Effectiveness of beach control operations

HR Wallingford

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NRA

National Rivers Authority

Effectiveness of beach control operations

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FOREWORD

In recent years there has been an increasing move away from traditional methods of coast protection (eg. seawalls, revetments, breakwaters and groynes) and towards a "softer" approach which involves active beach management (eg. beach nourishment, recycling, reprofiling and bypassing). However, despite this trend, and despite a wealth of literature, there is very little in the way of comprehensive and consistent information on active beach management.

Because of this lack of design guidelines the National Rivers Authority in conjunction with the Ministry of Agriculture, Fisheries and Food have been carrying out a number of interrelated research studies into beach management methods. These studies will be brought together within a Beach Management Manual, which will be prepared and published by the Construction Industry Research and Information Association (CIRIA). The present report describes one of these studies and assesses available information on the effectiveness of the various methods of active beach management.

The report has been prepared by members of the Coastal Group at HR Wallingford. The authors gratefully acknowledge the assistance of various NRA regions and of other local coast protection authorities who have provided information on the various forms of beach management currently in use.

EXECUTIVE SUMMARY

The effectiveness and performance of "passive" beach control structures such as groynes, offshore breakwaters, revetments and seawalls is well documented and understood. By contrast "active" beach control techniques involving mechanical or hydraulic manipulation of beach material, are relatively new, untested and poorly understood.

This report reviews existing knowledge on active beach management methods, including beach and nearshore seabed nourishment, alongshore recycling, cross-shore reprofiling, sediment bypassing and beach stabilisation by drainage of the water table. The effectiveness and suitability for different coastal conditions of these methods is assessed, and where present behaviour is poorly understood, the need for further studies is determined.

KEY WORDS

Beach management, beach nourishment, nearshore nourishment, beach recycling, beach reprofiling, sediment bypassing, beach drainage systems, perched beaches, coastal cells.

1. INTRODUCTION

This project forms part of a research programme which is being carried out within the National Rivers Authority R&D Commission "C - Flood Defence" under Topic "C06 - Coastal and Estuarine Works/Structures". The project is one of five interrelated studies which are aimed at contributing to a Beach Management Manual, which will incorporate current practice and research findings, to direct engineers on aspects of planning, design, implementation and management of beaches and beach recharge schemes.

The overall objective of the project as set out in the Terms of Reference is "To assess available information on the effectiveness of different beach control operations, and to examine the potential for field trials of sub-surface drainage and other methods, and present it in the required format of the Beach Management Manual."

The specific objectives (or aims) of the project are:

1. To examine and report on the effectiveness of:

   a. periodic nourishment, or "top-up" operations
   b. mechanical re-profiling of beaches
   c. recycling and by-passing of beach material
   d. altering flows through the beach by installing sub-surface drainage

   and any other methods, based on practical experience of their uses in the UK and abroad. The need for further research, particularly the need for field trials and monitoring, will be set out.

2. To advise, where possible, on the best method of beach control for a particular site, or type of beach.

3. To build upon, and extend, work currently being carried out by HR Wallingford in a research commission for MAFF (FD0704).

4. To include this information in the first edition of the Beach Management Manual.

Details of the project are found in the Research Contract whose reference is NRD058. Briefly, the research contractor (HR Wallingford) is to:

1. Review and define alternative beach control methods.

2. Carry out a search of literature, and provide complete list of relevant papers and articles. This should cover ICE, ASCE, ICCE conference proceedings, and other readily available sources covering practice and theory in the UK and abroad.

3. Contact NRA Regions, and local district authorities to obtain information and data on beach management methods and costs.

4. Summarise present knowledge on methods identified, including opinions on cost-effectiveness.

5. Draw out recommendations on potentially suitable control methods for different types of beach.

6. Recommend possible future research into beach control operations, including the need for field trials and monitoring of novel techniques in UK conditions.

This report describes the literature search and a review of present knowledge on beach control methods as gained from contacts with local coast protection authorities. The main findings will be used as input to the Beach Management Manual.

In the report we have concentrated our efforts on the assessment of "active beach control" techniques, that is, the reworking of beach material by mechanical or hydraulic means. This report also includes an examination of beach drainage methods where the beach is reworked indirectly, by means of lowering the water table by pumping or other means of enhancing natural drainage. We have not considered "passive beach control" structures, such as groynes, offshore breakwaters etc. However the effectiveness of perched beaches has been examined here since this method of erosion control is often linked to (active) beach nourishment.

Section 2 of the report gives a definition and very brief description of the various beach control methods examined in this study. This is followed by a literature search in Section 3. The effectiveness and applicability of the various control methods is described in Section 4, drawing upon the findings of the literature search, the questionnaire returns, anecdotal evidence and the general experience of the authors. Section 5 gives the main conclusions of the study, and is followed by recommendations for further work in Section 6.

2. DEFINITION OF BEACH CONTROL METHODS

2.1 General

Following the literature search a number of alternative beach control methods, in addition to those set out in the Research Contract, have been identified. The methods now covered by the review cover the following:

(a) periodic beach nourishment

(b) nearshore nourishment

(c) mechanical beach reprofiling

(d) bypassing or recycling of beach material

(e) beach drainage systems

(f) perched beaches.

2.2 Beach control methods

2.2.1 Periodic beach nourishment

Beach nourishment is the process of supplementing the natural supply of material to a beach, using imported material. Normally beach nourishment is used to make up losses which have occurred as a result of changes in the supply of material from updrift sources, or caused by offshore losses, for example, as a result of turbulence caused by wave reflection from a sea wall. More rarely beach nourishment is used to compensate for the organised removal of material from a beach for industrial use or by nearshore dredging (eg. of a port approach channel).

Once a beach has adjusted to the fresh supply of material it is usually subject to the same hydraulic forces prevailing previously and the process of beach depletion is likely to begin again. The beach is therefore likely to require further nourishment at some stage in the future. The definition given above encompasses both restoration, carried out to increase the size of a depleted beach, and renourishment, which normally consists of smaller additions of material for maintenance of the initial nourishment. In the present review no distinction has been made between the two.

2.2.2 Nearshore nourishment

Nearshore nourishment is the process of adding imported material by means of dumping dredged material in the nearshore zone, that is seaward of the low water mark. Nearshore nourishment has been used for the disposal of maintenance dredgings, which normally consist of fine sands and silts. There are two forms of dump sites, stable or dispersive ones. Stable dump sites can provide shelter to the adjacent beaches by attenuating wave energy, hence providing conditions favourable for beach accretion. Dispersive sites, if carefully designed, may not only attenuate wave energy but may also provide a source of material for beach nourishment.

2.2.3 Mechanical beach reprofiling

Mechanical beach reprofiling involves the adjustment of the beach profile from its natural profile to an artificial one, and is often used to slow down a natural process of beach change (eg. drawdown by storm wave action). It is carried out by land based plant and normally involves the transport of material from the lower part to the upper part of the beach. By doing so the upper beach width is increased while the intertidal beach slope is steepened. This form of beach adjustment is usually carried out as a short term protection against beach recession. Because of increased beach steepness, the wave reflectivity is increased and beaches are often destabilised by this measure. In rare circumstances beach reprofiling may also be carried out by transporting sand from the upper to the lower part of the beach as a means of controlling littoral transport (ie for controlling the feed of material to sand bypassing systems).

2.2.4 Recycling/bypassing of beach material

There is no universally acceptable definition of the term beach recycling. In the context of beach control operations recycling is considered to be the moving of material from the downdrift end of a stretch of coast and its return to the updrift end. Implicitly it is assumed that the recycled material will be available to be moved by longshore (wave induced) transport and that it will ultimately make its way back to its original position, from whence it can be recycled. Bypassing of material is defined in the CIRIA Rock Manual (1991) as "Moving of beach material from the accumulating updrift side to the eroding downdrift side of an obstruction to longshore transport (eg. inlet or harbour)."

2.2.5 Beach drainage systems

Beach drainage systems are artificial works by which the water table in the intertidal beach zone is lowered and the natural wave energy absorbing capacity of a beach is enhanced. Active drainage systems are ones in which the lowering of the water table is achieved by means of pumping. Passive drainage systems are ones in which "natural de-watering" of a beach is encouraged by the installation of drains.

2.2.6 Perched beaches

Perched beaches are artificial ones which are maintained at a higher than natural beach level. This is carried out to increase the width of the upper beach. Perched beaches are normally contained by an artificial sill, whose purpose is to attenuate wave energy as well as providing a containment structure. Such beaches are often of imported material and are associated with the construction of completely new beaches as well as the rehabilitation, or improvement of existing natural beaches.

3. LITERATURE REVIEW

3.1 Beach nourishment

3.1.1 General

There is an increased awareness of the role that healthy beaches can play in coast protection and as a result there has been a move from traditional hard defences (eg. revetments and sea walls) towards softer options such as beach nourishment. Beach nourishment can take a number of forms. On shingle beaches it is often economical to carry out recycling of material within an identifiable coastal unit. On sand beaches exposed to swell wave action, on the other hand, it may be possible to place sand in the nearshore zone and allow wave and tidal current action to disperse it within the littoral zone. The most widely used method, however, involves the direct placement of material on the beach, either from an offshore borrow area or, in the case of small renourishment operations particularly, from a landward source. Such nourishment usually has the most tangible benefits, both from the viewpoint of coast protection and beach usage. Davison *et al* (1992) list a number of benefits of beach nourishment, which include:-

(i) wider beaches, giving enhanced wave energy dissipation and hence a greater level of natural protection against storm induced damage;

(ii) a larger intertidal area having greater amenity value than a narrow beach backed by conventional hard defences;

(iii) addition of beach material being able to be carried out without the negative downdrift effects associated with hard coastal defences;

(iv) generally lower costs, which are more evenly spread in time, compared to capital schemes involving hard defences;

(v) the ability of protection to adjust to changing climatic conditions as a result of the beach profile being able to readjust readily, compared with hard defences which generally lose effectiveness with time.

Beach nourishment does have its critics, however, particularly in the USA where it has been practised on a large scale for many years. A heated debate continues to take place, particularly about the value and lifespan of beach nourishment and beach re-nourishment schemes (Leonard *et al* 1990, Houston 1991). Nourishment schemes have often been accused of failing to match the expectations of coastal users. Many early projects in the USA were built with little verification of predicted performance and with little post-project monitoring. As a result it has been difficult to judge the success or otherwise of many of these schemes. Many early schemes were also subject to very high losses as a result of rapid alongshore as well as seaward dispersal of the nourishment material. Quite often this was the result of the material from borrow areas being considerably finer than the native material and therefore being subject to much more rapid dispersion.

3.1.2 Overseas experience with sand beaches

The success or otherwise of a number of major nourishment projects is described by Walton and Purpura (1977). They evaluated the loss rates for a number of beach nourishment schemes ranging from relatively small losses at a number of locations in Florida (Key Biscayne, Florida) to losses in excess of the original placement volume in as short a time span as 2 years (Hunting Island, South Carolina). In all the USA case studies, beach nourishment was carried out with sand, in areas of low tidal range (typically 2m on spring tides) and low to moderate wave activity (in some cases the "average annual wave height" being about 0.3m). Among the reasons given for high initial erosion are (i) losses of fines from the sub-aerial beach seawards beyond the limits of monitoring; (ii) a poor understanding of littoral processes, resulting in losses of material into adjacent inlets, in some cases by littoral drift and in other cases by a combination of waves and strong tidal currents; (iii) underestimation of the losses likely to be incurred as a result of the impact of severe storms. The authors conclude that the variable success of these projects indicated that considerably greater effort was needed into assessing likely loss rates, fill characteristics, littoral processes etc. before it can be determined under what conditions beach nourishment is likely to be an efficient means for mitigating the effects of beach erosion. More recent studies by Ashley *et al* (1987) underline the need for careful assessment of the nature of the longshore regime into which nourishment material is to be introduced. The authors describe the fate of nourishment material placed downdrift of Barnegat Inlet on the New Jersey (Atlantic) coast. Extensive post-project monitoring has shown that the emergency beach fill, placed south of the inlet on an eroding beach, migrated northwards into the inlet as a result of local "counter drift". The sand thus migrated from an area where it was most needed, into an area in the lee of the jetty which least required protection. Because of this rapid and unexpected loss of material into the inlet the authors concluded that the nature of the beach fill and the disposition of local current patterns should have been investigated before embarking upon the scheme.

It is evident that the evaluation of beach fill performance is made difficult by the lack of good quality monitoring data. The point is made by a number of coastal engineers that the visible part of the beach is only part of the active beach profile. Initial losses from a beach nourishment are often necessary adjustments to a more natural profile from an initially unnaturally steep "construction" profile. The argument is made that these adjustments are allowed for in the design procedure by a so-called overfill allowance. While this is certainly the case in many instances, it is at the very least poor public relations to monitor just the sub-aerial part of the beach after completion of the scheme, if this argument is used to justify inclusion of the submerged beach as part of the nourishment profile.

One nourishment project which has been extensively monitored was that carried out at Indialantic/Melbourne Beach on the Atlantic coast of Florida (Stauble and Holem 1991). The area has a low tidal range (not specified, but less than 1m during mean tides) and a wave climate which is dominated by extreme extra tropical storms (occurring in late summer and autumn). There is a nett southward littoral drift (magnitude unknown). Beach profiles show that the active profile extends to 3m below MSL or more, from a dune crest height of up to 6m. Here some 195,000m^3 of sand were placed over 3.4km of beach in the winter of 1980. The beach had been surveyed for about 1 year prior to nourishment and surveys were continued for about 8 years after fill placement. The beach profiles and beach samples indicated that the beach fill had stabilised within 1 year, after which the nourishment material underwent seasonal cycles of erosion and accretion similar to those of the native material. The high losses directly after placement took place as a result of the nourished berm being rapidly reshaped by wave processes. This initial loss from the nourishment area caused deposition offshore, as well as gain in an alongshore direction. The frontage was hit by several severe storms and the beach profile analysis illustrated the beach losses and subsequent recovery following these storms. The cumulative changes in beach volume above low water showed that there was some 60% loss of material in the first 12 to 18 months and the beach then remained some 30% in excess of its pre-nourishment volume for about 2¾ years. A series of severe storms in 1984/5 and again in 1986 caused the beach to drop to below its pre-nourishment level. Recovery by natural processes was monitored, and this showed that after 7 years the beach had approximately 13% more sand above low water than before the project. Thus, despite the initially rapid losses the beach provided significant backshore protection for at least 4 years and marginal protection for a further 3 years. Dunes to the north and south of the nourished frontage exhibited retreat of 3 to 5m during a severe storm, known as the Thanksgiving Weekend storm of 1984. The storm caused significant beach erosion within the nourished area, but within the nourishment limits there was little or no dune line retreat. The post construction monitoring thus helped to demonstrate the effectiveness of the nourishment in reducing storm damage. Had this monitoring not been carried out, the very rapid "cross-shore adjustment" may well have been perceived as an effective loss, having little hand in protecting the upper beach. This project demonstrates the usefulness of a high beach berm as a means of "short-term" backshore protection. However, it also demonstrates the vulnerability of beach nourishment material to rapid erosion. The authors conclude that "More research is needed into long term fill project behaviour to assess the length of project viability and the prediction of renourishment requirements."

Another major nourishment project which is perceived to have performed with less than complete success is the latest in a series of beach fills at Atlantic City, New Jersey. The area is at the northern end of a 10 mile long barrier island. The sand beaches were once backed by dunes but the backshore is now intensely developed and the beaches stabilised by groynes and jetties. The mean tidal range in the area is 1.25m. Wave action is moderate with the 1:100 year significant wave height in 9m water depth being estimated as being 4.4m. The average annual littoral drift is estimated as being 190,000m^3 in a northeasterly direction and 305,000m^3 in a southwesterly direction, giving a nett southwesterly transport of about 115,000m^3. In the spring of 1986 some ¾ million m^3 of sand were obtained from a large submerged shoal at the mouth of Absecon Inlet and deposited along some 2700m of the highly developed Atlantic City shoreline south of the inlet. Beach profiles, extending seawards to "wading depth" showed that early losses above NGVD (approximately mean sea level) amounted to a 60% reduction in volume within 2 years of the operation, but after more than 4 years about 30% of the volume was still present on the sub-aerial beach. Despite these losses the scheme was considered to be more successful than earlier ones (Weggel and Sorensen 1991) because groyne and jetty maintenance works carried out 2 years before the fill operation, are believed to have retained the fill more effectively than earlier schemes in this area. In particular the raising of the crest of the inlet jetty in 1984 prevented the northward movement of the fill by a local counter drift, and by wind blown sand losses, as occurred in earlier operations (Everts *et al* 1974). Also it is believed that more of the fill remained within the nourishment area than the beach profiles reveal. (However actual offshore losses are unquantifiable due to lack of bathymetric data.) Certainly the earlier operations in 1963 and 1970 are deemed to have been less successful, with much higher loss rates for fill material than those of adjacent native beach sand (Everts *et al* 1974) indicating that an overfilled beach may lose material much more quickly than an already eroded beach. The authors make various recommendations about post-fill monitoring indicating that the offshore area should also be surveyed so as to be able to account for as much of the total sand budget as possible. This recommendation was clearly not taken up and the project performance suggests that some doubts remain as to the efficiency of the 1986 nourishment operation.

One beach fill operation which is notable for its extensive post-project monitoring is described by Houston (1991) in response to criticisms made by Pilkey (1990) about the lack of longevity of beach fills on the Atlantic coast of USA. The beaches at Ocean City, Maryland were nourished with some 1.7 million m ^{3} of sand over a 13km stretch of barrier beach, from Ocean City Inlet north to the county boundary. Extensive monitoring was carried out by the US Army Corps of Engineers, Coastal Engineering Research Centre, including profiles of the beach and sea bed, extending from the foot of the dunes seawards to 7.6m below NGVD (National Geodetic Vertical Datum). During a 2½ year monitoring period the beach was subject to a number of severe winter storms. Within 6 months of placement the "upper beach" reduced substantially in width but within a few months the beach had recovered significantly and continued to do so over the next two years. In terms of beach volume the sub-aerial beach was about 30% of its placed volume by April 1989, while the total volume was actually in excess of the fill volume. By September 1990 the beach had recovered so that the beach was about 60% of its placed volume. It is interesting to note that the changes in volume above and below NGVD mirror each other, reflecting the importance of cross-shore transport in beach recovery. The fill performed largely as expected. CERC had estimated that after initial short term adjustments the beach would be 45% of its placed width. One year after placement the beach was in fact 42% of its original width and increased to 52% of the original width one year later. Taking the whole of the active profile (ie to a closure depth of about 6.1m below NGVD) the monitoring also shows that 84% of the fill was still in place within the active beach profile. The average annual loss rate has been estimated at 163,000m^3 per year over the two year period. During this time the frontage was subjected to a number of severe northeasterly storms, with inshore significant wave heights in excess of 2.25m being measured by Ocean City wave gauges on 4 occasions.

From this experience it is now generally accepted that beach fill volumes have to be determined taking in the whole of the active profile. At Ocean City, for example, winter storms during the period while the fill was adjusting to an equilibrium produced sand movement to water depths ranging from 1.5m to 4.6m depending upon profile shape and location.

Where an active profile does not extend a very great distance offshore (perhaps due to a mild wave climate and a shallow nearshore sea bed) then beach nourishment is likely to produce a good overall performance on the visible beach. For example at Redington Beach, Florida, the beach was nourished with some 405,000m^3 of sand in 1988. Two years later the nourished beach had lost some 9% in volume but if the losses to downdrift beaches are accounted for then the loss was only 7% for the whole of the study area. Taking into account the whole of the active profile (from about 1.5m above to 1.5m below NGVD) then these losses were 10% and 6% respectively (Davis 1991). To put these promising results into context the area is clearly a sheltered one, with an active beach profile being about 3m. While the beach loss was small over the two years, amounting to only 28,340m^3, the littoral drift in the area is also small. The relative stability of the fill, quoted in percentage volume terms here, may therefore be slightly misleading.

At Wrightsville Beach, North Carolina, on the other hand, successive nourishments with fine sand from estuarine sources has proved largely unsuccessful (Pearson and Riggs 1981) because of the rapid dispersion in an offshore direction, extending well seawards of the closure depth for the native beach sand. Successive nourishments have taken place here since 1939 using material taken predominantly from estuarine sources. Because of the fine grain size the fill material is rapidly eroded during storms and the artificially formed beach berms are either totally eroded or a scarp up to 2.7m in height is formed. The process of hydraulic sorting is then enhanced by the waves being reflected from the vertical scarp face, promoting further offshore sediment transport. The authors thus believe that it is very important to match the replenishment fill material to the hydraulic regime of the recipient area, something which had clearly not been carried out in the nourishment schemes to date of reporting.

By comparison with USA experience most beach nourishment operations in Europe have been successful and performance has generally matched expectations. An evaluation of 9 projects, representing nourishment performance in various parts of the Dutch Coast, shows that 8 were successful in achieving the anticipated (design) life (Roelse 1990). In only one project was the beach renourished earlier than expected, the achieved design life being 4 years instead of the planned 5 years. In this case under-achievement was attributable to sand extraction from a nearby tidal inlet which influenced the behaviour of the nourished beach.

Today the response of a beach, both in profile and in planshape can be predicted with a reasonable degree of confidence "even in a dynamic coastal environment with a capricious morphological behaviour" (Roelse 1990). There is now an increasing use of interactive physical and numerical models to optimise beach nourishment schemes (Bunn *et al* 1993, Silva *et al* 1993). However there are no hard and fast rules as regards the design of beach nourishment schemes and indeed the whole design philosophy can vary from country to country. This varies from a largely empirical approach used in Holland (CUR 1987) based on long-term measurement of shoreline trends (and assuming that the nourishment material behaviour generally follows these trends) to a more analytical approach used in the USA (US Army Corps of Engineers 1984).

3.1.3 UK experience with sand beaches

In the United Kingdom the justification of many beach nourishment schemes has been that the cost of nourishment has been considerably less than the cost of repair or reinstatement of hard defences over a design lifespan of typically 10 years.

One of the first nourishment schemes to be justified on this basis was carried out at Portobello Beach, Edinburgh, in 1972. This beach had been denuded as a result of sand abstraction by the glass industry, which began in the 19th Century and continued to the mid 1930's. A sea wall was constructed in 1860, with subsequent additions in 1891 and 1925. Beach levels continued to fall and by the late 1950's the wall was under continuous wave attack and suffered very frequent overtopping. Following studies by HR Wallingford the beach was nourished from a borrow area off Fisherrow, in the Firth of Forth and some 3km east of Portobello. The frontage here is exposed to north-easterly winds with the fetch in other directions being limited. The tidal range in the area is 5.3m on spring tides. Some 180,000m^3 of coarse sand was extracted by bucket dredger, transported by barge and pumped over a 1.6km frontage to a foreshore gradient of 1:20. The median grain size of the native beach material was 0.2mm, while the nourishment material had a median size of 0.27mm. The nourishment material was placed over a depleted beach whose gradient had fallen as a result of erosion to 1:42. The cost of nourishment at 1972 prices was £1.6/m^3 (Newman 1976) with additional costs of £60,000 for the construction of 6 groynes to contain the fill. The beach has subsequently been monitored by Lothian Regional Council and the beach profile data analysed by HR. After 18 months the beach slope had adjusted to 1:23 but other than that there was no significant offshore movement. Littoral drift in this area is low so "end losses" have also been small. Beach volumes remained steady until 1978. By 1981 losses increased to about 50% of the original fill volume, but the beach subsequently recovered naturally, with 75% of the fill volume still present in 1984. By 1988 the volume lost had increased to 30% of the original fill. In late 1988 a further 102,000m^3 of sand were added as a "topping up and improvement" operation, since when the beach has essentially remained at about its post (second) nourishment volume.

The Portobello scheme has been the longest lasting, and the most successful sand nourishment operation in the United Kingdom. The success of the scheme has been due to a combination of factors. Very importantly the fill material was considerably coarser than the native beach material. The beach gradient below Mean Low Water is also low (about 1:100) and this together with the relatively sheltered wave conditions within the Firth of Forth have given an active beach profile for the fill material whose closure depth is of the same order of magnitude as the spring tidal range. Calculations made by HR prior to the scheme also indicated that under waves generated from the greatest fetch (north-east) wave orbital velocities were generally higher towards the beach than away from it. Thus coarse material would tend to be moved landwards at the bed, while fine material entrained in the water column would tend to be transported offshore in the mid-depth layer where water drift was seawards. Finally the continuing success of the scheme is also attributable to the careful and extensive monitoring on an approximately twice yearly basis. (The monitoring of individual beach profiles has allowed regrading to be carried out on a few occasions, preventing the wall being reached by wave action.) Analysis by HR over the period 1988 to 1992 (ie since the second nourishment) shows that levels at the top of the beach have been stable. The level of protection against flooding has thus been sustained and the performance of the nourished beach continues to be excellent, exceeding the most optimistic expectations of such schemes.

One of the most notable sand nourishment schemes was carried out at Bournemouth in 1974/75 involving the nourishment of 8½km of coast with some 840,000m^3 of dredged sand dumped at nearshore mounds and then pumped to the shoreline via a floating pipeline. Willmington (1983) gives the average cost of protection per lineal metre of nourishment beach as £116 (£353 at 1982 prices) as compared with the costs of strengthening the existing sea walls which was estimated at £628 (£1900 at 1982 prices). Some 6 years after completion of the scheme much of the nourishment material still remained on the beach (Willmington 1983) thus illustrating the cost-effectiveness of the scheme. By mid 1987 the nourished frontage still had a considerable residual beach volume compared with the pre-nourishment volume of the beach between MHW and 450m offshore (Lelliott 1989). Since this renourishment Bournemouth B C has not had to undertake the annual programme of sea wall maintenance which has been required previously. The scheme has been successful for a number of reasons. Firstly the nourishment material in the first major nourishment in 1975 had a D_{50} size of 0.3mm, considerably coarser than the native material, which has a D_{50} size of 0.2mm. The small tidal range (2m during spring tides) and the flat nearshore seabed have also tended to encourage material to be retained relatively close inshore. The wave breaker zone is quite wide because of the shallow nearshore water depths. Coarse grained material within this zone has tended to move onshore, although the finer fractions tend to be transported seawards by rip current action and then carried alongshore by tidal currents. Losses have tended to be as a result of littoral drift, as is evident by the arrival of material at Hengistbury Head at the eastern end of the frontage. Significant quantities of sand have also fed through to the beaches in Christchurch Bay. This has resulted in an improvement in beach levels at Mudeford after rock groyne construction east of Christchurch Harbour. In 1989/90 a further 1 million m^3 of sand, dredged from the approaches to Poole Harbour was added to the Bournemouth beach and has performed to expectations subsequently.

More recently a successful sand nourishment scheme has been carried out in Sand Bay on the south shore of the Bristol Channel. Sand Bay lies to the north of Weston super Mare and is contained to the north and south by major limestone headlands. The area has a very large tidal range of up to 14m on spring tides. The bay also has a westerly aspect, making it very exposed to westerly and south westerly gales. This severe exposure has resulted in a gradual reduction in beach levels in front of the flood embankment which protects the low lying, highly developed hinterland, from flooding. By the early 1980's beach levels in front of the flood embankment at Sand Bay had fallen to the extent that flooding occurred on two occasions when high tidal levels coincided with severe westerly gales. HR were instructed by the then Wessex Water Authority to assess the likely life expectancy of the scheme and to provide some general design guidelines. Due to the embayed nature and the extensive muddy lower foreshore it was decided that if the beach were nourished with a coarse sand that offshore losses would be insignificant following initial readjustment and loss of fines during construction. In 1983/4 the beach was nourished with 300,000m^3 of coarse sand, including a small portion of gravel, won from a nearby borrow area within the estuary. Material with a median particle size of 0.5mm was pumped ashore to form a 20m wide berm with a 1:10 seaward slope and extending over a 2.1km length of beach. The berm crest was 15.3m above Chart Datum, raising levels at the toe of the flood embankment by 3m. This berm dimension has been of sufficient size to eliminate all wave overtopping subsequent to the completion of the scheme. Within the Water Authority planning procedure there was a 30% allowance for topping-up after 10 years. However, only a very small loss in volume has occurred, principally due to wind blown sand, and hence no such action is likely to be needed in the foreseeable future. The major problem has indeed been the winnowing of fines by wind action. This problem has been solved by the construction of sand fencing. This has led to the development of sand dunes, which despite heavy public use of the beach, are now partly stabilised by vegetation.

Another recent nourishment scheme was carried out at Jaywick, a low lying residential area situated southwest of Clacton, Essex. Here seawalls have protected residential and holiday homes from flooding, but as the sand and shingle beaches have undergone severe erosion so the area had become prone to flooding and on occasions severe damage and breaching has also occurred. The most memorable event took place in the 1953 surge when long lengths of wall west of Jaywick breached and the whole low lying land flooded. In December 1978 some 100m of wall at Jaywick was severely damaged but a breach was averted by emergency works and a timely improvement in weather conditions.

In January 1983 serious overtopping occurred, with residential areas being flooded to depths of up to 1.0m. A feasibility study was begun in 1983 with the aim of protecting the frontage to a 1 in 1000 year combined wave and water level standard. Options examined included beach recharge with and without impoundment breakwaters, seawall rehabilitation and the Do-Nothing option. The Do-Nothing option was found to be unacceptable due to the inevitable increase in maintenance costs that it would incur, the lack of protection against flooding, and the inability of the present defences to prevent a major breach from occurring. A beach recharge scheme with impoundment breakwaters was found to be the least expensive of the other options as well as being considered to be the most effective in achieving the desired level of protection. The costs of reinstating the existing sea wall were estimated at £14.7 million. This proved to be the least acceptable option environmentally and one which would do nothing to prevent further beach erosion. An "open beach" nourishment scheme was costed at £11.3 million, including an allowance for future topping-up operations. However as this would give no protection against material being dispersed by littoral drift it was considered a high risk solution. The combined beach nourishment/breakwaters solution was considered to be the one which would keep beach losses to a minimum by not only reducing the littoral drift by the groyning effect of the breakwaters but also by means of absorbing wave energy and deflecting tidal currents away from the shoreline. The scheme had the added benefit of providing high amenity value.

Detailed site investigations were carried out which indicated that storm waves could move beach material of 0.2mm size as far offshore as 200m. Numerical modelling also showed that inshore tidal currents were significant and coupled with wave activity can cause substantial dispersal of beach material through littoral drift. It was also found that the direction of the most severe wave attack was from the east-southeast, with maximum wave heights at the beach being about 2.5m.

The scheme consisted of recharging the beach with sand to provide a 10m wide berm at 3.5mOD, and a seaward slope of 1:10, to intersect the existing foreshore some 65m seawards of the existing wall. The berm was 1.3m above MHWST, which was considered to be sufficient to prevent storm wave runup from reaching the wall during normal tides. (Analysis had shown that high waves are unlikely to occur with high tidal levels.) The 300mm freeboard of the seawall above the 1:1000 year water level was considered sufficient to prevent overtopping during the more extreme tidal levels. The scheme also included two massive "fishtail" breakwaters which not only acted as impoundment structures but which were also intended to deflect tidal currents so as to minimise beach erosion and to provide partial shelter against wave attack. These were strategically placed at two vulnerable areas, Lion Point and Eastness, where the convexity of the coast resulted in the strongest inshore tidal currents, a concentration of wave activity and hence lower beach levels than elsewhere on the frontage.

Progress was reported on when two-thirds of the scheme was complete (Biss and Craig 1987). This report had a March 1987 estimate of costs, which included £4.5 million for the construction of the two principal breakwaters and £3.3 million for beach recharge. Other works, including seawall repairs, terminal works and reconstruction of outfalls and engineering costs came to an additional estimated £3.0 million. The beach recharge itself was therefore not the major item in the cost of the scheme. On completion of the first stage of beach recharge in October 1986 some 100,000m^3 of sand and gravel had been pumped ashore to protect a frontage of some 2.2km, including a 1½km frontage downdrift of the west of the two breakwaters. (The source of material was a licence area at Long Sand Head some 30km offshore.) Subsequent operations included the addition of 132,000m^3 of material over a 1km frontage in 1987 and a further addition of 21,000m^3 over a 1.12km frontage in 1988. There is little published information on the performance of the scheme subsequent to the second and third stages of nourishment. It is understood that the recharge has prevented overtopping of the defences, but that in some places the nourished beach has cut back close to the original sea wall line.

3.1.4 UK experience with shingle beaches

In the United Kingdom, particularly on the south-east coast of England, shingle beaches occur widely and shingle nourishment has been a beach management tool for a number of decades. Unfortunately many small scale shingle nourishments are poorly documented, one of the reasons being that many schemes have been carried out on a maintenance basis and have therefore received less attention than today's major capital nourishment schemes.

Shingle nourishment and shingle recycling have been practised in the south-east of England since the 1950's (Thorn and Roberts 1981) and have been continuing since with increasing success (Foxley and Shave 1983). The scale of beach nourishment projects is also increasing and this has led to a much greater requirement for post-project monitoring. Foxley and Shave (1983) describe a number of such schemes which have been carried out at Pett, Walland and Sheerness. The Pett and Walland schemes involved the recycling of material from a downdrift boundary to an updrift "source". These fit in well with the littoral cell concept described by Motyka and Brampton (1993). A description of these two schemes can be found below and in Section 4.5 of the report, which deals with beach recycling.

The Sheerness scheme which was carried out in 1975, can be considered as the first large scale operation involving nourishment with "non-local material". At Sheerness low lying residential land was traditionally protected by means of a shingle beach stretching over a frontage of 900m, which connected up to seawalls to the east and west. Additional protection was served by means of a clay embankment to the landward and running approximately parallel to the natural shingle beach. When the decision was made to increase the standard of flood protection, two alternatives were considered, either to increase the embankment height or to increase the size of the shingle beach. There were a number of design objections to the raising of the clay embankment and the feasibility of raising the height of the shingle beach with marine aggregate was found to be a more cost effective option. The then existing shingle beach was therefore transformed into a massive bank, by importing 180,000m^3 of shingle from a North Sea licenced dredging area. The material was brought in at high tide using split bottom barges which deposited their cargo on the lower foreshore. The material was then rehandled by means of draglines and bulldozers to form a bank with a berm width of 6m, a crest height of 7mOD (4m above MHWST) and a seaward slope of 1:7. Littoral drift in this area is not strong and groynes were therefore not considered necessary to limit the alongshore movement of shingle (Thorn and Roberts 1981). Also avoiding the use of groynes would help to maintain a smooth beach planshape, thus avoiding the sawtooth configuration (and hence inevitable local erosion hot spots) of conventionally groyned beaches.

The contract was completed within four months, helped by the favourable weather conditions in the summer and autumn of 1975. During the first 7 years of the life of the scheme the beach performed very well indeed. The wave climate in this area is relatively mild and littoral drift is low. It was therefore found to be necessary to recycle material only on occasions. Six years after construction some 2400m^3 of material was recycled from the west (downdrift) to the eastern end of the frontage. More recently the beach has been subject to a number of severe storms and the amount of recycling, while still low, has increased. The planshape of the nourished beach is slightly convex leading to a concentration of wave energy at Barton's Point at the western (downdrift) end of the nourished frontage. By 1986 erosion at Barton's Point had necessitated reinforcement by means of gabion matresses. Loss of material has increased in recent years and the beach has been nourished with 8000m^3 of "as dug" material on three occasions since 1986 (NRA Engineers Report 1993).

Given that the nourished beach has now been in place for nearly 18 years, and has required a very low level of maintenance to date, the scheme has to be considered as one of the most successful and innovative schemes to be carried out using marine dredged shingle.

A major shingle renourishment scheme was carried out in 1985/6 at the east end of Hayling Island . This end of the Island has a long history of beach erosion and flooding and the existing concrete seawalls there were coming under increasing attack, resulting in considerable structural damage to the walls as well as flooding of the houses behind them. These seawalls and houses had been built on an existing beach ridge and since the walls prevented natural readjustments of the beach profile it was inevitable that the area would be one of beach instability. Problems were further compounded by the presence of a littoral drift divide along this frontage, with an estimated eastward transport of 5000m^3 pa and a westward transport of 17000m^3 pa from the area (Harlow 1979), ie a general loss of 22,000m^3. A number of solutions were examined by the Council, including the feasibility of raising the wall, protecting the toe with armour, recycling material from the western (downdrift) end of the Island and bringing in material by road or by sea. Most of the schemes proved to be environmentally unacceptable, leaving nourishment from offshore as the favoured solution. The eastern end of the Island was therefore renourished with approximately ½ million m^3 of shingle over a frontage of 2.2km at a capital cost of £4 million. The shingle was sorted on site to provide a 0.5m deep armour layer over the remaining fill material to form a 27.5m wide berm in front of the existing seawalls with a crest level of 5.6mAOD. The scheme was unusual in that while the western end of the nourishment fill merged into an existing groyne field, the eastern end was feathered in landwards in an area where littoral drift had traditionally been very low. The new beach was expected to adjust to a "weathered profile" during a relatively short timespan after which an average annual retreat of about 0.6m pa was allowed for (Harlow 1985). In the event littoral drift and the sorting process by waves have been somewhat greater than anticipated and the beach has been subsequently stabilised by the construction of timber groynes. However, with regard to backshore protection and reduction of wave overtopping the scheme has been very successful and continues to prevent flooding of the hinterland some 8 years after construction. The scheme has also had a beneficial impact on the adjacent coast, in particular feeding the western end of the Island and helping to mitigate downdrift erosion problems. With time, as the shingle beach has adjusted to an equilibrium profile, so the beach has taken on a more natural appearance and the early problems of scarping have since disappeared, improving both the hydraulic performance and the visual impact of the scheme.

Another major beach nourishment scheme which has proved to be successful in providing full "backshore protection" is that carried out in Seaford in 1987. Interruption of littoral drift resulting from the development of Newhaven harbour has meant that the shingle beach at Seaford has received a dwindling supply of shingle. This has resulted in beach levels in front of the seawall falling at an increasing rate during this century. By 1980 the beach in the eastern half of the frontage had fallen to such an extent that it was providing very little support to the old mass concrete seawall. (This wall had originally been built as a secondary line of defence, behind a then substantial shingle beach). In places erosion exposed the underlying chalk platform, allowing waves up to 6m high to reach the wall without breaking. In 1981 parts of the wall were badly damaged and in 1985 it was undermined in one area causing local collapse of the promenade.

Following hydraulic and numerical model testing at HR Wallingford an "open beach" nourishment scheme (ie an ungroyned main frontage) was adopted as the most economical solution. Because of the low rates of littoral drift at the partly sheltered western end of the frontage it was determined that a terminal groyne was not necessary here. At the eastern end of the frontage a large terminal concrete groyne was already in place but this was reconstructed to a greater height and length so as to prevent loss of material to the natural cliffed coastline to the east. The main element of the scheme was nourishment of 2.5km of frontage with just over 1.5 million m^3 of shingle at a placed cost of £4/m^3 at 1985 prices (Chester 1988). The material was won by suction dredger from an existing licence area on Owers Bank, off Selsey Bill. The scheme has been particularly successful and following the initial period of adjustment the beach actually increased in volume within the active beach profile (taken as above -4m OD) (HR Wallingford 1992).

In order to maintain sufficient beach width at all points on the frontage it was assessed that recycling would need to be carried out at a rate of 20000 to 25000 m^3 per annum. The volume which has had to be recycled has in fact varied considerably from year to year, averaging at present at about 85,0000 m^3 per annum.

It would appear that a nourished fill is considerably more mobile than the native beach material. The reasons for this are not entirely clear but it is considered that movement on what is a relatively steep "non-equilibrium" beach may be enhanced by tidal current action. Certainly there is evidence in the form of shingle "waves" which indicate that the littoral drift may be enhanced by tidal current action on the relatively steep beach face. This aspect of rapid shingle movement has been observed in other recent shingle nourishment schemes. At Hastings for example there was a rapid movement of shingle in a downdrift direction following a beach nourishment operation involving placement of 250,000 m^3 of shingle at the west end of the town frontage in 1990.

Summary

The nourishment of beaches is now a widely accepted method of "soft" engineering. The advantages of nourishment over traditional methods of coast protection (Owen 1983) include:-

- Dissipation of wave energy before it reaches the shoreline, and with little interference with natural processes,
- Provision of a direct remedy for shortage of beach material which is frequently the main cause of shoreline recession,
- Relatively low capital cost,
- Improvement of recreational facilities.

Other advantages are:-

- Reduction or elimination of flooding by preventing waves and/or high tidal levels from reaching the line of existing backshore defences,
- Provision of a source of supply for downdrift beaches,
- Providing a store of material which acts as a buffer to erosion in extreme storms,
- The flexibility of this form of protection - giving a level of protection which can be increased by addition of fresh material or if necessary decreased by allowing the dispersion of material by littoral processes. This aspect is particularly relevant to the protection of conservation sites; for instance allowing cliff or backshore erosion to continue at a controlled rate,
- In the case of sand beaches providing a method of protection which only has a short term impact upon the benthos.

There are, however, a number of disadvantages (Owen 1983) including :-

- The protection is not usually a permanent solution - needs careful monitoring and occasional topping up,
- Maintenance costs are not normally eligible for grant aid (though this situation is now changing).

Other disadvantages are:-

- Difficulty in predicting the expected lifespan and assessing future maintenance requirements, particularly for sand beaches,
- Difficulty in assessing the behaviour of widely graded fills including enhanced littoral transport, enhanced cross-shore sediment distribution (the latter often resulting in beach scarping), and possible initial loss of fines,
- Difficulty in assessing maintenance requirements in view of the unpredictability of the UK wave climate,

- Difficulty in matching the borrow material to the native material in the case of coarse shingle beaches,

- Difficulty in obtaining the suitable grade of material in areas which are distant to existing licence areas,

- In the case of sand nourishment, wind blown sand causing an amenity nuisance.

- In the case of massive recharge schemes the beach nourishment having an adverse visual impact, particularly when used in conjunction with massive impounding structures (eg groynes or breakwaters).

- The need for detailed site investigations including an accurate assessment of historical rates of shoreline erosion, an accurate prediction of losses during construction and during the adjustment of the profile towards an equilibrium with the local hydrodynamic regime.

When the nourishment material is well sorted and of "unimodal" size distribution the matching of fill to native beach material is relatively straightforward. Under these conditions it is normal to use a sediment which is significantly coarser than the beach material. Great success has been achieved on beaches where sand fill material had a 50% larger diameter than the native beach material. However a high content of fines should be avoided since particles less than 0.15mm in diameter tend to suffer offshore losses (Bruun 1990). The fines will tend to accrete on the submerged part of the beach profile and are therefore still useful if the nearshore zone requires to be nourished. In the case of shingle, success is likely to be achieved almost irrespective of material size. Shingle will always have a tendency to migrate onshore, although of course the beach slope (and hence beach volume required to reach a curtain protective crest height) will be strongly dependent upon the grain size and the local hydrodynamic conditions.

The behaviour of a mixed sand/shingle fill clearly warrants further study since the as-placed mixture has a different behaviour to that of a natural beach. On a natural beach the process of sorting is a slow one; it results in the finer material settling out 1m or more below the shingle surface, leaving a well drained surface layer well able to absorb incident wave energy. By contrast a mixture of shingle and sand as placed during nourishment has the interstices infilled, giving a relatively impermeable beach. Lack of drainage during wave action results in high reflectivity and causes rapid erosion of the mixture, often leading to a distinctive scarp which may be 2 to 3m high, depending upon wave exposure. Such scarping is unavoidable when nourishing with sand and shingle mixtures and should be taken into account in the management process. Severe scarping may not only result in rapid adjustments in beach profile (leading to problems with groyne adjustment) but can also be a public hazard.

This aspect can be examined by means of numerical models coupled with extensive post project monitoring of recent beach nourishment schemes (ie ones where the process of sorting is still taking place). Certainly assessing the compatibility of fill by numerically matching beach and fill gradings, as carried out for relatively well sorted fine grained sediments (James 1975) is likely to prove both impractical and possibly misleading for mixed sand and gravel beach fills which often have two distinct grain size populations.

The position of placement of the nourishment material has an important influence on the design of a scheme. Material can be placed on the backshore on the above tidal part of the beach, where it will provide a reservoir of material against storm induced erosion. The public perception of such an exercise is almost always highly favourable as the tangible benefits of the scheme are clear. When nourishment is used to widen an existing beach then the public perception is initially favourable. However public acceptance can soon turn to criticism if the beach undergoes sudden erosion and loss of supratidal width. To date few UK nourishment schemes have been subject to this kind of criticism. However experience with US schemes can show that such nourishment can be a public relations disaster and can often lead to scientific disagreements about the pros and cons of this type of beach management. To avoid possible criticisms in future beach nourishment schemes we think it is therefore necessary to involve both public and private bodies at an early stage of design.

3.2 Nearshore nourishment

3.2.1 General

Similar to the way in which beach nourishment by bypassing can be linked to the maintenance of inlets and harbour mouths so nearshore nourishment can be part of an overall dredging strategy for the nearshore zone (eg where dredging in the approaches to an inlet is being carried out).

3.2.2 Overseas experience

Sand can be dumped in the nearshore zone and natural hydrodynamic processes harnessed to achieve the feeding of the nearshore zone or of the beach itself. The efficiency of this method for nourishment of the above tidal beach is open to doubt (CUR 1987). The Dutch recommendation is that the material should be placed as close to the shore as possible by means of suitable plant (ie suction hopper dredgers with sliding bottom doors, split hull hopper dredgers or split hull barges). Walton and Purpura (1977) describe a number of early nourishment projects, in which dredge spoil dumping was carried out in water depths ranging from 6m (off Santa Barbara, California) to 11.6m (off Long Beach, New Jersey). In none of these operations was there any significant dispersal of the dumped sand or any improvement in beach conditions that could be attributable to the dumping operations. The authors concluded that:-

"experience has shown that for conditions along Florida's coast and much of the rest of the United States coastline, that offshore dumping of material is an unwise practice outside the limits of the seasonal offshore bar".

In Japan this method of beach nourishment has been tried on an experimental basis off the Iioka coast. Traditional methods of bypassing (eg by land based vehicles or by hydraulic pipeline transfer) are considered to be expensive especially where sand has to be transported over a considerable distance (Udo *et al* 1991). It was therefore considered desirable to find a technique which minimises the distance from the borrow area to the release location ie by dumping sand in shallow water and allowing wave action to transport it in a downdrift direction. A field experiment was therefore carried out by dumping 5000m^3 of sand on the 4m depth contour, and tracing its movement by means of artificial sand tracers and by bathymetric surveys. The results of the experiment were encouraging in that the tracers indicated a nett landward and downdrift dispersion of tracer. However the bathymetric surveys results were less conclusive since after the second survey the material had dispersed and bottom changes were too small to detect any trends in bed movement. Other factors reducing the usefulness of the experiment were:

(a) the short tracer survey period (4 months)

(b) the presence of offshore breakwaters landward and downdrift of the injection point which significantly altered the inshore coastal processes.

A dredgings disposal site in Coos Bay, Oregon, has recently been monitored to determine its "dispersive characteristics". Dumping of sand (with a median grain size of 0.25 to 0.3mm) has been taking place here at an average rate of 460,000m^3 per year over the period 1979 to 1988. The spoil mound, which is in 20 to 26m of water relative to MLLW, has attained a crest level of 15.2m below MLLW. In terms of hydrodynamics the area is a fairly active one. The average annual significant wave height is 2.7m (varying from a monthly average value of 1.6m in July to as high as 3.6m in November). Tidal current velocities, on the other hand, are low, being of the order of 10 to 20 cm/s near the bed. Hydrographic surveys indicate that some 70% of the material dumped can still be accounted for within the disposal zone (Hartman *et al* 1991). Theoretical calculations by the authors were used to show that the combined action of waves and tidal currents is able to move the material as bed load. However although the material can be mobile during the months November to February the nett transport rate is minor, relative to the rate of spoil dumping. Clearly while wave action is able to initiate motion for part of the year tidal currents are insufficiently high to cause widespread dispersal of the material. During the rest of the year there is little bed movement activity. This area was designated as a dispersive site for dredgings disposal. However the lack of movement indicates that it is in fact difficult to categorise such sites accurately as dispersive or non dispersive ones. It is even more difficult to ascertain whether or not movement from such areas will take place in significant quantities.

A more optimistic outlook is that of Hands and Allison (1991) who consider that greater use of nearshore nourishment methods should be made to conserve sands obtained from inlet dredging operations. The authors give a historic account of the fate of early nearshore nourishment schemes which performed disappointingly and of the improved performance of more recent schemes due to disposal at shallower depths. They describe an experiment in 1935 which was conducted off the California coast, involving the construction of a sand bar in 6.7m water depth. The intention was that the bar should feed the eroding coastline south (downdrift) off Santa Barbara harbour. After 21 months there was no measurable movement of this bar and there was no alleviation of coastal erosion. As a result the project was abandoned in favour of direct dumping of sand onto the foreshore. Further experiments carried out on the Atlantic coast of USA in more energetic locations also showed no landward displacement of material and no benefits accruing from the operations.

Reported successes overseas rekindled interests in the USA. The introduction of shallow-water split-bottom dredge barges (Schwartz and Musialowski 1980) led to further experiments which proved to be more successful as described below.

Hands and Allison (1991) cite a number of examples where dispersal in the nearshore zone has led to modest volumes of material being returned to the littoral zone by wave action. At the National Berm Demonstration site in Mobile Bay, Alabama, three dump sites of varying height and situated in water depths ranging from 14m to 4m have been constructed and are being monitored. The tests have shown that migration landwards can take place in 4-5m of water. The significance of this is that onshore movement, and hence nearshore nourishment, may be feasible outside the surf zone and in areas not subject to long period wave action. The authors examine berm response as a function of wave and sediment parameters and propose a methodology by which to select retentive or dispersive disposal sites.

Design guidance for nearshore berm design is also given by McLellan and Kraus (1991). The timing of placement is considered and the authors develop criteria for "accretion" and "erosion" based on the deep water wave steepness and sand settling velocity parameters. For feeder berms the authors consider that material should be placed as close to the beach as possible, as the increased frequency of wave breaking over the berm is likely to lead to a greater potential for material to move off the berm and into the littoral zone.

Comprehensive monitoring of an underwater dispersal mound, built off San Diego Bay in 1988, has been carried out recently and the results documented by Andrassy (1991). The mound was built from some 113,000m^3 of material, dredged from the entrance to San Diego Bay, and its subsequent movement monitored by 7 "profile" lines perpendicular to the long axis of the mound. A landward movement of the mound was clearly distinguishable in the first few months after construction. Thereafter the mound became less well defined as a result of shoreward dispersal of sediment. During the monitoring period, from December 1988 to November 1988, the berm is believed to have contributed material directly to the nearshore zone (+3 to -3m relative to MLLW). Also by breaking incident waves, it also created a relatively low energy zone, resulting in conditions conducive to beach accretion.

In 1990 a field trial was carried out off Tauranga Harbour, New Zealand, in which some 80,000m^3 of sand were dredged from the entrance channel and dumped off Mt. Manqanui beach, downdrift (south) of the harbour. Extensive monitoring showed that over a period of 1½ years most of the dumped material (placed in 4 to 7m of water) had moved onshore to the beach (Healy 1992).

Summary

These case histories, particularly those for recent monitoring operations appear at first sight to be encouraging as regards the concept of nearshore disposal of dredging material. Where material is dumped by means of bottom door or split hull barges then the costs are likely to be considerably lower than those of "beach dumping", being typically of the order of \$2.3 to \$2.5/m^3 (about £1.5 to £1.7/m^3) for sand sized material (Bruun 1992).

Developments, such as the design of split hull barges which can place material in 2 to 4m of water also give cause for optimism (Schwartz and Musialowski 1977). While such methods appear to be highly attractive as a means of disposing large volumes of spoil from dredged channels, inlets etc, they carry a large element of risk if the primary function is beach rather than "profile" nourishment. Not only is the material prone to rapid dispersal if placed in the nearshore zone (possibly resulting in the feeding of more distant beaches) the material is also susceptible to offshore losses under adverse weather conditions. The Dutch experience with sand nourishment raises doubts as to the efficiency of this method of operation (CUR 1987). While there is little experience with such operations in the United Kingdom indirect experience obtained by tracking of artificial beach material suggests that onshore movement may be sporadic even when material is placed within the intertidal zone. There is however anecdotal evidence that beach material migrated onshore, following a pilot nourishment scheme at Bournemouth in 1970. This contract involved the dredging of some 90,000m^3 of sand from a licenced dredging area off the Isle of Wight and the dumping of this material in the nearshore zone prior to pumping it ashore. Subsequently during the main 1974 nourishment, loss of sand occurred from the nearshore dump sites as a result of the dispersal of the material by tidal currents. However, some of this material is believed to have been brought ashore by wave action, as indicated by subsequent beach monitoring (Willmington 1983).

At present we do not consider that nearshore methods of sediment disposal have a strong role in the management of beaches in the United Kingdom. However, the research currently being undertaken by the US Waterways Experiment Station (Pollock *et al* 1993) into wave attenuation by nearshore berms may in due course identify more positively the impacts of nearshore dumping on the condition of adjacent beaches. Also a major European research project involving similar experiments at sites off the coasts of Denmark, Belgium, Germany and the Netherlands is underway and will provide further useful data.

3.3 Mechanical beach reprofiling

3.3.1 General

Mechanical reprofiling is a method quite extensively used in the USA for nourishing the upper beach in an effort to protect backshore and beach front structures at the expense of material from the lower beach. The effect of beach reprofiling on beach stability has been examined by Bruun (1983) and the author argues that scraping material from a summer berm which is in transit landwards can only disturb beach stability very slightly and may in some circumstances induce regrowth of the summer berm from the seaward. Scraping the winter profile is seen to be a possible beach control measure, by reducing the rate of natural offshore beach movement. At best this form of beach management is regarded as a temporary measure for preventing storm induced erosion from threatening developed areas in the hinterland. This method is certainly not intended to replace beach nourishment since it does not supply additional material to the beach system. In the USA beach reprofiling is subject to a licensing procedure and while it is an accepted method of shoreline management in some areas, in other areas, it has been prohibited. Reprofiling is a generally accepted practice in Denmark, where it is used for coastal protection, but prohibited for any other purpose.

3.3.2 Overseas experience

Beach reprofiling has been used extensively in an emergency works programme on the South Carolina Coast, following the landfall of Hurricane Hugo in September 1989 (Kana et al 1991). This storm was the worst storm in 35 years, during which peak water levels were reported as being between 3.1m and 6.1m above NGVD (the normal tidal range being 1.58m). About 105km of dunes were destroyed and many shorefront structures came into the active beach profile. The coast was so badly hit that in many areas dunes were completely flattened, wash over fans were developed, islands were breached and enhanced alongshore transport caused extensive migration of beach sand into inlets and the extension of sand spits and shoals. An emergency programme on a massive scale was instigated with the aim of restoring beach profiles to their pre-storm conditions. Beach restoration works included scraping sand from the lower beach face onto the beach crest, returning material from spits which had extended into tidal inlets, and extensive dune revegetation. The emergency works cost some £9.8 million and involved the transporting of some 950,000m^3 of sand in this operation. It would appear that under these critical conditions beach scraping can be beneficial or even vital as a beach conservation measure, as otherwise much of the material would have been lost from the beach system.

The effectiveness of scraping as a means of erosion control has been examined by means of field trials in the USA. McNinch and Wells (1992) describe a monitoring study carried out at Topsail Beach, North Carolina, during which changes after reprofiling were compared against the performance of an adjacent unaltered control beach. Topsail Beach is situated at the southern end of Topsail Island, a 36km long barrier island. The beach consists of medium sized sand, sloping at about 1:17 from the toe of the dunes to mean low water. The mean tidal range is only 1m and the wave height averages at 0.6m to 0.9m in 5.1m water depth. The nett longshore transport is northwards but has strong seasonal reversals. Extra-tropical storms (northeasters) account for a large part of the wave climate. Ten beach profiling stations were set out over 1km of scraped beach and adjacent 1km of unaltered control beach. During the monitoring period the coast was hit by two severe storms, including Hurricane Hugo. On average the control section lost a greater amount of its primary dune than the scraped section (2.82 m^3/m as compared with 2.06 m^3/m). However the two storms produced different beach response, with greater erosion in the scraped section than in the control section during the hurricane. It appears that a scraped beach is more susceptible to damage than a natural beach under catastrophic events but less so under less severe conditions. Over an annual cycle the scraped beach retained a larger volume of sediment than the control beach, indicating no adverse impacts. The fears that beach handling may result in nett losses thus appear to be unjustified. After a year of monitoring it was concluded that while beach reprofiling can be beneficial to protection of the backshore, oversteepening of the beach by reprofiling can have a locally destabilising effect on sand beaches. It is therefore recommended that controlled scraping should only be carried out for backshore protection, and that it should only be carried out with simultaneous beach monitoring. Ideally material should be removed from the beach face at a slower rate than the expected rate of natural recovery (as determined by profile measurements).

Other monitoring studies (Kana and Svetlichny 1982) examined the response of natural and of protected beaches to this form of manipulation. Between March 1981 and May 1982 some 100,000 m^3 of sand were transferred from the lower beach to the backshore on three separate occasions over a 14km length of mainland beach at Myrtle Beach, South Carolina. The area has a mean tidal range of 1.6m and a spring tidal range of 1.8m. Wave action is the principal transporting mechanism with both alongshore transport and onshore/offshore transport being significant. The general philosophy adopted was to scrape material to a depth of 0.3 to 0.5m from a low tide bar, and to deposit it as a 9 to 15m wide fillet at the high water mark. The typical volume of material transported across shore in this manner was 6 to $8m^3/m$ of beach frontage. In general it was found that the amount of change brought about by artificial manipulation was dwarfed by the natural (seasonal) beach changes at this locality. Scraping on duned stretches had little impact upon the seasonal cycle of beach changes. However where it was carried out in front of shore protection structures, material eroded in as short a period as several weeks to four months. This loss was seen as a result of producing an oversteep profile on narrow eroding beaches, leading to wave reflectivity. On wide stable or mildly eroding beaches, the transfer of sand from the lower to the upper beach led to less disturbance of the natural profile. Field studies of the response of Myrtle Beach, South Carolina thus indicate that sand beach reprofiling may be a suitable interim measure for backshore protection on mildly eroding coasts. However on rapidly eroding coasts this form of management is considered to have little positive benefit and may in some instances accelerate beach erosion, with similar effects to those produced by hard defences.

In terms of cost the project was seen to be a relatively inexpensive one. The unit costs were $5.0 to $6.7/m of frontage treated, this being less than one tenth of the cost of bulkhead (vertical wall) construction. The exercise appeared to be most beneficial in duned areas, where the addition of sand to the backshore significantly delayed the onset of erosion and scarping of the underlying beach. By contrast the exercise was least effective where it was most necessary; in front of vertical walls it had a very short residence period.

3.3.3 UK experience with shingle beaches

In the United Kingdom shingle beach reprofiling has been practised for many years as a means of maintaining storm beach crest height and hence reducing the possibility of breakthrough of beaches otherwise prone to overtopping. Raising the shingle beach crest has often been carried out in conjunction with artificial recharge at Medmerry, west of Selsey Bill. This practice, while sometimes carried out in response to wave overtopping events, has certainly reduced the damaging effects of flooding the low lying hinterland. The American experience of beach instability as a result of beach oversteepening does not seem to have such dramatically deleterious effects on UK shingle beaches which are naturally much steeper, and are not exposed to hurricane conditions (ie. swell waves on a very elevated tidal level).

Summary

Beach scraping or reprofiling has been used on both sand and shingle beaches as a means of backshore protection. In the USA it has been used to increase the reservoir of sand at the top of the beach so as to minimise the impacts of storm damage. In general it is recommended that the volume of material moved and the manner in which it is moved should be carefully monitored and managed. Areas of beach which do not show any natural patterns of recovery should not be scraped but should be artificially nourished. However, by beach monitoring and understanding the beach recovery mechanism, recovery can be accelerated by reprofiling by "working in conjunction with the natural recovery cycle" (Tye 1983). In the United Kingdom it has been used to raise the crest of shingle beaches so as to reduce the risk of wave overwashing or breaching.

In the USA beach scraping is subject to various permit restrictions. This is quite reasonable, given that:-

> "Beach scraping or beach bulldozing is one of these remaining alternatives (of beach management), but one that has received limited scientific study relative to its widespread authorization and practise. The lack of research on beach scraping has led to a diversity of opinions and considerable controversy regarding its effectiveness in erosion control and on its overall impact to the beach" (McNinch and Wells 1992).

Despite reservations about its performance and its possible impact on adjacent beaches, beach reprofiling is without a doubt a very cheap method of beach manipulation and one that warrants further study. More work needs to be carried out to determine its effictiveness under storm conditions and the potential losses which may result from repeated rehandling need to be quantified by means of field trails. At present the unit cost of recyling sand are largely unkown. However, estimates of unit costs for shingle handling are available from the questionnaire returns (see Chapter 4) though the results are very approximate, and to be treated as order of magnitude estimates only.

3.4 Sediment bypassing or recycling

3.4.1 General

The stabilisation of tidal inlets and the development of harbours usually involves the construction of jetties or harbour arms, which "cut through" the intertidal zone. The positive benefits of maintaining navigation depths at the entrances to inlets and harbours are therefore usually accompanied by adverse impacts at the adjacent coastline.

The construction of a barrier to alongshore transport will result in updrift accretion and downdrift erosion. In some cases deflection of material in a seaward direction may also lead to the formation of shoals to the seaward. In flood dominated inlets, on the other hand, sediment may sometimes become trapped upstream, leading to loss of navigable depths.

Attempts to overcome the problems of excessive accretion, shoal formation or downdrift erosion have led to the development of a number of management techniques including that of sand bypassing. This form of shoreline control has been used widely in USA and this is where the most sophisticated bypassing systems are to be found.

3.4.2 Overseas experience

In the USA the criteria which lead one to determine the most suitable form of bypassing include a consideration of the type of littoral barrier which has to be bypassed. A classification of various littoral barriers can be found in the Shore Protection Manual (US Army Corps of Engineers 1984). Five types of littoral barriers for which sand bypassing operations have been made are recognised. These types are illustrated in Figure 3.1. Type 1 is the so-called jettied inlet where the tidal flow is constrained between jetties. Type 2 is an inlet with a sand trap situated upstream of the inlet entrance. The trap is situated at a point of natural siltation and is used as a reservoir for material, which is periodically dredged and transported to a receiver area downdrift of the inlet. Type 3 is a jettied inlet accompanied by an offshore breakwater. Inclusion of the breakwater creates a zone of shelter in which the littoral material is allowed to accumulate, giving a degree of control over the location of the accretion area. Type 4 is also a jetty and breakwater combination similar to Type 3, except that the breakwater in this case is connected to the shoreline. The zone of accumulation is then situated at the seaward end, or in the shadow of the breakwater tip. Type 5 is a breakwater with a weir section at its landward end, allowing sediment to pass over it into a deposition basin, from whence it can be dredged.

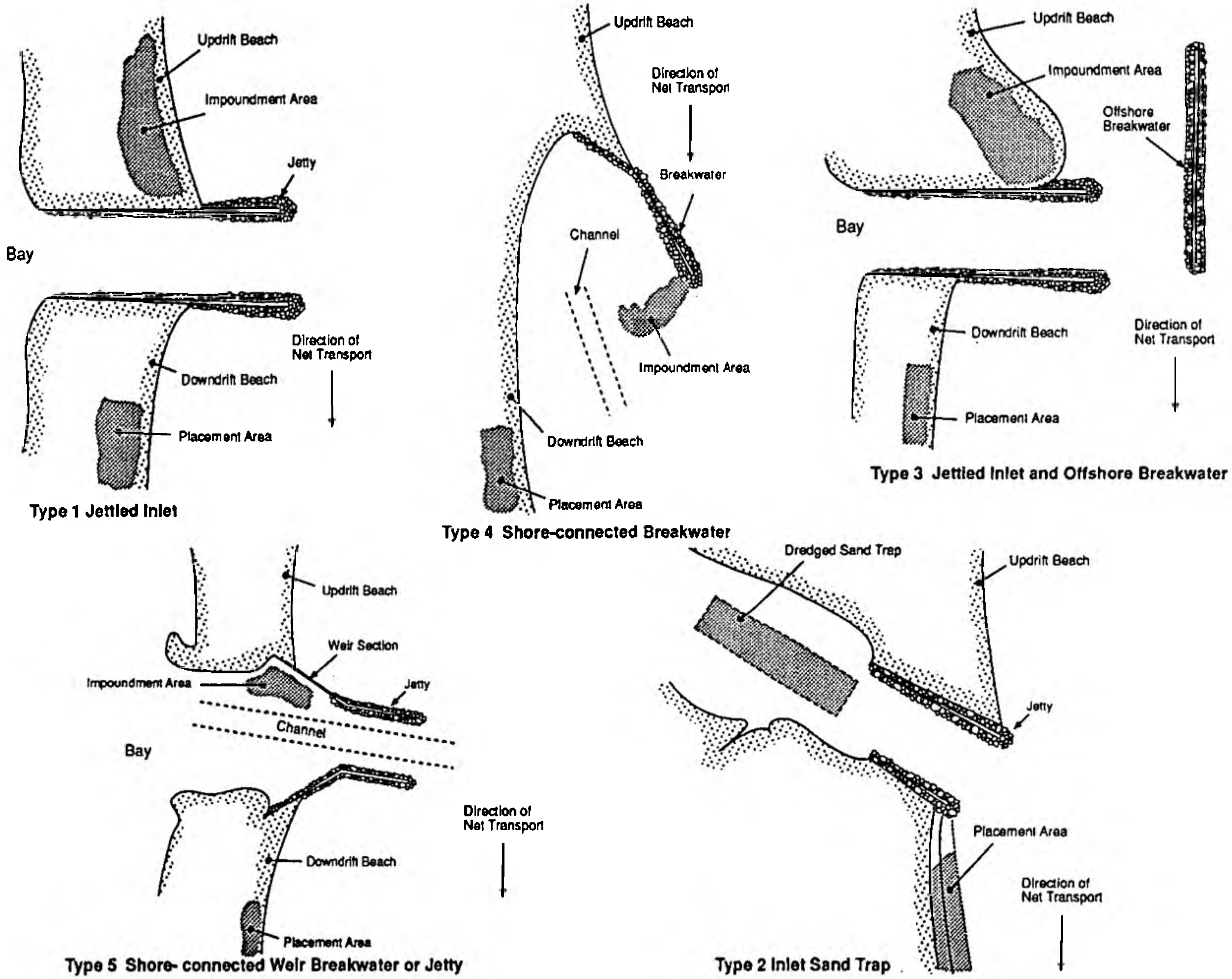
In all the situations where these configurations have been used, the beaches consist of sand and the tidal range is small. Essentially none of these systems are appropriate for shingle beaches, since they rely on a high mobility of beach material, in most cases sand being transported in suspension into the chosen area of deposition.

Associated with these littoral barrier configurations are three systems of bypassing which have been widely used in the USA:

(a) fixed bypassing plants (sand pumping)
(b) floating bypassing plants (sand pumping)
(c) land based bypassing plant (involving use of lorries/draglines for mechanical sand transfer).

Bypass systems used elsewhere in the world can also broadly be put into these three categories, irrespective of the type of beach material to be bypassed.

Figure 3.1 Sediment bypassing, US Army Corps of Engineers (1984)



Type 1 Jettied Inlet

Type 4 Shore-connected Breakwater

Type 3 Jettied Inlet and Offshore Breakwater

Type 5 Shore- connected Weir Breakwater or Jetty

Type 2 Inlet Sand Trap

Fixed bypassing plant

Fixed bypassing plant, involving the pumping of sand as a slurry from the updrift to the downdrift side of a littoral barrier is the most common type of bypassing operation in use today. The obvious advantage of this system is permanent plant which, once in place, requires a relatively low degree of maintenance. This is the type of plant which can most easily be constructed on a relatively modest scale. A major disadvantage of the method is that the pump, or pumps, can become ineffective as a result of too rapid a rate of beach accretion, when the pump head may become stranded landward of the high water line. Under such conditions additional equipment is needed to fluidise the beach sand and hence make it transportable to the pump head.

Fixed sand bypassing plant has been extensively used on the Florida coast of the USA and some of the earliest bypassing plants were developed here.

The Shore Protection Manual gives a detailed description of two well known fixed bypassing plants, one at South Lake Worth Inlet and the other at Lake Worth Inlet, both situated on the same barrier island. South Lake Worth Inlet was dredged and stabilised by means of twin jetties in 1927. The construction of the inlet through the barrier beach was primarily to provide more efficient water exchange between Lake Worth and the open sea. The inlet channel is also sufficiently large to allow passage for small craft, drawing between 1.8m and 2.4m of water. The inlet channel at South Lake Worth is 38m wide and 182m long while the entrance jetties extend about 76m seawards. Construction of the inlet caused erosion of the beaches to the south and it became necessary to protect the coastline there by means of a seawall and groyne system. These measures failed to stabilise the coastline, since the groyne field had effectively little material which it could trap. In 1937, therefore, a fixed bypassing plant began operation, transferring material from a pumping plant on the north jetty, via a pipeline, to the coast south of the inlet, at an annual average rate of 37000m^3 per year. Between 1937 and 1941 operations were discontinued and the coastline south of the inlet receded rapidly. Operations resumed in 1945, and in 1948 the plant was enlarged and modified, increasing the discharge capacity of the system by nearly 100%. In 1967 the north jetty was extended and the bypassing plant moved seaward so as to remain in the intertidal zone. The capacity of the system was further increased. The system now consists of a 30cm suction pipe (as compared with a 20cm pipe originally), a centrifugal pump driven by a 400 horse power diesel engine (as compared with a 65 horse power engine originally) and a discharge pipeline. The rate of bypassing for this and other Florida bypassing systems has been analysed by Jones and Mehta (1980). On the basis of plant operating times and an assumed pumping rate of 150m^3 per hour it has been estimated that the rate of transfer between 1967 and 1978 has varied from 24,000m^3 per year (1967/8) to as high as 115,000m^3 per year (1976/7). The average rate of transfer over this period is estimated at about 58,000m^3 per year. The nett north to south alongshore transport is considerably higher than this, being estimated at about 172,000m^3 per year (U S Army Corps of Engineers 1984). The unit costs of bypassing, averaged over the period 1967/8 to 1977/8, have been assessed by Jones and Mehta (1980) as being $1.63 per m^3 at 1979 prices.

Undoubtedly the bypassing system has helped reduce the rate of downdrift erosion. This has been supplemented by maintenance dredging operations, by which means some 20,000m^3 of additional material were transferred annually to downdrift beaches between 1960 and 1976. However, beach erosion south of the inlet persists, despite the continuous operation of the bypassing plant and the maintenance dredging activities.

At Lake Worth Inlet, a higher rate of sand transfer has been achieved by means of a more complex arrangement. Here the bypassing system consists of a 30cm suction pipe, a 400 horse power electric motor/pump combination and two 25cm discharge pipes laid across the channel bed. Estimates by Jones and Mehta (1980) indicate that over the period 1967 to 1978 the average bypassing rate has been about 100,000m^3, equivalent to about 60% of the nett littoral drift volume. The efficiency of the bypassing has been enhanced by maintenance dredging operations, which have removed some 227,000m^3 of sand from the channel to the downdrift coast between 1970 and 1973. The unit costs of bypassing, averaged over the period 1967/8 to 1977/8, were assessed by Jones and Mehta as being $1.27 per m^3 at 1979 prices.

Fixed bypassing plants have also been used in other countries, with varying degrees of success. At Santa Cruz, Mexico the plant became rapidly land locked and was abandoned for other methods of channel maintenance. In the 1960's fixed sand bypassing systems were installed at Viareggio and at Marina di Carrara harbours, both of which are situated on the northwest coast of Italy. In both systems the sand could not be transferred at a sufficiently rapid rate to prevent the sediment sinks from becoming either blocked up with debris or land locked (Fiorentino *et al* 1985). The system at Marina Di Carrara was abandoned, while that at Viareggio was replaced by mobile plant during a subsequent reconstruction phase of the harbour.

More recently a very large scale bypassing scheme was put into operation on the Queensland coast of Australia. During the development of the Gold Coast Seaway the Nerang River entrance was stabilised by twin training walls. The wave climate on the Gold Coast of Queensland is quite severe and the nett alongshore transport of sand is very high, being about 600,000m^3 per year in a northward direction. While offshore wave heights at this site are on average between 0.8m and 1.2m, wave heights as large as 10m can occur during tropical cyclones. The range on mean spring tides is 1.3m. The river entrance which cuts through the barrier beach has had a history of instability, with migration of the river mouth having taken place at between 20 and 40m per year prior to training in 1984. To prevent any potential migration of the river entrance, and to stabilise the adjacent coast, a massive fixed sand transfer plant was constructed, and this has been operational since the opening of the inlet in 1986. The system consists of an array of 10 jet pumps set at a 30m spacing on a trestle located south of the south training wall, with the jet pumps being at 11m below mean sea level. The pumps are capable of transporting up to 500,000m^3 of sand per year to a feeder beach north of the inlet (Coughlan and Robinson 1990).

The system has performed successfully and efficiently and during the first two years of operation some 300,000 to 400,000m^3 of sand in excess of the littoral transport rate were bypassed, substantially reducing the updrift accumulation (which had built up in a 20 month time lag between the start of training wall construction and beginning of bypass operations). There have been some operational problems, however. Since early 1989 there has been a reduction in the bypassing rate due to debris being transported by storms into the stilling trap from which the jet pumps collect the sand. This debris has had to be removed mechanically to allow operations to continue, usually with the assistance of divers. The reduction in performance has not resulted in any entrance shoaling problems, however. At the time of writing, trials were under way with a large jet pump to remove debris from the sand trap. The system is considered to be a major coastal engineering achievement, being the first inlet stabilisation scheme in Australia incorporating a sand bypassing system to mitigate any possible deleterious effects on the coast resulting from the "permanent stabilisation" of an inlet. The system is also one of the largest of its kind and had bypassed more than 1.2 million m^3 of sand over the period March 1986 to December 1988. The cost of the design/construct contract was approximately $A6.3 million for the sand bypassing jetty and pumping system which formed a relatively small portion of the total costs of the entrance stabilisation project.

Other notable fixed bypass schemes which have been constructed in recent years include that at Indian River Inlet, Delaware and that at Oceanside Small Craft Harbour, California. In both cases jet pumps are being used to draw in a sand/water slurry which is then delivered by discharge pipelines to downdrift beaches, via booster stations.

The Indian River Inlet System was completed in January 1990. It has been designed to bypass sand at an average rate of 77,000m^3 per year, ie at about the same rate as the nett northward transport in this area (which has been estimated at between 77,000 and 84,000m^3 per year). Between February and December 1990 the plant achieved a bypassing volume of 86,000m^3, thereby exceeding its design value (Clausner *et al* 1991). During February, April and October bypassing volumes at Indian River Inlet ranged between 12,000 and 18,000m^3 per month. During the summer months output was reduced due to social and environmental constraints, eg the need to minimise disturbance to beach users and the need to protect bird nesting areas. Impacts of the system on beach stability are being monitored and it would appear that significant changes have been restricted to an area immediately adjoining the updrift jetty where the beach had narrowed by about 15m over some 180m frontage south of the south jetty. It has not been possible to determine the impact of operations to the north, due to other beach nourishment operations in that area. The cost of plant construction was $1.7 million. The running costs (operating and maintenance and allowance for future replacement of major components) have been estimated at $290,000 for bypassing of 76500m^3 of sand annually. This is equivalent to a cost of $3.8 (about £2.5) per m^3 of sand bypassed and discharged over a distance of up to 460m north of the inlet (up to about 610m north of the pumphouse).

The Oceanside experimental sand bypass scheme is also at an experimental stage. The jet pumps have achieved a maximum transfer rate of 118m^3 per hour; however due to variations in the sand supply to the jet pump craters the average pumping rate has been as low as 50m^3 per hour (Patterson *et al* 1991). It is hoped eventually to achieve a more consistent supply to the jet pumps, by means of "fluidising" the seabed material. The fluidisation technique involves pumping water through a perforated pipe buried beneath the seabed surface. (Once the overburden is liquified the sand is then able to flow freely into the jet pump crater).

Other similar schemes involving fluidization techniques for enhancing the sand trapping ability of jet pump sand craters are being tested, at several sites in Maryland and Florida (Parks 1991). The cost effectiveness of this and various other bypassing systems is rather open to question, especially under conditions of high tidal range, mixed beach materials, and moderate to severe wave activity found on most coastlines of the UK.

Floating bypassing plant

Except for relatively simple inlet geometries (Type 1 classification, see Figure 3.1) fixed bypass systems are normally unsuitable for sand transfer or channel maintenance. They rely on the littoral transport being relatively uniform throughout the year and on transport being concentrated in a relatively narrow zone. Also being fixed in position they are limited in the amount of sand they can pick up from any particular location, and to a large degree are dependent on natural forces to supply sand to the pick-up area. Very rarely are such systems able to pick up more than just a fraction of the littoral transport volume (Richardson 1977).

Floating bypassing plant, being more mobile, is more adaptable and therefore more suited for use at complex channel geometries (Type 2 to 5 classification). The main disadvantage is the vulnerability of the plant to mechanical damage, particularly by wave induced forces. Nevertheless floating bypass systems are commonly used to dredge sediment impoundment basins (Type 2), impoundment basins in the lee of breakwaters (Type 3 and 4), and to dredge out sand traps downdrift of sand weirs (Type 5).

The basic design of a floating bypass plant system includes the establishment of a fixed location for the major part of the pumping apparatus and for the discharge system, while allowing the delivery system to be moved within a designated area. Operational costs with such systems can be higher than those for fixed plant because of the higher maintenance costs, the greater number of personnel needed for operations and due to the more complex plant. They also have the disadvantage that dredging operations may interfere with other users of the inlet or harbour, since discharge is normally carried out via a floating pipeline (Richardson 1977). A detailed description of the use of floating bypassing plant for various inlet types can be found in the Shore Protection Manual (1984).

A few examples of the use of floating bypassing plant serve to illustrate the pros and cons of this type of operation.

The harbour of Viarregio, Italy has had a long history of problems associated with the interruption of the alongshore drift of sand (Fiorentino et al 1985). Fixed sand bypassing was attempted as far back as 1936 but it was not until 1980 that a successful scheme was established by the installation of a flexible bypassing plant in 1980. The system uses floating dredges which can be connected up from various parts of the harbour to a fixed pumping station sited on the downdrift side of the harbour. These floating dredges can be used to remove material from within the harbour area, from the updrift (south) beach or from a shoal at the harbour entrance. Over the period 1980 to 1985 the bypassing system has achieved an average rate of transfer of 95,000m^3 per year. Despite the fact that littoral drift is estimated as being northwards at 200,000m^3 per year, shoreline surveys downdrift of the harbour have shown that (at least locally) there has been considerable accretion as compared with recession prior to the installation of the floating dredge system. It is interesting to note that this form of bypassing has been estimated to be 50% less expensive than operations involving mechanical bypassing of the harbour by lorry (Fiorentino *et al* 1985). The successful use of the system of floating dredges is attributed to the low tidal range and the moderate wave conditions in the harbour area.

A rather novel approach to the control of littoral transport is that employed at several inlets in the USA involving the use of weir jetties. These jetty systems evolved from the "exploitation" of an existing reef at Hillsboro Inlet, Florida where observations showed that during the winter sand was carried over a low part of the jetty and adjoining reef into a "still area" inside the inlet. This led to the concept of a weir jetty which would control sand transport by impoundment in a sheltered area, from where it could be removed at reasonable cost (Parker 1979). There is not doubt that such systems can be made to transport material into a deposition basin, but the rate at which this happens is less easy to predict.

The rate of alongshore drift along almost all coastlines varies significantly not only from season to season, but also from year to year. Hence experience with such systems, all of which have been used in the USA, has been rather mixed. Weggel (1983) believes that the littoral environment is rarely understood sufficiently well to allow an optimal design to be achieved, and hence any such system should be able to tolerate a wide range of conditions.

A relatively successful solution has been achieved at Boca Raton, Florida, where the inlet has been maintained by the City since 1972. In 1975 the north jetty was extended by nearly 60m so as to improve navigation through Boca Raton inlet. This, however, caused very rapid erosion and the shoreline south of the inlet receded at about 4.5m per year over the period 1975 to 1979. (At one point, about 27m south of the inlet, the shoreline recession was as much as 17m per year over this period.) By 1979 erosion had become so severe that the southern jetty was in danger of being outflanked. In 1980 the City of Boca Raton constructed an experimental weir jetty by lowering the height of a 20m long section of the northern jetty at a position corresponding to the 1975 high water mark. The weir elevation was at about mean sea level and as a result the shoreline updrift of the jetty adjusted rapidly to that position. The channel between the jetties and as far seawards as the outer bar has been dredged by a hydraulic pipeline dredge, weather permitting. The weir is said to have achieved "the desired balance between erosion control south of the Inlet while retaining navigation conditions in the inlet" (Spadoni *et al* 1983). The dredging rates in themselves are relatively modest, averaging at 52,000m^3 and 49,000 m^3 in 1981 and 1982 respectively. They have, in fact, been exceeded in operations prior to the construction of the weir jetty. (During 1973 and 1974 the dredged volumes were 53,000m^3 and 54,000m^3 respectively.) It is possible that the feed to the sand bar seawards of the inlet may have been enhanced by sand being flushed on to it. The sand bar appears to be more effective, as a result, in feeding the downdrift beaches.

The problems which may arise with sediment bypassing systems are well illustrated by a brief review of the history of Barnegat Inlet, New Jersey. Barnegat is one of a number of inlets which dissect the barrier beaches of the New Jersey coast. They have a long history of instability. Records show that in addition to the principal inlets which are open today there were a number of others, which were liable to open and close unpredictably as a result of storm induced changes to the barrier beach system (Caccese and Spies 1977). Barnegat Inlet was first canalised in 1940: prior to this it had a history of instability, migrating southwards at about 30m per year over the period 1840 to 1866, for example. Numerous "improvements" have been tried over the years including increasing the height of the jetties and repeated dredging of the inlet channel (at an average annual rate of 60,000m^3 per year). Apart from stopping its southward migration, these have achieved little in the way of effective control of the navigation channel through the inlet. Long Beach, which is to the south of the inlet, due to its high population density and its vulnerability to storm damage, was designated a "priority beach" after a number of severe storms caused "critical erosion" of the northern end of Long Beach Island. An emergency replenishment project was put in hand in 1979 and the northern end of the frontage was fed with over 1 million m^3 of sand dredged from the inlet channel at Barnegat. This material was intended to alleviate local erosion (which it did) and also to serve as a supply of material for the beaches to the southward. However the material placed close to the south jetty was within the zone of influence of the jetty/nearshore sand bar system and rather than moving southward it moved northward against the general direction of littoral drift, eventually returning to the inlet channel itself (Ashley *et al* 1987).

A more recent and possibly a more successful example of a bypassing operation took place on the Huelva coast of Spain, when in 1988/9 some 1,690,000m^3 of sand was dredged from a sand bar west of the entrance to Huelva harbour and deposited on the Playa de Castilla to the east of the entrance. The coast at Playa de Castilla has been receding at a rate of 1.5m per year over the last 30 years, partly as a result of the reduction in the supply of sand (because of less rainfall, dam construction, construction of littoral barriers further up-coast etc). The nett littoral drift of sand is southwards (ie away from Huelva harbour) at the rate of about 390,000m^3 per year. During the bypassing operation the sand was transported from the accretion zone by a trailing suction hopper dredger and then pumped onto the beach through a 2km long submerged pipeline. The material was placed as a 115m wide and 2km long berm and has been dispersed downdrift naturally by wave action. The project was carried out at a relatively low unit cost of \$3.4/m^3 (about £2.3/m^3) (Fernandez *et al* 1990) and it is anticipated that the bypassing operation will be repeated every 4-5 years. In this manner it is intended to alleviate the erosion on the 25km stretch of coast wet of Huelva which has been subject to severe erosion.

Another method which is gaining in use in the USA is the transfer of material from a sand trap sited typically within the throat of a tidal inlet and material encouraged to settle out there by means of jet pumps or fluidisation pumps. The trap is then emptied as and when necessary by means of a shallow draught hopper dredger with the capability to pump the sand trap material to adjacent beaches. Bruun and Willekes (1992) have estimated that the cost of such operations for transferring "quantities of the order of some hundred thousands of cubic yards per year" will be of the order of \$4 to \$5/m^3 (about £2.7/m^3 to £3.3/m^3).

Land based bypassing or recycling

Land based bypassing operations have not been widely used and in the USA, where there is a long history of inlet bypassing, only a few examples of such systems can be found.

A land based bypassing scheme was carried out at Shark River Inlet, New Jersey in 1958 and 1959, involving the transfer of sand from a borrow area immediately south (updrift) of the south jetty to a 760m long feeder area immediately north of the north jetty. The beach on the north side of the inlet had been one of the most heavily eroded as well as being one of the most highly developed frontages in New Jersey. Here the nett northward rate of alongshore sand transport has been estimated at being 203,000m^3 per year. Although it was evident that sand bypassed the inlet naturally via a nearshore bar it appeared that it did not reach the shore in any significant quantities until it had been transported several miles north of the inlet. A scheme was therefore put in hand for making up the deficit immediately north of the inlet. The beaches on either side of the inlet are publicly owned and as the local community was in favour of the project the necessary permission for the operation was obtained without undue difficulty. The location of a bridge over the inlet immediately behind the beach favoured the use of a "trucking operation". To facilitate the transport operation a trestle was constructed south of the inlet extending to a little beyond the low water line, thus allowing trucks access to a crane situated on the trestle. Three groyne compartments immediately north of the inlet, where erosion was greatest, were nourished by means of the construction of three shorter trestles, which allowed the trucks easy access from the highway to the beach. Transport was carried out by means of two 15m^3 capacity trucks and one 7.5m^3 capacity truck, which were filled up by means of a crane with a 2m^3 capacity "clam shell" type bucket. A bulldozer was also used to stockpile the sand within reach of the crane. At one stage it was thought that a bulldozer would also be needed to spread material over the beach. However as the operation was carried out over winter periods redistribution was effectively carried out by wave action. Over two successive winters some 190,000m^3 of sand were transported across the inlet in this manner. The scheme proved to be successful for a number of reasons. At one stage it was considered that dredging from the inlet might be feasible. However, the sand bypassed was coarser, better graded and made a better beach fill than in other operations on the New Jersey coast involving dredging from inlet shoals. Visually the sand was more acceptable to this high value tourist beach, being free of shell fragments, clay balls, silt etc. Finally the operation provided sand at a cheaper rate than other methods of operation available at that time. The proposals for the works included the winning bid to transport the sand by trucks at a price of \$1.15 per m^3 (Angas 1960). Another proposal to dredge the sand by dragline, place it into a hopper and then transport it by means of a dredge pump and discharge pipeline, had a bid price of \$1.70 per m^3. Finally a proposal to carry out the work by means of a hydraulic dredge plus discharge pipeline, had a bid price of \$1.85 per m^3.

While there is little in the way of direct comparison that can be made with present day operations it is likely that such operations will be limited by fuel expense and by the requirement of easy access from the borrow to the discharge areas. Certainly this type of operation was considered to be likely to be much more expensive than the semi-mobile operation used at Viarregio (Fiorentino *et al* 1985).

As part of a programme of emergency beach restoration in South Carolina beach recycling was extensively used to make up beaches and restore dune systems (Kana *et al* 1990). Beach material was trucked from inland sources or from accreting shoals at tidal inlets. Five beaches were nourished in this manner with a total volume of approximately 800,000m^3 at an average unit cost of \$7.7/m^3 (about £5.1/m^3). In fact the costs varied from \$3.3 to \$11.29/m^3, the lowest costs being for Pawleys Island where work was done on an irregular basis and unit costs were not directly available. Excluding this particular scheme the costs at the other four sites varied from \$6.7 to \$11.2/m^3, averaging out at \$9.3/m^3 (about £6.2/m^3). Haul distances varied greatly since extensive lengths of coast were nourished; sand sources varied from 7 miles to as much as 15 miles from the frontage to be nourished.

3.4.3 UK experience with shingle beaches

Beach recycling or alongshore transfer of material in the United Kingdom has been traditionally carried out by mechanical plant. This has been carried out most notably on shingle beaches on the east and south-east coasts of England. The problem of downdrift erosion south of Aldeburgh was tackled by means of shingle recycling in the post-war years. A railway track was laid on the shingle backshore of Orford Ness and a small train was used to transport shingle from the Ness northwards to the southern end of Aldeburgh, where the town's defences finished at a terminal groyne. This practise has long since ceased and indeed there are no details of the efficiency of this operation available.

The "lower sand/upper shingle" beaches of the southeast coast also have a long history of shingle recycling (Foxley and Shave 1983). These operations have traditionally involved the transport of shingle by lorry from downdrift to updrift areas of individual stretches of beach. Shingle recycling or recharge was pioneered in Kent and Sussex in the 1950's and 1960's, for maintaining or improving existing sea defences. The Pett foreshore, to the west of the river Rother has only a limited amount of natural beach feed at its western end, while the harbour arm at the eastern end traps most of the eastward moving drift of shingle. Until about 1930 the shingle ridge along this frontage was of adequate size to form a natural flood defence. Progressive erosion at the western end resulted in a succession of increasingly "hard" defences being constructed over the period 1933 to 1952. By 1952 a seawall and groyne system protected the western 5km of the frontage. Continued erosion and the persistent danger of sea wall undermining led to a change of coast protection policy. Access ramps were constructed over the existing sea wall and an initial transfer of 150,000m^3 of shingle was made from east to west. This has been followed by annual recycling of shingle at the rate of 19,000m^3 per year (Foxley and Shave 1983). The shingle is dug from the beach face immediately updrift of the western jetty at the mouth of the River Rother. Experience has shown that recycling at this rate has kept the river entrance free from blockage by shingle (although some blockage by sand drift does occur).

A similar scheme has been in operation on the Walland foreshore to the east of the river Rother. There, the storm bank was built up with 141,000m^3 of shingle from an "inland" source on the Dungeness foreland. Annual recycling has taken place at an average of 31,000m^3 per year, with material being obtained from the eastern face of the Dungeness shingle foreland, where material accumulates naturally. More recently a major nourishment scheme was carried out in Sheerness involving the construction of a massive shingle bank to form a flood defence embankment. In 1975 some 180,000m^3 of sea dredged shingle was brought in to the beach at high tide using split bottom barges and deposited on the lower foreshore. Bulldozers and draglines were then used to form the shingle berm to the design profile. A substantial shingle bank was thus formed to protect the low lying hinterland to the 1000 year level of flood defence. The way in which the bank was constructed resulted in a consolidation of the nourishment material, which was relatively resistant to wave sorting, and this may have reduced the alongshore movement. The area is relatively sheltered from wave action and recycling was first necessary 6 years after completion of the scheme when 2400m^3

of material was transported from the west to the east end of the frontage (ie. an average requirement for recycling of 400m^3 per year). Over the years the bank has been subject to more severe wave and tidal events so that the process of sorting by wave action has resulted in a natural-looking lower sand/upper shingle beach. Littoral drift is now more rapid than in the early years of the scheme. Since 1986 the western half of the beach has been nourished with sand and shingle from inland sources, 8000m^3 of material being added to the beach on three occasions. Tipping unconsolidated material from the crest of the beach has led to the formation of a high steep scarp after storms. Because of the concave plan shape of the bank contours, nourishment losses are considerable and there are plans currently to reduce these losses by the construction of a rock groyne at the downdrift end of the frontage.

One of the most thoroughly documented shingle recycling operation in the United Kingdom is that used in connection with protecting the frontage of Dungeness Power Station, which is situated on the west face of the Dungeness foreland (Townend and Fleming 1991). The site provides quite a severe test case for this form of beach management. The foreland extends out to the 20m depth contour and is exposed to a large south-westerly wave fetch. The foreland is also not a stationary feature, but one which slowly migrates eastward with shingle being transported south to Dungeness Point and some shingle then being carried up to 5.5km north of the point along the east face of the foreland. After extensive studies of the historic evolution of the Dungeness it was decided to recycle shingle from east to west at the rate of 30,000m^3 per year over the Power Station frontage. Of three methods of transport which were considered (road haulage, hydraulic pipeline, mechanical conveyor) the road haulage method was assessed to be the most cost effective. Beach nourishment was begun in 1965 and has been continuing since. Detailed monitoring of beach volume changes has shown that the requirement for annual recycling had been very accurately determined. The additional recycling volume, above the design rate of 30,000m^3 per year, has been increasing at about 540m^3 per year and is believed to be (at least in part) due to the reduced shingle supply from the west. In 1983 a review of coast protection options for the frontage was re-evaluated, in relation to a possible new power station. The estimated costs, over a design life of 105 years, based on 1983 prices were as follows:-

Beach recycling	£ 3.1 million
Timber groynes and breastwork	£ 5.7 million
Mass concrete groyne and timber breastwork	£ 6.5 million
Steel sheet piled groynes and timber breastwork	£ 9.4 million
Two artificial headlands and a single beach recharge	£ 4.4 million
Revetment of concrete armour units	£15.2 million

The beach recycling operations at Dungeness proved to have a number of other advantages over other ways of maintenance. These included lack of downdrift erosion problems and a flexible system of working which enables a rapid response to be made to changes in the rate of littoral drift.

Summary

Inlet bypassing operations have reached a high degree of sophistication in the USA. In all cases beach material has been sand and this has been transferred across relatively narrow inlets at rates of up to 77000m^3 per annum. In Australia a major bypassing plant has been developed which is capable of transporting sand at rates of up to 500,000m^3 per year via an array of 10 jet pumps. In Italy a system involving floating pumps has proved to be capable of transferring sand at the rate of up to 95000m^3 per year. In all cases the bypass systems have been used in areas of low tidal range, where the majority of intertidal beach movement is constrained within a relatively modest foreshore width.

We see little future for these fixed or floating permanent systems for bypassing sand in UK coastal conditions. There is even less likelihood of such systems being able to operate on sand and shingle mixtures which can be found on a majority of the UK beaches.

"One off" operations associated with capital dredging projects, as typified by the scheme in which 1.7 million m^3 of sand bypassed across the entrance to Huelva harbour, Spain, show more promise for UK coastal conditions. A number of harbours in the UK are situated in the entrances to estuaries and a number of these have a heavy maintenance dredging requirement.

At present spoil dredgings in the UK are dumped offshore and the material effectively lost from the system (to avoid the material resettling in navigation channels, material is normally deposited at some distance offshore and at a depth in which dispersal will be slow). With the co-operation of harbour and local coast protection authorities it is conceivable that dredged material could be pumped onto downdrift beaches. It should be borne in mind that almost inevitably the dredgings will include a proportion of silt material. Field trials will be necessary to assess the rate of disperal of this fine material and research using mathematical modelling techniques will need to be carried out in specific areas to determine the ultimate "fate" of the silt fractions.

It is likely that bypassing operations, unless associated with capital dredging projects, will be prohibitively costly. An alternative is to recycle beach material within carefully defined coastal cells. In this manner the best use can be made of existing beach deposits and beach losses into tidal inlets etc, can be minimised.

Beach recycling has been widely used in South-East England by the NRA, with material being transported in some instances over frontages of several kilometres at relatively low unit cost. With the present trend towards the development of groups of coastal authorities this method of recycling can be carried out in a systematic and controlled fashion to the benefit of all. A strategic approach will be needed for recycling to be effective as clearly it will not be feasible to transport material many kilometres and over several local authority boundaries. Instead recycling within coastal cells can be developed, on the principles described by Motyka and Brampton (1993). The boundaries of such cells can be defined precisely by numerical model techniques, using which littoral transport rates within adjoining groyne fields etc can be evaluated. Such beach management techniques, of course require careful monitoring to take into account short term fluctuations in littoral drift rates. By assessing rates of transport by means of volumetric beach changes the rates of recycling can be "tuned" to suit the changing conditions from one year to the next.

3.5 Beach drainage systems

3.5.1 General

Beach drainage and subsequent lowering of the water table is considered to enhance the settling out of sand during wave uprush while reducing the amount of material transported seaward during the backwash (Davis *et al* 1992). It has been observed that beaches tend to erode as the tide falls and accrete as the tide rises, this being attributable by some researchers to the relative difference in level between the beach water table and the offshore mean water level. Davis *et al* (1992) state:-

"If this argument is correct, then it is the local watertable exit point and its movement over a tidal cycle which is important for beach accretion and erosion and not the overall back beach watertable. Increasing the drainage capacity of the beach could be expected to decrease the time lag between oscillations of the beach watertable and the offshore mean water level and lower the watertable exit point within the wave run-up distribution of the beach."

3.5.2 Overseas experience

Beach stabilisation by means of lowering the beach watertable by drainage is a recent technique which has been developed primarily for sand beaches. The method has been developed from the discovery that pumping seawater landwards through a beach has a stabilising effect on the intertidal zone. The technique and subsequent development of the Coastal Drain System dates back to 1981, when a system of pipe drains and pumps was installed west of Hirsthals harbour, North Jutland. The pumping system was installed to provide large volumes of filtered sea water for use in heat-pump systems and for providing water for aquaria. A series of shore parallel pipes were set into the beach at just below mean sea level and to the landward of the high water line. Only a fortnight after pumping was begun the water yield had decreased substantially and upon inspection it was found that the beach had accreted in the meantime. It was determined that the accretion had significantly increased the flow path from the beach face to the drains and hence reduced the input of water substantially. Results with regard to beach accretion were sufficiently encouraging for a further installation to be made east of Hirsthals, followed by a further full scale experiment at Thorsminde in Jutland in 1985, on a sandy coast exposed to North Sea waves. The coast at Thorsminde had experienced seasonal fluctuations in the shoreline (MSL) position of ±15m, with an underlying trend of recession at 4m per year. Following installation, the coastline stabilised about 25m seawards of the "drain line". Subsequently, beach retreat during storm events has been followed by accretion, attributed to pumping making good the storm losses. During 1988, when the system was closed down, the coastline reverted back to erosion. Subsequently there has been recovery, following restarting of pumping.

It is concluded from these early tests that the system can be used to stabilise the upper beach and make post-storm recovery more rapid (Vesterby 1991). However, this system is not seen by most researchers as a substitute for beach nourishment, but more as a means of stabilising the upper foreshore (with material being added from the lower part of the beach or from offshore). Beach management by drainage is thus seen to be well suited to be carried out in association with beach nourishment, holding the nourishment material in place for a longer time period before renourishment is needed.

There has been sufficient interest in this form of beach management for a similar scheme to be built at Hutchinson Island, Florida, in 1988. As in Denmark, the test beach is sandy, is exposed to moderate wave activity, and has a small tidal range (0.9m on springs). Littoral Environmental Observations (LEO) indicate that during north east swells wave heights of 1.5m can occur in the nearshore zone. Conditions at the beach itself are somewhat calmer due to the protection afforded by a shore parallel coral reef. Over a short monitoring period (July to November 1988) there was a net increase in beach volume in the drained beach area, with erosion to the north and south (Terchunian 1989). No adverse impacts were identified and it is believed that the drained beach also acted as a feeder to the downdrift beach. Further monitoring has taken place subsequently, with significant periods of shut-down. Beach volume calculations indicate that up to the first shut-down period (mid to late 1991) the beach had been slowly accreting. Thereafter a period of rapid erosion took place and, while there has been some recovery, the beach volume shows a net loss over the period 1988 to 1992. Over the same period the beach to the north has had much more substantial erosion. The downdrift beach to the south, on the other hand, has had a nett increase in volume over the same period. Since the operation of the system resumed in late 1992 there has been evidence of recovery in the drained beach area with aerial photographs taken at low tide showing a distinct bulge in the vicinity of the installation (Coastal Stabilization Inc, 1993). While the results provide fairly strong evidence that the beach within the drained area is more stable than adjacent control beach sections, it is somewhat unfortunate that these control sections are subject to rather varying beach and hydraulic conditions, because of the presence of the nearshore reef.

A drainage system has also been in operation in Australia, at Dee Why beach, NSW. The beach is sandy and is part of a barrier system enclosing a small lagoon. The tidal range is small (2m) and wave action is moderate (deep water H_{rms} can exceed 2.5m on occasions). A system of gravity drains was installed in early 1991 and monitored over an 18 month period. The project proved that it is possible to lower the water-table by a system of gravity drains (ie without recourse to pumping). Analysis of morphological changes indicates that lowering of the water table resulted in a significantly more stable beach within the drained area, with greater variance in the position of the beach contours outside the drained area than inside it. However, it was not possible to detect any actual increase in beach volume, because natural beach fluctuations due to cusps/rips, cycles of erosion/accretion had impacts which were of the same order of magnitude as the impacts of the drainage system (Davis *et al* 1992).

Summary

Beach drainage systems function by means of lowering the beach watertable, which in turn leads to the "capture" of suspended material brought to the beach crest by wave uprush, and reduced offshore loss as a result of decreased intensity of wave backwash. Drainage systems can be passive, consisting of a system of gravity drain pipes set into the beach face, or can be active by means of pumping. For either type of system the best results are obtained on beaches with sand sized material. The presence of fines makes pumping difficult and may result in little or no depression of the watertable. The presence of a large proportion of gravel, or too coarse a sand size, will result in little change in water table level, even at a high pumping rate. Laboratory tests indicate that beach drainage using gravity methods may not be effective in areas of negligible tidal range (Ogden and Weisman 1991)

Experience with active drains has shown that continuous pumping can lead to a definite improvement of beach width, with material tending to collect at or above mean sea level. This material is brought in from alongshore or from offshore. As such there is no actual increase in the volume of material within the nearshore system. There can be, however, a significant increase in the width of the upper beach. It must be remembered that with cessation of pumping an artificially widened and steepened beach may have a steeper face, may be more reflective, and may possibly undergo more rapid erosion than a natural beach. At present it is difficult to determine the cost effectiveness of such systems. Both costs and beach behaviour will clearly be very dependent upon local site conditions. Bruun (1989) assessed the likely costs of construction as being of the order of \$800/m (about £500/m) and running costs of the order of \$30/m (about £20/m). These costs are not site specific and probably relate to less "harsh" conditions than those found in the United Kingdom.

Experience with passive drains has produced less conclusive results. Comparison with control beaches indicates that a drained beach area may be subject to less variability, but not necessarily experience any increase in beach volume.

No beach drainage systems have been installed in conditions similar to typical UK coastal conditions. Their likely behaviour is difficult to predict but we consider that it is likely that active drainage systems will prove to be more effective than passive drainage systems. Active drainage will also be easier to monitor in a controlled manner; pumping can be continued for a specified time period, the system can then be easily switched off and the changed behaviour of the beach monitored. The pumping system can also be easily restarted, after a shut down period of several months.

It is recommended that field trials should be made to assess the effectiveness of active beach drainage systems. Ideally a site should be chosen where the historic changes in beach behaviour have been monitored or can be determined (eg by examination of historic Ordnance Survey maps, tithe maps etc). Monitoring should extend over a period of no less than two years, and the effects of shut down need to be examined. As a first trial it is recommended that a relatively stable beach, subject to a moderate level of wave activity, should be chosen. Should positive results be obtained then further trials will need to be made on more strongly eroding beaches to assess the applicability of this system for beach management purposes. We note that a trial scheme involving both gravity and pumped drainage systems is due to be installed at Newquay, Cornwall in 1994.

3.6 Perched beaches

3.6.1 General

In areas of persistent erosion or areas where there is little margin left for shoreline retreat (ie. in front of old sea walls) beach nourishment is becoming increasingly popular for widening the "margin of safety" against incursion by the sea. Where the morphology of the nearshore system has been significantly changed by beach/sea bed lowering, nourishment material may have a relatively short residence life and a strategy may need to be adopted which will reduce the rate of loss of the nourishment material. One method by which this can be carried out is by constructing a shore parallel barrier at the toe of the nourished beach. By doing so it is considered to be possible to change conditions to such a degree as to change the beach from an eroding to an accreting one, under certain circumstances (de Ruig and Roelse 1992).

The concept of perched beaches is by no means new but there has been some reluctance to use it on large scale projects because of difficulties in predicting the behaviour of a dynamic system of this type. Offshore sills have proven to be effective in combination with beach nourishment schemes, and in areas of low tidal range and low to moderate wave activity they can be constructed quickly and cheaply (Motyka and Welsby 1987). Under such conditions even relatively small structures can cause a significant improvement in beach width and even a relatively low sill may be effective in attenuating wave energy.

Up to recent times the performance of such beaches has been difficult to predict and design has been based largely on experience. With the increased use of interactive numerical and physical models (Corsini and Guiducci 1993, Bunn *et al* 1993) the design of perched beaches has now reached a stage of some sophistication. Perched beaches are now widely used in Italy, in the USA on sandy microtidal coastlines and there are plans to use such systems in Holland under conditions of somewhat higher tidal range. The use of modelling as part of the design process is now very extensive with over 30% of projects in an examination of 100 coastal studies in Italy involving the use of physical and numerical modelling techniques (Ferrante *et al* 1993).

3.6.2 Overseas experience

As part of a programme to demonstrate low cost methods of erosion control, the US Army Corps of Engineers (1981) constructed a perched beach in a relatively sheltered wave environment with conditions of low tidal range within Delaware Bay on the east coast of USA. The shoreline here is sandy and subject to considerably less littoral drift than is expected on an open coast location. The average annual drift has been estimated to be as low as 6000m^3 northwards and 4500m^3 southwards. A 300m long sill was constructed 76m offshore, with returns connecting it back to the shoreline at either end. The sill was 0.5m high with the crest at about mean low water. The enclosure was then filled with some 20,000m^3 of coarse sand from an offshore borrow area. Its performance was monitored by the Corps of Engineers from March 1978 to November 1980, and a further survey was carried out by the University of Delaware 3 years later. By the time of the last survey the beach had reverted to its "pre-fill" position. It is thought that the presence of the sill had probably slowed down the rate of natural beach loss, although the results were not conclusive, due to the large time-lag between the last two surveys. One aspect which appears to have not worked well in this instance, was the function of the sill as a "one way valve", allowing sand to be transported offshore, but preventing onshore transport (Douglass and Weggel 1987).

Other perched beach projects include an emergency protection scheme at Singer Island, Florida, where a series of storms during 1970 caused severe erosion, endangering a shoreline hotel which was then under construction. Rapid shoreline recession left a 1½m high scarp in the dune line which was within 15m of the hotel. Large quantities of concrete rubble were deposited seawards of this scarp in an attempt to halt erosion. A relatively high rate of drift and a plentiful supply of sand in the littoral zone led to the concept of a shore connected sill, constructed of sand-filled artificial fabric bags (Sivard 1971). The 1m high shore-parallel 91m length of sill was constructed below mean low water, but because of the low tidal range its crest protruded 0.5m at low tide and was barely submerged at high tide. Profile surveys indicate that the impoundment area filled naturally, as a result of the strong littoral drift, and indeed less than 3 months after completion a substantial beach had accreted, almost to the level of the dune scarp. Build-up to the seaward of the sill indicates that the period may have been one of general natural recovery. Nevertheless photographic evidence indicates a substantial improvement in conditions in front of the hotel even before the installation was complete. It is unfortunate that there has been no available information about the longer term performance of the scheme. Certainly the concept of using in-situ filled sand bags would appear to have been a successful short term response to an emergency.

The perched beach concept has also been widely used in Italy on sandy shorelines, under conditions of low tidal range. A particularly well-documented project is one carried out at Lido Di Ostia, some 25km south of the mouth of the river Tiber, on the relatively exposed west coast of Italy. Here, after long term accretion the coastline is now retreating as a result of reduced supply of riverine sand and due to coast protection works around the river mouth, which have resulted in a sediment deficit at downdrift beaches. A project to recreate a wide tourist beach and at the same time provide an effective coastal defence was initiated in 1988. The solution was a beach nourishment scheme in combination with an offshore sill to retain the fill material. The sill consists of a rubble mound structure sitting in 4 to 5m depths of water and having a crest level at -1.5m MSL. The seaward slope is 1:5 and to prevent scour it also has a 5m wide horizontal rock apron, trenched in to a depth of 1m below the sand bed surface. The fill is sandy gravel overlain by a 1m thick layer of sand constructed to give a 60m wide berm at +1m MSL sloping seawards at 1:4 to intersect the landward face of the sill at a level of -2.3m MSL. The project, which was completed in June 1990, has been a successful one, having been subjected to a number of severe storms without significant loss of beach volume (Ferrante *et al* 1992). However, there has been a migration of material in a downdrift direction, leading to a 20 to 30m advance at the southern end and a similar amount of retreat at the northern end of the frontage. There has also been some scour at the toe of the rock sill and deposition further seawards, and some leaching of the nourishment material into the core of the rock sill. Reshaping by wave action at one stage led to some ponding and construction of a natural berm at +1.5m to 2.0m MSL. It is concluded that it would have been better to place the coarser fill at a steeper slope, thereby avoiding this problem, and that the finer more expensive sand sized material should have been placed on the upper beach for maximum benefit. Doing so would not only have improved beach amenity but would have increased the level of backshore protection. Impacts downdrift and offshore have not been significant and the rock sill itself has resulted in the growth of marine fauna and has stimulated leisure fishing. The main hydraulic problems, namely loss of nourishment material in an alongshore direction and in a cross-shore direction were analysed by means of a combination of hydraulic model and numerical model techniques. Both the stability of the rock sill and the changes in profile of the artificial beach were examined in a 2-D mobile bed hydraulic model. The planshape evolution of the coastline (ie. littoral drift changes) on the other hand were examined by means of a 1-D numerical model based upon the theory of Pelnard-Considere. Both the longshore and cross-shore evolution of the nourished beach have been in line with model predictions. This gives encouragement to the development of such schemes, in which physical and numerical models are used interactively to provide design predictions.

There have been a number of other such applications of modelling techniques in the design of nourishment projects in Italy. Corsini and Guidicci (1993) describe the design of a beach nourishment project incorporating a submerged sill to protect the coast of Focene, north of the mouth of the Tiber. The study involved both 3-D physical models to examine beach evolution as well as 2-D physical models to examine sill stability and beach profile response. Details of model scaling, validation etc, are given. A combination of 2-D and 3-D mobile bed physical models is also applied by the authors to the design of a beach nourishment project at Pietre Neve beach east of Pozallo, Sicily. These tests indicated a strong tendency for offshore transport, which would be greatly reduced in the presence of a submerged sill.

A massive programme of coastal defence reconstruction and beach restoration is under way at the Adriatic coast of Italy, which will rehabilitate the barrier beaches separating the Venice lagoon from the Adriatic. As part of the beach restoration programme some 6 million m^3 of sand is being dredged from offshore to make up the deficit in beach sediments. (Reduced riverine sand supply and the interruption of littoral drift at the three Venice inlets having been identified as being the major causes of erosion.) The optimisation of design solutions has been carried out by the interactive use of numerical and physical mobile bed models "allowing the strengths of one technique to be exploited to compensate for weaknesses in the other" (Silva *et al* 1993).

Summary

Perched beaches in combination with offshore sills have an increasingly important role in the management of sand beaches on coastlines with a low tidal range, and a low to moderate wave exposure. Under these conditions the sill can be constructed with a relatively low degree of submergence and still be of moderate size. Also with a restricted tidal range and hence restricted intertidal beach width it can be built with ancillary structures (groynes or breakwaters) which can be effective in reducing end losses due to littoral transport. The sill is thus able to maintain a considerable volume of material in relation to the natural beach volume and hence produce a significant improvement in beach width for a modest sill dimension.

The performance of offshore sills and perched beaches in areas of high tidal range and moderate to severe wave activity, typical of UK coastlines, is likely to be less effective. The problems of scour holes both to the landward of the sill as a result of wave translation over the sill crest, and seaward of the sill as a result of wave reflection (Ferrante *et al* 1992), will be enhanced under these more energetic conditions. The relatively large sill size, because of the greater tidal range and increased wave exposure, will result in an escalation of the costs of this type of protection. Also with a relatively large sill size, the problems of cutting off the natural onshore movement of sand during fair weather (Douglas and Weggel 1987) may greatly reduce the lifespan of the perched beach. Added to this the problems of a large change in elevation from the seaward to the landward side of the sill are likely to make this type of protection unaccepetable on amenity beaches.

In Holland consideration is being given to the use of perched beaches in areas of high sand loss (eg on beaches bordering tidal channels). In such areas the problems with amenity do not arise, neither is there any serious danger of interruption of onshore supply of beach material. Indeed the construction of a sill of suitable dimensions may influence the nearshore bed dynamics to change the situation from an eroding to a stable or accreting one (deRuig and Roelse 1992). This type of defence strategy is very much in the feasibility stage and will require further research before it is likely to be implemented.

In the United Kingdom the potential of using perched beaches in conjunction with offshore sills appears to be rather limited. It is unlikely that beaches with a low tidal range on the coasts of Hampshire and Dorset would be protected in this manner, as existing methods, (beach nourishment in conjunction with groyne systems) have proved to be particularly effective. Other areas of the United Kingdom, with a higher tidal range and subject to severe storm wave activity, would not lend themselves to ths type of beach management. The use of perched beaches is likely to be confined to protecting local erosion "hotspots", perhaps on the borders of inlets subject to rapid tidal flow. Even in these areas the more traditional methods of beach protection (eg nourishment in conjunction with groyne construction) have proved to be effective and are likely to be preferred options. Perhaps the most promising areas for this type of protection are pocket beaches, situated in relatively sheltered estuarial conditions. Parts of the Essex coastline are bordered by extensive mudflats and saltmarshes which are underoging erosion and beach steepening. The construction of perched beaches in these areas may help reduce beach erosion, but unless the sills are of a massive size, they are unlikely to have a significant impact on the reduction of wave overtopping.

4. EFFECTIVENESS OF SOFT ENGINEERING METHODS

4.1 Method of assessment

This chapter, which assesses the effectiveness of active beach management techniques and their suitability under UK coastal conditions, is based on questionnaire returns, the literature review above, anecdotal evidence and the general coastal engineering experience of the authors. Returns for the questionnaire which was sent to NRA regions and to a selected number of local coast protection authorities, provided information about the effectiveness of beach nourishment, beach recycling and beach reprofiling operations. In these questionnaires information was sought about the various methods of beach control in use by local coast protection authorities. As well as specific details (operation type, date, costs etc) the authority was asked to make an assessment of the efectiveness of each type of operation used, with a marking of 1 for 10 lowest performance and 10 for best performance, using the following criteria:-

(i) Reduction of wave overtopping
(ii) Protection of backshore
(iii) Promotion of beach accretion/recovery
(iv) Long term performance / design life
(v) Low and / or beneficial impact on adjacent coast
(vi) Low and / or beneficial environmental impact
(vii) High amenity value / public acceptance

Details of the persons consulted can be found in Appendix A. The questionnaire returns, reproduced in the format "as returned" can be found in Appendix B.

The effectiveness of other soft engineering options examined here is based largely on the results of the literature review and the authors' general experience. There is a clear need for further information before a balanced view can be obtained about the effectiveness of all beach management methods examined here.

4.2 Beach nourishment

4.2.1 General

Beach nourishment has become widely used in the United Kingdom during the last twenty years or so and is now considered to be the principal "soft engineering" option. Compared with hard engineering methods it has the following advantages:-

- a widened beach and healthy profile which dissipates wave energy before it reaches the shoreline. A healthy backshore can protect the hinterlands from flooding and other forms of storm damage

- the increased volume of beach material provides a direct solution to natural beach losses

- a beach which is aesthetically more pleasing than hard engineering structures

- nourishment does not produce the adverse downdrift effects associated with hard defences such as groynes, offshore breakwaters, seawalls and revetments

- beach nourishment adds material to the coastal budget and therefore also provides benefits to adjacent beaches

- in the eventuality of "failure" due to unexpectedly high alongshore losses the nourishment adds material to the regional sediment budget

- where badly eroded beaches have been nourished, energy dissipative characteristics may be altered to the extent that an increase in beach volume results after nourishment is complete

- the costs of beach nourishment are generally substantially lower than the costs of hard engineering structures

- from the view point of general applicability beach nourishment offers flexibility of design which means that it can be adapted to suit local site conditions. A recent study by CIRIA (1992) indicates that all eroding beaches are potential locations for beach nourishment schemes.

The evaluation of recent beach nourishment projects has highlighted a number of potential disadvantages:-

- nourishment is rarely a permanent solution

- because it is a soft engineering method it will require monitoring and may require periodic nourishment or recycling to maintain the necessary level of protection

- beach nourishment projects may potentially have a short design life, particularly when the nourishment material is sand

- a main factor causing project failure is the susceptibility of beach nourishment to rapid erosion during storms. (It has to be said that in the United Kingdom beach nourishment projects have had a high success rate, with nourishment "lives" of 10 years or greater being the norm)

- experience of beach nourishment projects in the USA suggests that in certain situations nourished beaches have eroded faster than natural ones. (In the United Kingdom such experience is uncommon rather than the norm)

4.2.2 Evaluation of performance

Evaluation of project performance indicates that beach nourishment in the United Kingdom has generally fulfilled its expectations. The life of both sand and shingle nourishment schemes has generally been in excess of 10 years and in one instance a life of 20 years has been achieved.

In a number of cases the life expectancy of nourishment schemes could have been improved through a more detailed investigation of likely performance. In this respect a combination of numerical and physical modelling techniques could have been used to optimise beach nourishment requirements and determine the best means of containment of nourishment material by means of control structures.

The life expectancy of future schemes could be improved by means of more extensive post project monitoring. The assessment of post project beach losses has unfortunately been subjective and is rarely implemented unless the schemes are perceived to be performing less than satisfactorily. For a consistent assessment of beach nourishment performance, monitoring needs to be carried out by regular beach and bathymetric surveys. Such surveys need to extend from the backshore, seawards to the limit (or closure depth) of the active beach profile.

Questionnaire returns indicate that typically beach nourishment schemes have been very successful in preventing wave overtopping. They have also been very successful in protecting the backshore, preventing damage to existing backshore defences, and greatly extending the useful life of existing seawalls and revetments.

Beach nourishment schemes have been shown to have a beneficial impact on adjacent coasts, in some cases preventing the erosion of downdrift beaches. However in a number of instances the dispersion of nourishment material by enhanced littoral drift has been higher than expected. It is considered that further research into groyne efficiency may be needed. The enhancement of littoral transport by nearshore currents also needs to be taken into consideration in the design of beach nourishment schemes. The sensitivity of the nourished beach to climatic changes and variations in the littoral drift regime can also be examined by means of mathematical modelling techniques (Bunn *et al* 1993).

A number of adverse side effects have been identified. Beach nourishment with sand can result in considerable quantities of wind blown sand being transported landward. This may necessitate the construction of sand fences and the encouragement of the growth of dune grasses. Such measures may be difficult to achieve where beaches have a high usage. Nourishment with shingle can result in cliffing or scarping taking place as a result of berm erosion during storms. Such cliffing may result in a danger to beach users. Nourishment with cobbles may result in the formation of swathes of very coarse material at the toe of the beach which may also be detrimental to bathing.

Public acceptance of beach nourishment schemes has not always been favourable. The loss of the lower sand foreshore at the foot of the existing defences has led to some loss of beach amenity, following nourishment with coarser material. The public is notoriously fickle and people may choose to forget that the original beach material (ie prior to erosion losses) may also have been shingle.

In some areas the improvements of shingle storm ridges has gained high public acceptance, particularly in those areas which have experienced beach overtopping or breaching in the recent past.

As may be expected the cost of beach nourishment varies widely being dependent upon numerous factors, including local geomorphologic and hydraulic conditions. Only approximate figures can be quoted on the basis of the present review. The unit costs of beach material won from marine sources may be as low as £5/m^3 or as high as £10/m^3 at current prices. However, where the work involves double handling of the material the costs may be substantially higher. For example, at Heacham, placement of 4000,000m^3 marine dredged sand and shingle was carried out in 1990 at a unit cost of £13.6/m^3 (CIRIA 1992). The costs of obtaining material from inland sources are generally higher and likely to be of the order of £12/m^3 to £15/m^3 at current prices.

4.2.3 Applicability

It is considered that most eroding beaches are potential locations for beach nourishment schemes. However, the cost effectiveness of major beach nourishment operations will depend on the availability of material from offshore sources. Material from land based sources, apart from being more expensive, is likely to be available only in limited quantities.

Beach nourishment in the North-East of England is not commonplace and where it has taken place it has been done so on a small scale. The coast is generally lightly developed and the need for beach nourishment does not appear to be great. Also there are no licensed dredging areas within a reasonable distance of this coastline. Nourishment has, as far as we know, only taken place at two locations (CIRIA 1992) at Blyth Beach, Northumberland and at Hartlepool, Cleveland.

Should the need for major beach nourishment in this part of the UK coastline arise, then it will be necessary to carry out prospecting surveys of the seabed to assess the nature and suitability of sea bed material as a "beach" resource.

The East Coast of England from the Humber to the Wash is low lying, much of it being below the level of high spring tides. Beaches in this area have been undergoing long term erosion. The reasons for this extensive erosion are not clear but are probably related to the presence of extensive hard defences. The coastline of Lincolnshire will require nourishment on a massive scale to make good the beach losses. It is estimated that some 3.3 million m^3 of material will be required within the next three years. In the longer term a demand for up to 60 million m^3 of material is anticipated. The existing licensed dredging areas between the Humber and the Wash, which are heavily used for providing aggregate for the construction industry, are unlikely to be able to meet this extra demand. New dredging areas will need to be opened and with sources of aggregate quality sand and gravel being limited, mixtures of sand and gravel incorporating a significant content of fines may have to be utilised.

Beach nourishment is also likely to be a preferred alternative to hard defences on the coastline of East Anglia. Existing licence areas may not be able to provide shingle of the right quality and the shingle ridges of North Norfolk may have to be nourished from land based sources. Rates of littoral drift of shingle between Hunstanton and Sheringham are relatively low, so inland sources may well be able to meet the demand. However, the relatively high drift rates from Sheringham south to Harwich may make shingle nourishment expensive and recourse may have to be made for recycling existing shingle material. Recycling sand on this coast is unlikely to be a feasible proposition due to high littoral drift and it may be necessary to feed the beaches with large volumes of sand from marine reserves. Existing licence areas off Great Yarmouth may be unable to provide the large volume of material needed and consideration should be given to opening up the vast reserve of sand within the system of nearshore banks off the East Anglian coast. Beach nourishment is seen to be particularly suited for beach management in this case. Material fed at the "updrift boundary" near Sheringham will be dispersed in a nett southward direction. The harbours of Great Yarmouth and Lowestoft may tend to interrupt the supply of material and this aspect will need to be examined by numerical modelling of wave and tidal current induced littoral transport.

South of Harwich the shelter provided by the sand banks in the Outer Thames estuary significantly reduces the nett southward transport of beach material. Beach nourishment may be one of several options in this area. The possibility of beach nourishment from dredgings in the approaches to Harwich harbour should be examined as an alternative to the use of aggregate material from existing dredging licence areas.

The beaches between the Isle of Grain and the Isle of Thanet are also sheltered from wave action and littoral drift here is low. The present method of beach nourishment from inland sources is likely to continue to be the preferred method of beach renourishment. (Roberts 1985).

The highly developed coast from the Isle of Thanet to the Isle of Purbeck has long stretches of sand lower/shingle upper beaches many of which are undergoing erosion. These areas have been nourished from both marine and land based sources. There is evidence of difficulty in obtaining material with a similar grading to that of native beach material. Nourishment in these areas of critical erosion may have to be carried out using non-aggregate materials, that is materials which because of their fines content are not suitable for use as aggregate (CIRIA 1992).

The demand for beach nourishment material in the relatively undeveloped coasts of South-West England and West Wales appears to be limited. With the exception of the Bristol Channel there are few licensed dredging areas in close proximity to eroding beaches. It is likely therefore that supply of material will be met from inland sources.

There is an increasing demand for nourishment material on the coasts of North Wales most of which are eroding. At present there is only one licensed dredging area within Liverpool Bay and nourishment material has tended to be in short supply. There are large reserves of sand sized material within Liverpool Bay and it should be possible to open up these reserves for the purpose of beach nourishment.

The extensive sand beaches between the River Mersey and Morecambe Bay are also undergoing erosion. These beaches are generally so wide that beach nourishment is unlikely to be an economic proposition. Thus in rapidly eroding areas such as Formby Point a laissez - faire approach to beach management seems to be the most appropriate option. In areas of critical erosion, for example on the Blackpool frontage, other methods of beach management such as beach reprofiling, or recycling, may be more realistic options than beach nourishment.

On the North-West coast of England, between Morecambe Bay and the Solway Firth the coastline has a weak littoral drift. However, north of St Bees Head the drift is strongly unidirectional and consequently serious downdrift erosion effects are apparent north of most harbours. Updrift frontages are also subject to erosion particularly where developments have been made on reclaimed land (Motyka and Brampton 1993). It may not prove to be possible to use soft engineering options in such instances, and backshore protection by means of hard defences may be necessary here.

4.3 Nearshore nourishment

4.3.1 General

The feasibility of nearshore nourishment, in which sand is placed on the submerged part of the active beach profile, is presently undergoing investigation in the USA. This form of nourishment has several advantages over nourishment of the visible part of the beach:-

- If the problems of controlling the dispersal of sediment and identifying nourishment requirements can be solved, this type of nourishment may offer significant cost savings due to a reduction in delivery costs.

- The presence of an underwater mound formed by nearshore nourishment may significantly reduce the wave energy reaching the shoreline.

- The onshore movement of material in fine weather may gradually bring material into the beach system from the site of nourishment.

The disadvantages of this type of operation are self evident:-

- In terms of public acceptance this type of operation will have a poor rating since the public will not consider nourishment a success unless the benefits are visible to the eye.

- To achieve a significant damping of wave energy large volumes of material will be required.

- To achieve an increase in the size of the visible part of the beach very large volumes will be required since material will be rapidly spread out over the full width of the actual beach profile.

- The likelihood of promoting an increase in the width of the upper beach is difficult to predict, and performance will be dependant upon the vagaries of the wave climate.

4.3.2 Evaluation of performance

The likely performance of this form of nourishment is uncertain. Indeed it will be difficult to prove whether any improvement in beach conditions is attributable to the nourishment or whether an improvement is the result of natural causes. Following the beach nourishment scheme carried out in Bournemouth in 1974 sand is believed to have migrated onshore from the dumpsites. The evidence of onshore movement is largely anecdotal (the volume of beach material increased after beach nourishment operations had been completed).

Field trials are presently being undertaken in the USA by the US Army Corps of Engineers into the behaviour of nearshore sediment disposal sites. Numerical model tests are also presently being conducted at the US Army's Waterways Experiment Station, into the "fine tuning" of nearshore berm geometry so as to attenuate waves effectively and promote conditions under which beach accretion might be enhanced. Despite these very extensive studies there is presently insufficient data by which means one might be able to judge the potential of this type of nourishment.

4.3.3 Applicability

It is considered that at present this form of nourishment probably has limited applicability. Also with the present state of knowledge it would be difficult to justify the major expenditure associated with the necessary field trials to test this potential method of nourishment. However the situation should be kept under review, by following the course of the investigations being undertaken in USA. There is however scope for numerical modelling of nearshore processes so as to determine under what wave and tidal conditions material is likely to migrate onshore. It will also be necessary to consider the mechanisms of longshore transport since the material from dump sites will also be subject to dispersal by tidal current action.

4.4 Mechanical beach reprofiling

4.4.1 General

On a number of shingle beaches (eg Salthouse, Norfolk) it has been the practise for many years to rework existing shingle beach deposits so as to raise the beach crest and to repair the damage resulting from washovers and localised breaching. Another aim of this form of management is to reduce the rate of beach recession (eg Hurst Castle Spit).

In general this form of beach control has been used in rural areas where beaches are relatively inaccessible and in areas where the costs associated with more traditional forms of protection have been found difficult to justify.

Advantages of this form of protection are:-

- a lower cost than most other methods of beach manipulation, principally because of the short haul distance involved in bringing materials from the lower to the upper part of the beach profile,
- the flexibility of this form of operation, allowing emergency repairs to be made at short notice, for example,
- this approach has merit at coastal locations for which funds are unavailable for more costly protection measures.

The disadvantages are:-

- this form of beach "recycling" does not deal directly with the reason for shoreline recession which is usually an insufficient cross-sectional beach area,
- the repeated reworking of beach deposits results in the removal of fines from the shingle interstices and possibly their permanent removal from the beach system,
- the steepening of the beach profile results in increased wave reflectivity and reduced beach stability.

4.4.2 Evaluation of performance

While there is a considerable amount of information regarding the performance of beach reprofiling at USA coastal sites, this information is not particularly relevant to UK coastal conditions. From USA experience one would deduce that mechanical reprofiling of sand beaches is probably mainly suited as an emergency measure for beach protection.

There is possibly scope for using mechanical reprofiling on extensive sand beaches, when the beach gradient is very low and where removal of material from the low tide mark does little to alter this gradient. The wide sand beaches found on the North Wales coast, for example, may be suitable sites for this form of beach management. The wide sand beaches in Lancashire may also be possible candidates. It should be stressed that this form of beach management requires extensive testing and monitoring by comparing the performance against adjacent unaltered control areas. It should be stressed that tidal currents play an important role in the alongshore movement of sand in UK waters. It will therefore be necessary to model both alongshore and across shore sediment dispersion processes to determine whether reprofiling of sand beaches is likely to be effective.

Mechanical reprofiling of shingle beaches has been practised in a number of areas of the United Kingdom. However, monitoring appears to be the exception rather than the rule. Our assessment of likely performance is based on a small number of case studies, carried out in dissimilar coastal areas. Existing data from USA and other sources is thus not a very good basis for judging the applicability of beach reprofiling.

Evaluation of two schemes in West Wales and one in North Norfolk suggests that mechanical reprofiling is not particularly effective in terms of backshore protection or reduction of wave overtopping. Promotion of beach accretion and/or beach recovery is, not surprisingly, also assessed as being poor. The long term performance / design life is also estimated to be very short. Mechanical reprofiling would appear to have only a short term impact and is therefore probably more suited for emergency protection than for preventing beach recession.

Rather more mixed results are reported in terms of environmental impact. Beach reprofiling operations carried out in Tywyn and Harlech, West Wales, involving scraping of sand and gravel, both from the backshore as well as the lower part of the beach, are perceived to have had a negative environmental impact. By contrast reprofiling of Salthouse shingle bank, Norfolk, appears to have been carried out over a period of possibly 50 years with little adverse environmental impact, while maintaining a high level of protection for both grazing land and an important nature reserve to its rear.

Interestingly from the point of view of high amenity value / public acceptance, operations in both areas score highly.

From the viewpoint of low cost, operations in both areas also score highly, with costs of reworking being estimated at £0.5/m^3 and £0.75/m^3 of material handled.

In the case of the operations in West Wales beach reprofiling is shortly to be discontinued and a more formal beach management strategy is to be implemented in the future.

In the case of operations in North Norfolk, which are believed to have been ongoing since the 1940's, there is a good understanding of the shortcomings of this form of management. It is recognised that because the operations do not include an element of beach nourishment into the system, and in view of the loss of beach feed material, the beach is undergoing a slow reduction in cross-sectional area. The expected lifespan of the shingle ridge has been assessed as being of the order of 10-20 years, in the absence of any active beach nourishment measures.

4.4.3 Applicability

This form of beach management is considered to have limited applicability even as a short term protection against wave overtopping. This is because the creation of an artificially steep profile will inevitably result in increased reflection from the beach face and hence reduced beach stability. The continued reworking of the beach face may result in the loss of fines, increased porosity, and increased flow through the core of the beach. If the crest of the beach becomes very porous it may be more subject to damage by overtopping waves. The long term impact is likely to be a depletion of the sediment budget.

4.5 Bypassing or recycling of beach material

4.5.1 General

Sediment bypassing plant, which is generally considered for sand, has been extensively used in USA, to transfer material across tidal inlets and across harbour mouths. This type of operation, involving fixed plant, has without exception been used in areas of very low tidal range and generally in moderate levels of wave activity. It would appear to have very limited potential for beach management under UK coastal conditions. (Only between the Isle of Wight and Portland Bill on the South coast and between approximately Sheringham and Southwold is the mean tidal range less than 2m).

In the South Coast area there are few harbours which block off drift sufficiently that tangible benefits might be achieved by artificial bypassing. For example, experience with beach nourishment operations at Bournemouth and research into water movements by means of float tracking indicate a free exchange of material carried in suspension across the entrance to Christchurch harbour in an easterly direction, from the Bournemouth to the Christchurch frontage. There is thus a free exchange of sediment from Poole Bay into Christchurch Bay and there is little potential for artificial sand bypassing in this area. As regards the East Anglian coastline there also appears to be a relatively free exchange of material across harbour mouths and tidal inlets (Motyka and Brampton 1993). Indeed, there are very few areas in the United Kingdom where there are such persistent areas of rapid and sustained shoreline retreat downdrift of harbour mouths or inlets to make artificial sand bypassing an economic proposition.

In certain areas, for example the entrance to Harwich Harbour, there is a slow loss of material from updrift and some of this material is then removed from the nearshore system as a result of navigational dredgings operations. Capital dredging operations might usefully nourish downdrift beaches in these instances, eg. at Port Talbot, South Wales.

Beach recycling on the other hand is an option which has considerable potential in effective beach management, particularly for shingle beaches. Beach recycling has a number of advantages which it shares with beach nourishment.

Additional advantages are:-

- relatively cheap cost by comparison with beach nourishment and certainly much cheaper than "hard engineering" solutions,
- a high degree of flexibility due to use of land based mechanical plant, particularly when transport is carried out by truck. This flexibility is particularly important since on many coasts in the United Kingdom littoral drift rates fluctuate on an annual basis and often change in direction on a seasonal basis,
- negative impacts associated with beach nourishment such as beach scarping do not appear to be a problem.

Disadvantages are:-

- because of the varying wave climate around the United Kingdom coastline recycling always needs to be assessed on a site specific basis. Inevitably this will require extensive studies prior to commencement of recycling,

- because of the variability of wave conditions with time, littoral drift rates will fluctuate greatly and extensive monitoring will need to be made to assess recycling requirements.

4.5.2 Evaluation of performance

Evaluation of questionnaires on recycling operations indicates that this form of bach management has been effective in making use of often limited resources of beach material. It has been in vogue in the South-East coast of England for a number of decades, where it is used to "counteract" the littoral drift of shingle. It has also been used elsewhere on the South and South-West coasts on a rather more piecemeal basis. At West Bay, Dorset, for example, recycling has been used to counter the effects of recent erosion brought about by a change in the long term littoral regime. Elsewhere it has been used to make up deficiencies in the beaches brought about by increased rate of drift during storms (eg Hurst Castle Spit).

The questionnaire returns indicate that recycling has proved to be highly effective both in terms of reducing wave overtopping as well as providing a high level of backshore protection.

Recycling operations have not promoted beach recovery and the low performance rating indicates that recycling operations need careful monitoring and planning, so as to minimise detrimental impacts locally.

In terms of good performance / long design life recycling operations in the South-East are given a high marking. This is not surprising since this form of management has been operating with success for many years. Elsewhere, where recycling is performed on a less regular basis, the marking regarding design life is given a more varied and generally lower score.

Experience with recycling operations shows this to have had a low / beneficial impact on adjacent stretches of coast. Information recieved from NRA indicates that the recycling operations at Pett, which are carried out within a self contained littoral cell, have very little impact on adjacent stretches of coast.

The ratings as regards the environmental impacts of recycling vary considerably from a very high rating at Church Norton Spit (where the operations are important in protecting a nature reserve to the landward) to a score of "variable" in the Wessex / Somerset area where information obtained is not site specific.

In terms of high amenity value / public acceptance beach recycling achieves a relatively high rating, since in most rural areas beach users are rarely inconvenienced by this form of operation. A very high score is achieved at Hurst Castle Spit, Hampshire, where the shingle spit provides access from the mainland to Hurst Castle. The spit also protects the hinterland from flooding. It is not surprising that beach maintenance operations on this frontage (which include beach nourishment, beach recycling and beach reprofiling) have generally strong public acceptance.

In terms of cost the results vary widely and are to a large degree dependent upon the haulage distance, though other factors such as the volume moved, must also have some bearing. In general the costs of operations vary from about £0.8/m^3 to £2.0/m^3 for relatively short hauls (of up to 3km). For longer hauls (5 to 14km) costs are considerably higher, varying from £3.8/m^3 to £7.5/m^3.

In general recycling operations are scheduled for the autumn and winter period or after individual storm events.

In terms of material type, operations are for shingle. Recycling of sand is only carried out as a maintenance requirement in areas where wind blown sand becomes an amenity nuisance.

4.5.3 Applicability

Beach recycling operations are most suited to areas with a low to moderate rate of shingle drift and within relatively small coastal cells, where material can be recycled in short hauls. Recycling with shingle has proved to be successful on many parts of the South-Coast of England. This area is where the most extensive stretches of shingle are to be found and is clearly the most suitable area for recycling. There is no good reason why recycling should not be applied to other areas of the coast, providing that the haul distances can be kept short.

Shingle recycling does not solve the problem of lack of sediment supply and we would only recommend this form of management for relatively healthy beaches.

Because of the more rapid transport of sand by waves and tidal currents, recycling operations on sandy coastlines are likely to be prohibitive in cost. We therefore see little scope for sand recycling except under very exceptional circumstances. Such circumstances are most likely to be emergency rehabilitation of beaches following extensive storm damage.

4.6 Beach drainage systems

4.6.1 General

Beach drainage systems have not been used in the United Kingdom or in conditions similar to UK coastal conditions (ie a relatively high tidal range and moderate or high wave exposure). Their likely behaviour is thus difficult to judge. Some potential advantages are:

- low capital and very low maintenance costs
- high public acceptance if there is a significant increase in upper beach width

Likely disadvantages are:-

- no increase in the overall sediment budget is likely to result from drainage operations.
- the upper beach may be more susceptible to storm damage than a beach with a natural foreshore gradient
- difficulty in identifying the benefits accruing, since natural beach fluctuations may mask changes brought about by the operation of drainage systems.
- low public acceptance if the installation were to be exposed by beach erosion

4.6.2 Evaluation of performance

Evaluation of performance on the basis of field trials, which have been carried out abroad in areas of low tidal range, provides little basis for assessing its likely performance in the United Kingdom. Results abroad, however, have been sufficiently encouraging for making it worthwhile to carry out a trial installation in this country. (A trial installation is scheduled to be carried out at Towan beach, Newquay in 1994).

4.6.3 Applicability

Pumped drainage systems are more likely to succeed than gravity drainage systems and are more "amenable" to monitoring under closely controlled conditions. We would recommend that drainage systems should be tested in areas where conditions are not too dissimilar to those under which they have already been tested. A relatively straight stretch of coastline will need to be chosen so that control areas updrift and downdrift of the drainage system are subject to closely similar wave and tidal conditions as the system itself. The system needs to be installed in an area which has a relatively uniform sand sized grading, so that morphological conditions are similar in both the test and the control areas. The site should be open to wave action and should be in an area where inshore wave parameters can easily be determined. The test site should have a wave climate which is dominated by waves from one sector and if possible waves should not hit the coast at too acute an angle. The coast should not be subject to secondary wave effects, such as wave diffraction and breaking over nearshore banks. Littoral drift should not be too large and the beach should be subject to a fairly regular or seasonal change in beach profile. The site should have a considerable tidal range, since there is some laboratory evidence that the system would not be effective where there is a negligible tide. However too large a tidal range may also not be suitable since the build up might then spread over a considerable beach width and the resulting change in elevation may be small and difficult to monitor.

4.7 Perched Beaches

4.7.1 General

Perched beaches have been examined in this review because of their wide usage overseas in conjunction with beach nourishment schemes. They are considered to have a very limited applicability for UK coastal conditions and do not appear to provide any significant advantage over existing beach maintenance systems.

4.7.2 Evaluation of performance

Perched beaches perform best in areas of low tidal range and low to moderate wave activity. It is likely that on UK coastlines such structures would be unacceptable in most areas on the grounds of amenity. We also see a number of potential problems regarding sill size, susceptibility to wave induced erosion and wash out of the material by rip currents. Where a beach needs to be secured, offshore breakwaters such as those being constructed at Elmer, West Sussex, or similar structures (eg fishtail groynes) offer much greater potential.

4.7.3 Applicability

A suitable area for the use of perched beaches is the coastline between the Isle of Wight and Purbeck, because of its low tidal range and because of a moderate level of wave activity.

5. CONCLUSIONS

5.1 General

A number of techniques are available for "soft engineering" applications including beach nourishment, reprofiling and recycling, all of which are in regular use both in the U.K. and elsewhere. Other techniques such as nearshore sea bed nourishment and perched beaches, which have been examined in this study, have been tested overseas but have not been used in the United Kingdom. A recently developed technique involving the artificial drainage of beaches has not been widely used, but has proven to be effective under conditions of low tidal range. All of these techniques have some potential but the cost-effictiveness of some is yet to be proven, despite an extensive literature search and questionnaire.

5.2 Beach nourishment

Beach nourishment is the most widely used method of soft engineering and the one which has the greatest general applicability. Both sand and shingle nourishment have been used in the United Kingdom with considerable success. We see this as the primary tool in the soft engineering "armoury" because of its relatively low cost, its flexibility of design, its positive impact on beach aesthetics, its low adverse environmental impacts and because of its proven success in mitigating the effects of beach erosion. Most areas of the coastline which are eroding or which have a deficit in beach material supply are candidate areas for beach nourishment.

However, problems are likely to arise in the near future due to the large demand for beach nourishment material. Existing dredging licenses produce aggregate which is tailored to the requirements of the construction industry. The existing reserves will not produce material in sufficient quantities to meet beach nourishment needs as well as industrial demand, and it is therefore necessary to consider the feasibility of opening up new licence areas, with a possible change in philosophy as regards assessing the likely effects of dredging. The overall benefits to a whole "coastal cell" will need to be balanced against the possible disbenefits at an isolated location.

It will also be necessary to consider utilising sediments which are dissimilar to those of natural beach sediments by virtue of size or grading. Mathematical modelling techniques exist for assessing the behaviour of beaches composed of "dissimilar sediments" and both modelling and post project monitoring (to determine the effectiveness of the model predictions) will need to be carried out as part of the management of individual coastal cells.

5.3 Nearshore nourishment

Nourishment of the submarine part of the beach profile and of the nearshore seabed has been used in an attempt to attenuate wave energy and to promote the build up of material in the seasonal offshore bar. From there the nourishment material may, under the right conditions, be transported onshore by wave action. Field trails and model tests in the USA have proven the ability of nearshore nourishment to attenuate wave energy, but the benefits to the beach (eg. increased volume) are very difficult to prove.

At present nearshore methods of sediment disposal have not had a strong role in beach management in the UK and are unlikely to have one in the near future. However, new techniques presently being tested in the USA may identify more positively the effects and benefits of nearshore nourishment.

5.4 Beach recycling

Beach management by recycling from the downdrift end to the updrift end of a coastal cell should not be seen as an alternative to beach nourishment but complementary to it. Extensive monitoring should be carried out to determine the sediment budget (as at Dungeness) and any deficiency in supply should be made good by periodic renourishment.

Shingle beaches can be managed by recycling at relatively low cost, if haul distances are short. Sand beaches are less amenable to beach recycling because of the potentially higher rates of drift and hence the higher volumes of material which would have to be handled. The scope for beach recycling is also rather limited. Those areas which have an acute deficiency in sand supply tend to be long open beaches such as those of East Anglia, the North Wales coast and South Lancashire. The large haul distances and large sediment volumes in transport will probably make recycling impractical in such situations.

5.5 Beach reprofiling

Beach reprofiling is an attractive management option, primarily because of low cost, and it is often used in inaccessible areas or areas where the coast protection authority finds it difficult to justify more permanent solutions.

Beach regrading by mechanical reprofiling is used to maintain an artificially high crest on shingle beaches which are prone to overtopping or breaching. Its use should be carefully controlled, since continual reworking of beach deposits may result in the loss of fines and a loss in beach stability due to increased reflectivity from the artificially steep beach profiles.

Beach reprofiling should primarily be used as an emergency measure or an interim solution to storm induced damage. Also it should be carried out in conjunction with beach monitoring on a regular basis. Mathematical modelling of beach profile changes should also be carried out to assess the ability of the artifically raised crest to protect the backshore under the design wave and tidal conditions. (At present crest height, beach profile shape etc are chosen arbitrarily, on the basis of past performance).

5.6 Sediment bypassing

Bypassing of inlets and harbours by means of fixed sand bypassing installations has been used widely overseas but has very little applicability to UK coastal conditions, because it works most effectively for well graded sand in areas of low tidal range. Such conditions are not present in many areas of the United Kingdom.

Sediment bypassing associated with capital dredging operations, at the entrances to major ports and estuaries, however, may prove to be an effective means of nourishing downdrift beaches. It requires the co-operation of both harbour and coast protection authorities, who often have conflicting interests. There are also environmental risks with this type of operation, relating to the fouling of beaches with fines. This is on the face of it an attractive alternative but one which may be difficult to implement within a management strategy.

5.7 Beach drainage systems

Beach drainage systems show considerable promise in terms of improving beach width at low installation cost and very low maintenance cost. The ability to operate such systems in areas of high tidal range, severe wave exposure and where beach levels may fluctuate significantly as a result of changes in wave activity is not yet proven.

5.8 Perched beaches

Perched beaches are a means of artificially raising foreshore levels by means of impounding beach nourishment within a shore parallel sill or breakwater. These are relatively difficult to construct in areas of high tidal range, where the sill size will have to be large and may approach the size of an offshore breakwater. On the grounds of beach amenity such beach management methods cannot be recommended strongly in UK coastal conditions.

Perched beaches are to be tested in the Netherlands and their performance will be followed with great interest.

6. RECOMMENDATIONS

6.1 Beach nourishment

The life expectancy of beach nourishment schemes needs to be examined more thoroughly in future schemes than it has in the past, in order to improve beach fill performance. A combination of post-project monitoring and mathematical modelling should be used to assess offshore movement of fill material, its rate of alongshore dispersion and its impact on adjacent beaches, to improve our understanding of beach processes taking place after nourishment.

Existing and future beach nourishment schemes need to be monitored by means of beach and bathymetric surveys extending to the seaward limit of the "active beach profile" ie to a depth of about 10m. The inshore wave climate and tidal current regime will need to be assessed to determine beach reaction to storms, long term behaviour etc.

Suitable candidate schemes for study are existing shingle nourishment schemes at Hastings and Seaford, the mixed sand and shingle beaches at Clacton and Elmer, and the sand beaches at Bournemouth and Sand Bay. Many other existing nourishment schemes are also suitable monitoring sites. However, we feel strongly that all nourishment schemes should be monitored with the minimum requirement being beach profiling at regular intervals (twice yearly as a minimum) over the nourishment frontage and ideally over adjacent "control" sections of beach.

6.2 Nearshore nourishment

It is recommended that follow up studies should be carried out to further examine the potential of nearshore nourishment as a means of disposal of dredged material. Field trials are presently being carried out by the U S Army Corps of Engineers into the effectiveness of nearshore spoil disposal mounds as a means of attenuating wave energy and enhancing beach accretion. These trials will determine the ultimate fate of sediments dumped at so-called "dispersal" dumping sites.

There is also a major experiment being carried out off the island of Terschelling in the Netherlands. This will involve placing dredged material between two bars of a nearshore bar system. A detailed monitoring exercise will be carried out in the next two years. It is expected that this will provide important calibration data for fine tuning of existing mathematical models of sediment transport under wave and current action. Such models can be used to assess the performance not only of nearshore nourishment operations but also other forms of beach management (eg. beach reprofiling).

6.3 Beach recycling

At present recycling operations are carried out in a largely uncontrolled manner. It is recommended that existing shingle recycling operations (eg. in East Sussex and Kent) should be examined by means of beach monitoring, and that operations should be optimised so as to minimise haul distance, reduce downdrift impacts etc. More detailed information is also needed to assess beach response to recycling. In particular it is necessary to establish whether the regular reworking of beach sediments has any adverse impact upon the stability of the beaches and on the overall sediment budget of the coastal cell within which the recycling operations are carried out. Numerical modelling of alongshore transport processes will be useful in this respect.

6.4 Beach reprofiling

There is considerable controversy about the effectiveness of beach reprofiling as a means of erosion control, and its overall impact on beach "stability".

It is recommended that any shingle reprofiling operations which take place on a regular basis should be monitored over a period of years and that attempts should be made to assess their impact on beach dynamics. Such assessments will need to separate out natural seasonal beach fluctuations from those caused by beach reprofiling. In that respect, control sections of beach subject to a similar wave and current regime, will need to be set up adjacent to the actively worked areas of beach. Mathematical models of cross-shore transport will be useful in assessing the behaviour of reprofiled against natural beaches under the extreme events which may not occur during the monitoring period.

The relatively low cost of sand beach scraping makes it an attractive proposition for emergency backshore protection in duned areas of coast and those frontages subject to rapid drawdown of the upper beach. The wide sandy, multi barred foreshores of North Wales and South Lancashire are potential candidate areas for field trials. Such trials will have to be carefully controlled if adverse impacts to adjacent beaches are to be prevented. Again such trials would provide valuable data for the calibration of mathematical models of sediment transport under waves and currents, referred to earlier.

6.5 Sediment bypassing

There is little role for fixed bypassing operations in UK coastal waters. However, bypassing operations as part of a capital dredging programme, may be used to transfer material to downcoast beaches at relatively low unit cost. Extensive environmental impact studies would be necessary to determine the ultimate fate of dredged spoil, its environmental impact and its impact on the quality of the beaches with regard to public amenity.

A number of ports (eg. Harwich and Port Talbot) require capital dredging on a regular basis, and these may be candidate areas for sediment bypassing operations.

6.6 Beach drainage systems

Beach drainage systems have not been tested in the UK and their likely performance is therefore largely an unknown factor. It is recommended that a test installation should be monitored for several years to assess the ability of beach drainage systems to build up beach levels. The test site should be on a relatively open stretch of coast subject to seasonal changes in beach profile. The site should have stretches of beach close by which are subject to the same wave and current conditions as the test site. These beaches should be used as control sections to enable watertable drainage effects to be seperated out from natural beach fluctuation effects. Ideally the site and the control sections should also have a low rate of littoral drift, so as to avoid the need for considering "end effects".

6.7 Perched beaches

Perched beaches are considered to have very limited applicability under UK coastal conditions of substantial tidal range and high levels of wave activity. No further research is recommended, though it may be useful to carry out follow up studies of the performance of perched beach installations in Europe and elsewhere.

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Appendices

APPENDIX A: LIST OF CONSULTEES

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NRA Wessex Region
Rivers House
East Quay
Bridgwater
Somerset
TA6 4YS

A Bradbury
New Forest District Council
Town Hall
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Hampshire
SO4 9ZG

R Crossland
NRA Southern Region
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East Sussex
BN24 6ND

H Davies
Meirionnydd District Council
Caer Penarlag
Dolgellau
Gwynedd
LL40 2YB

S Jeavons
NRA Anglian Region
Eastern Area
79 Thorpe Road
Norwich
NR1 1EW

R Nickerson
NRA Southern Region
Scots Float Depot
Military Road
Playden
Rye
West Sussex
TN31 7PH

C W Bray
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DT11 8ST

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NRA Welsh Region
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G Roe
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F Tyhurst *
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NRA South West Region
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Aqua Houses
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Lincoln
NN1 1TF

* No questionnaires returned from these persons

APPENDIX B: QUESTIONNAIRE RETURNS

This appendix includes all the questionnaires received by HR Wallingford. It should be noted that in certain cases the consultees did not have sufficient data for the completion of these questionnaires. However much useful advise was obtained by general discussions with a number of persons consulted during the course of this study. We would like to thank all those people connected with this study for their invaluable help.

NATIONAL RIVERS AUTHORITY R&D COMMISSION

Effectiveness of beach control operations

This questionnaire forms part of an appraisal of the effectiveness of beach control operations, which is an R&D commission undertaken by HR Wallingford for NRA. The results of the appraisal will be incorporated into a Beach Management Manual, incorporating current practice and research findings, to direct engineers involved with planning, design, implementation and management of beaches and beach recharge schemes. This project is linked to a MAFF sponsored research programme which is being run concurrently with the present programme, and the information from this questionnaire will be used in both projects.

Your help with this appraisal will be greatly appreciated and an early reply will also be very welcome. I would be grateful if you could return the completed questionnaire to:-

Mr J M Motyka
Coastal Group
HR Wallingford
Howbery Park
Wallingford
Oxon OX10 8BA

Tel No. 0491 835381
Fax No. 0491 825539

Where you feel additional information may be of relevance to this project please include this if possible with the questionnaire.

Please fill in details of your organisation:-

Contact Name: DAN ALSOP

Organisation: NRA WESSEX /SOMERSET AREA

Telephone: 0278 457333

1. Please indicate the type of control operations with which you are familiar

Recycling of beach material	YES	☑	NO	☐
By-passing of beach material	YES	☐	NO	☑
Periodic beach nourishment/top up	YES	☑	NO	☐
Mechanical beach reprofiling	YES	☑	NO	☐
Other forms of beach stabilisation	YES	☑	NO	☐

2. Please give details of the type of beach control operation in use

Type of operation	Re-cycling, nourishment, profiling, others.
Date of first operation	Not known
Approximate number of maintenance ops per year	6
Capital cost	Usually a revenue item.
Approximate annual maintenance costs	£30k.
Native beach material type/grading	Varies
Type and grading of material used in operation	Usually native beach material
Source of material	" " " "
Volume of material transported or recycled	Approx 30 000 tonnes/annum
Haulage distance	Typically 1 km.
Approximate cost of operation per m^3 of material handled	£1/m^3
Time of year (if applicable)	Varies

3. Your best estimate of performance, with marks from 1 to 10, with high marks for best performance

Reduction of wave overtopping	7
Protection of backshore	7
Promotion of beach accretion/recovery	2
Long term performance/design life	2
Low and/or beneficial impact on adjacent coast	Varies
Low and/or beneficial environmental impact	Varies
High amenity value/public acceptance	5

4. Design details

Crest height
Crest width
Beach slope
} Varies on site

Beach profiles taken? Yes.

Nett drift direction Varies From ☐ To ☐

5. Other information

Approximate littoral drift rate — Not known. m^{3}p.a. Measured ☐ Calculated ☐

Wave/tidal data? — Yes

Limited

6. Are there any publications, references or other documents which could be made available for inspection?

Yes - Contact Area Flood Defences Engineer - D G Allsop

7. If you feel there are other important factors of relevance please give details below.

NATIONAL RIVERS AUTHORITY R&D COMMISSION

Effectiveness of beach control operations

This questionnaire forms part of an appraisal of the effectiveness of beach control operations, which is an R&D commission undertaken by HR Wallingford for NRA. The results of the appraisal will be incorporated into a Beach Management Manual, incorporating current practice and research findings, to direct engineers involved with planning, design, implementation and management of beaches and beach recharge schemes. This project is linked to a MAFF sponsored research programme which is being run concurrently with the present programme, and the information from this questionnaire will be used in both projects.

Your help with this appraisal will be greatly appreciated and an early reply will also be very welcome. I would be grateful if you could return the completed questionnaire to:-

Mr J M Motyka
Coastal Group
HR Wallingford
Howbery Park
Wallingford
Oxon OX10 8BA

Tel No. 0491 835381
Fax No. 0491 825539

Where you feel additional information may be of relevance to this project please include this if possible with the questionnaire.

Please fill in details of your organisation:-

Contact Name: MICHAEL BECK

Organisation: CANTERBURY CITY COUNCIL

Telephone: 0227 763763 X4913.

1. Please indicate the type of control operations with which you ~~are familiar~~ Carry out.

Recycling of beach material	YES	☐	NO	☑
By-passing of beach material	YES	☐	NO	☑
Periodic beach nourishment/top up	YES	☑	NO	☐
Mechanical beach reprofiling	YES	☐	NO	☑
Other forms of beach stabilisation	YES	☐	NO	☑

(We are familiar with all).

2. Please give details of the type of beach control operation in use

Type of operation ANNUAL REPLENISHMENT.

Date of first operation BEFORE 1974.

Approximate number of maintenance ops per year ONE

Capital cost £100,000 per year.

Approximate annual maintenance costs

Native beach material type/grading SEE ATTACHED. }*

Type and grading of material used in operation SEE ATTACHED. }*

Source of material VARIES EACH YEAR.

Volume of material ~~transported or recycled~~ PLACED ≃ 8,000 to 14,000 tonnes

Haulage distance VARIES EACH YEAR.

Approximate cost of operation per m^3 of material handled £15.00 (CURRENT.

Time of year (if applicable) DECEMBER / JANUARY.

* NOTE: THE REPLENISHMENT MATERIAL MUST LIE WITHIN THE GRADING ENVELOPE DERIVED FROM SAMPLING THE EXISTING BEACH.

3. Your best estimate of performance, with marks from 1 to 10, with high marks for best performance

VARIES ACCORDING TO LOCATION AND BEACH CROSS SECTION SIZE.

Reduction of wave overtopping	
Protection of backshore	
Promotion of beach accretion/recovery	
Long term performance/design life	
Low and/or beneficial impact on adjacent coast	
Low and/or beneficial environmental impact	
High amenity value/public acceptance	

BEACH FORMS MAJOR DEFENCE ALONG WHOLE COAST LINE.

4. Design details

Crest height
Crest width
Beach slope

VARIES ACCORDING TO LOCATION ALONG COAST LINE.

Beach profiles taken? YES. (QUARTERLY)

Nett drift direction From E To W

5. Other information

Approximate littoral drift rate / m^{3}p.a. Measured ☐ Calculated ☐

NOT KNOWN

Wave/tidal data? YES. (MEASURED CONTINUOUSLY).

6. Are there any publications, references or other documents which could be made available for inspection?

BEACH MANAGEMENT PROGRAMME.

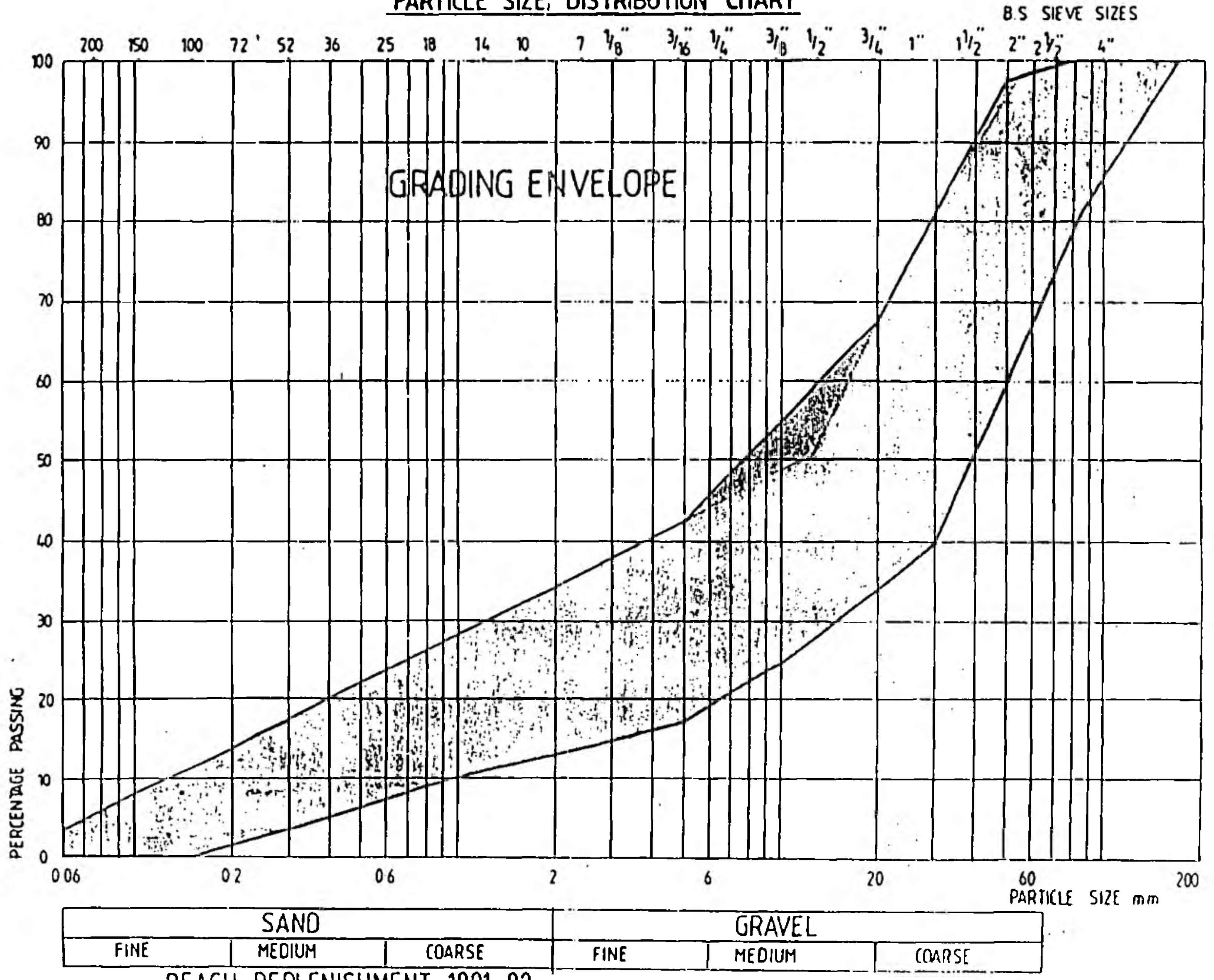
BEACH CROSS SECTIONS

BEACH REPLENISHMENT SCHEDULE.

WAVE, WIND, TIDE RECORDS.

7. If you feel there are other important factors of relevance please give details below.

PARTICLE SIZE DISTRIBUTION CHART



PROJECT BEACH REPLENISHMENT 1991-92

SITE

DATE OCTOBER 1991

GRADING ENVELOPE

NATIONAL RIVERS AUTHORITY R&D COMMISSION

Effectiveness of beach control operations

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Your help with this appraisal will be greatly appreciated and an early reply will also be very welcome. I would be grateful if you could return the completed questionnaire to:-

Mr J M Motyka
Coastal Group
HR Wallingford
Howbery Park
Wallingford
Oxon OX10 8BA

Tel No. 0491 835381
Fax No. 0491 825539

Where you feel additional information may be of relevance to this project please include this if possible with the questionnaire.

Please fill in details of your organisation:-

Contact Name: Andrew Bradbury

Organisation: New Forest District Council

Telephone: 0703 285911

1. Please indicate the type of control operations with which you are familiar

Recycling of beach material	YES	☑	NO	☐
By-passing of beach material	YES	☐	NO	☐
Periodic beach nourishment/top up	YES	☑	NO	☐
Mechanical beach reprofiling	YES	☑	NO	☐
Other forms of beach stabilisation	YES	☑	NO	☐

2. Please give details of the type of beach control operation in use

Type of operation Shingle recharge and recycling (at Hurst)

Date of first operation 1980

Approximate number of maintenance ops per year Varies generally 1 – 2 after severe storms

Capital cost £4.5m – 300,000m^3 + rock structures. (to be constructed)

Approximate annual maintenance costs £50K (£450k in 1989-90 followin storms.

Native beach material type/grading D_{50} ~ 15mm shingle

Type and grading of material used in operation Shingle from gravel pits 40-75mm and dredged material - (too fine from Owers)

Source of material local gravel pits
Offshore dredging areas

Volume of material transported or recycled – 5000 t /year recycled from North point of Hurst

Haulage distance Recycled material from northpoint → Hurst Spit approx 1 mile.

Approximate cost of operation per m^3 of material handled
£6/m^3 dredged £12/m^3 gravel pit £2/m^3 recycled.

Time of year (if applicable)
Routine maintenance ~ September.

Other following storms.

3. Your best estimate of performance, with marks from 1 to 10, with high marks for best performance

Reduction of wave overtopping	7
Protection of backshore	8
Promotion of beach accretion/recovery	6
Long term performance/design life	4
Low and/or beneficial impact on adjacent coast	5
Low and/or beneficial environmental impact	8
High amenity value/public acceptance	10

4. Design details – Capital replenishment to be constructed

	Capital replenishment to be constructed	Current
Crest height	7m ODN	4-5m ODN
Crest width	12m	3-5m
Beach slope	~1:5	~1:5
Beach profiles taken?	Yes	Yes

Nett drift direction From W To E

5. Other information

Approximate littoral drift rate m^{3}p.a. Measured ☑ ~15,000 Calculated ☑ 5,000 - 30,000

Wave/tidal data? Yes

Wave rider at nearshore site

Tide gauge in lee of spit.

6. Are there any publications, references or other documents which could be made available for inspection?

Beach profile data held on PC database

Physical / mathematical model reports (HR) - not published yet!!

7. If you feel there are other important factors of relevance please give details below.

NATIONAL RIVERS AUTHORITY R&D COMMISSION

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Howbery Park
Wallingford
Oxon OX10 8BA

Tel No. 0491 835381
Fax No. 0491 825539

Where you feel additional information may be of relevance to this project please include this if possible with the questionnaire.

Please fill in details of your organisation:-

Contact Name: C.W. BRAY

Organisation: NRA - South Western
South Wessex Area

Telephone: 0258-456080

1. Please indicate the type of control operations with which you are familiar

Recycling of beach material	YES	☑	NO	☐
By-passing of beach material	YES	☐	NO	☑
Periodic beach nourishment/top up	YES	☑	NO	☐
Mechanical beach reprofiling	YES	☑	NO	☐
Other forms of beach stabilisation	YES	☐	NO	☑

2. Please give details of the type of beach control operation in use

Type of operation Chesil (Cheswell) (reprofile) + East Beach West Bay (re-nourishment). + Freshw

Date of first operation 1978 1990 ≈ 1980

Approximate number of maintenance ops per year Dependant on storms. Freshwater 1 per year.

Capital cost –

Approximate annual maintenance costs £3000/yr. Occasional £20,000 +

Native beach material type/grading Chesil beach shingle.

Type and grading of material used in operation " "

Source of material Chesil beach.

Volume of material transported or recycled 5000 m^3 max. – one operation at Freshwater (not yearly

Haulage distance Freshwater 3 miles. – W-Bay.

Approximate cost of operation per m^3 of material handled ~~5000~~ £4/m^3

Time of year (if applicable) Nov – Jan.

3. Your best estimate of performance, with marks from 1 to 10, with high marks for best performance

Reduction of wave overtopping	6
Protection of backshore	6
Promotion of beach accretion/recovery	3
Long term performance/design life	5
Low and/or beneficial impact on adjacent coast	5
Low and/or beneficial environmental impact	5
High amenity value/public acceptance	9

4. Design details

Cannot supply without more time. (low priority agreed with line manager).

Crest height

Crest width

Beach slope

Beach profiles taken?

Nett drift direction From ☐ To ☐

5. Other information

Approximate littoral drift rate m^3p.a. Measured ☐ Calculated ☐

Wave/tidal data?

6. Are there any publications, references or other documents which could be made available for inspection?

Dobbies reports – feasibility on Chesil / Chiswell.

7. If you feel there are other important factors of relevance please give details below.

Client Study

Useful contacts – Dorset County Council.
– Weymouth & Portland Borough Council
– West Dorset District Council

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Coastal Group
HR Wallingford
Howbery Park
Wallingford
Oxon OX10 8BA

Tel No. 0491 835381
Fax No. 0491 825539

Where you feel additional information may be of relevance to this project please include this if possible with the questionnaire.

Please fill in details of your organisation:-

Contact Name: R. Crowland

Organisation: N-R-A Pevensey district East Sussex

Telephone: 0323/ 762691

1. Please indicate the type of control operations with which you are familiar

Recycling of beach material	YES	☑	NO	☐
By-passing of beach material	YES	☐	NO	☑
Periodic beach nourishment/top up	YES	☑	NO	☐
Mechanical beach reprofiling	YES	☑	NO	☐
Other forms of beach stabilisation	YES	☐	NO	☑

2. Please give details of the type of beach control operation in use Eg SEAFORD.

Type of operation RECYCLE

Date of first operation OCT 1988

Approximate number of maintenance ops per year 2 .

Capital cost SEAFORD SCHEME including Terminal Groyne, Rock Protection & Shingle Renourishment £9 million .

Approximate annual maintenance costs £80,000 .

Native beach material type/grading Shingle

Type and grading of material used in operation N/A

Source of material N/A

Volume of material transported or recycled Up to 100 000 m^3/year

Haulage distance 1.2 to 1.8 miles

Approximate cost of operation per m^3 of material handled 0.80

Time of year (if applicable) October - March .

3. Your best estimate of performance, with marks from 1 to 10, with high marks for best performance

Reduction of wave overtopping	8
Protection of backshore	8
Promotion of beach accretion/recovery	2
Long term performance/design life	8
Low and/or beneficial impact on adjacent coast	8
Low and/or beneficial environmental impact	8
High amenity value/public acceptance	7

4. Design details

Crest height To match existing promenade.

Crest width 25 metres

Beach slope 1 in 7

Beach profiles taken?

Nett drift direction From West To East

5. Other information

Approximate littoral drift rate m^3p.a. Measured ☐ Calculated ☐

Wave/tidal data?

Original prediction (in study) 20 — 28 000 m^3/annum

See study report.

6. Are there any publications, references or other documents which could be made available for inspection?

Various Seaford papers and HR study (c 1985).

7. If you feel there are other important factors of relevance please give details below.

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Coastal Group
HR Wallingford
Howbery Park
Wallingford
Oxon OX10 8BA

Tel No. 0491 835381
Fax No. 0491 825539

Where you feel additional information may be of relevance to this project please include this if possible with the questionnaire.

Please fill in details of your organisation:-

Contact Name: ANDREW DAVIES

Organisation: HAVANT BOROUGH COUNCIL

Telephone: 0705 446452 : FAX : 0705 446455

1. Please indicate the type of control operations with which you are familiar

Recycling of beach material	YES	☑	NO	☐
By-passing of beach material	YES	☐	NO	☑
Periodic beach nourishment/top up	YES	☑	NO	☐
Mechanical beach reprofiling	YES	☑	NO	☐
Other forms of beach stabilisation	YES	☑	NO	☐

36 TIMBER GROYNES
1 ROCK GROYNE .

2. Please give details of the type of beach control operation in use

Type of operation RECYLING

Date of first operation 1987

Approximate number of maintenance ops per year ONE

Capital cost 4 . MILLION

Approximate annual maintenance costs £60,000.

Native beach material type/grading FINE SAND OVERLAYING CLAY. SMALL QUANTITIES OF 5-20mm SHINGLE.

Type and grading of material used in operation RE-NOURISHMENT – 6-40mm SHINGLE MINOR QUANTITIES ABOVE & BELOW THIS SIZE.

Source of material LICENSED AREA OFF LITTLEHAMPTON ENGLISH CHANNEL.

Volume of material transported or recycled RE-NOURISHMENT – 500,000 m³. RE-CYCLING – 20 – 40,000 m³/ANNUM

Haulage distance MAX 5 km.

Approximate cost of operation per m^3 of material handled £1.40 FOR 3km.

Time of year (if applicable) POST SUMMER, DEPENDANT UPON BEACH PERFORMANCE.

3. Your best estimate of performance, with marks from 1 to 10, with high marks for best performance

TO DATE.

Reduction of wave overtopping	8
Protection of backshore	8
Promotion of beach accretion/recovery	3
Long term performance/design life	4
Low and/or beneficial impact on adjacent coast	7
Low and/or beneficial environmental impact	5.
High amenity value/public acceptance	5.

4. Design details

Crest height 5.5 m AODN.

Crest width MAX 15M.

Beach slope APPROX 1 : 5.

Beach profiles taken? APRIL & OCTOBER EACH YEAR.

Nett drift direction DRIFT DIVIDE ON MAIN BEACH. From E To W
AND W TO E.

5. Other information

Approximate littoral drift rate 30,000
40,000 m^3p.a. Measured ☑ Calculated ☑

Wave/tidal data?

WAVE DATA COLLECTED BY HR. 1987-88. WINTER PERIOD (NOV - APRIL)

TIDAL DATA RECORDED AUTOMATICALLY AT PORTSMOUTH, CLASS A PORT, VISUAL OBSERVATIONS AND COMPARISONS TO PREDICTION UNDERTAKEN DURING ANY OFFSHORE SURVEY WORK.

6. Are there any publications, references or other documents which could be made available for inspection?

1) PHD THESIS : SEDIMENT TRANSPORT - DA. HARLOW

2) PHD THESIS : SEDIMENT TRANSPORT. - L. WHITCOMBE.

3) NRA AERIEL SURVEY 1976 - 1992, WITH VOLUME CALCULATIONS.

4) IN HOUSE BEACH SURVEY RESULTS 1987 -1993

5) HYDROGRAPHIC SURVEYS 1980 - 1992.

7. If you feel there are other important factors of relevance please give details below.

MODIFICATION AND FURTHER RESEARCH INTO THE NEW & EXISTING GROYNE FIELD MAY ACHIEVE GREATER STABILISATION OF BEACH MATERIAL.

NATIONAL RIVERS AUTHORITY R&D COMMISSION

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Howbery Park
Wallingford
Oxon OX10 8BA

Tel No. 0491 835381
Fax No. 0491 825539

Where you feel additional information may be of relevance to this project please include this if possible with the questionnaire.

Please fill in details of your organisation:-

Contact Name: HUW DAVIES

Organisation: MEIRIONNYDD DISTRICT COUNCIL

Telephone: 0341 422 341 EXT 2420

1. Please indicate the type of control operations with which you are familiar

Recycling of beach material	YES	☐	NO	☑
By-passing of beach material	YES	☐	NO	☑
Periodic beach nourishment/top up	YES	☐	NO	☑
Mechanical beach reprofiling	YES	☑	NO	☐
Other forms of beach stabilisation	YES	☐	NO	☑

2. Please give details of the type of beach control operation in use

Type of operation BULK SAND SHIFTING

Date of first operation NOT KNOWN BUT HAS BEEN DONE FOR OVER 10 YEARS.

Approximate number of maintenance ops per year ONE AT TWO LOCATIONS

Capital cost 92/93 £ 13.5 K

Approximate annual maintenance costs MINIMAL. OCCASIONAL JCB HIRE ONLY.

Native beach material type/grading WINDBLOWN SAND

Type and grading of material used in operation NOT KNOWN

Source of material DRY SAND BETWEEN MEAN HIGH WATER AND TOP OF BEACH.

Volume of material transported or recycled APPROX 50 000 TONNES.

Haulage distance TYPICALLY 500 M

Approximate cost of operation per m^3 of material handled 27p / M^3

Time of year (if applicable) IMMEDIATELY BEFORE EASTER.

3. Your best estimate of performance, with marks from 1 to 10, with high marks for best performance

Reduction of wave overtopping	
Protection of backshore	
Promotion of beach accretion/recovery	
Long term performance/design life	
Low and/or beneficial impact on adjacent coast	
Low and/or beneficial environmental impact	
High amenity value/public acceptance	10

4. Design details

Crest height

Crest width N/A.

Beach slope

Beach profiles taken?

Nett drift direction From ☐ To ☐

5. Other information

Approximate littoral drift rate m^3p.a. Measured ☐ Calculated ☐

Wave/tidal data?

N/A.

6. Are there any publications, references or other documents which could be made available for inspection?

N/A.

7. If you feel there are other important factors of relevance please give details below.

THE BULK SAND SHIFT EXERCISE IS CARRIED OUT ANNUALLY AT ABERDYFI AND BARMOUTH.
BOTH LOCATIONS SUFFER PROBLEMS FROM WIND BLOWN SAND CAUSED BY WINDS BETWEEN 270° AND 360° MOVING DRY SAND.

NATIONAL RIVERS AUTHORITY R&D COMMISSION

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Wallingford
Oxon OX10 8BA

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Fax No. 0491 825539

Where you feel additional information may be of relevance to this project please include this if possible with the questionnaire.

Please fill in details of your organisation:-

Contact Name: Tony Davison

Organisation: NRA Southern - Chichester District

Telephone: (0243) 786431

1. Please indicate the type of control operations with which you are familiar

Recycling of beach material	YES	☑	NO	☐
By-passing of beach material	YES	☐	NO	☐
Periodic beach nourishment/top up	YES	☑	NO	☐
Mechanical beach reprofiling	YES	☑	NO	☐
Other forms of beach stabilisation	YES	☐	NO	☐

2. Please give details of the type of beach control operation in use

Type of operation Recycling at Church Norton Spit.

Date of first operation Circa - 1980.

Approximate number of maintenance ops per year One

Capital cost Average £20,000 over 8 week period.

Approximate annual maintenance costs approx. £20,000

Native beach material type/grading Shingle - 50 mm average

Type and grading of material used in operation —

Source of material Drift material

Volume of material transported or recycled c. 16,000 Tonnes.

Haulage distance average 800 m. & return

Approximate cost of operation per m^3 of material handled £1.87 per m^3.

Time of year (if applicable) January

Has to be completed prior to nesting period, due to Nature Reserve.

3. Your best estimate of performance, with marks from 1 to 10, with high marks for best performance

Reduction of wave overtopping		8
Protection of backshore		10
Promotion of beach accretion/recovery		5
Long term performance/design life	— annually ———	9
Low and/or beneficial impact on adjacent coast		7
Low and/or beneficial environmental impact	protects nature reserve	10
High amenity value/public acceptance		7

4. Design details

Crest height 5·00 m. AOD.

Crest width 15 m. minimum

Beach slope 1:10

Beach profiles taken? No.

Nett drift direction From W To E

5. Other information

Approximate littoral drift rate ? m^3p.a. Measured ☐ Calculated ☐

Wave/tidal data?

6. Are there any publications, references or other documents which could be made available for inspection?

7. If you feel there are other important factors of relevance please give details below.

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Coastal Group
HR Wallingford
Howbery Park
Wallingford
Oxon OX10 8BA

Tel No. 0491 835381
Fax No. 0491 825539

Where you feel additional information may be of relevance to this project please include this if possible with the questionnaire.

Please fill in details of your organisation:-

Contact Name: Stan Jeavons

Organisation: Catchment Engineer Norfolk & Suffolk
NRA

Telephone: 0603 662800

Date: 27.9.93

1. Please indicate the type of control operations with which you are familiar.

Recycling of beach material	YES	☐	NO	☑
By-passing of beach material	YES	☐	NO	☑
Periodic beach nourishment/top up	YES	☑	NO	☐
Mechanical beach reprofiling	YES	☑	NO	☐
Other forms of beach stabilisation	YES	☑	NO	☐

2. Please give details of the type of beach control operation in use

i.e. one typical site — Salthouse Shingle Bank.

Type of operation Reprofiling shingle sea defence bank

Date of first operation on going from 1940's ?

Approximate number of maintenance ops per year 1 minimum.

Revenue ~~Capital~~ cost £25,000 - £30,000 p.a.

Approximate annual maintenance costs No capital cost - originally a 'natural' bank.

Native beach material type/grading Course aggregate no apparent grading curve

Type and grading of material used in operation No importation of material.

Source of material Cliff erosion / offshore source.

Volume of material transported or recycled Up to 40,000 cu.m. p.a.

Haulage distance Up to 100m.

Approximate cost of operation per m^3 of material handled approx 75p cu.m.

Time of year (if applicable) Usually autumn / spring.

3. Your best estimate of performance, with marks from 1 to 10, with high marks for best performance

Reduction of wave overtopping	4
Protection of backshore	1
Promotion of beach accretion/recovery	5
Long term performance/design life	2
Low/beneficial impact on adjacent coast	3
Low/beneficial environmental impact	3
Amenity value/high public acceptance	8

4. Other information

Approximate littoral drift rate m^{3}p.a. Measured ☐ Calculated ☐

Nett drift direction From ☐ To ☐

Design details: Not known.

Beach slope Littoral drift is westwards

Beach crest to Blakeney Point.

Beach height +8.5 m OD(N).

Beach width 15 - 25 m.

Other

Design wave conditions up to 3 m.

Design tidal conditions

Beach profiles taken? Yes - from 1979.

Final beach slope, crest height, width, if known

Wave/tide data collected? Yes.

5. Are there any publications, references or other documents which could be made available for inspection?

Some capital reports prepared by our Engineering Dept. in Peterborough.

6. If you feel there are other important factors of relevance please give details below.

The loss of beach feed material into the system is slowly resulting in a reduction of bank profile.

Expected life of shingle bank is 10-20 years without any beach feed of appropriate material.

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Coastal Group
HR Wallingford
Howbery Park
Wallingford
Oxon OX10 8BA

Tel No. 0491 835381
Fax No. 0491 825539

Where you feel additional information may be of relevance to this project please include this if possible with the questionnaire.

Please fill in details of your organisation:-

Contact Name: Brian Killingworth

Organisation: National Rivers Authority/ Welsh Region

Telephone: 0248-370970

1. Please indicate the type of control operations with which you are familiar

Recycling of beach material	YES	☑	NO	☐
By-passing of beach material	YES	☐	NO	☑
Periodic beach nourishment/top up	YES	☑	NO	☐
Mechanical beach reprofiling	YES	☑	NO	☐
Other forms of beach stabilisation	YES	☐	NO	☑

2. Please give details of the type of beach control operation in use

Type of operation MECHANICAL BEACH REPROFILING

Date of first operation 1987

Approximate number of maintenance ops per year 1

Capital cost £800

Approximate annual maintenance costs £800

Native beach material type/grading SAND & SHINGLE

Type and grading of material used in operation NOT KNOWN

Source of material LAND BEHIND BEACH ALSO BEACH AT LOW WATER.

Volume of material transported or recycled NOT KNOWN

Haulage distance 100 YDS AWAY.

Approximate cost of operation per m^3 of material handled 50p (GUESS)

Time of year (if applicable) SEPTEMBER / OCTOBER

3. Your best estimate of performance, with marks from 1 to 10, with high marks for best performance

Reduction of wave overtopping	3
Protection of backshore	3
Promotion of beach accretion/recovery	1
Long term performance/design life	1
Low and/or beneficial impact on adjacent coast	1
Low and/or beneficial environmental impact	1
High amenity value/public acceptance	7

4. Design details

Crest height	2-3 m.
Crest width	1 m.
Beach slope	NOT KNOWN
Beach profiles taken?	NO

Nett drift direction From S To N

5. Other information

Approximate littoral drift rate m^3p.a. Measured ☐ Calculated ☐

Wave/tidal data? NOT KNOWN.

6. Are there any publications, references or other documents which could be made available for inspection?

The operation briefly described takes place at two sites – Penllyn, Tywyn and Sunnysands, Harlech.

They will shortly be discontinued as formalised strategy from the schemes identified in the Meirionnydd coastal management plan take over.

7. If you feel there are other important factors of relevance please give details below.

RECEIVED
16 SEPT 93
OPERATIONS
HR WALLINGFORD

NRA

National Rivers Authority
Southern Region

Our ref: FAR SDOO RAN/JJ
Your ref: C/N/1/4(i)

Date: 14 September 1993

Sirly
2.AHG. 2

Mr J M Motyka
Coastal Group
HR Wallingford Ltd.
Howbery Park
Wallingford
Oxfordshire 0X10 8BA

Dear Mr Motyka

EFFECTIVENESS OF BEACH CONTROL OPERATIONS

I have answered your questionnaire to the best of my ability.

The situation in my district has developed over the years - the Pett defences for instance were a natural shingle beach with an ongoing shingle recharge along the beach. This was then improved with a hard defence (lightly protected clay bank) with the shingle seaward of the wall - the littoral drift being checked by groynes. The ongoing recharge diminished to nothing due to work by the adjacent council, and recycling from the upwind (NE) to the downwind (SW) length of the frontage was introduced.

The situation was similar at the Walland frontage where the original shingle storm crest was stabilised by groynes which were constantly maintained. The groynes were abandoned, the defence being maintained by recycling shingle instead.

The defences have proved themselves against many storms, and recent studies on both frontages have only been carried out, to consider the possibility of upgrading, by consultants and would be available from the Regional Office at Worthing.

Small recycling projects are also carried out at Denge and Littlestone, some 4,000 m^3 being recycled at each site.

I trust the information will be of assistance.

Yours sincerely

R A NICKERSON
District Controller

Encs.

1. Please indicate the type of control operations with which you are familiar Pett

Recycling of beach material	YES	☑	NO	☐
By-passing of beach material	YES	☐	NO	☐
Periodic beach nourishment/top up	YES	☑	NO	☐
Mechanical beach reprofiling	YES	☑	NO	☐
Other forms of beach stabilisation	YES	☑	NO	☐

2. Please give details of the type of beach control operation in use

Type of operation Shingle Recycling (Lorries) & Groynes.

Date of first operation Over 25 years ago

Approximate number of maintenance ops per year ?

~~Capital~~ cost £134 K. / year

Approximate annual maintenance costs

Native beach material type/grading ?

Type and grading of material used in operation ?

Source of material From foreshore

Volume of material transported or recycled 35,000 m^3 approx

Haulage distance 8 Km

Approximate cost of operation per m^3 of material handled £3.8/m^3

Time of year (if applicable) Majority Sept → March (Winter months.)

3. Your best estimate of performance, with marks from 1 to 10, with high marks for best performance

Reduction of wave overtopping	8
Protection of backshore	9
Promotion of beach accretion/recovery	8
Long term performance/design life	8
Low and/or beneficial impact on adjacent coast	Self Contained.
Low and/or beneficial environmental impact	7
High amenity value/public acceptance	8

4. Design details

Crest height

Crest width

Beach slope

Beach profiles taken?

Nett drift direction From SW To NE

5. Other information

Approximate littoral drift rate 30,000m³ m³p.a. Measured ☐ Calculated ☐

Wave/tidal data? Recent Study available at our Head Office (Worthing)

1. Please indicate the type of control operations with which you are familiar Walland

Recycling of beach material	YES	☑	NO	☐
By-passing of beach material	YES	☐	NO	☐
Periodic beach nourishment/top up	YES	☑	NO	☐
Mechanical beach reprofiling	YES	☑	NO	☐
Other forms of beach stabilisation	YES	☑	NO	☐

2. Please give details of the type of beach control operation in use

Type of operation Shingle Recycling (Lorries) & Groynes

Date of first operation Over 25 years ago

Approximate number of maintenance ops per year ?

Capital cost £260 k.n /year. Royalties/Rent £75 k/year.

Approximate annual maintenance costs

Native beach material type/grading ?

Type and grading of material used in operation ?

Source of material Foreshore at Dungeness

Volume of material transported or recycled 35000

Haulage distance 14 Km approx

Approximate cost of operation per m^3 of material handled £7.5/tn

Time of year (if applicable) Sept → March (Winter months.)

3. Your best estimate of performance, with marks from 1 to 10, with high marks for best performance

Reduction of wave overtopping	8
Protection of backshore	9
Promotion of beach accretion/recovery	8
Long term performance/design life	8
Low and/or beneficial impact on adjacent coast	8
Low and/or beneficial environmental impact	?
High amenity value/public acceptance	8

4. Design details

Crest height

Crest width

Beach slope

Beach profiles taken?

Nett drift direction From W To E

5. Other information

Approximate littoral drift rate 35000 m^3/yr m^{3}p.a. Measured ☐ Calculated ☐

Wave/tidal data? Recent Study available at our Regional Head Office (Worthing)

D.N. GOUGH C.Eng., M.I.C.E., M.I.H.T., M.I.W.M.
Director of Housing & Technical Services/
Cyfarwyddwr Tai a Gwasanaethau Technegol

Colwyn

My Ref: / Ein Cyf: GMR/D/-X/1/1
Your Ref: / Eich Cyf: C/N/1/4(i)

Please Reply to: / Atebwch i: Mr. G.M. Roe
Tel. Extension: / Est. Tel: 321
Dept. Fax No. (0492) 513717

Sum
~~[illegible]~~ AHB.
2 [illegible]
3 [illegible]

Mr. J.M. Motyka,
Coastal Group,
H.R. Wallingford Ltd.,
Howbery Park,
WALLINGFORD,
Oxfordshire. OX10 8BA

RECEIVED
22 SEPT 93
OPERATIONS
HR WALLINGFORD

20th September, 1993

Dear Sir,

Beach Control Operation

Thank you for your letter and forms.

The only beach nourishment I have completed recently is the area immediately to the east of the British Rail works in Towyn. This area has eroded since the installation of British Rail's revetment as was predicted by my Principal Officer (Design), Mr. Gordon Roe, and your goodselves.

As a general rule I spend about £10,000 per year on groyne repair/management on a total coastline length of 19km.

Beach nourishment would come from the local quarries in Llanddulas (5km) or if rounded stone was needed then Borras (Wrexham), or Cefn Graianog (Caernarfon).

You will be well aware of the drift rate on the coastline from previous H.R. Reports.

I enclose your forms, incompleted, as it is not particularly relevant to my stretch of coastline.

Yours faithfully,

Director of Housing and
Technical Services

Enc.

CYNGOR BWRDEISDREF **COLWYN** BOROUGH COUNCIL

NATIONAL RIVERS AUTHORITY R&D COMMISSION

Effectiveness of beach control operations

This questionnaire forms part of an appraisal of the effectiveness of beach control operations, which is an R&D commission undertaken by HR Wallingford for NRA. The results of the appraisal will be incorporated into a Beach Management Manual, incorporating current practice and research findings, to direct engineers involved with planning, design, implementation and management of beaches and beach recharge schemes. This project is linked to a MAFF sponsored research programme which is being run concurrently with the present programme, and the information from this questionnaire will be used in both projects.

Your help with this appraisal will be greatly appreciated and an early reply will also be very welcome. I would be grateful if you could return the completed questionnaire to:-

Mr J M Motyka
Coastal Group
HR Wallingford
Howbery Park
Wallingford
Oxon OX10 8BA

Tel No. 0491 835381
Fax No. 0491 825539

Where you feel additional information may be of relevance to this project please include this if possible with the questionnaire.

Please fill in details of your organisation:-

Contact Name: Mr G Trapmore
Area Flood Defence Manager Cornwall Area

Organisation: N R A

Telephone: 0208 78301

The NRA is responsible for only 1 No sea defence in the Cornwall Area. This is Loe Bar nr Helston. The bar is a natural feature through which the R. Cober drains via a tunnel. No action is required to maintain its integrity

G. Trapmore

30/9/93