# BEACH NOURISHMENT AS A MANAGEMENT TECHNIQUE

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## 1) INTRODUCTION

Beach nourishment is considered an environmentally safe management technique, since an unsuccessful nourishment project would simply result in the redistribution of borrow material by wave action into environments more in keeping with a state of equilibrium. No permanent modifications of the beach and nearshore environment need result, and since no permanent structures are required for beach nourishment, the management commitment allows rapid project abortion if necessary. Beach nourishment monitoring has usually been concerned with evaluating changes in the extent of subaerial beach and/or retention of fill volume. These parameters are important, but it is also necessary to consider the way in which nourishment sand is taken up by the beach system since relationships between volume change, change in extent of subaerial beach, and changes in beach morphology are complex. This paper is concerned with evaluating beach nourishment on the Gold Coast (Figure 1), Australia's major resort, where 2.4 million cubic metres of fill were applied in the largest beach nourishment project attempted in this country at the time of writing.

Methodology, reported in Chapman & Smith (1977) and Chapman (1978a) included repetitive profile survey from backshore to point of zero change in inshore zone (over 400 profiles) using highly accurate techniques, and use of 38 tonnes of tracer, which was injected into the dredge line at a controlled rate.

## 2) BEACH BEHAVIOUR

### 2.1 Width/Volume Relationships

Analysis of Gold Coast survey data showed that subaerial (or "dry") beach width, taken alone, is a poor indicator of the volume of sand present in the active zone, or swept prism (Chapman & Smith, 1980), and is therefore not a reliable index of resistance to erosion. Correlation of subaerial beach width, *per se*, and sand prism volume is poor, and comparisons only become meaningful if beach morphologic states are taken into consideration.

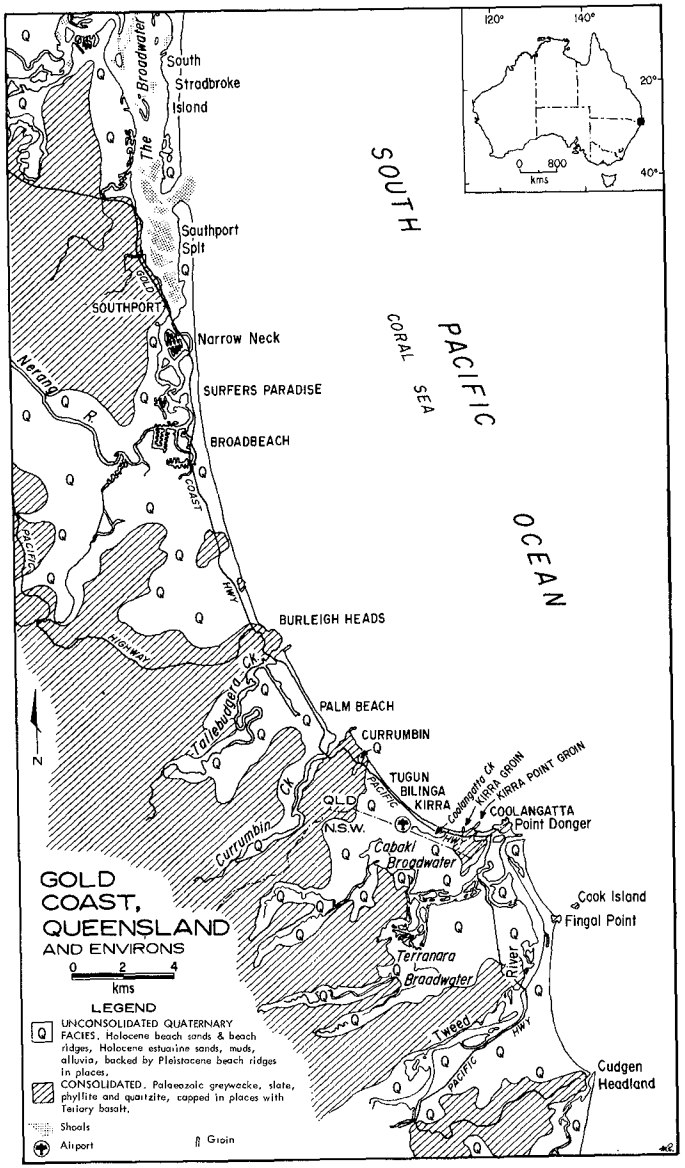

South Stradbroke Island
The Broadwater
Southport Spit
SOUTHPORT
Narrow Neck
SURFERS PARADISE
BROADBEACH
Nerang R.
PACIFIC COAST HWY
BURLEIGH HEADS
HIGHWAY
Tallebudgera Ck
PALM BEACH
CURRUMBIN
Currumbin Ck
TUGUN
BILINGA
KIRRA
Coolangatta Ck
KIRRA GROIN
KIRRA POINT GROIN
COOLANGATTA
Point Donger
QLD
N.S.W.
Coolangatta Broadwater
Cook Island
Fingal Point
Terranara Broadwater
Tweed River
Tweed
PACIFIC HWY
Cudgen Headland
SOUTH PACIFIC OCEAN
CORAL SEA
120°
140°
20°
40°
0 800 kms
N
GOLD COAST, QUEENSLAND AND ENVIRONS
0 2 4 kms
LEGEND
Q UNCONSOLIDATED QUATERNARY FACIES. Holocene beach sands & beach ridges, Holocene estuarine sands, muds, alluvia, backed by Pleistocene beach ridges in places.
CONSOLIDATED. Palaeozoic greywacke, slate, phyllite and quartzite, capped in places with Tertiary basalt.
Shoals
Airport
Groin

FIGURE 1

Net change in volume of the Lower Gold Coast beaches following nourishment is shown in Figure 2, with change in width of the subaerial beach shown in Figure 3. Datum in both cases is the beach state at commencement of survey. Although a net gain of volume occurred, Fig. 2 demonstrates that distribution of change at end of survey was very uneven, with the bulk of the fill remaining close to the delivery point in the form of two large "slugs", or parcels of sand. Comparison of Figures 2 and 3 also shows the importance of the subaqueous profile (or in-shore zone). Shoreline changes do not reflect the true state of erosion or accretion following beach nourishment. The total sand volume contained in the nourished area is critically dependent on the subaqueous profile. Shoreline recessions may be accompanied by accretion of the subaqueous profile. The lack of correlation between Figs. 2 & 3 is significant, showing as it does that width of subaerial beach is not a good indication of sand storage in the total beach system.

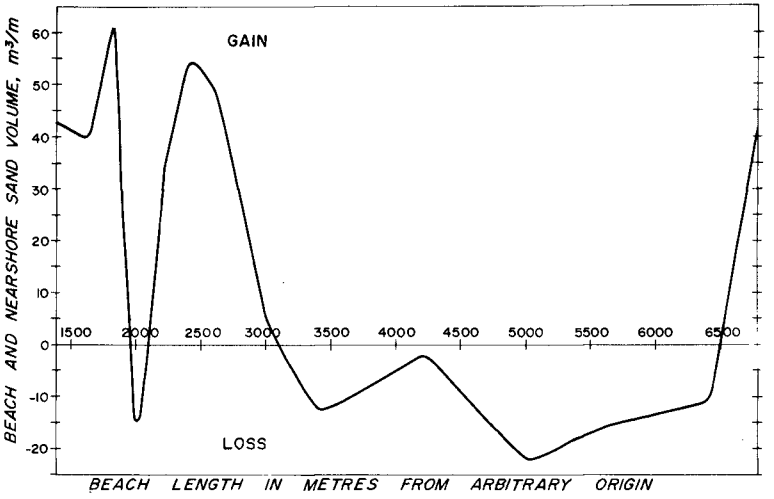
The large slug of sand centred on 2500 metres is almost wholly contained in the subaqueous part of the profile, being poorly reflected in added beach width, whilst small gains in beach width at 2000metres and 3,500 metres do not reflect added volume in the beach prism at these points, but rather the reverse is true.

Most of the active zone of the beach is subaqueous (Chapman & Smith, 1980); a wide subaerial beach may give a deceptive appearance of security to resource managers, since the widest subaerial beach for a given fixed volume of sediment in the active zone, is associated with fully accreted, highly reflective beach states (cf. Short, 1978; Wright, et al., 1979). Beaches in this condition are very sensitive to sudden increase in wave power, which causes rapid transfer of sediment to the subaqueous beach, and corresponding loss of subaerial beach width.

Re-distribution of beach sand by high energy waves was observed on the Lower Gold Coast seven months after project completion, when tropical cyclone "David" crossed the shoreline at about Lat 24°S. A reduction in dry beach width of over 20m occurred over the study area, with overall gradient being reduced from approx. 1:40 to approx. 1:80. The volume of the swept prism (Chapman & Smith, 1980) remained unchanged.

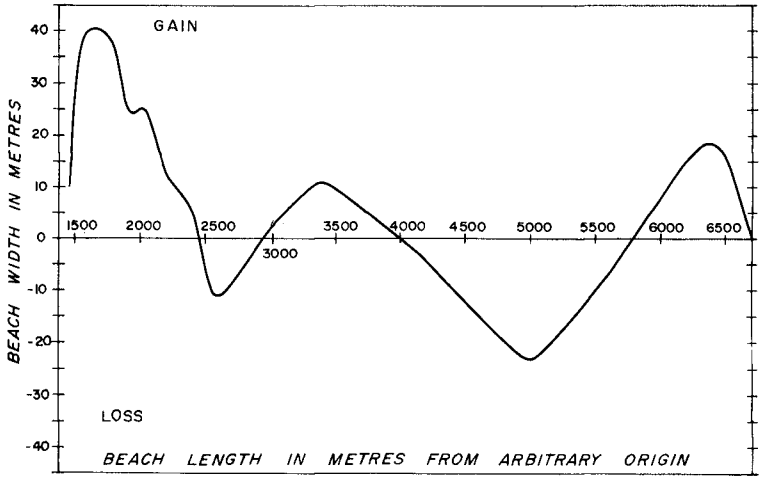
## 2.2 Manner of Sand Movement

It was found that the phenomenon of slugs of sand discussed above was not restricted to the nourishment project. Slugs of sand have been observed at three scales: (a) small-scale irregularities in beach volume revealed by survey as in Fig. 2; (b) medium-scale parcels of several hundred thousand cubic metres, usually associated with the flushing of flood-tidal deltas from estuarine inlets, and their subsequent accession to adjacent beaches; and (c) large-scale slugs of a million cubic metres or more, which appear as somewhat




CHANGE IN BEACH AND NEARSHORE SAND VOLUME

FIGURE 2




CHANGE IN BEACH WIDTHS, KIRRA - CURRUMBIN

FIGURE 3

subtle, low amplitude variations in subaerial and subaqueous sand storage over beach lengths of several kilometres.

Longshore transport, both in the short term of the nourishment monitoring study, and the longer term of some years, was effected by the alongshore migration of these slugs rather than as a continuous longshore flow of sand. Small and medium scale slugs tended to retain their identity whilst moving alongshore (drift direction is south-to-north, or left to right in Figs. 2 &3) for distances of one or two kilometres, but then to diminish in amplitude and to coalesce into large-scale slugs.

Observations of large-scale slug movement, made over a period of 10 years, have revealed the slow longshore progression of forms illustrated schematically in Figure 4. Drift direction is from left to right; longshore movement of identifiable forms is indicated by the oblique arrows. The alongshore movement of the slugs of fill material from Kirra ($1.0 \times 10^6 m^3$) and Surfers' Paradise ($1.4 \times 10^6 m^3$) was particularly evident, since, although diffused with native sand, the fill slugs still exhibited a slightly different hue compared with the native sand in 1980. Calculations of volumes present in the slugs and rates of movement of their centroids indicated that longshore transport volume effected thereby was of the order of $2.0 - 2.5 \times 10^5 m^3 yr^{-1}$, a result remarkably similar to the figures of $2.84$ and $2.52 \times 10^5 m^3 yr^{-1}$ derived for the Lower Gold Coast by intensive volumetric survey and tracer analysis (Chapman, 1978b).

The phenomenon of shore-parallel sediment movement in the form of discrete slugs has also been reported from the New Jersey coast of the U.S., where slugs of wavelength 4000–5000m were observed by Everts (pers. comm.)

## 2.3 Nourishment and Beach Topography

Fill application to the Lower Gold Coast resulted in a beach and inshore morphologic response similar to that observed on the beach sections adjacent to estuarine inlets following flushing by floods of flood-tidal deltas of marine sand contained in them, viz., amorphous inshore shoals, expansion of surf zone width, highly dissipative (as defined by Wright, et al., 1979) conditions, and considerable wave setup.

As the slugs of fill moved alongshore, intensified and persistent rips developed ahead of them, leading to loss of beach width and volume as revealed in Figures 2 & 3. It is thought that a longshore gradient of radiation stress associated with wave setup over the fill slugs may have contributed to scour at the downdrift toe. The intensified rip at 3600 metres from the origin locally modified wave behaviour in the course of a short and relatively minor storm such that wave attack caused sea-wall collapse and property erosion behind the cell.

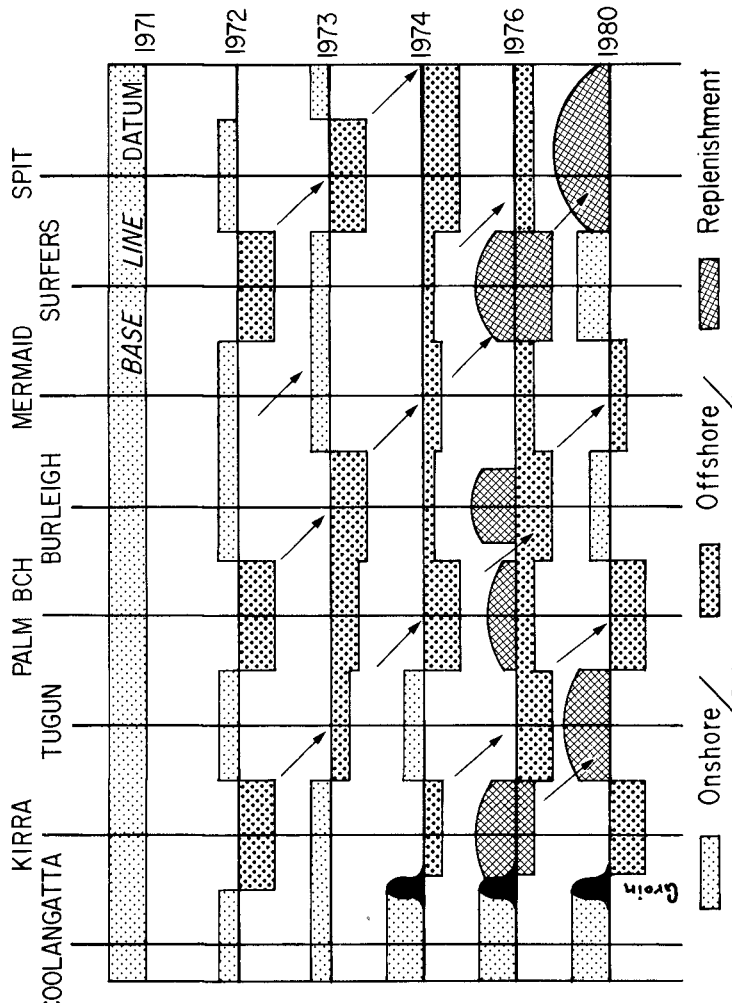

COOLANGATTA
KIRRA
TUGUN
PALM BCH
BURLEIGH
MERMAID
SURFERS
SPIT
BASE LINE DATUM
1971
1972
1973
1974
1976
1980
Groin
Onshore / Gain
Offshore / Loss
Replenishment

FIGURE 4

The phenomenon of scour at the downdrift end of fill on the Lower Gold Coast did not occur at the site of the contemporaneous nourishment project at nearby Surfer's Paradise. At Surfer's Paradise, it was more convenient for the contractor to place the fill by extending the delivery pipe incrementally in the opposite direction to the longshore transport system. No perturbations at the downdrift end of the nourished beach were observed.

## 3) FILL SELECTION & PLACEMENT

### 3.1 Fill Evaluation Criteria

A priori, one might expect that nourishment sand should be texturally matched to native sand if the "artificial" beach is to be successful. It may be anticipated that erosive forces would be less competent to remove sand of a coarser texture, hence use of nourishment sand substantially coarser than native might be expected to produce a more durable beach. Newman (1976) for example, considered that nourishment sand should have a median diameter $1\frac{1}{2}$ - 2 times that of native sand, and the well-known critical ratio concept has been developed around the foregoing assumption (Krumbein and James, 1965) to define the ratio of volume of nourishment sand required to be placed to the volume retained on the beach in equilibrium with shore processes. In most cases critical ratios considerably exceed unity, predicting that the proposed borrow material is less than ideal and that winnowing will selectively remove unsuitable fractions of the fill until it becomes compatible with the existing beach regime.

An alternative approach to evaluating the modification of nourishment sand by beach processes was proposed by James (1975), in the form of the re-nourishment factor which attempts to predict frequency of re-nourishment and to evaluate the long-term performance of proposed fill materials with regard to suitability, maintenance, and expense. The active beach system is considered a compartment which gains sediment through longshore transport and from gradual erosion of the store of sediments forming the backshore, and loses sediment by longshore and offshore transport beyond its boundaries. Fill is viewed as an increase to the backshore store. Sediment particle residence time in the compartment is longer for coarse grained material than for fine; thus a comparison between composite size distributions of native and borrow sediments is used to predict the "lifetime" of fill. A renourishment factor of $\frac{1}{2}$ means that borrow material would be expected to erode at half the rate of native material; renourishment with such borrow material should be required half as often as renourishment with sediment of identical composition to native material. Conversely a renourishment factor of 2 indicates that renourishment would be required twice as often as would be the case if native type sediment were used. The renourishment factor increases with an increasing difference between native and borrow means; the finer the borrow material compared with native, the higher the predicted retreat rate. Poorly sorted borrow material results lower predicted retreat rate since it contains a larger fraction of coarser material which is considered to provide a stable armour.

As the textural correspondence between native and borrow materials used in the Lower Gold Coast project was almost perfect , both the critical ratio and renourishment factor formulae gave values close to unity. However, using data derived from sediments actually present within the dynamic swept prism (Chapman & Smith, 1980) of the Lower Gold Coast, sensitivity analyses made on the formulae cast doubt on their validity. Aggregated samples varied between the limits (mean = 2.0$\phi$, s=0.4$\phi$) and (mean = 2.5$\phi$, s=0.5$\phi$), a remarkably homogeneous sand body; nevertheless both the critical ratio and renourishment formulae predicted that one or the other of these materials would generate quite marked changes in beach behaviour* in an environment where both were demonstrably in equilibrium.

Losses of beach nourishment material have often been ascribed to supposed winnowing of the finer fraction of such material, with the assumption that the fine sediment is lost to the system. Such is not neccessarily the case, for, if a beach is moved into a different state by fill application, and redistribution of material to the inshore and inner nearshore takes place as a result, introduced material is not lost, but merely distributed in a different way to native material. In many cases the "lost" material will still be found within the dynamic swept prism (Chapman & Smith, 1980); absolute loss presupposes the existence of a sink. Accession of fill to the subaqueous part of the swept prism may produce a beach of lower overall gradient, with but slight increase in width, but one in which the swept prism has the capacity to absorb a great deal of wave energy without substantial withdrawal of sand from the subaerial part of the prism.

Introduction of finer-than-native material may well shift the beach regime into a more dissipative regime (cf. Wright, et al, 1979) with wider inshore zone, which could, by causing greater frictional dissipation of wave energy at greater distance from the backshore than in the pre-fill state, enhance erosion resistance. The fine sand, highly dissipative beach also requires more wave energy, compared to other beach states, to produce substantial erosion (Wright, 1980).

Use of coarser-than-native material, on the other hand, could conceivably cause a shift to a more reflective beach regime associated with a narrower inshore zone; this beach state is the one most delicately poised and subject to rapid collapse and removal of sand from the subaerial beach with input of increased wave energy (Wright, et al., 1979).

However, Gold Coast experience indicates that diffusion of fill into native sand may be rapid enough to warrant consideration of a new sand population formed as a mixture of fill and native materials. For the first two months after commencement of fill delivery, advection of added volume occurred principally over the first 1.5 km downdrift of the input point (Fig. 2) but diffusion of nourishment sand was very rapid, and revealed a high degree of over-turning within the sand prism.

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* e.g. the renourishment factor varied between 0.41 and 1.92 in tests cited

Coring of the prism and analyses of tracer concentration (Chapman & Smith 1977) that the ratio of nourishment to native sand could be described by $r = e^{-(y-0.1)}$ where y is distance alongshore in kilometres.

Fill evaluation formulae as discussed above also presuppose the loss of the finest sand from the beach system. However, many microscopic examinations of beach sediments from a wide range of energy environments in eastern Australia have invariably revealed a significant tail of very fine sand, even in the extreme case where phi mean approached zero. Since Hobson & James (1978) have shown that elutriation of fines not in equilibrium with the beach environment can be very rapid, the persistent presence of very fine tails in beach sands suggests that these form part of the normal populations of the beaches concerned. Work in progress also suggests that behaviour of the sediments may be related to the frequency distribution of specific surface, as distinct from mean diameter (Smith & Gordon, 1980), in which case the fine tail achieves greater prominence.

The critical ratio and renourishment factor concepts appear to have evolved from the perception of a wide subaerial beach as the most desirable state, and assume uniform profile retreat under erosion. Rather than searching for field data for verification of the concepts, as has been suggested (e.g. Dean, 1976) it may be that criteria are required for the evaluation of fill suitability in terms of its effect on beach morphology within a given energy environment.

### 3.2 Fill Placement

Fill placement has usually been thought of in terms of a design profile of beach nourishment distribution (Delft, 1970; Silvester, 1974; Vallianos, 1975). Silvester suggested the calculation of an "equilibrium" profile form, whilst Vallianos used the concept of a design profile, complete with shaped dune form. Experience from the Gold Coast suggests that, whilst the design profile concept may be useful for calculation of fill quantities, it is of little value as a practical working criterion for the reconstruction of beaches by means of nourishment, since the procedure assumes both fill retention and morphology are predictable.

The concept of an artificially shaped profile, complete with formed dune, was an essential element in the scheme for the Gold Coast (B.P.A., 1973). The sand supplied to the beach was to be distributed above high water level by bulldozer and vegetation was to be established upon an artificially formed dune. The design concept envisaged that the fill would be placed as high on the beach as possible, covering any boulder walls present, and allowing the surplus only to escape to the swash zone.

However, execution of the concept proved impractical. Emplacement of fill sand in the design profile meant that the unnaturally high "berm" was scarped at high tide. This not only gave the public the impression that fill was being lost by erosion, but made beach access

difficult for swimmers which resulted in public relations problems for the Local Authority.

The artificially formed "dune" concept also proved impractical. Immediately upon drying out, sand began to drift onto the backshore and enroach upon parking areas and esplanades. Moreover, attempts at establishment of the sand-binding grass, Spinifex hirsutus, in the pumped sand proved abortive. The tight packing characteristics and fines content of pumped sand were dissimilar to the lightly packed, free moving sand of the normal accreting foredune. It appears that the dissimilarity was great enough to inhibit Spinifex development.*

Much of the literature on beach management is imbued with static notions of beach equilibrium. The beach must be recognised as a dynamic system, and managed within its dynamic range, for management to be effective. The concept of the equilibrium inshore profile was shown by Chapman (1978b) to be a chimera. Use of an appropriate three-dimensional model allows a number of more-or-less discrete beach stages (or equilibria) to be recognized, as described by (e.g.) Short (1978) or Wright, et al., (1979). Viewed in this context, management of a beach by means of nourishment involves more than merely the addition to the active zone of sand having a suitable 'critical ratio' or 'renourishment factor'. Manipulation of the beach system could involve consideration of the characteristic morphologic states of the beach in question with their probabilities of occurrence spatially and temporally and in relation to most probable energy inputs. Given a variety of possible sediment sources it may be possible to induce beach behaviour of more dissipative or more reflective modes if these were considered desirable. Timing of application of nourishment with respect to existing or probable morphologic states and energy inputs, both from sea and wind, in order to maximise fill utility and encourage formation of backshore dunes, also may be seen as a management variable.

## 4) CONCLUSION

To the lay beach user, or even to the resource manager unfamiliar with inshore morphodynamics, a wide subaerial beach is interpreted as a sign of the presence of a large sediment volume. Results reported above show this perception may be quite erroneous.

A commonly applied guideline of one square foot of beach area gained per cubic yard of fill, may be seen in its general form as an attempt to relate subaerial beach area to volume of the sand prism; however it was shown above that width (or area) of subaerial beach is

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* S.hirsutus is propagated by seed. Vegetative propagation is possible but not practical. The popular Ammophila spp. used in many cool temperate areas, A. Arenaria and A. breviligulata, were unsuitable for the Gold Coast as the sub-tropical location is beyond the environmental tolerance of the latter species.

poorly correlated with volume in the sand prism. Width will depend, inter alia, on beach state and on texture of added sediment.

Commonly-used renourishment factor or critical ratio concepts are unsoundly based; since both use simplistic data as basic input they can at best provide over-simplified approximations of the complex and dynamic beach regime, and no process terms are included in either. Basic to both concepts is the assumption that a coarser-than-native sediment is desirable for fill purposes, and is likely to prove more stable under the wave climate of the problem area. Whilst coarser non-cohesive sediment is less likely to be moved by any given wave than is fine sediment, it does not necessarily follow that coarser sediment will ultimately produce a more stable beach or more desirable beach state than native material.

A beach will be built, by waves, of whatever suitable material is available; high energy wave climates are not necessarily always associated with beaches of coarse sediment, or vice versa.

Sediment size is but one of a matrix of factors responsible for beach behaviour at a site under any given wave climate; varying sand grainsize may simply cause a shift into a different stage in the morphodynamic continuum rather than producing a beach of different erosion resistance.

The design profile concept is useful for computing required fill amounts by comparison with existing beach profiles; however, it assumes that both fill retention and morphology are predictable and that the design profile can be constructed. In practice, in a moderate-to-high energy environment, the concept may be operationally impractical, and establishment of vegetation by seed in pumped-sand "dunes" proved difficult. Fill redistribution by natural marine and aeolian processes proved more effective and economic than attempts to create an idealised profile. Apparent "losses" from the dry beach were accounted for by redistribution in the inshore zone.

Perturbations of the inshore system caused by fill application may affect local erosion patterns and longshore transport in ways which would be unexpected from observation of the beach in its normal state. Radiation stress gradients developed as a result of topography associated with nourishment may lead to intensified erosion adjacent to the filled beach.

If fill redistribution within the dynamic swept prism is seen as normal, and the movement of sediment to the subaqueous part of the prism as morphodynamic change rather than loss of material, it may be possible to consider a wide variety of potential nourishment sources to increase the erosion resistance of a given beach, and even to think of "tuning" to achieve desirable morphologic states.

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