AN APPROACH TO UNDERSTANDING COASTAL PROCESSES

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ABSTRACT

The approach adopted in N.S.W. for investigating coastal processes leading to development of a numero-descriptive model for management purposes is outlined. The technique involves the formation of a regional coastal model and its adaptation to site specific cases. This site specific conceptual model is then tested and modified on the basis of theoretical calculation and field data collection. Two specific case histories are outlined.

1. INTRODUCTION

With increasing pressure for development of the coastal zone, a growing community awareness of the nearshore environment, and the harsh economic realities of man's attempts to do battle with the sea, there has been a rapidly growing need for greater understanding of coastal process systems. Both planning and environmental impact requirements have necessitated the development of regional coastal process models to facilitate the assessment of factors which pattern the coastline.

It is desirable that such models be based on rigorous analytical solutions of mathematically described mechanisms. However, both the complex nature of coastal processes, and the recency of scientific endeavour in this field, have resulted in simplifying assumptions and empirically derived relationships being substituted for the more rigorous approach so that pressing problems may be attacked within an acceptable time frame.

In developing coastal models which can describe the historical coastal formation, determine present beach response and predict future trends, an accounting type philosophy has been adopted. "Sediment Budgeting", an expression of the conservation of mass principle, provides a useful framework within which a variety of techniques may be used to determine the coastal processes of a particular region. One further advantage offered by the flexibility of this budget philosophy is that the degree of sophistication to which mechanisms are described and calculations executed, can be tailored to the requirements of a particular study.

2. COASTAL PROCESS ANALYSIS

Two types of coastal process models have been developed for the New South Wales coastline; the criteria for categorisation being that of time scales.

(i) Engineering/planning time scale (1-100 years)

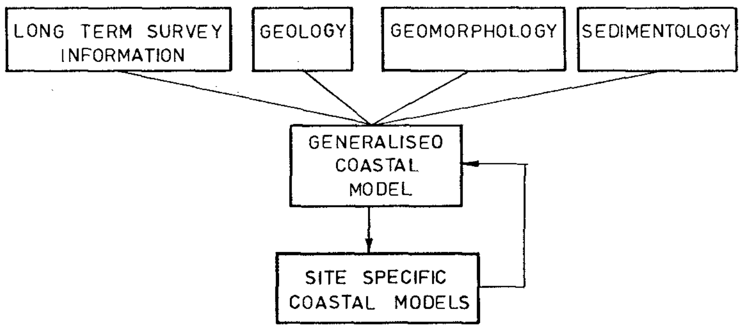
(ii) Geological time scale (100 + years).

While it is recognised that far shorter time scales must be employed when considering specific mechanisms of the coastal processes within the sediment budget, it is argued that for the purpose of engineering/planning and environmental impact analyses, the time scales nominated above are most appropriate for model development.

Both the engineering time scale model (site specific), and the geological time scale model (generalised coastal), are developmental; each supplementing and complementing the other.

The remainder of this paper will be devoted to:

- Outlining the generalised N.S.W. coastal model and demonstrating its relevance.
- A documentation of the methodology used in developing site specific models and illustration of the strengths and short comings of the approaches and techniques employed.



GENERALISED COASTAL MODEL

FIG. 1.

3. GENERALISED COASTAL MODEL

This is an overall coastal model which explains the historic development of the observed present day coastal features and is invaluable basic information for any site specific engineering study.

The methodology adopted in formulating the generalised coastal model is shown in Figure 1. In simplistic terms the resulting model for the New South Wales coastline can be presented as follows:

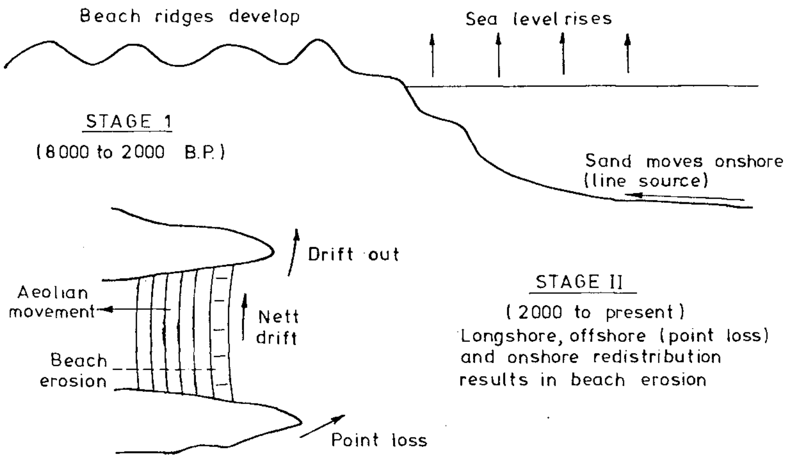
Three major natural factors have contributed to the present day coastal morphology.

(i) Bedrock outcrops and sediment deposits which pre-date the Holocene sea level rise.

(ii) The onshore movement of sand which accompanied the Holocene sea level rise.

(iii) The alongshore and onshore/offshore re-working of coastal deposits by wind wave and current action.

While the contribution of the first factor may be obvious, the subtle inter-relationship of the other two is not so obvious. It is however essential that an understanding of this inter-relationship be developed in order that an apparent existing anomaly may be explained.



GENERALISED COASTAL DEVELOPMENT MODEL

FIG. 2.

Thom et. al. (1978) have shown at many locations along the N.S.W. coastline, that the development of beach ridges and barrier deposits followed the Holocene sea level rise and still stand (ref. Figure 2).

These accretionary features have resulted from the onshore movement of sand in response to the "new" sea level condition. Radio carbon dating carried out by Thom on N.S.W. beach ridge plains indicates that they were formed during the period approximately 8,000-2,000 years B.P. A decreasing rate of ridge formation is evident with time. Little evidence exists past 2,000-1,500 years B.P. of any general coastal accretion and in fact the reverse, a state of beach recession is now apparent on a majority of N.S.W. beaches. Hence an anomaly exists - coastal accretion having occurred approximately 8,000-2,000 years B.P., coastal erosion 2,000 years B.P. to the present.

Competing theories have been advanced to explain this apparent reversal in shoreline behaviour. The first is that there has been a major shift in weather patterns. The second theory which is favoured by the authors is that while longshore and aeolian redistribution mechanisms have operated throughout the 6,000 year still stand, during the period up until 2,000 years B.P., the onshore movement of sand dominated coastal development. The diminishing quantities of onshore moving sediment in the period 6,000-2,000 years B.P. reflected the decreasing availability of sand in the offshore region. By approximately 2,000 years B.P. the offshore source had been depleted to such an extent that longshore redistribution due to wave obliquity and onshore movement of sediments under aeolian processes dominated. In coastal compartments where longshore redistribution is possible, and the sediment losses to the compartment due to this redistribution exceed the onshore supply, a state of beach erosion exists.

Thus the generalised coastal model predicts that at the present time, where there is no new source of suitable sediments, the beaches will be:

(i) In a state of dynamic equilibrium where no longshore or aeolian losses occur.

(ii) Undergoing long term erosion where either aeolian and/or longshore losses occur.

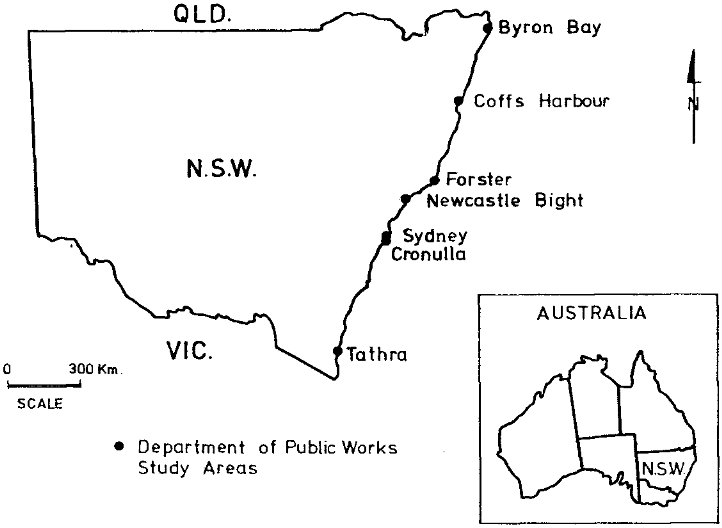
4. SITE SPECIFIC MODELS

Site specific models have been developed at a number of locations on the New South Wales coast (ref. Figure 3). While the aims of individual investigations may vary, the underlying philosophy of analysis adopted in each case is the sediment budget approach. Further, the application of this approach has taken a particular form:

- Development of a conceptual model.

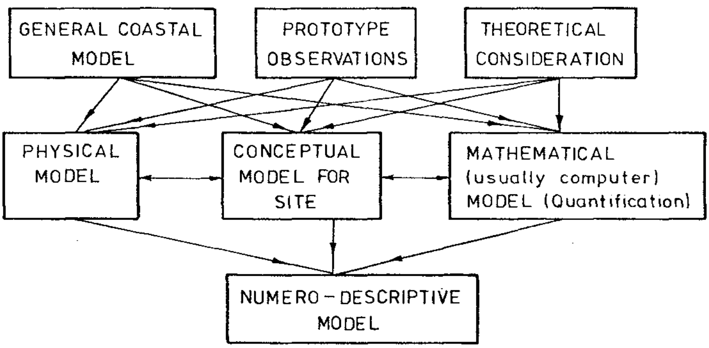
- Quantification of that model.

- Formulation of a numero-descriptive (predictive) model.



LOCATION OF STUDY SITES FIG. 3

An outline of this methodology is shown in Figure 4.



SITE SPECIFIC MODEL

FIG. 4

Boundary determination precedes model development. The onshore boundaries are usually obtained from morphological considerations while longshore boundaries are based on geomorphological criteria. Offshore boundary delineation is more complex as it is necessary to take into account sedimentological and/or bathymetric discontinuities as well as the hydrodynamic factors.

The final form of a site specific conceptual model is only obtained following a period of rigorous testing and modification. To facilitate this process of model development an extensive prototype data programme is required.

Data collection programmes have included:

- Sea and swell data - height, period from Datawell Waverider Buoys, and directions from ship and shore observations supplemented by hindcast analysis.

- Wind records - speed, duration and direction using Lambrecht anemometers at fixed locations and Ventimeters - hand held anemometers - for mobile stations.

- Currents - Lagrangian patterns obtained by drogue tracking and Eulerian information using ONO directional and, more recently, Marsh McBirney X-Y electro-magnetic current meters. Rip currents - metered, surveyed and aerially photographed.

- Bathymetry - 5.5 metre long twin hull boats powered by two 115 h.p. outboard engines give surf zone capability. These have been equipped with Raytheon type DE914 Fathometers and Motorola Miniranger Mk III position fixing equipment to enable accurate bathymetric data collection. This data is then reduced by a reduction/plot programme presently based on a VARIAN V75 computer.

- Erosion history - including differential longshore, onshore and offshore movements. Standard terrestrial survey techniques are used onshore, and the technique outlined above is used offshore. Historical survey data collection from existing plans and photogrammetric analysis using stereo restitution instruments on present and historical photography. The latter is usually restricted to vertical aerial photography with a 60% overlap and scales typically in the range 1:4,000 to 1:50,000.

- Sediment distribution patterns - spatial distribution of onshore and offshore sediment types, grain size parameters and lithology. This data is obtained from - dredge samples (a 75 mm x 300 mm steel tube with towing yoke at one end and sealed at the other is lowered to the sea floor and dragged a short distance by the survey boat); core samples up to 2 metre length obtained by divers using both suction coring equipment and hammer corers, diving is usually carried out from the survey boat; side scan sonographs produced using a Klein model 400 side scan unit operated from 15-25 metre trawlers. All position fixing is based on the

Motorola Miniranger system. Sand samples are examined under binocular microscopes to determine the composition and texture, and grain size characteristics are determined by both sieving and settling tube analysis. Further research is under way as to methods of classifying sediments under turbulent conditions (Smith and Gordon, 1980).

- Geological and geomorphological history - analysis and age structure of sediment and bedrock: Sparker, boomer and magnetometer surveys to develop seismic profiles of both bedrock and the various sediment interfaces. The equipment is operated from the trawlers used for side scan operations with the same position fixing procedure. Auger boreholes are used to obtain material for dating from the back beach barrier ridge systems and to provide a check on seismic interpretation.

- Bedforms - spatial and temporal distribution of ripples and dunes, their height, wave length, composition and direction of orientation. Data is collected by diver operations and from interpretation of side scan sonographs.

The quantification of the conceptual model requires an analysis of the various sources and sinks coupled with a mathematical description of the sediment movement between them. The techniques employed to quantify these sources and sinks will be illustrated in part in the following sections which deal with two site specific studies.

It is the quantification of sediment movements within the model boundaries which, of the coastal sciences, suffers most from the lack of adequate theoretical development. Hybrid modelling techniques have been employed in an attempt to offset these theoretical limitations.

Refraction and diffraction of waves provide particular problems. The accuracy of calculated longshore transport rates reflect to a considerable degree the ability to determine correctly the coastwise inshore wave energy distributions. Physical models, computer based mathematical models and prototype observations have been combined to synthesise inshore wave energy conditions. Because of inaccuracies in the available recorded wave data, particularly with respect to direction spectrum, the reliability of calculated values has been appraised by undertaking sensitivity analyses on the refraction and transport studies. Geomorphological and sedimentological indicators are also employed as independent references.

Sediment transport equations; the relationships between the driving forces and the sediment reaction to those forces, are in their infancy from the viewpoint of theoretical understanding.

The Bijker (1967) approach of increased bed shear under waves, represents a significant contribution to attaining a more scientific description of coastal sediment transport. However its inherent simplifications when applied to a beach system of complex morphology; rip cells and multiple offshore bars, has resulted in the continued use of the more simplistic empirical approach outlined in the Shore Protection Manual (CERC, 1977); better known as the C.E.R.C. equation. More recent work by Longuett Higgins (1970, 1972) has lent some degree of theoretical credence to this relationship between wave thrust and longshore sand transport.

A mathematical model, at present based on a modified C.E.R.C. philosophy, has been adapted to local conditions and placed on a P.D.P. II computer for ease of calculation, alteration and testing against prototype data.

To illustrate the methodology employed in site specific model generation, and to highlight the shortcomings and strengths of both this approach and the theoretical considerations upon which it is based, two typical studies will be discussed. Both studies are from regions of the New South Wales coast which are believed to be undergoing long term recession.

- Newcastle Bight (Figure 3), a 30 kilometre long embayment located 120 kilometres north of Sydney. This is an example of a shoreline which is eroding due to aeolian losses.

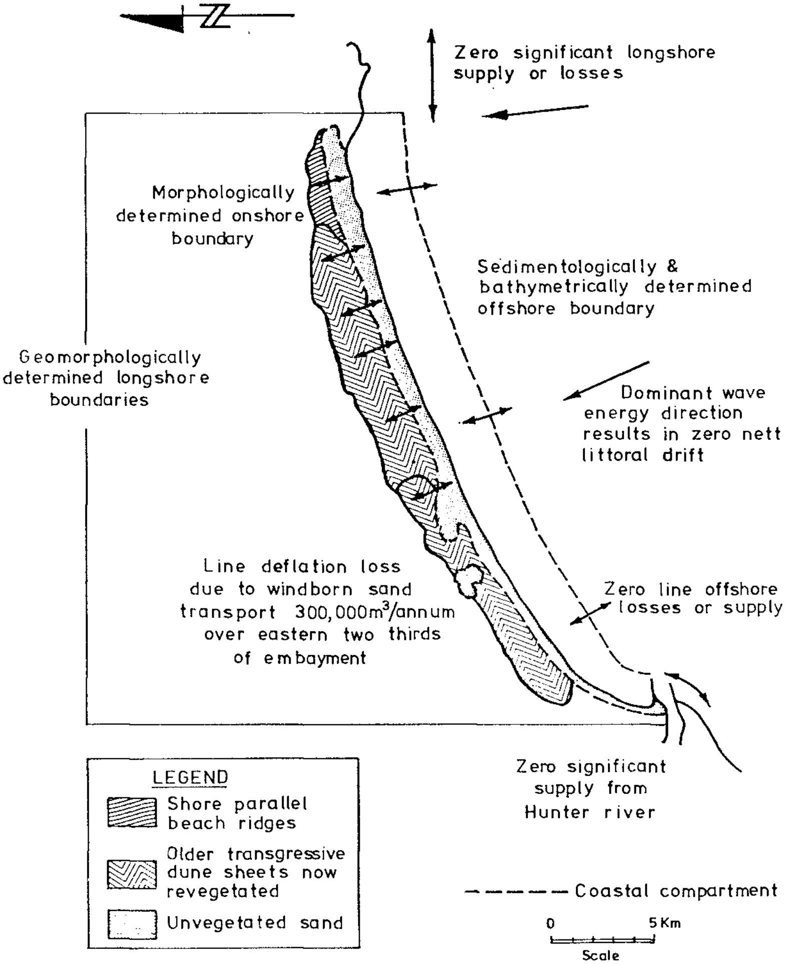
- Byron Bay - Hastings Point (Figure 3), a 30 kilometre long stretch of coastline located 750 kilometres north of Sydney. This is an area which is eroding due to an imbalance between overall coastal alignment and dominant wave energy approach direction. An interesting offshore loss mechanism intensifies the erosion problem.

4.1 Newcastle Bight

Newcastle Bight has a long history of beach erosion. It is backed by a massive transgressive dune sheet which is moving inland over forest and farming areas. Interest in the area followed a proposal to excavate a large new harbour in the transgressive dunes and to construct a breakwater protected entrance through the beach and surf zone.

The numero-descriptive model for Newcastle Bight has been summarised in Figure 5. It is not intended to discuss the study (Gordon and Roy 1977, D.P.W. 1977) in detail, but rather a number of interesting points have been singled out for presentation:

- A major N.S.W. river discharges into the southern end of the coastal compartment. Calculations based on Colby's work (Colby 1964) showed that during major flood events the river had the capability to transport sand to the coast. Sand of suitable size was known to be present in the upper reaches of the river. Compositional and textural sedimentological studies showed no significant contribution of these terrestrial sands to the coastal sediment system. Further analysis of the flood data indicated that these events were infrequent, and that dry weather flows were incapable of transporting the material. The river was thus eliminated as a present day source of significant quantities of coastal sediments.



NUMERO-DESCRIPTIVE MODEL
NEWCASTLE BIGHT

FIG. 5

• Initial calculations using hindcast wave statistics, the wave refraction programmes and sediment transport calculations gave a nett northerly drift of 200,000 cubic metres per year. Analysis of wave rider data showed that the hindcast statistics overestimated the frequency of waves of heights above 2-3 metres whilst underestimating the frequency of smaller waves. Using the waverider statistics, the calculated nett littoral drift was 135,000 cubic metres per year to the south (Table 1). Following doubts as to the accuracy of the recorded wave direction data, and particularly with respect to the assignment errors between True and Magnetic North (12 degrees), a sensitivity analysis was carried out on the effects of wave direction on transport volumes. It was found that a 7.5 degree shift in the nett energy flux pattern applied to the refraction programme resulted in a zero nett littoral drift condition for the embayment. Sedimentological evidence supported this latter finding (Gordon and Roy, 1977). As it was felt that at best, the wave directional data which was recorded to sixteen compass points was only accurate to $\pm$ 11.25 degrees, a model which predicted a zero nett littoral drift condition was adopted. The model was calibrated accordingly and the gross littoral drift quantities were adjusted.

TABLE 1

Deepwater Wave Approach Direction	Average Annual Sand Transport (m^3/yr) and Direction of Transport	
	From Wave Statistics based on True North	From Statistics based on Magnetic North (12^{o} shift)
E	224,000 South	242,000 South
ESE	345,000 South	262,000 South
SE	235,000 South	86,000 South
SSE	212,000 North	304,000 North
S	457,000 North	396,000 North
Gross Drift	1,473,000	1,290,000
Nett Drift	135,000 South	110,000 North

• The numero-descriptive model confirmed that the measured 1 to 2 metre per year (long term average) shoreline recession could be accounted for by the deflation losses associated with the landward moving transgressive dunes. The initial numerical analysis did not, however, produce this result. Aeolian transport was assessed by the Bagnold approach (Kadib, 1964) using long term wind data from anemometers located at both the southern end and the centre of the embayment. This formula was applied in the form:

$$Q = 1.8 \times t \times 3.6 \times 10^3 \sqrt{d/D \cdot \gamma/g \cdot U_*^3}$$

and

Q = total transportation in kg/year/metre

t = wind duration in hours/year

d = d_{50} diameter of sand in millimetres

D = 0.25 mm Bagnold standard sand particle size

γ = Specific weight of air kg/m^3

g = gravitational acceleration m/sec^2

U_* = shear velocity in m/sec

These calculations showed that some 20 cubic metres/year/metre of beach (long term average) was moving in an offshore direction. This resultant was 120 degrees opposed to the known landward transport obtained by direct measurements and aerial photographic interpretation which gave a landward encroachment of the transgressive dune sheet of from 5 to 10 metres per annum, landward transport of some 25 to 50 cubic metres/metre of beach. Examination of this anomaly showed that as the onshore movement was into a well vegetated region, the trapping effect of the trees, and their local modification of the wind field resulted in their acting as a 'sand diode'; selectively modifying the aeolian mechanism. Thus it was concluded that the nett movement was chiefly dependent on the onshore component of wind energy, and hence the aeolian transport calculations were modified accordingly.

- Monthly surveys (D.P.W. 1977) and sand samples taken in the offshore zone produced evidence of a break in sediment characteristics and movement at depths of 12 to 14 metres throughout the Bight; shallower at the southern end in the hook of the zeta curve. This break was interpreted as being the base of the highly active inner nearshore zone and as such was useful in the further development of the "generalised model" and provided information relevant to the development of sediment transport models.

- The quantity of material involved in the onshore-offshore movement during storm events was estimated from the profiling data. In March 1973 a 3 day storm occurred. The peak significant wave height from wave rider records was 6.2 metres while the maximum wave height was 9.9 metres. The recurrance interval of this storm was estimated as 1 in 1 year. The storm produced an average 35 metre recession of the mean water mark and between 100 and 150 cubic metres/m of beach were removed from the sub aerial beach and placed on the offshore bar. Experience at other locations on exposed ocean beaches in N.S.W. indicate that for a more intense storm with wave heights of 10 to 12 metres this storm demand may be of the order of 200 to 400 cubic metres/metre of beach.

The accuracy of the final numero-descriptive model (Figure 5) constructed for Newcastle Bight was enhanced by the adoption of the approach outlined in Section 3 - the quantification of a conceptual model with emphasis on testing against prototype information and observations.

4.2 Byron Bay - Hastings Point

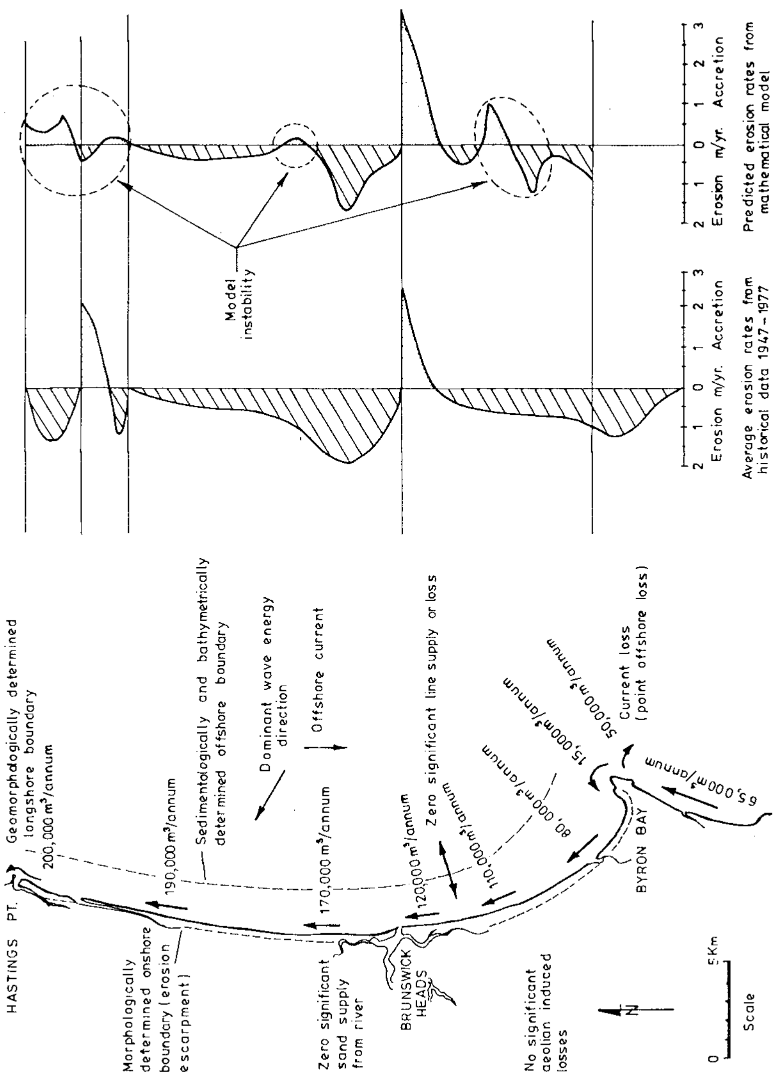
Shoreline recession in the Byron Bay - Hastings Point region was drawn to public attention dramatically with the loss of houses during the late 1960's and the severe damage to a small village located mid way along this stretch of coast. In 1972, after further severe cyclone activity, this village of 17 houses had to be totally abandoned. To provide a basis for future management and planning of the area, a site specific coastal study was undertaken (Gordon, Lord and Nolan, 1978).

This study showed that a time averaged nett longshore drift occurs from south to north throughout the Byron Bay - Hastings Point embayment, which is an open ended compartment. Throughout the embayment an unfavourable coastal alignment promotes a differential littoral drift situation which results in a greater quantity of sand leaving the compartment to the north than is entering it at the southern end.

The existing coastal sediments have responded to this increasing sediment demand, resulting in recession of the shoreline. This recession can be viewed as a "line source" of littoral drift material.

The numero-descriptive model which resulted from the study has been summarised as Figure 6. This study provided interesting insights into offshore loss mechanisms, and methods by which longshore transport formulae can be calibrated and used to reproduce time histories of differential shoreline recession.

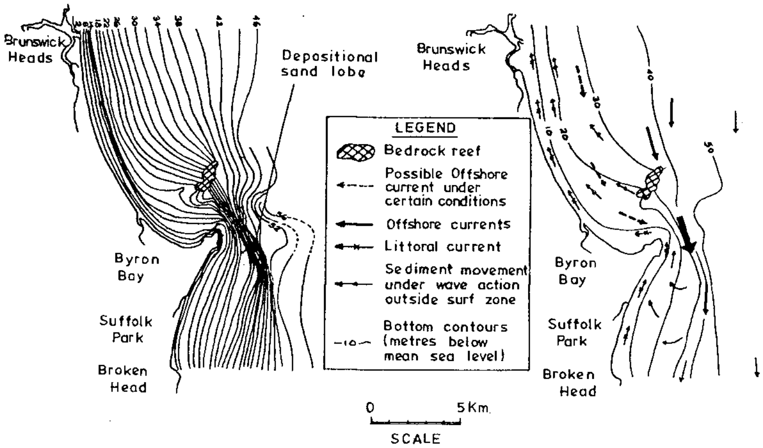
- Although it was recognised that littoral drift imbalance within the compartment was a major contributing factor to shoreline recession, it became apparent during the investigation that a significant offshore loss mechanism was active off the southern headland. Current studies, sedimentological evidence, and unusual bathymetric features (ref. Figure 7) off Cape Byron were examined to facilitate description and then quantification of this loss.



NUMERO-DESCRIPTIVE MODEL
BYRON BAY - HASTINGS POINT

FIG. 6

Intermittent excursions of the East Australia Coast Current onto the contintental shelf in this region at certain times produce south bound currents in excess of 0.5 m/s close to the Cape where wave reflection from the near vertical cliffs ensure that sediment suspension occurs even under low wave conditions. Thus northerly drifting sand in the littoral stream which would normally bypass Cape Byron may, under certain conditions, be intercepted and transported offshore and to the south where it forms a prominent bathymetric feature; a sink for littoral material in some 30 to 50 metres water depth (ref. Figure 8). Using sedimentological



OFFSHORE BATHYMETRY BYRON BAY

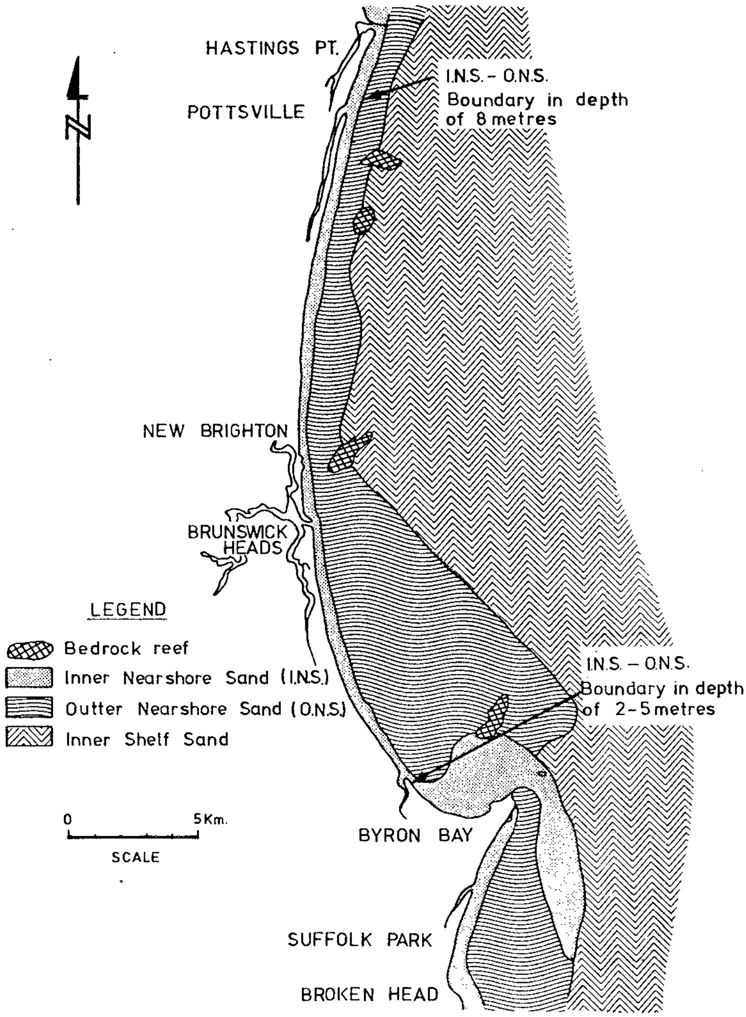
FIG. 7

OFFSHORE CURRENTS AROUND CAPE BYRON

FIG. 8

analyses to define the extent of this feature, and bathymetric evidence to calculate the quantities of sediment lost to the sink, it was estimated that 50,000 cubic metres per annum of sand had been removed on average from the littoral drift system over the last 6,000 years. The assumption that this loss has occurred at a steady rate over 6,000 years is tentative. Further work is required to examine the validity and implications of this assumption.

To examine and predict the pattern of shoreline recession, a computer based transport model was adapted and extensively modified to this location. The model divided the coastal compartment into a number of shore normal elements (Figure 9). The wave refraction programme, sediment transport formula and local wave data were combined to calculate the longshore transport rate into and out of each element for discrete time steps. At each time step the "budget" of the individual elements



OFFSHORE SEDIMENT TYPES
BROKEN HEAD TO HASTING POINT

FIG. 9.

was assessed and sediment deficits or excesses were distributed to the adjacent elements. The onshore element boundary was flexible and reflected overall sediment gains or losses as beach erosion or accretion (Gordon, Lord and Nolan, 1978).

Instabilities occurred in the model at discontinuities such as breakwaters and in regions where refraction/diffraction patterns were complex or interacted (Figure 6). These instabilities were mainly associated with inappropriate selection of element size and the techniques employed to assign refraction, diffraction and bypass coefficients.

Model calibration was carried out by comparing the resulting shoreline recession patterns with those obtained historically from survey and photogrammetric analyses. The structure of this model, enabling it to be run both backward and forward from any point in time, allowed verification of the model against prototype data prior to its usage as a predictive tool for shoreline recession.

The model employed the C.E.R.C. formula in the form:

$$Q = K.C_g.\frac{\rho g H^2}{8}.\sin\alpha.\cos\alpha$$

where

Q = longshore transport rate

K = an empirical coefficient which involves a number of parameters

C_g = wave group velocity

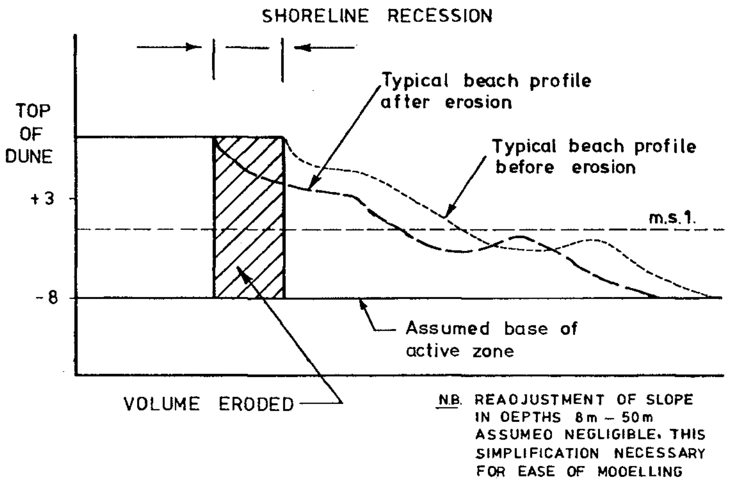
$\frac{\rho g H^2}{8}.\sin\alpha.\cos\alpha$ = wave thrust

Initial results using a K value obtained from the Shore Protection Manual (C.E.R.C., 1977) produced erosion and transport rates approximately three times those measured in the prototype. The K value was adjusted accordingly and the model was then used to predict future trends.

- As with the Newcastle Bight study, offshore sediment patterns provided data on offshore boundary considerations. A marked change in sand type was noted at a depth of 8 metres in the exposed regions of the embayment, shallowing to 2-5 metres in the sheltered hook of Byron Bay.

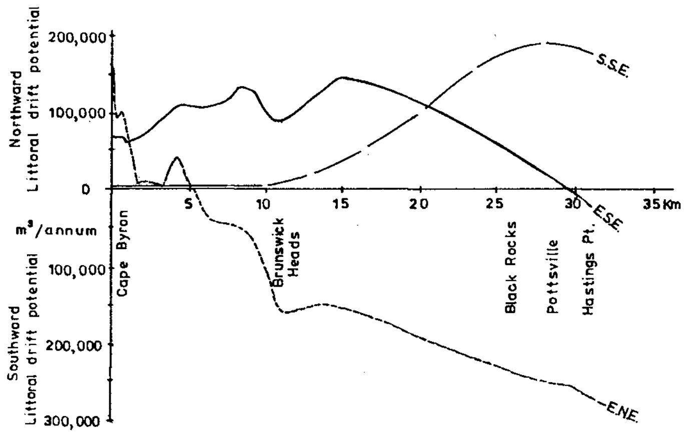
- The offshore boundary for the model elements was taken as the break in sediment patterns referred to above. The inner boundary was the back of the beach at the base of the erosion escarpment; typically +3 metres to +4 metres above I.S.L.W. In a fully

3-dimensional model, profile changes due to varying input data should be modelled as well as plan form changes in shoreline. It is argued that in a long term erosion situation, it is reasonable to assume that whilst dramatic day to day changes in profile shape may occur, the nett result is a mean profile which migrates landward as erosion progresses. Obviously, this is a gross simplification for the convenience of model operation. However it is believed that profile changes between depths of between 50 metres and 10 to 8 metres are subtle on an engineering time scale. It is further believed that no significant modification to the profile solely due to wave induced effects occurs at depths greater than 50 metres, although wave penetration to the bed may exceed this figure on certain occasions. Thus, the eroded volume per unit time, per unit length was obtained as illustrated in Figure 10.



ACTIVE ZONE ZONE FIG 10

Sensitivity of the model to directional wave data was investigated by generating 100% occurrence nett transport rates along the embayment for three major offshore directions (Figure 11). It was then a simple process to test the effects of various directional distributions on the longshore transport rates and, hence, the erosion patterns.



100% OCCURRENCE NETT TRANSPORT RATES
CAPE BYRON TO HASTINGS POINT

FIG 11

TABLE 2 - Sediment Budget

SOURCE	VALUE (m^3/year)	SINK	VALUE (m^3/year)
Q^+_1 (offshore point supply)	0	Q^-_1 (offshore current loss)	50,000
Q^+_2 (rivers and creeks)	0	Q^-_2 (inlet loss)	0
Q^+_3 (beach nourishment)	0	Q^-_3 (sand extraction)	0
Q^+_4 (longshore transport in)	65,000	Q^-_4 (longshore transport out)	200,000
q^+_1 x (offshore line supply)	0	q^-_1 x (offshore line loss)	0
q^+_2 x (dune and terrace erosion)	180,000	q^-_2 x (overwash and wind loss)	0
q^+_3 x (beach erosion and shell production)	0	q^-_3 x (beach storage and shell loss)	0
TOTAL of Sources	245,000	TOTAL of Sinks	250,000

- The quantified conceptual model is presented in traditional sediment budget terms as Table 2. Emphasis has been placed on the use of point sources/sinks (Q) and line sources/sinks (q) because of their significance in this particular study. The total sediment budget therefore took the form:

$$\sum_{i=1}^{4} Q_i^{+} + \sum_{i=1}^{3} \left(\sum_{o}^{x} q_i^{+} x_i \right) = \sum_{i=1}^{4} Q_i^{-} + \sum_{i=1}^{3} \left(\sum_{o}^{x} q_i^{-} x_i \right)$$

In the Byron Bay - Hastings Point study, the adaptation of the methodology outlined in Section 3, enabled a model to be constructed which showed not only the total sediment budget of the coastal compartment, but also enabled predictions to be made concerning future differential shoreline movement throughout the compartment.

5. CONCLUSIONS

By invoking a conceptual model/numerical model approach the concept of sediment budgeting has been expanded to provide an insight into processes operating within the coastal compartment under study. The use of geomorphological and sedimentological indicators has assisted in quantifying and testing the models. The development of a general coastal model has provided an invaluable frame of reference and starting point for any site specific studies.

The modelling process is an ongoing development. Recognition that generalisation is dependent on mechanism understanding has resulted in increasing emphasis being placed on the methods used to calculate actual sediment movement paths.

Accuracy and confidence in results have been increased by the carrying out of sensitivity analyses and a process of constantly reviewing proposed mechanisms and transport paths against prototype observations and data.

Not withstanding the above, it is plainly apparent that there exists a compelling need for greater understanding of sediment transport mechanisms, and hence the development of more appropriate formulae for both the aeolian and littoral regions of the coastal zone. In concert with this, far more sophisticated data collection is required, particularly with respect to inshore wave directional spectra, current information, and sediment characteristics.

The results of any computation are only as good as the input data and the validity of the assumptions used.

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