THE DYNAMIC SWEPT PRISM

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INTRODUCTION

In the course of an intensive study of beach and inshore morphodynamics associated with a nourishment project on the Lower Gold Coast, Australia (Chapman, 1978), approximately 400 profile lines were surveyed from backshore to the point of zero change in the nearshore zone, to a high degree of accuracy (Chapman & Smith, 1977). Analysis of this data base has led, inter alia, to the development of the concept of the dynamic swept prism, since the maximum and minimum ordinates on a shore-normal profile line, over a specified time period, form the vertices of an irregular polygon which may be regarded as the cross-section of the prism of sand which is worked over by waves during that time period. Representative prism cross-sections from the Lower Gold Coast are displayed in Figure 1. The important limits of the swept prism, viz., the landward and seaward extremities and the lower surface, are probabilistically, not deterministically defined. Prism cross sections as illustrated are not isotropic with respect to the probability of disturbance by waves. Isolines of probability may be conceptually defined, with the zone of maximum probability of disturbance corresponding to that zone which is re-worked during the tidal cycle (cf. Duncan, 1964). Moreover, although the

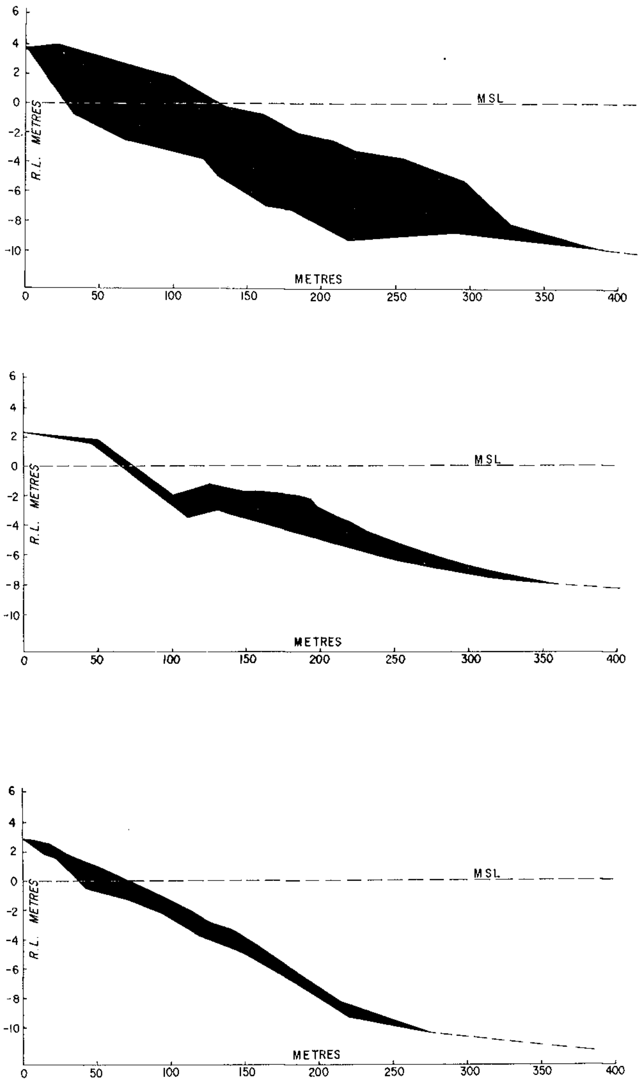


FIGURE 1. Representative Swept Prism Cross-Sections, Lower Gold Coast.

surveyed cross-sections illustrated are closed at the landward and seaward extremeties, in probabilistic terms these extremeties are undefined, being asymptotic at each end.

The swept prism, especially in its subaqueous zone, may also be recognized as the envelope enclosing the range of beach and inshore morphologies described by workers such as Short (1978) or Wright, et. al. (1979).

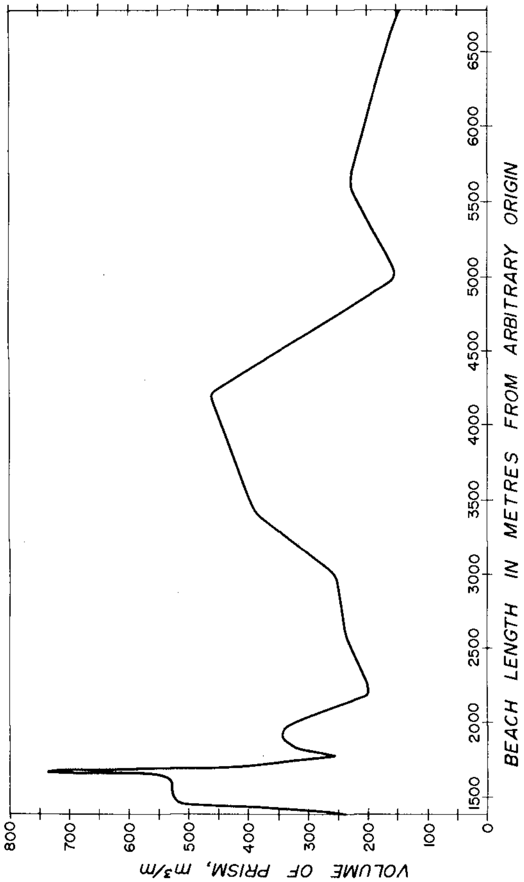
It is the purpose of this paper to discuss the behaviour of a swept prism as observed on the lower Gold Coast, and to comment on the implications of the concept for management and planning, since effective planning and design must be cognizant of the probabilistic nature of the prism limits with respect to structures which may be placed therein.

BEHAVIOUR OF THE SWEPT PRISM, LOWER GOLD COAST

The lower Gold Coast is located in the southern end of a large zetaform embayment, extending from Point Danger to Stradbroke Island (a location map is provided in Chapman, 1980). Environmental characteristics include a relatively narrow and steep continental shelf, reaching 200 metres depth at 40km. offshore, and average deep water wave power of 10kw/m of wave crest. There is no seasonal pattern of cut and fill such as is reported from many North American sites.

Figure 2 illustrates the alongshore variation in the cross-sectional area of the swept prism during the Gold Coast study, when mean breaking wave power was approximately 6.4 kilowatts m^{-1} over the 5km. of shoreline surveyed. Mean cross-sectional area was $312m^2$; the large maximum value of $737m^2$ at 1617 metres from the arbitrary origin was due to input of beach fill at that point. The mean value of $312m^2$, during normal wave energy conditions, is comparable with $420m^3/m$ of sand eroded from the subaerial beach and translated to the inshore zone by cyclone induced storm activity in 1967 (McGrath, 1968), and reveals that considerable re-working of the beach and inshore zone occurs, even under moderate energy conditions.

Examination of the swept prism cross-sections



VOLUME OF SWEPT PRISM

FIGURE 2. Alongshore Variation in Swept Prism Cross-Section Area, Lower Gold Coast.

illustrated in Fig. 1 reveals that the beach as defined by the recreational user (and indeed by most lay people) is merely the residuum of inshore processes. The prism cross sections also illustrate the fact that variability in the prism is principally accommodated within the subaqueous zone; most of this variability would not be apparent to the recreational beach user or resource manager who was merely concerned with evaluating the subaerial beach.

The large proportion of the swept prism in the subaqueous zone is significant in accounting for the re-distribution of beach fills, since re-distribution can involve substantial apparent losses from the subaerial beach without material being lost from the prism. If nourishment material applied is of such a nature that the upper surface of the prism is induced to adopt a lower overall gradient, a large volume of fill material would be absorbed in order for this redistribution to take place, but would result in little gain in beach width.

The lower boundary of the swept prism, is a scour surface, activated by vigorous reworking of the prism. The scour surface as derived statistically from over 400 lower Gold Coast profiles is illustrated in Fig. 3 where the mean surface is illustrated together with its standard deviation bounds. Observations on the Gold Coast suggest that the scour surface under high energy storm conditions may be underlain by a fluidised sediment layer. Direct measurement during storm conditions is not possible with presently available techniques, but the existence of a fluidised layer is suggested by events such as the collapse of a boulder wall during high energy conditions and subsequent settlement of the armour to a depth of over 1 metre below the sand surface within a matter of minutes. Observation of the event in progress suggested that the boulders sank through a semi-quick layer rather than having the sand scoured from around them by the waves. The result of this event is illustrated in Fig. 4. We also found that measuring stakes embedded to a depth of 1m. below the sand surface in the inshore zone showed pronounced departures from the vertical after a week or

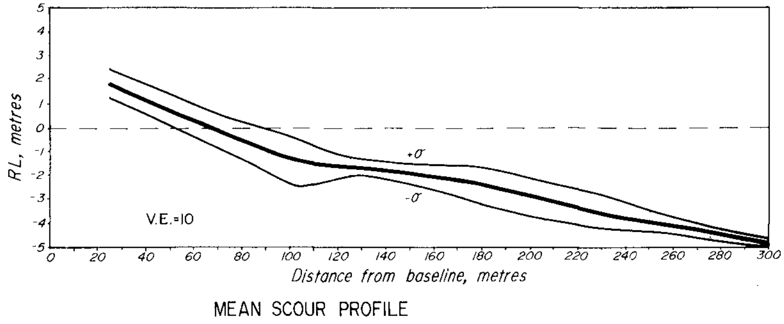


FIGURE 3. Mean Scour Surface, Lower Limit of Swept Prism, Lower Gold Coast.

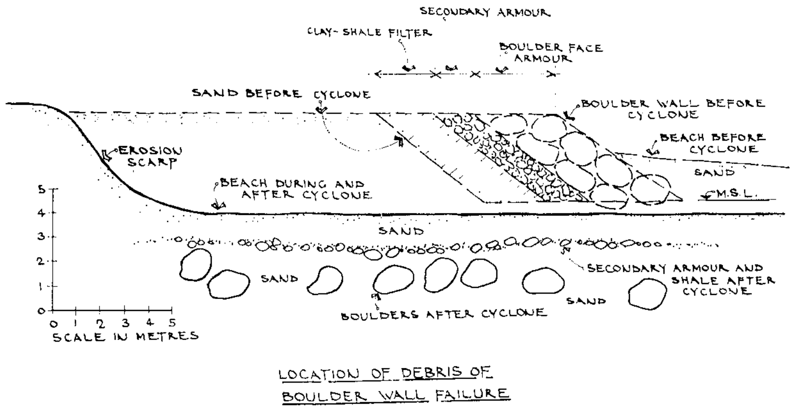


FIGURE 4. Location of Debris of Boulder Wall Failure.

two of moderate energy wave action.

The landward asymptote of the prism would normally include the frontal dune and foredune, as these are mobilized by the highest energy events. In the case of a beach in its natural state the landward extension of the prism under high energy conditions will encounter that part of the cross section which is capped by a dune so that the high energy event which causes the extension of the prism is also responsible for the release of a large volume of stored sand into the active zone.

The modes of cut and recovery are not complementary. During periods of cut (which may involve recession of the dune scarp) rapid removal of sand occurs from the subaerial part of the swept prism; however during periods of recovery the replacement of this sand occurs over a longer period and in addition involves the development of an incipient foredune. Initial stabilization of this foredune requires pioneer dune species which are sensitive to recreational pressure so that the stabilization of the replaced sand by woody vegetation may be extremely slow or non-existent on a recreational beach. In this way a mechanism for cut without replacement exists.

The cut of the subaerial beach, even under cyclone conditions, is normally quite localised with the incidence of the most severe cut along the Gold Coast being fairly random. Therefore, in the three dimensional sense the re-working of the swept prism is also a probabilistic phenomenon.

The seaward asymptote of the prism represents the seaward limit of sediment exchange between bed and beach. It corresponds in broad terms with the limiting depth of erosion as postulated by Hallermeier (1978), or the seaward limit of Swart's (1974) equilibrium profile. It does not correspond to surf base, the seaward limit of incipient sediment motion, which would be reached some considerable distance seaward of the prism limits.

IMPLICATIONS FOR MANAGEMENT

The probability of activation of the swept prism decreases landward, and will be inversely related to the magnitude of the wave power which is applied to it. The well known inverse relationship between magnitude and frequency of geomorphological phenomena (see, e.g., Chorley & Kennedy, 1971) applies. As shown in Fig. 5 a minor storm event is virtually certain to occur in any given year (i.e. probability $\simeq 1$). Events of moderate magnitude, which may cause significant activation of the subaerial beach but little or no damage to shore front property, fall within the "normal" range at about the point of inflexion of the curve, whilst the high magnitude event which causes damage to shore front property has very low probability of occurrence; e.g. the event of magnitude m has a probability of 5%, or a 1 in 20 year recurrence interval, with the curve becoming asymptotic to the vertical axis for events of very high magnitude. Thus it may be seen that damages incurred as a result of high energy wave events are related to magnitude such that the events of low or moderate magnitude cause no damage at all to man-made structures, with extremely high magnitude events required to cause significant damage. The probability of damage to shore-front property may therefore be expressed as shown in Fig. 6. There is a finite probability of (100 - x)% that no damage at all will be incurred in any given year and a moderately high probability that the damages incurred will be trivial. The probability of high damages is extremely low and asymptotic to the vertical axis for very large values.

It follows that in a situation where secular sea level rise is not a major causal factor in coastal erosion, losses to shore-front property due to landward extension of the swept prism have some probability less that 1 of occurring and may be related to shore-front property values as shown in Figure 7. Curve (7a) illustrates cumulative property value as a function of distance from the present high water mark. If shoreline retreat is progressive and inevitable this curve also relates losses and time since secular erosion will consume property according to some function relating

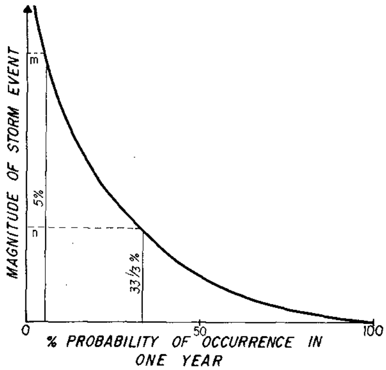


FIGURE 5. Magnitude Vs Frequency of Storm Events.

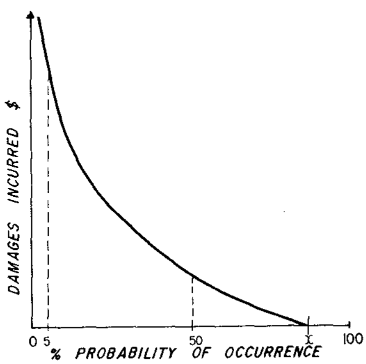


FIGURE 6. Probability of Damage, Storm Events.

distance from the present high water mark to time. However, in the absence of secular sea level rise as a major causal factor, the probability of loss becomes a function of the extension of the swept prism, and is therefore an asymptotic function of distance from the shore line as illustrated by curve (7b). On the one hand some loss of shore-front property is virtually certain to occur, since the maximum storm event has probably not been recorded*, but on the other hand there is some point inland from the present shore-line at which zero loss from coastal erosion is also a certainty.

A realistic appraisal of probable loss from coastal erosion then becomes a function of both cumulative property value and the probability of activation of the landward asymptote of the swept prism, i.e. one should multiply together the ordinates of curves (a) and (b) in order to arrive at the function of probable loss (curve 7c).

Under normal processes of planning and development, a coastal land value gradient decreasing inland from the shore-line applies. The implications of the foregoing analysis are that the appropriate land uses should be arranged so that capital intensive development is not placed in the zone where the probability-cumulative loss function is highest. In other words the application of capital to land would be controlled so that investment would be minimised at the point where probability of loss is highest and allowed to increase inland to some point where the probability of loss is low but shoreline amenity still obtains.

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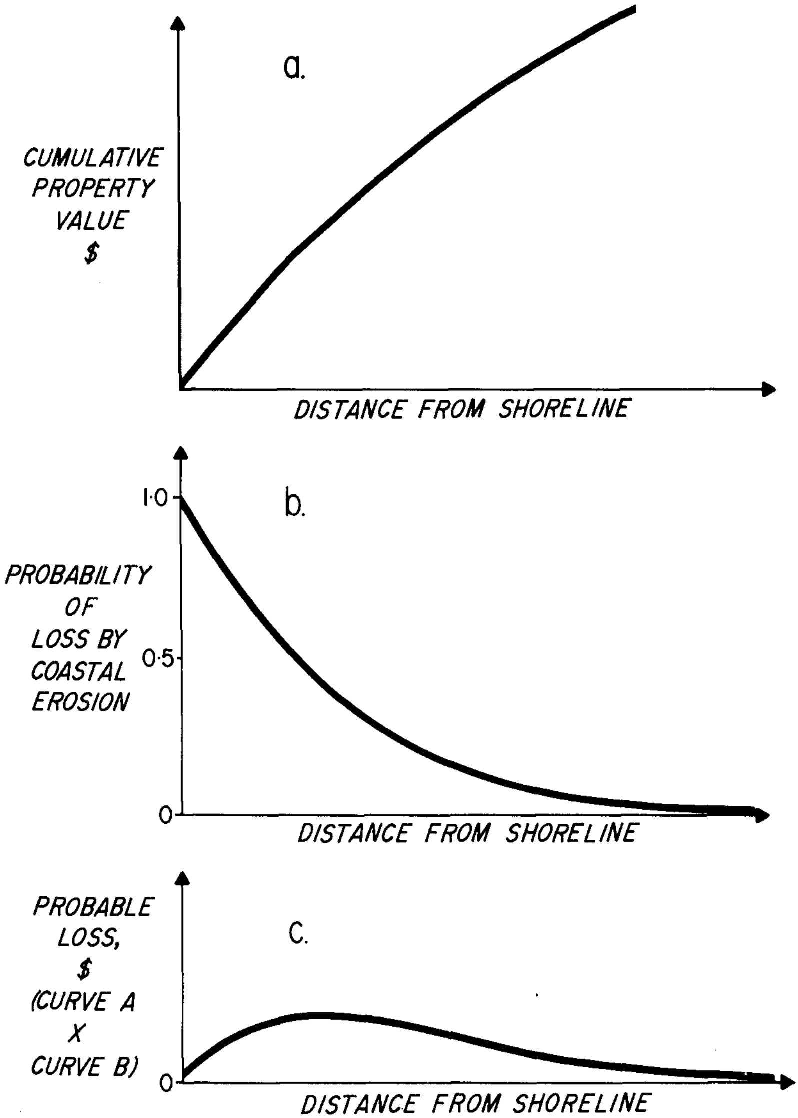
* A familiar concept in civil engineering practice which has been given legal recognition in doctrine derived from Rylands & Fletcher, e.g. in Ruck Vs Williams, 1868, Bramwell (B) stated "in truth it is not an extraordinary storm which happens once in a century or once in fifty or twenty years; on the contrary, it would be extraordinary if it did not happen."

Management of land use thus becomes part of a strategy of shoreline protection. A variety of shoreline protection options is available to the resource manager as displayed in Table 1. These have been subdivided into structural and nonstructural categories. The resource manager charged with the responsibility of planning for the protection of the shore-front community from coastal erosion must choose an appropriate strategy (which may involve one or a mix of management options) in order that the total benefit to the community is maximised.

The optimum management strategy will not necessarily provide maximum protection or minimise expenditure, but will be that point where the sum of losses incurred by the community and costs to the community of protective measures is minimised, as illustrated in Figure 8. The vertical axis is one of dollar values, either the value of losses incurred by the community or the costs of management strategies, whilst the horizontal axis plots either the degree of protection afforded by management strategies or the amount of physical damage incurred as a result of coastal erosion. The loss curve (AA') is (ideally) inversely related to the degree of protection afforded by the management strategy (curve BB'), although it will be observed that the loss curve (AA') does not reach the zero point on the vertical axis. At the point where losses are minimised the cost of protective strategies is likely to be exceedingly high, therefore the optimum point for management is neither that point where losses alone are minimised, or costs alone minimised, but the minimum point on the curve CC', which shows the sum, added vertically, of costs and losses. Expressed in the language of conventional land management economics, this would be the point where marginal benefit equals marginal cost.

CONCLUSION

The active zone of a beach may be conceptually defined as a prism of sand within which the probability of disturbance by waves varies greatly. Recognition of the three-dimensional nature of the swept prism, and of its varying probability of excitation is required for effective planning and design.



a.
CUMULATIVE PROPERTY VALUE $
DISTANCE FROM SHORELINE
b.
1·0
0·5
0
PROBABILITY OF LOSS BY COASTAL EROSION
DISTANCE FROM SHORELINE
c.
PROBABLE LOSS, $ (CURVE A X CURVE B)
0
DISTANCE FROM SHORELINE

FIGURE 7.

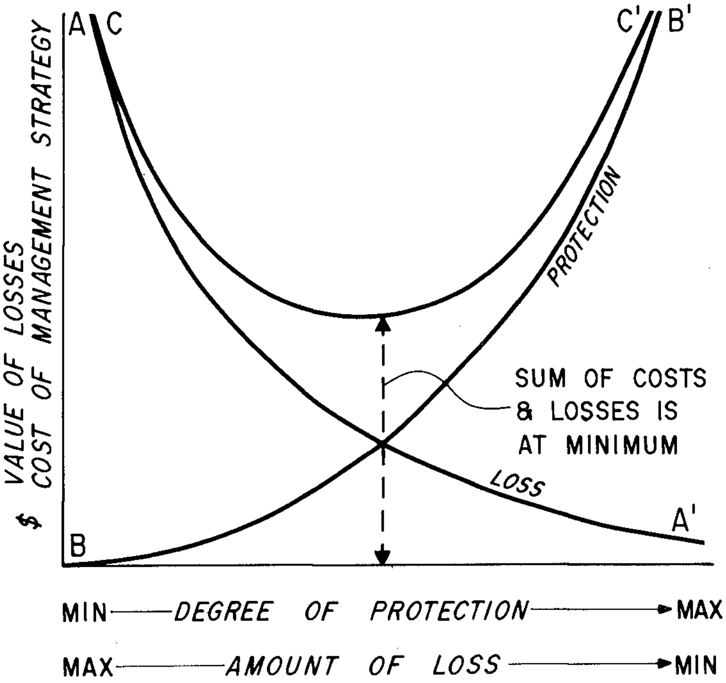

$ VALUE OF LOSSES
COST OF MANAGEMENT STRATEGY
A
C
C'
B'
PROTECTION
SUM OF COSTS
& LOSSES IS
AT MINIMUM
LOSS
A'
B
MIN—DEGREE OF PROTECTION→MAX
MAX—AMOUNT OF LOSS→MIN

FIGURE 8.

TABLE 1. COASTAL EROSION - MANAGEMENT OPTIONS

NON-STRUCTURAL	Dedicate land to remain in natural state e.g. National Park. Regulations preventing location of structures in hazard zone.	Regulations against removal of sand from system. Regulations against destruction of dune vegetation.	Storm prediction/ warning/evacuation systems. Civil Defence. Land Use Zoning (incl. Buffer zones). Relocation Schemes. Building Codes. Public ownership of hazard zone and/or structures thereon. Regulations against re-building of severely damaged structures.	Loss Bearing. Loss Sharing: a) Insurance schemes b) Compensation of loss bearers from community funds - appeals, government assistance etc.
STRUCTURAL	Movement of endangered structures; a) moving "permanent" structures. b) use of portable structures only in hazard zone.	Protective structures, a) "hard": Seawalls, revetments, breakwaters, groins, etc. b) "soft": Beach nourishment, emergency fill, sand fences, dune planting, construction of dunes and stabilization thereof.	Deep Piling. Landfill. Use of Expendable structures in hazard zone.	Rebuilding.

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