transport (upcoast and downcoast) are also required for the design of *fixed* sand bypassing schemes at harbours. For these schemes, a jetty is normally constructed perpendicular to the shore, from which sand pumps (either jet or submersible pumps) are deployed (Coppoolse & Schoonees 1992; CSIR 1992). Usually all the longshore transport should be bypassed; that is, extracted from the surf zone and pumped to the downdrift side of the port. This is to ensure that the sand will not be deposited in the entrance channel of the harbour and also to prevent downdrift beach erosion. To bypass all the longshore transport, it is imperative to know how long this jetty must be (and what the capacity of the pumps should be). The weighted mean longshore transport distributions provide this information.

The longshore transport model also has applications in the three-dimensional (3D) modelling of coastal morphology (ie the prediction of changes in seabed levels over time). By integrating the longshore sediment transport rates predicted across the surf zone and beyond with such a 3D model (eg the Delft3D-MOR model being used by the CSIR), the 3D model can be calibrated against the results of the longshore transport model. For such sophisticated modelling, it is required to schematise the number of wave conditions to be run in the 3D model; that is, a limited number of waves must typically represent an annual wave climate so that the predicted morphology will be correct. In a further application of the longshore transport model, the full wave climate (all the wave conditions) and the schematised wave conditions are run with the model in order to ascertain that the longshore sediment transport rates are correctly represented.

CONCLUSIONS

A software package (the longshore sediment transport model) has been developed, which has a sound theoretical basis (Schoonees 2001). The model has been calibrated and verified against a wide range of conditions (Schoonees & Theron 1993, 1994 and 1996; and Schoonees 2001). These conditions include virtually all the conditions that are encountered on natural beaches around the world. Like any model, the longshore transport model should be used only for the applications for which it has been designed. The model is robust and efficient to run.

Apart from giving the total longshore sediment transport rate for each wave condition at a particular site, the model also provides information on the cross-shore distributions of the wave height (eg through the surf zone), the mean water level, and the longshore transport. In addition, the longshore transport climate at the site is summarised, namely, the upcoast, downcoast, gross and net transport rates. The weighted mean longshore transport distributions for both upcoast and downcoast transport supply valuable information necessary for the design of groynes, breakwaters and sand bypassing systems at ports. The results of the model can also be used to calibrate 3D morphological models and to schematise wave conditions for morphological models.

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References

Chadwick, A J 1989. Field measurements and numerical model verification of coastal shingle transport. In Palmer, M H (ed), *Advances in water modelling and measurement.* BHRA, Cranfield, Bedford.

Coppoolse, R C & Schoonees, J S 1991. Maintenance dredging at Richards Bay: sensitivity analysis of predictive models and the location of an offshore dump site. In *CEDA-PIANC Conference, Amsterdam.*

Coppoolse, R C & Schoonees, J S 1992. Evaluation of modern dredging/sand bypassing techniques applicable for South African conditions. CSIR Report EMAS-I 92018, Stellenbosch.

CSIR 1992. Alternative sand by-passing methods for the port of Durban: a preliminary investigation. CSIR Report EMAS-C 92008.

Dally, W R, Dean, R G & Dalrymple, R A 1985. Wave height variation across beaches of arbitrary profile. *J of Geophysical Res,* 90(C6):11917-11927.

Galvin, C J (Jr) 1972. A gross longshore transport rate formula. *13 Intern Conf on Coastal Eng,* ASCE, Vancouver, vol 2:953–970.

Kamphuis, J W 1991. Alongshore sediment transport rate. *J Waterway, Port, Coastal and Ocean Eng,* ASCE, 117(6):624–640.

Laubscher, W I, Coppoolse, R C, Schoonees, J S & Swart, D H 1991. A calibrated longshore transport model for Richards Bay. *Proc of Coastal Sediments* '91. ASCE, Seattle, 1:197–211.

Mocke, G P, Luger, S A, Schoonees, J S, Smit, F & Theron, A K 1996. The effects of proposed dredging activities on turbidity levels and shoreline stability in Saldanha Bay. Specialist Study Report S3. In Environmental impact assessment of the proposed changes to the oil transfer operations, Saldanha Bay. Volume 2: Specialist studies report. CSIR Report EMAS-C 96005D, Stellenbosch.

Schoonees, J S 2000. Annual variation in the net longshore sediment transport rate. *Coastal Eng,* 40(2):141–160.

Schoonees, J S 2001. Longshore sediment transport: applied wave power approach, field data analysis and evaluation of the formulae. PhD thesis, University of Stellenbosch, Stellenbosch.

Schoonees, J S & Barwell, L 1991. Waenhuiskrans: sediment budget and reactivation of a sediment pathway. *Coastal Sediments '91,* ASCE, Seattle, Washington, 2:2277–2291.

Schoonees, J S & Theron, A K 1993. Review of the field-data base for longshore sediment transport. *Coastal Eng,* 19:1–25.

Schoonees, J S & Theron, A K 1994. Accuracy and applicability of the SPM longshore transport formula. *24 Intern Conf on Coastal Eng,* ASCE, Kobe, 3:2595–2609.

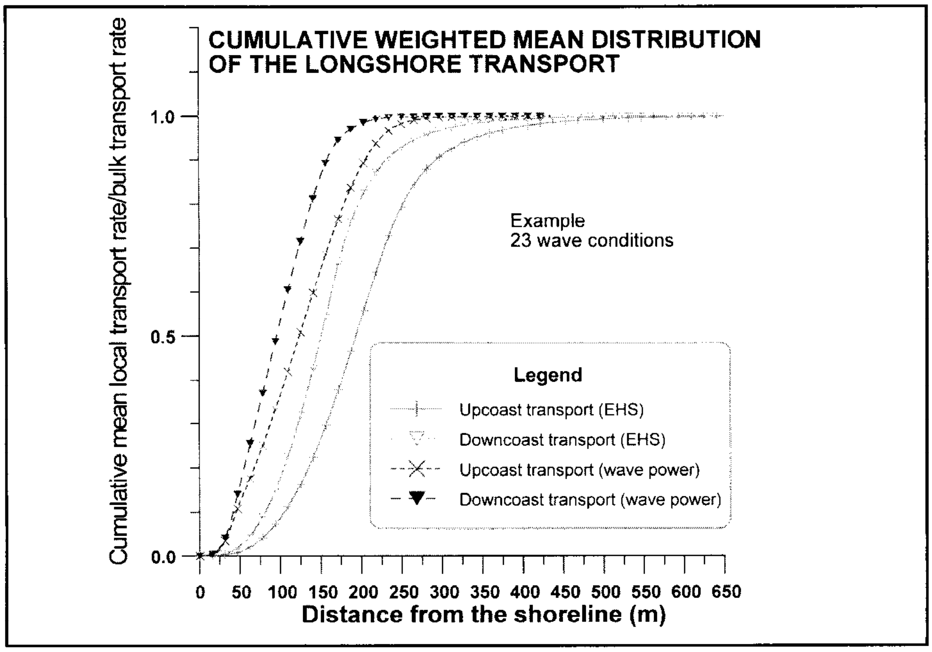
Schoonees, J S & Theron, A K 1996. Improvement of the most accurate longshore transport formula. *25 Intern Conf on Coastal Eng,* ASCE, Orlando, Florida, 3:3652–3665.

Swart, D H & Fleming, C A 1980. Longshore water and sediment movement. *17 Intern Conf on Coastal Eng,* ASCE, Sydney, 2:1275–1294.

US Army, Corps of Engineers 1984. *Shore protection manual,* Volumes I and II, Coastal Engineering Research Center, Vicksburg.

Van der Meer, J W 1990. Static and dynamic stability of loose materials. In Pilarczyk, K W (ed), *Coastal protection.* Rotterdam: Balkema.

Van Rijn, L C 1989. *Handbook: sediment transport by currents and waves.* Report H461, Delft Hydraulics Laboratory, Delft.



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References

Chadwick, A J 1989. Field measurements and numerical model verification of coastal shingle transport. In Palmer, M H (ed), *Advances in water modelling and measurement.* BHRA, Cranfield, Bedford.

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CSIR 1992. Alternative sand by-passing methods for the port of Durban: a preliminary investigation. CSIR Report EMAS-C 92008.

Dally, W R, Dean, R G & Dalrymple, R A 1985. Wave height variation across beaches of arbitrary profile. *J of Geophysical Res,* 90(C6):11917-11927.

Galvin, C J (Jr) 1972. A gross longshore transport rate formula. *13 Intern Conf on Coastal Eng,* ASCE, Vancouver, vol 2:953–970.

Kamphuis, J W 1991. Alongshore sediment transport rate. *J Waterway, Port, Coastal and Ocean Eng,* ASCE, 117(6):624–640.

Laubscher, W I, Coppoolse, R C, Schoonees, J S & Swart, D H 1991. A calibrated longshore transport model for Richards Bay. *Proc of Coastal Sediments* '91. ASCE, Seattle, 1:197–211.

Mocke, G P, Luger, S A, Schoonees, J S, Smit, F & Theron, A K 1996. The effects of proposed dredging activities on turbidity levels and shoreline stability in Saldanha Bay. Specialist Study Report S3. In Environmental impact assessment of the proposed changes to the oil transfer operations, Saldanha Bay. Volume 2: Specialist studies report. CSIR Report EMAS-C 96005D, Stellenbosch.

Schoonees, J S 2000. Annual variation in the net longshore sediment transport rate. *Coastal Eng,* 40(2):141–160.

Schoonees, J S 2001. Longshore sediment transport: applied wave power approach, field data analysis and evaluation of the formulae. PhD thesis, University of Stellenbosch, Stellenbosch.

Schoonees, J S & Barwell, L 1991. Waenhuiskrans: sediment budget and reactivation of a sediment pathway. *Coastal Sediments '91,* ASCE, Seattle, Washington, 2:2277–2291.

Schoonees, J S & Theron, A K 1993. Review of the field-data base for longshore sediment transport. *Coastal Eng,* 19:1–25.

Schoonees, J S & Theron, A K 1994. Accuracy and applicability of the SPM longshore transport formula. *24 Intern Conf on Coastal Eng,* ASCE, Kobe, 3:2595–2609.

Schoonees, J S & Theron, A K 1996. Improvement of the most accurate longshore transport formula. *25 Intern Conf on Coastal Eng,* ASCE, Orlando, Florida, 3:3652–3665.

Swart, D H & Fleming, C A 1980. Longshore water and sediment movement. *17 Intern Conf on Coastal Eng,* ASCE, Sydney, 2:1275–1294.

US Army, Corps of Engineers 1984. *Shore protection manual,* Volumes I and II, Coastal Engineering Research Center, Vicksburg.

Van der Meer, J W 1990. Static and dynamic stability of loose materials. In Pilarczyk, K W (ed), *Coastal protection.* Rotterdam: Balkema.

Van Rijn, L C 1989. *Handbook: sediment transport by currents and waves.* Report H461, Delft Hydraulics Laboratory, Delft.