CHAPTER 83

Evaluation of Models of Nearshore Processes

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Summary

The Canadian Coastal Sediment Study, known as C2S2, included numerous activities related to improving the measurement and prediction of sand transport in the nearshore zone. The data was used to evaluate a number of predictive techniques commonly used for coastal zone modelling for both alongshore and onshore/offshore sediment transport modelling. Field experiments were carried out at two sites. This paper is concerned with the first of these sites at Pointe Sapin, New Brunswick. Computed transport rates were compared with volumes of sand that accumulated in a sand trap formed by an offshore breakwater upstream of the mouth of Pointe Sapin harbour. The predictive techniques used were a parametric wave hindcasting model, a spectral wave refraction model, alongshore current predictors, seven of which rely on computed alongshore current distributions.

1 INTRODUCTION

The Canadian Coastal Sediment Study was a multi-departmentally sponsored research programme aimed at improving the knowledge of sand transport on beaches. The original objectives of the study were to develop instrumentation for measuring instantaneous rates of nearshore sand transport, to evaluate existing methods of measuring and predicting nearshore transport, to sponsor co-operative field studies and to encourage the development of new and improved nearshore transport predictors. The authors were contracted to carry out engineering predictions of waves, wave-generated currents and nearshore sediment transport of two sites: Pointe Sapin, New Brunswick and Pointe Deroche, Prince Edward Island. In addition they were contracted to compare these predictions to measurements made at Pointe Sapin between September and November 1983. This whole exercise implicitly involved the extensive application of numerical modelling of nearshore processes including wave hindcasting, wave induced currents and prediction of both alongshore and onshore/offshore sediment transport.

Pointe Sapin, New Brunswick is located at the northern entrance to the Northumberland Strait and that section of the coastline generally faces south-east. The site is exposed to waves generated in the Gulf of St Lawrence (See Figure 1) and is sheltered approximately from east to south by Prince Edward Island. Thus, the wave climate is dominated by waves approaching from the northeast quandrant. The beach at

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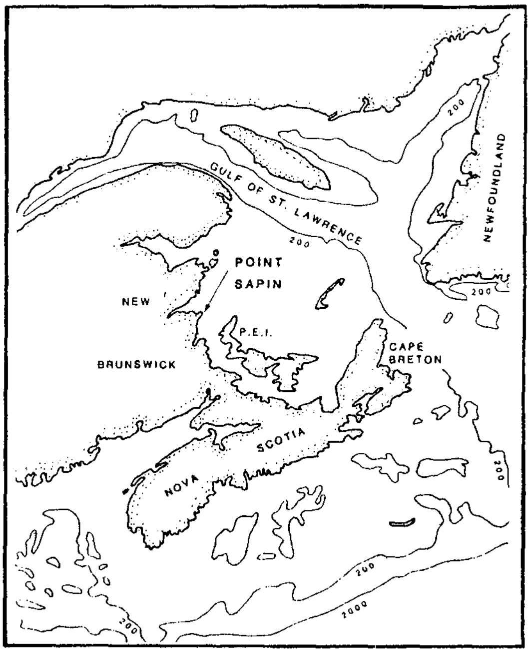

Figure 1: Location of Pointe Sapin

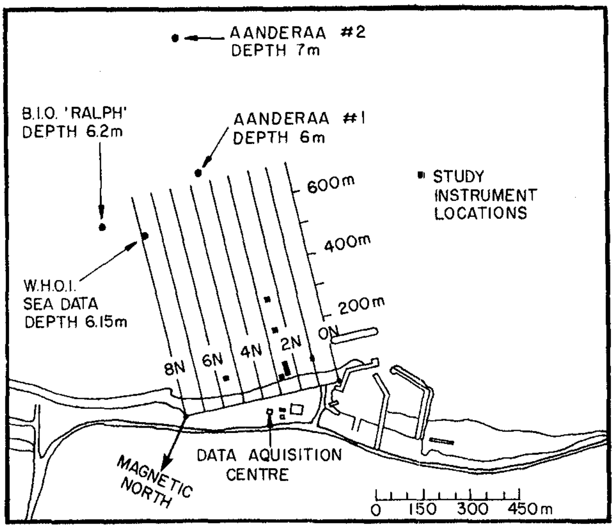

Figure 2: Survey Lines and Instrument Positions

Pointe Sapin is a wedge shaped body of sand between 2 and 3 metres thick on the backshore thinning to nothing between 60 and 75 metres offshore. Thus, the beach overlies a wide rock shelf which is composed of reddish-brown siltstone. The offshore bedrock is covered by a thin layer of gravelly sands. The sediments in the littoral zone are predominantly fine sand sized particles which are well sorted with a mean diameter between 0.18 and 0.25mm. Local deposits of pebbles do occur.

There is a small fishing harbour at Pointe Sapin which has suffered quite severe sedimentation problems in the past. As a result an offshore breakwater was constructed to act as a sand trap and this has been effective in significantly reducing the siltation problem. The offshore breakwater, the layout of which is shown in Figure 2, lies approximately 100 m off the main breakwater of the fishing harbour. It has been estimated that in an average year at least 60% of the littoral drift should be caught in the sand trap. The existence of the sand trap on the south side of the study site was one of the factors that led to the selection of this site. The mean tide range at the site is 0.9 metres and the tidal currents run reversing parallel to the coast with speeds generally less than 0.1 metre/sec.

2 FIELD MEASUREMENTS

The field programme at Pointe Sapin was carried out during the latter part of 1983. Many measurements were made, including offshore wave measurements 8.3km west of the site in 16.5m depth of water (Skafel, 1984), nearshore wave measurements (Aubrey and Spencer, 1984), nearshore current measurements and various sediment concentration devices all of which are summarised by Daniel, 1985.

In addition macro-scale experiments were carried out using a number of different types of bottom drifters as well as radioactive tracers. The sand trap was dredged clear immediately prior to the experiment and profile surveys of the sand trap area and adjacent beaches were carried out at regular intervals throughout the experiment period (Gillie, 1984 a).

3 PREDICTIVE TECHNIQUES

3.1 Wind Hindcasting

A parametric wave hindcasting model was used which included options to use four difference hindcasting models; SMB deep water, SMB shallow water, Derbyshire-Draper and JONSWAP. The wind data required is a time series of wind speed and direction, adjusted if necessary to a standard elevation above mean sea level. For each forward step of the hindcast an effective wave, defined by height, period and direction, is the resultant hindcast wave composed of a generated and a decayed wave train. The larger of the two components was treated as dominant in defining the wave period and direction.

The effective wave for each timestep was computed by examining the wind data and dominant wave conditions for a preceding duration time equal to the selected maximum wave generation sequence. Thus, by backstepping through the data from the current record every combination of wind speed and duration is examined up to a limiting condition, in this case 2 days, or to a point where the wind direction differs from the average of the preceding sequence by an amount exceeding a defined wave divergence angle eg 22.5 or 45 degrees. The wave decay sequence was initiated either when a calm was encountered or when the wave divergence angle was exceeded. A number of wave decay functions were considered. (See Fleming et al, 1984)

3.2 Wave Transformations

The two principal components of the computational procedure are a wave refraction model and a post-processor that calculates the specteal transfer functions which in turn provide wave height coefficients and direction shifts from deep water to a shallow water point of interest.

The wave refraction model used was based on the highly efficient 'circular arc' technique allowing the high ray density backtracking for several frequencies from each point of interest to be carried out. The seabed was defined by ten digitized depth grids which varied in both overall dimensions and mesh size according to the water depth and proximity to the field investigation site.

The process of refracting a wave spectrum is based on the assumption that the wave energy flux in a frequency band will remain in that band as each component of the wave spectrum is transferred inshore. It is thus possible to discretise a deepwater directional wave spectrum and independently transfer it inshore applying appropriate shoaling coefficients. In this case the JONSWAP model was used. Its applicability to this site was verified by matching computed spectra with offshore spectra measured in 1982 (Fleming et al, 1984).

The direct application of this procedure to the offshore wave measurements led to a substantial over-estimation of inshore wave heights during one of the storms. This led to an investigation into energy dissipation mechanisms and as a result wave spectrum saturation for shallow water were incorporated into the wave spectrum transformation procedure. The shallow water equilibrium spectrum theories used were due to Kitaigorodskii et al, 1975 and Bouws et al, 1981. Comparative results are presented in Section 4.

3.3 Nearshore Sediment Transport

The inshore wave climate defined by the above procedure allowed calculation of alongshore sediment transport rates for the same breaker line, surf zone geometry and hence, alongshore current distribution for up to ten sediment transport models.

A complete description of the theories underlying the models used in these studies has been given (Fleming et al, 1984). This was based on an earlier publication (Fleming and Swart, 1982) in which the theory proposed by Longuet-Higgins was adapted to allow for contribution to the shear term by the longshore current itself and to rationalise the variation of friction coefficient as a function of beach slope and both wave and current friction factors. A similar treatment was carried out based on Battjes (1974) theoretical approach. This is comparable to Longuet-Higgins approach for regular waves, but considers linear random waves together with the same momentum balance equation.

The friction factor for alongshore currents has been based on roughness length and it is this parameter that is most open to debate. In the absence of bed forms there are a number of different estimates for grain roughness and the one considered in this study has been proposed by Kamphuis (1975) as 2D90 (2D90 refers to the grain size for which 90% of the sediment distribution by weight is smaller). In the presence of ripples the roughness length may simply be taken as some multiple of the ripple height or the expression proposed by Swart (1976a) which includes both the ripple height and the ripple steepness. Whilst this formulation has relatively little data to confirm its validity it seems to have gained quite wide acceptance for lack of any more substantiated work. However, having adopted that expression the problem then shifts to applying a ripple height and length predictor.

Three different ripple models have been considered in this study. They are due to Mogridge and Kamphuis (1972), Swart (1976a) and Nielsen (1978). All three models may be used to determine both ripple height and ripple length as a function of local water depths, wave height, wave period, sediment size and relative density of the material. The formulations are essentially empirical and primarily based on physical models together with some limited field data.

The computational procedures were as follows:

i) The beach profile was divided into a number of representative sections of variable size.

ii) The inshore wave conditions were used to find the breaker position and corresponding properties. These were used in the bulk predictors.

iii) The mean wave height was calculated according to a Rayleigh probability function. The mean wave height was found by integrating the distribution truncated by the maximum possible wave.

iv) Wave and sediment characteristics were used to calculate ripple dimensions. This in turn provided data for the hydraulic bed roughness to be evaluated.

v) The wave and current parameters were used to calculate the alongshore current distribution across the profile.

vi) Wave properties, currents and the various coefficients calculated were used to determine bed shear stresses which in turn are used to drive some of the detailed prediction models.

vii) Each wave condition was taken in turn and running totals of gross and net transport and relative distribution kept as a running total.

Both bulk energy sediment transport predictors as well as detailed predictors were applied as outlined in Table 1.

	MODEL	**GENERAL CLASSIFICATION**
1	CERC Formula (1977)	Bulk energy model
2	Davies and Kamphius (1985)	Bulk energy model, includes grain size and beach slope
3	Sayao et al (1985)	" " " " " " " "
4	Engelund and Hansen adaptation by Swart (1976)	Based on bed and suspended loan concentrations with a background current, no incipient motion criterion
5	Willis (1978)	Adaptation of Ackers and White (1973), includes an incipient motion criterion
6	van der Graaf and van Overeem (1979)	Adaptation of Ackers and White (1973), includes an incipient motion criterion
7	Nielsen (1979) (for breaking waves)	Based on bed and suspended load concentrations with a background current, includes an incipient motion criterion
8	Nielsen (1979) (for non-breaking waves)	Ditto
9	Fleming (1977)	Ditto
10	Swart (Fleming & Swart, 1982)	Adaptation of Ackers and White (1973), includes an incipient motion criterion derived from a wide range of wave and current conditions

Table 1: General Description of Alongshore Sediment Transport Predictors

4 COMPARISONS OF MEASUREMENTS WITH PREDICTIONS

4.1 Offshore Waves

Figure 3 shows three sets of hindcast and measure wave heights and periods between the 21st and 31st October 1983 for one of the storms that occurred during the experimental period. Set (A) used the SMB deep water parametric hindcast model. It is seen that the hindcast wave heights were in reasonably good agreement with the measurement with the exception of the peak of the storm when the predictions grossly exceeded measurements. The hindcast wave periods were generally in good agreement with measurements throughout the period shown. Set (B) used the

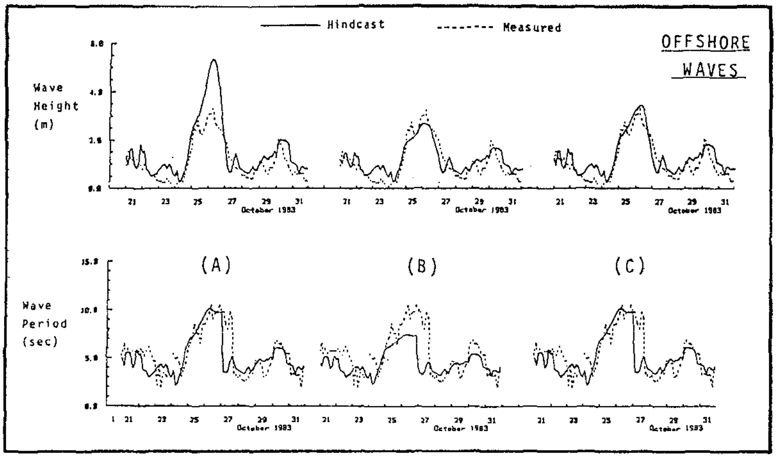

Figure 3: Hindcast and Measured Offshore Wave Data

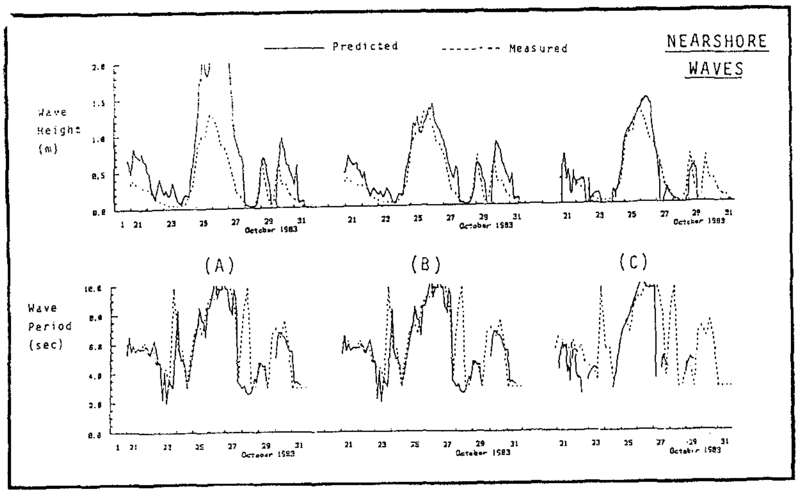

Figure 4: Hindcast and Measured Nearshore Wave Data

SMB shallow water parametric hindcast model. However, instead of using water depths characteristic of the entire fetch the water depth at the wave recording site (16m) has been used. it may be circumstantial, but the hindcast wave heights show much better agreement with measurements during the peak of the storm, but are little changed at other times. In contrast the hindcast wave periods became rather less than the measured particularly through the storm. At this point it might be noted that combination of SMB shallow for wave heights and SMB deep for wave periods would give a reasonably respectable result. The final set (C) was obtained by applying the SMB deep water hindcast model modified for spectral saturation which is a function of depth (Bouws et al, 1985). Here both the hindcast wave height and wave period show excellent agreement with measured values.

4.2 Nearshore Waves

The nearshore wave measurements were made in a little over 6 m mean water depth. Both deep water measured and hindcast wave sets were transferred to this shallow water site by applying the wave height coefficients and directions deduced from the spectral wave refraction model described in Section 3.2.

Figure 4 shows three sets of predicted and measured wave heights and periods between 21st and 31st October 1983 and can thus be compared directly with the previous figure. Set (A) represents the offshore measured waves transferred to shallow water by direct application of the spectral transfer results. It can be seen that the predicted wave heights were largely excessive by up to a factor of two for most of the record length, whilst the wave periods were in reasonably good agreement. Set (B) represents the offshore measured waves transferred to shallow water by application of spectral refraction results modified to include shallow water spectral saturation limits in each frequency band. Here it is seen that the predicted wave heights show excellent agreement with those measured. The wave periods remain largely un- changed and in good agreement with measured values. Set (C) represents the hindcast wave climate offshore which included saturation limits (ie Set (C) in Figure 3) transferred to the shallow water recording site by application of spectral refraction results modified to include shallow water spectral saturation limits as above. The agreement on wave height remains good but the wave period predictions appear to show a slight deterioration.

4.3 Alongshore Currents

The first storm during the experiment occurred between 24 October and 27 October 1983. Two of the current meter records were suitable, but not ideal, for testing purposes. The measured currents were on two profiles (1.0N and 2.5N) both at a baseline offset of 86 m (see Figure 2). The points lie seawards of the point of maximum alongshore current velocity and there was no information with regard to distribution of current velocity across the profile.

Tests were carried out in a sequence that represents a progression from the simplest assumptions to those which incorporate all the relevant parameters. Only one example of the numerous test is given in Figure 5. In this case the match during the first half of the storm was quite good with the Battjes model. However, none of the model runs managed to predict the large currents at the two separate instruments during the latter part of the first storm. It seems apparent that currents measured after hour 50 were not wave induced and if it possible that this might be the case from as early as hour 25. Other types of currents might be wind-induced, tidal currents and large-scale ocean circulation.

While a quantitative assessment of the contribution of wind stress to longshore currents was not performed, an examination of wind velocities precluded this possibility. Tidal currents at Pointe Sapin are generally less then 0.1 m/sec (Gillie, 1985) and consequently could not have a significant influence on measured values. Large scale circulations were also ruled out as currents of a similar magnitude were not measured at the nearshore wave recorder site in 6 m of water. it was finally concluded that there was most likely some data logger error.

The second storm occurred between 4 and 7 November. In this case the results from two current meters on line 2.5 N at baseline offsets of 71 m and 86 m were compared to predicted results. The wave heights for this storm were rather less so that the measurements were even further down the tail of the cross shore distribution. An example of one of the predictions compared to measurement is shown in Figure 6.

4.4 Alongshore Sand Transport

The volume of sand transported during the two storms that occurred during the experimental period have been estimated by a number of investigators (Kooistra and Kamphuis, 1984, Morse, 1984 and Gillie, 1984) using both the profile surveys of the sand trap and adjacent beach as well as the radioactive sand tracer experiments. The estimate of net volume of sand transported during a particular event is dependent on whether only the sand trap itself is considered as the control volume or whether some part of the beach upstream of the sand trap should also be included. Considering the period of 22nd and 27th October estimated volumes vary from about 5000 cu m to nearly 11000 cu m. These figures do not account for efficiency of the sand trap. A reasonable estimate would increase the range to between 6500 m^3 to 13000 m^3 with an average magnitude of 10,000 m^3.

Less attention has been paid to the second storm which occurred betwen the 4th and 7th November 1983 and during which wave heights were not as large as for Storm 1. In this case estimates of volumes accumulated during the storm have varied between 2,000 m^3 (Gillie, 1984b), 2,600 m^3 $\pm$ 140 m^3 (Morse, 1984) and 3,100 m^3 (Kooistra and Kamphuis, 1984)

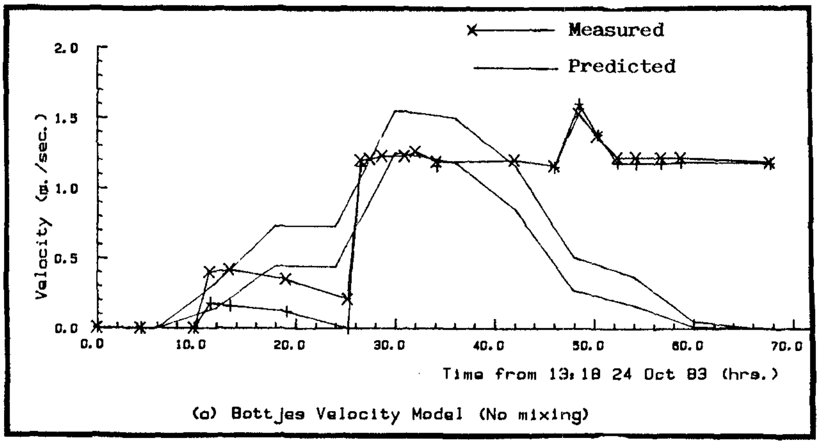

Figure 5: Predicted and Measured Alongshore Currents, Storm 1

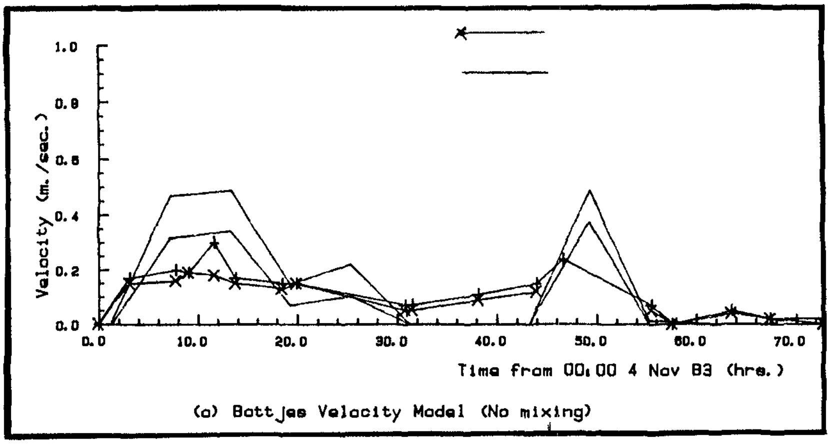

Figure 6: Predicted and Measured Alongshore Currents, Storm 2

A selection of the analyses that were carried out for each storm are given in Table 2. Many more variations and sensitivity tests and details can be found in the Pahse II report (Fleming et al, 1986). In the case of the second storm there were no deep water wave measurements.

Table 2: SELECTION OF ALONGSHORE SAND TRANSPORT PREDICTIONS

STORM 1 October 24 - October 27 1983

	1	2	3	4	5	6
CERC	149,600	63,400	32,610	49,720	27,480	27,480
Queens 1	111,700	31,620	17,630	24,100	24.740	27,740
Queens 2	9,470	26,700	15,100	20,700	21,560	21,560
Bijker	40,740	1,916	96	648	36	8,787
E & H	519,900	95,280	20,570	50,520	11,420	35,040
Willis	530,600	120,500	33,110	70,740	18,450	80,300
V de G et al	580,200	94,380	19,390	46,800	10,480	87,750
Neilson (br)	77,900	24,760	11,100	17,050	8,514	9,508
Neilson (N br)	65,380	18,110	6,609	11,580	4,335	9,589
Fleming	166,100	22,390	5,140	11,900	2,958	16,780
Swart	335,100	47,960	9,067	23,880	4,913	56.360

STORM 2 November 4 - November 7 1983

	1	3	5	6
CERC	6,972	3,749	19,690	19,690
Queens 1	3,162	1,806	15,270	15,560
Queens 2	3,628	2,053	13,500	10,390
Bijker	45	-	42	5,066
E & H	3,719	370	6,588	20,860
Willis	8,455	765	11,110	49,130
V de G et al	2,929	278	5,898	53,460
Neilson (br)	815	391	6,044	3,806
Neilson (N br)	623	132	2,886	5,765
Fleming	961	120	1,752	9,807
Swart	1,186	118	2,698	34,040

Note: All runs use Battjas type alongshore current velocity distribution, variable water level, variable slope and an average sediment grading. Wave climate and ripple models vary as follows:

1 Hindcast using deep water SMB model, refracted inshore without saturation limits, S/L ripple roughness.
2 Measured deep water waves, refracted inshore without saturation limits, S/L ripple roughness.
3 Hindcast using deep water SMB model, refracted inshore with saturation limits, S/L ripple roughness.
4 Measured deepwater waves, refracted inshore with saturation limits, S/L ripple roughness.
5 Measured inshore waves, Swart/Lenhoff ripple roughness.
6 Measured inshore wave, Neilsen ripple roughness.

4.4.1 Storm 1

Referring to Table 2, Run 1 used a hindcast deep water wave climate refracted inshore using standard spectral transfer techniques It has been shown that this will have overestimated the wave heights quite considerably and the estimated transport volumes were correspondingly excessive. Run 2 was similar but used the measured deep water wave climate and hence gave an improved estimate, but still in excess of measured volumes. Run 3 was similar to Run 1 except that spectral saturation was included in the wave transformation to shallow water. Here, the predicted volumes for two of the detailed predictors lie within the range of volumes estimated for measurements. Similarly Run 4 was similar to Run 1 and predicted volumes for three of the detailed predictors fall within the estimated range and in general values for all models were closest.

Run 5 used the measured inshore wave records and generally gave lower predictions than Run 4 due to slightly lower wave heights. All of these runs used the ripple predictor adopted by Swart (1976a). Run 6 is similar to Run 5 except that the Neilsen ripple predictor has been used. Three of the detailed predictors gave reasonable results but others gave quite large over estimates.

Assimilating all of the results from the Storm 1 tests there are a number of observations that can be made:

(i) The Battjes longshore current velocity model used in conjunction with the Fleming and Swart (1982) friction factor gave consistent results.

(ii) For the bulk predictors tested the Queen's 2 predictor gave the closest net volumes transported to those measured in the field in all cases tested but the estimates in these investigations were higher than those made by Kooistra and Kamphuis (1984) for the Queen's 1 model.

(iii) The Nielsen (breaking wave) sediment transport model was the most stable of all of the detailed predictors tested and gave results very close to the measured volume even when the input parameters are varied quite widely.

(iv) The use of different ripple models in conjunction with the Fleming and Swart (1982) friction factor formulation is not strictly valid and will result in higher current velocities for grain roughness or the Nielsen ripple model.

(v) The need to accurately define the nearshore wave climate cannot be over-emphasised, the sensitivity of all predictors having been clearly demonstrated. In the absence of nearshore wave measurements a good wave transformation model is clearly required. In the absence of offshore wave measurements the quality of the result obviously rests almost entirely on the quality of the offshore wave hindcast.

4.4.2 Storm 2

Again referring to Table 2, Run 1,3,5 and 6 were for identical combinations of input parameters as previously described for Storm 1. In this case the inclusion of spectral saturation in the wave transformation to shallow water resulted in an under-estimate of transported volumes for all except the bulk predictors. The 'best' results for the detailed predictors was given for Runs 5 and 6 which correspond to the measured nearshore wave data with different ripple models. However, the bulk predictors gave excessive values for these combinations.

The overall observations relating to Storm 2 results are:

(i) The offshore wave hindcast for Storm 2 did not predict the magnitude and duraction of the waves very well. Consequently both sets of predictions made on this basis significantly underestimate the net volume of sand transported for many of the detailed predictors.

(ii) The bulk predictors overestimated the net transport voumes for all combinations of variables tested except the offshore wave hindcast cases which were known to underestimate the wave conditions. The Queen's 2 predictor gave marginally better results than Queen's 1.

(iii) The results for the detailed predictors are generally much closer to the measured field volumes.

(iv) The Nielsen (breaking wave) model was again the most stable of the detailed predictors under all conditions tested and gave predictions close to measured when nearshore measured wave data is used.

(v) The importance of accurately defining the nearshore wave climate was once again clearly demonstrated.

5 CONCLUSIONS

Wave hindcasts for the offshore measurement site showed that shallow water effects in 16m of water were relatively large. The accuracy of the prediction could apparently be improved significantly by introducing depth dependent energy saturation principles into the hindcast models. Computation of nearshore wave heights and directions on the basis of two dimensional spectral refraction techniques did not provide good estimates for the larger of two storm sequences measured. Again the inclusions of depth-dependent energy saturation modifications to the transformation process improved the predictions considerably. This is not a new application in this context (see for example Resio, 1978). Application of the frequency saturation principles into the wave transformation process can most conveniently be incorporated into the spectral transformation method. As far as the frequency saturation limits are concerned there remain a number of issues that need to be resolved.

The use of the Longuet-Higgins formulation for the distribution of alongshore currents had no advantage or showed no distinctly better fit to the recorded data than the Battjes type model. In fact it suffers one positive disadvantage in that it requires the definition of a mixing coefficient for which there are no real guidelines as to what are appropriate values for different conditions. It may be anticipated that in the case of the existence of offshore bars or beaches with predominantly plunging breakers there will be problems in applying models derived for plane beaches.

It is also abvious that the roughness model used in the sediment transport predictors as well as the alongshore current friction factor empirical relationship plays a very central role in determining the level of shear forces acting on the bed.

Finally turning to the question of the performance of the sediment transport models themselves. Amongst the bulk predictors the Queen's formulations clearly performed better than the CERC formula. For the detailed predictors the Ackers and White derivations appear to be extremely sensitive to current velocities particularly when they exceed a threshold of about 1 m/s. The latest of these derivations reported in Swart and Fleming (1982) appeared to give results closest to the measured values. The Engelund and Hansen adaptation gave results that were quite comparable to the Ackers and White adaptations, but generally overpredicted transport rates, not surprisingly as it does not contain any threshold of movement criterion. Nevertheless it is extremely simple to apply. Results from the Fleming and Nielsen based models were comparable for many conditions, but the latter have proved to be by far the most stable in this application. It is therefore concluded that the Nielsen based models gave the best overall performance of all the detailed predictors tested. That was not without some anomalies related to varying grain sizes and wave heights which appeared to change the bed roughness in the opposite sense to the other models.

To summarise predictions of alongshore transport rates have been made using both bulk energy and detailed predictors which rely on computed alongshore current distributions. A number of comparative estimates have shown (i) the sensitivity of the detailed predictors to the friction factors used which are indirectly dependent upon the ripple roughness model, (ii) the magnitude of error that would have occurred from using an unverified deep water wave hidncast model, (iii) the magnitude of error that would have resulted in using an offshore wave climate transformed by consideration of refraction alone and (iv) a close comparison in results between measured and predicted rates when the improved method of estimating the nearshore wave climate is used. It should also be noted that the best prediction of net volume transported were largely within the range of volumes deduced from various field measurements. However, there is considerable scope for improvement of the sediment transport predictors.

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