MANAGING EROSION PROBLEMS ON SHINGLE BEACHES:
EXAMPLES FROM BRITAIN

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ABSTRACT: While in general the response to shoreline recession on all beaches is similar, there are significant differences in the best approach on shingle beaches when compared to sand beaches due to their distinct characteristics. Soft engineering, particularly shingle nourishment, is increasingly being favored over hard engineering as it offers greater flexibility at an economic cost. Unlike sand nourishment, offshore losses are usually negligible. Planned retreat is not seriously considered at present, but it may become important if the projected acceleration in sea-level rise becomes reality in the next century.

INTRODUCTION

Shoreline recession appears to be a worldwide problem with over 70% of the sandy shores in retreat (Bird, 1976). Beaches which are composed of significant quantities of shingle (i.e.; pebbles and cobbles) are probably similarly affected by these problems, although detailed figures are unavailable. Such beaches are common where geologic and hydraulic conditions are favorable (e.g.; Carter et al, 1987; Moutzouris, 1988), but are of most coastal engineering and management significance in Britain (Carr, 1983a) (Figure 1). This paper reviews the British experience of managing erosion problems on shingle beaches with reference to the three active responses to shoreline recession, namely: (i) hard engineering; (ii) soft engineering; and (iii) planned...
retreat. The distinct characteristics of shingle as opposed to sand beaches (e.g.; Nicholls and Webber, 1989) needs to be considered when selecting the best solution to recession problems. The last approach, planned retreat, is not being implemented at present in Britain. The background and conditions necessary for such a policy are considered.

SHINGLE BEACH CHARACTERISTICS

The characteristics of beaches composed predominantly of shingle are distinct from sandy beaches due to a number of factors (Table 1). Firstly, shingle is less mobile than sand under comparable wave conditions (e.g.; Komar, 1989). Net littoral drift rates are comparatively small, but still involve significant quantities of material; for instance about $10^5 \text{ m}^3 \text{a}^{-1}$ at Dungeness, Kent (Muir-Wood, 1970). Considerable inter-annual variability of net littoral drift also appears to be the norm (cf. Changkuan and Brampton, 1988). The high threshold of shingle means that movement is usually confined to the wave-dominated portion of the beach profile and hence, unlike sand-sized sediments, offshore losses are very unusual. Exceptions may occur where there is high tidal energy such as Hurst Castle Spit, Hampshire (Nicholls and Webber, 1987a).

Secondly, a shingle beach profile is relatively steep and thus, volumetrically small compared to a sand beach profile (Nicholls, 1988). Vertical wave-induced accretion produces a storm beach with crest heights of over 10 meters above mean high water in some exposed locations (assuming enough material is available). Wave energy is largely absorbed, although there is more wave reflection than on a sand beach. In morphodynamic terms, shingle beaches are reflective (Wright and Short, 1984), although physical model studies have found that the amount of wave reflection is constant at about 10% for a wave steepness greater than 0.02 (Powell, 1989).

Thirdly, all shingle beaches contain some sand even if it is a minor component, and this greatly influences properties such as permeability (Nicholls, 1988; Nicholls and Webber, 1989). It is important to distinguish between steep high-tide shingle/steep low-tide shingle (or Sh/Sh) beaches such as Chesil Beach and steep high-tide shingle/low gradient low-tide sand (or Sh/Sa) beaches such as Bognor Regis (Nicholls, 1988) (Figure 2). The distinction between these two forms is largely controlled by the proportion of sand and nearshore gradients. The pronounced cross-shore sorting on a Sh/Sa beach provides a seaward limit for shingle transport and thus, largely
confines the shingle to the upper beach (Figure 2(b)). In contrast, on Sh/Sh beaches the shingle transport extends offshore and run-up is generally higher.

It is also important to distinguish between shingle banks (analogous to sandy barrier beaches) which protect low-lying land from erosion and flooding (e.g.; much of Chesil Beach, Dorset) and shingle beaches which protect upland from erosion (Figure 3). Shingle banks are important natural features of the coastal landscape in Britain and provide considerable protection for their size. The tendency for vertical accretion and the development of a storm beach and crest reinforces their protective role. Beach recession occurs by two distinct forms of overwashing (Nicholls and Webber, 1989), illustrated in Figure 4:

(a) crest-maintaining (or C-M) overwashing which occurs without reduction in crest height producing a reasonable steady 'rollover' of the shingle bank; most seawater is confined to the seaward side;
(b) throat-confined (or T-C) overwashing which reduces the crest height, causing major 'failure' of the shingle bank and allowing much more wave penetration and onshore sediment transport than C-M overwashing.

An extension of this process reducing whole lengths of the bank to washover flats can occur in extreme events.

When a shingle beach protects upland areas, recession does not occur by overwashing, rather it depends on removal of beach material offshore allowing wave attack of the material behind the beach. When the upland is fronted by cliffs, the engineering geological and geotechnical characteristics of the cliff may need to be considered in addition to the beach. This matter is not considered further in this paper.

SHORELINE RECESSION ON SHINGLE BEACHES

Shoreline position is a function of sediment supply, relative sea-level and wave conditions (e.g.; Swift, 1976). Thus, shoreline recession implies one, or a combination of the following:

(i) deficiency of the local sediment budget;
(ii) rising relative sea-level;
(iii) more severe wave conditions.

Only (i) and (ii) can be demonstrated to be significant at present. While available measurements do suggest
increasing mean wave heights in the North-East Atlantic (Carter and Draper, 1988), these results could be due to natural variability. In the future, with the probability of changing weather patterns due to the 'Greenhouse Effect', (iii) may become important, although in Britain less severe wave conditions appear more likely (Intergovernmental Panel on Climate Change (or IPCC), Working Group I, 1990).

While limited accretion is occurring, most shingle beaches in Britain have been retreating landward during the thousands of years since their formation (e.g.; Blakeney Point, Norfolk (Hardy, 1964; Clymo, 1967); the southern shore of Dungeness, Kent (Eddison, 1983); Hurst Castle Spit, Hampshire (Nicholls and Webber, 1987b); Chesil Beach, Dorset (Carr and Blackley, 1973; 1974); and Slapton Sands, Devon (Morey, 1983)). The rate of retreat is variable, modern rates being in excess of 1 m a\(^{-1}\) at some sites (e.g.; Hurst Castle Spit), while at other sites retreat is most clearly illustrated by geological evidence (e.g.; Chesil Beach and Slapton Sands). Relative sea-level rise would seem to be the most significant factor in these changes, but a lack of new sources of shingle is also of significance.

This long-term recession has been exacerbated at many sites over the last century by various anthropogenic impacts whose importance varies from site to site (e.g.; (i) protecting eroding cliffs which formerly produced shingle; (ii) stopping or reducing bypassing of tidal inlets; or (iii) trapping littoral drift using groins). One of the most dramatic examples of this process is Hurst Castle Spit, Hampshire, a shingle spit which was formerly stable in a dynamic sense (Nicholls and Webber, 1987a; 1987b). This stability depended upon a local source of shingle which was progressively removed starting in the 1930s, causing increased recession rates from a maximum of 1.3 m a\(^{-1}\) (1867 to 1939) to about 3.0 m a\(^{-1}\) during the 1980s. There was a near breaching of the Spit in late December, 1989 which was only averted by emergency engineering works, including extensive cross-shore recycling (see below) and the importation of about 15,000 m\(^3\) of shingle to raise the beach crest.

RESPONSES TO SHORELINE RECESSION

There are three active responses to shoreline recession (National Research Council, 1987):

(a) hard engineering - e.g.; seawalls and groins;
(b) soft engineering - e.g.; beach nourishment;
(c) planned retreat.
The hard and soft approaches can be combined. A fourth inactive response: 'do nothing', may be considered and in some locations this is the de facto policy at present.

Historically, hard engineering was the only response to shoreline recession, but in recent years there has been a move towards soft engineering. One factor is that hard engineering methods generally involve more skilled labor than soft engineering methods (e.g.; building a seawall versus recycling sediment with a truck) with consequently higher labor costs. Furthermore, while the behavior of a beach fill is never completely certain, the soft engineering approach has more flexibility than hard engineering (cf. Anonymous, 1987).

**Hard Engineering**

As on sand beaches, hard engineering approaches can be divided into shore-parallel structures (e.g.; seawalls) and shore-normal structures (e.g.; groins). A number of innovative or unusual schemes have also been implemented where conventional engineering solutions are inappropriate.

**Shore-parallel structures.** A shore-parallel structure will protect the land behind it, but it adds no new material to the beach and if erosion is already a problem there is no reason for it to cease (cf. Kraus, 1988). On the contrary, it can be argued that there are reasons for erosion to increase, particularly as impermeable boundaries, such as seawalls, may promote offshore shingle movement during storms (e.g.; Longuet-Higgins and Parkin, 1962). Thus, over time, the toe or base of the seawall or revetment may have to be repeatedly strengthened as the declining beach offers lower and lower protection to the structure. Thus, these additional costs should be considered when arriving at a solution appropriate to a particular problem.

Seawalls have been built at many sites on the south coast of England (e.g.; May, 1964), often with groins which trap sufficient shingle to maintain a beach and prevent undermining. In some cases shingle banks have been armored to form revetments (e.g.; the most landward 600 m of Hurst Beach in 1967/68). Both of these approaches are presently much less in favor.

**Shore-normal structures.** On Sh/Sa beaches, the shingle is largely 'trapped' at the shore by the natural cross-shore sorting and thus, groins are often more
effective on such beaches than on sand beaches. Groin fields are often designed to limit only longshore shingle movement, letting sand pass alongshore unimpeded (e.g.; Brampton and Motyka, 1987). This ability to trap shingle, either in a field of groins or with a more substantial artificial headland, is extensively utilized in front of seawalls and in shingle nourishment (see below). However, if the littoral drift is limited, groins are ineffectual.

Innovative structures. Flooding at Chiswell behind Chesil Beach, Dorset due to both overwashing (waves passing over the crest) and seepage through the highly permeable shingle is a longstanding problem. These problems were exacerbated by the removal of shingle for construction. In recent years, it was felt necessary to protect the area, but traditional structures and beach nourishment were inappropriate as Chesil Beach is of international scientific importance, particularly because of the almost perfect longshore sorting (Carr, 1983b). Infrequent high energy swell events generated in the Atlantic (e.g.; Nicholls and Webber, 1989) are a problem at the site, but complete protection required an offshore breakwater which was too expensive ($60 million at 1980 prices). Improved drainage and other measures were implemented behind the bank, while the crest was raised and reinforced with a gabion mattress filled with indigenous shingle plus local limestone which would not alter the geological composition of the beach (Figure 5). The gabions are as permeable as the natural beach and yet they hold the crest rigid. Furthermore, as the gabions seaward of the crest are undermined by offshore shingle movement during wave action they will work into the beach until no further movement can occur. Thus, the gabion lends stability to the beach with less material than on an ungabioned beach. To date, an experimental length of this scheme constructed in 1982 has performed successfully and may be extended.

It is unlikely that this method will be applied at other sites as similar constraints do not apply. However, this example stresses the importance of developing innovative techniques for unusual circumstances.

Soft Engineering

Soft engineering is often considered to only have one form, namely beach nourishment, but three distinct categories can be identified:

(1) Cross-shore recycling;
(2) Longshore recycling - from an area of accretion to an area of erosion;
(3) Beach nourishment - importing shingle from outside the sediment system.

The compatibility of beach fill with the natural beach sediments is normally an important consideration in soft engineering (e.g.; Dean, 1983). This is particularly so on shingle beaches as soft engineering often introduces a mixture of shingle and sand to the beach face. Such sediment mixtures are rarely present on the surface of the supratidal portion of 'natural' shingle beaches, largely because they are relatively impermeable when compared to openwork shingle (i.e.; with little or no sand) and are readily eroded by wave action. Furthermore, any subsequent onshore sediment transport returns openwork shingle to the beach face. Shingle and sand beach fill is similarly eroded, sometimes producing near vertical beach scarps up to 2 m high (Nicholls and Webber, 1989). Beach scarps of this size are not a feature of 'natural' shingle beaches and may cause safety problems with public use of the beach. Although in some cases it may be possible to avoid the problem at source, when sand and shingle mixtures are placed on the beach face, scarping should be expected and included within the design process. In effect, scarping is part of the sorting and profile adjustment of the beach fill which is necessary to produce an hydraulically stable cross-shore sediment distribution.

Cross-shore recycling. On some shingle banks (e.g.; Hurst Castle Spit) it has been a common practice to recycle shingle across the beach to raise the crest; particularly to fill any washover throats which develop with the associated washover deposits (Figure 4). The aim is obviously to reduce beach recession and in the short-term this approach can have some success. However, T-C washover deposits often contain significant quantities of sand in addition to shingle. Thus, the washover deposits are often less than ideal as beach fill and such sites are preferentially eroded and overwashed in subsequent storms. It would be more effective (although probably more costly) to import small quantities of sand-free shingle to infill throats.

More fundamentally, cross-shore recycling does not remove the fundamental reason for shoreline recession which is insufficient cross-sectional beach volume. It should only be seen as a short-term measure to reduce recession rates while a more permanent solution is determined. The net effect of this procedure on recession rates is unknown, but there is every reason to assume that erosion rates are reduced. Thus, this approach has merit at sites where no money is available for more
costly alternatives, but it must be appreciated that recession will continue, albeit at a reduced rate.

Longshore recycling. Where beaches are prograding and there is an excess of shingle, such as Rye Harbour, Sussex (near Dungeness), it can be recycled to eroding updrift (or other) sites by truck, a solution which is relatively cheap when compared to the cost of building structures. This approach does increase the beach cross-sectional area and thus is a much more effective solution to shoreline recession than cross-shore recycling. However, the downdrift implications of such recycling always need to be considered. Longshore recycling has been applied successfully in Sussex (Foxley and Shave, 1983) and at Dungeness nuclear power stations (Muir-Wood, 1970). It offers great flexibility on coasts where the littoral drift fluctuates significantly on an annual basis (to exploit this flexibility requires regular beach monitoring so that beach volume is known in real-time). Beach scarping does not appear to be a major problem because the recycled shingle is usually undersaturated with sand. However, each site must be considered on a case-by-case basis.

Beach nourishment. Nourishment of sand beaches is presently a controversial topic in the United States with the utility of the approach being called fundamentally into question (Houston, 1990; Pilkey and Leonard, 1990). A detailed literature review of nourishment projects has clearly demonstrated that shingle nourishment on several continents is more successful and less controversial than sand nourishment (Davison, Nicholls and Leatherman, in prep). In Britain, interest in shingle nourishment grew largely from an appreciation of the benefits of longshore recycling (e.g.; Foxley and Shave, 1983). The available material for recycling was limited, so external sources of shingle were considered. Another benefit is that relatively small volumes of beach fill are required because of the steep reflective nature of shingle beaches. Shingle nourishment is becoming increasingly important because it is often the most cost effective solution (cf. Powell, 1989). The largest projects to date are at Hayling Island, Hampshire in 1985 (0.5*10^6 m^3 - about $8 million) and Seaford, Sussex in 1987 (1.5*10^6 m^3 - about $24 million).

The compatibility of the shingle beach fill with the native beach is of less concern than the role of the sand fraction. Normally, a similar or coarser grain size is selected. In the later case this can lead to selective sorting of the beach fill and native sediments (Nicholls and Webber, 1987c). In large-scale nourishment the
original beach is largely buried and such interaction is less important.

Offshore losses are generally negligible due to the cross-shore sorting already described. On Sh/Sa beaches, the depth of closure for the shingle portion of the beach (cf. Hallermeier, 1981) can be measured at low tide with a simple beach profile greatly simplifying the design. The low-tide sand portion of the beach can be virtually ignored. On Sh/Sh beaches, the depth of closure extends offshore, but not to as great depths as on a sand beach and with no negligible loss to the system under typical conditions. Longshore losses can be controlled by groins or more substantial artificial headlands. This approach is most effective on Sh/Sa beaches for the reasons already outlined. Longshore recycling, or effectively managing the longshore redistribution of the shingle after nourishment, can also be integrated into a nourishment scheme where appropriate. This approach contrasts with sand nourishment where longshore losses are accepted (e.g.; Dean, 1983). Thus, in general the beach fill is more easily controlled during shingle than sand nourishment and a combination of shingle nourishment and groin or artificial headland construction is usually most effective.

Shingle nourishment can use one of two sources: (i) land-derived; or (ii) marine-dredged beach fill. The latter method is normal for the larger schemes and has thus been dominant in Britain on a tonnage basis in the last few years. The land-derived beach fill usually consists of cobble-sized gravel rejects from aggregate sources. They are highly permeable and hence stable in supratidal environments. In contrast, marine-dredged shingle normally contains considerable quantities of sand due to (i) source and (ii) delivery methods. At Hayling Island, the dredged shingle was pumped into split bottom barges and dropped on the foreshore on the rising tide. On the falling tide, the shingle was recovered to form the design profile. This method inevitably mixes the sandy foreshore sediments with the already sandy beach fill and 1.5 m high beach scarps developed. At Seaford, the shingle was pumped directly to the shore with a consequent reduction in the proportion of sand and the problem of scarping was significantly reduced. Thus, marine-dredged beach fill is usually initially unstable on the beach face of a shingle beach with consequent scarping. While improvements in technology such as at Seaford may reduce this problem, scarping should be expected and included in the design.

An interesting example of the future development of
shingle nourishment is given by the problems at Hurst Castle Spit which have already been mentioned. The main sediment sink at this site is a large offshore shingle bank, called the Shingles Bank (Nicholls and Webber, 1987a; 1987b). Using this source of shingle could be considered recycling rather than nourishment as the Shingles Bank is part of the same sediment system, but this is largely a matter of semantics as a nourishment approach is required. The Shingles Bank is very shallow and large waves partly break on it providing significant protection to the Spit. Thus, removal of shingle from this source is permissible to maintain the Spit, but inappropriate for commercial use of the aggregate.

Planned Retreat

There is presently little experience with planned retreat (as opposed to 'do nothing') in Britain. Although more developed, such policies are still in their infancy in the United States. Recent and pending U.S. legislation may soon make this alternative more attractive. Any future change in Britain will obviously depend largely upon cost benefit decisions. For instance, an alternative to the construction of gabions, etc. at Chesil Beach (see Hard Engineering) was to abandon Chiswell with suitable compensation to the affected property owners. This option had a clearly defined reasonable cost and complete success was guaranteed, including solving the problem of the infrequent, long period swells. While Chesil Beach is receding landward, the rate of retreat is barely discernable on maps (Carr, 1983b) so the problem would have been solved for the foreseeable future. However, political considerations obstructed any detailed exploration of this option (Carr, 1983b).

In general, planned retreat involves establishing one or more setbacks using some projection of future shoreline behavior. Seaward of any setback, certain or all types of construction would be forbidden. Any construction would have to be up to certain rigorous standards. National Research Council (1990) looked at the erosion setbacks required for Federal flood insurance purposes and recommended various setbacks using 10, 30 and 60 times the average annual erosion rate (or AAER) (Figure 6). The AAER is to be established using historical shorelines from maps and aerial photographs. In the longer term, more sophisticated Monte Carlo simulations of shoreline evolution should be developed and utilized. This approach projects future shoreline position in a statistical sense. A similar approach could be applied on shingle shorelines.
A setback (S) can be defined by:

\[ S_n = C + N \times Y \]  

Equation 1.

where:
- \( C \) is a constant for a particular site;
- \( N \) is the time interval in years of the setback;
- \( Y \) is the AAER.

Any setback should be mobile in time and migrate inland with shoreline recession.

The value of \( N \) will depend upon land use and policy considerations. Regarding the AAER, in Britain as in the U.S.A., there is a sufficient database of maps and aerial photographs to establish meaningful values. The value of \( C \) (which is set to zero in National Research Council, 1990) should take into account:

(a) the variance of shoreline position about that predicted by the AAER (e.g.; (i) seasonal fluctuations, or (ii) what is the probability of an extreme storm causing recession many times the AAER);
(b) the recession process.

For instance, there is a higher risk of damage to property behind a shingle bank prone to T-C overwashing than one prone to C-M overwashing (Figure 4). Any proposed setback should take this greater risk into account by specifying a larger value of \( C \). Unfortunately many shingle banks are subject to both forms of overwashing (e.g.; Hurst Castle Spit - Nicholls and Webber, 1989). When the shingle beach protects upland the danger of flooding associated with the loss of shingle bank protection is not present. This is not to say that significant recession cannot occur in single storms. Assigning values to \( C \) is beyond the scope of this paper.

If rates of shoreline recession increase because of accelerated sea-level rise planned retreat will require more serious consideration (IPCC Working Group III, 1990). The long lead time to make this strategy most effective requires that some attention be given to this problem today and studies such as Halcrow (1988) are to be welcomed. For instance, the high land values in Britain may mean that such a policy will never make economic sense, even if the worst sea-level rise scenarios become reality, while in parts of the United States it may be an important response, albeit on non-shingle shorelines.
DISCUSSION

The success or failure of any particular strategy depends upon the initial aims and objectives. Normally, protection at reasonable cost is favored and as such it appears that soft engineering and, in particular, beach nourishment is presently best achieving this aim. Continued use of shingle nourishment can be expected as the problems associated with this approach, such as scarping, are relatively trivial and easily managed. However, it is unlikely that shingle will be used on major resort sandy beaches such as Bournemouth since it reduces their recreational potential. Rather, nourishment with sand can be expected (e.g.; Lelliott, 1989). The widespread acceptance of shingle nourishment in Britain can be attributed to replacing like-with-like. Shingle nourishment has been utilized on a sand beach at Highcliffef, 10 km west of Hurst Castle Spit (Tyhurst, 1985), but this was not a major resort. How widespread such an approach will become is uncertain and will depend largely on political and public acceptance.

An important characteristic of Sh/Sa beaches, which represent a significant proportion of the shingle beaches in Britain, is that the high-tide shingle portion and the low-tide sand portion can be considered almost independently of one another. In essence, the low-tide sand portion of the beach can be virtually ignored, greatly simplifying the problem of boundary conditions. This contrasts with sand beaches where whole profile out to the depth of closure must be considered (e.g.: Dean, 1983). Thus, it is important to distinguish between Sh/Sh beaches and Sh/Sa beaches, for instance in any large-scale coastal mapping or coastal management decisions. In general, it will be much cheaper to deal with shoreline recession on a Sh/Sa beach than a Sh/Sh beach, because less shingle will be required to attain a stable profile and the movement of the shingle is more restricted.

However, this raises the question of the long-term impact of the present engineering approach on shingle beaches. The preferential trapping of shingle in groins and shingle nourishment may lead to a decline in the proportion of sand with time. At many sites, the sand is only a thin veneer over easily-eroded geological deposits. The erosion of these deposits can be expected to continue into the future. Thus, with time many beaches in Britain may become steeper although the timescale of these changes is uncertain. A complete change from Sh/Sa beaches to Sh/Sh beaches is possible with the attendant
changes in beach processes. Such a trend is already apparent in some long-term cartographic analyses of beaches (May, 1964), particularly where the shingle is being held by seawalls and groins (e.g.; Bognor Regis). In a more general study, Halcrow (1988) found that 78% of the beaches in East Anglia were steepening, although many of these were not composed of shingle. However, these results could be questioned and more rigorous and complete analyses would be useful using both maps and aerial photographs (cf. Carr, 1980; Leatherman, 1983) and any profile data.

This is not to say that present management practices on shingle beaches are wrong; rather these long-term changes in the beach composition and slope should be expected although the rate is uncertain.

CONCLUSIONS

All shingle beaches offer the considerable advantage over sand beaches of protection from wave action for comparatively small beach volume. However, the distinction between Sh/Sh and Sh/Sa beaches is fundamental and useful to combat shoreline recession. In general, solutions to such problems will be much cheaper on Sh/Sa beaches because of the favorable boundary conditions.

Soft engineering is increasingly favored over hard engineering on shingle beaches, although this does not preclude the use of hard engineering (e.g.; groins or artificial headlands). Beach nourishment, generally using offshore sources of shingle, is becoming the most common form of soft engineering. This trend is expected to continue. The long-term consequences of this policy on beach composition and slope could usefully be evaluated and quantified.

Planned retreat is not presently considered as a serious option in Britain. The strong likelihood of accelerated sea-level rise due to global warming means that it may have to be considered more seriously in the future. A sound understanding of shingle beach dynamics is essential for all the management strategies outlined in this paper.
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REFERENCES


Table 1. Characteristics of shingle versus sand beaches.

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<td>5. Cross-shore sorting: significant v. less significant.</td>
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Figure 1. The British Isles, indicating locations referred to in the text: BO - Bournemouth; BR - Bognor Regis; BP - Blakeney Point; C - Chesil Beach; D - Dungeness; HU - Hurst Castle Spit; HI - Hayling Island; S - Seaford; SS - Slapton Sands.
Figure 2. Diagrammatic cross-section of: (a) a high-tide shingle/low-tide shingle (Sh/Sh) beach; and (b) a high-tide shingle/low tide sand (Sh/Sa) beach, including the cross-shore distribution of the percentage of sand in the surface sediments. In (b), X indicates the seaward limit of significant cross-shore shingle transport and may occur below low water.

Figure 3. Diagrammatic cross-section of: (a) a shingle bank (or barrier); and (b) a shingle beach protecting upland or cliffs.
Figure 4. Diagrammatic cross-section illustrating: (a) crest-maintaining (C-M) overwashing; and (b) throat-confined (T-C) overwashing. Erosion seaward of the crest is not shown.

Figure 5. Diagrammatic cross-section of gabion reinforcement of a beach crest: (a) at time of installation; and (b) after an equilibrium has been attained.
RECEDING SHORELINE

ZONES

E-10 Imminent Hazard
E-30 Intermediate Zone
E-60 Longer Term Hazard

SETBACKS

No New Habitable Structures
Moveable Single Family Structures
Readily Movable Structures

FLOOD INSURANCE

Existing Coverage Required To Be Maintained

Eligible For Relocation Benefits, No New NFIP Policies

NOTICE OF EROSION HAZARD

Large Structures Allowed

Reference Feature
E-10 Line
E-30 Line
E-60 Line

E-10 Zone
E-30 Zone
E-60 Zone

Example Profile With Lines and Zones Illustrated (Not to scale)

Summary chart of E-lines and E-zones.

Figure 6. Example of setbacks (after National Research Council, 1990).