CIRIA RP444 June 1992

Non-aggregate marine materials for beach recharge – Stage 1

Prepared under contract to CIRIA by
Babtie Dobbie Limited

THE CROWN ESTATE

NRA

National Rivers Authority

CIRIA
CONSTRUCTION INDUSTRY RESEARCH AND INFORMATION ASSOCIATION
6 Storey's Gate, Westminster, London SW1P 3AU
Tel 071-222 8891 Fax 071-222 1708

R&D Note 57

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Summary

Beach recharge offers a soft engineering solution to the problems of sea defence and coast protection and is increasingly being considered as an alternative to traditional solutions such as seawalls. However, if coastal authorities' specifications for material are identical to those for concreting aggregate, costs will be high because of competition from the construction industry.

This report examines the potential for the use of non-aggregate marine material for beach recharge. Non-aggregate material is defined as that not used by the construction industry because of its properties, or because it is not available to the construction industry.

Issues covered include potential locations for beach recharge schemes in the UK; the availability of non-aggregate marine material; factors affecting the performance of recharged beaches; legislation; economics; environmental considerations and beach design.

Over one quarter of beaches considered important for coast protection and sea defence in England and Wales are eroding and therefore potential sites for recharge. The demand for recharge material is increasing, and it is estimated that 1.3 million cubic metres per year will be needed between now and the end of this century. Potential sources of material include offshore deposits not used by the construction industry, nearshore deposits not available to the construction industry and dredged spoil; but very little is known about their quantities and properties. Similarly, little information exists on the performance of beaches recharged using non-aggregate quality material; and there are no accepted standard procedures or guidelines for beach design.

The need for research into coastal processes, sediment transport, model development and the performance of beaches is recognised by MAFF, the NRA and SERC; and numerous relevant projects are underway or about to start. These projects have not necessarily been designed to produce information for beach recharge schemes, but many will produce highly relevant results.

The report concludes that there is considerable potential for the use of non-aggregate marine materials in beach recharge schemes, but that further work is needed to establish the availability of materials and to be confident about their use for coast protection.

It is recommended that interim guidance for coastal engineers should be produced in the short term, followed by more authoritative guidance in the long term. In the short term, there is an urgent need for immediate guidance, and a manual of best practice is therefore proposed. Work could begin on producing this manual immediately.

In the long term, a co-ordinated approach to the whole issue of beach recharge is recommended, covering design; material availability; and environmental factors; leading to the production of an authoritative manual on beach recharge.

One option for the production of an authoritative manual in the long term is a co-ordinated programme of research carried out as Stage 2 of the project which produced this report. A framework for this programme is proposed in which maximum benefit would be obtained from existing research and knowledge through co-ordination and enhancement. Additional projects are proposed to cover issues not currently being addressed, such as extension of BGS cover of the nearshore zone and the streamlining of procedures to speed up the consultation process leading to production licences for beach recharge material.

Finally, it is proposed that a Working Group is formed to consider the report's recommendations and agree priorities for Stage 2 of the project.

Non-aggregate marine materials for beach recharge
Construction Industry Research and Information Association
Research Project 444, 1992

Foreword and acknowledgements

This report was produced as a result of the first stage of CIRIA Research Project 444, *Non-aggregate marine materials for beach recharge*, carried out on behalf of CIRIA by Babtie Dobbie Limited. The project was developed by CIRIA in consultation with the Crown Estate, the National Rivers Authority and the Ministry of Agriculture, Fisheries and Food. Stage 1 of the project investigated the potential for the use of non-aggregate marine materials for beach recharge.

Messrs Keith Riddell and John Gorham were project supervisors for Babtie Dobbie Limited and the work was guided by a Steering Group, chaired by Mr Gordon Gray of CIRIA. The proposal was initiated by Mr Garry Stephenson and managed by Dr Judy Payne of CIRIA.

CIRIA expresses its gratitude to the National Rivers Authority and the Crown Estate who funded the project. This report represents NRA R&D Note 57.

Principal Authors

Mr J B Gorham	Babtie Dobbie Limited
Mr K J Riddell	Babtie Dobbie Limited

Steering Group

Mr G M Gray (Chairman)	CIRIA
Mr R S Arthurton	British Geological Survey
Mr G Fisher	National Rivers Authority, Southern Region
Mr A B Hughes	Ministry of Agriculture, Fisheries and Food
Dr A J Murray	The Crown Estate
Mr K Powell	HR Wallingford
Mr M J Watkiss	Posford Duvivier
Dr J A Payne (Research Manager)	CIRIA

Corresponding Steering Group Members

Mr F A Aberg*	Royal Commission on the Historic Monuments of England
Mr P Bide	Department of the Environment
Dr S Bolt*	Joint Nature Conservation Committee
Mr G K Boyes	Ministry of Agriculture, Fisheries and Food
Dr C Eno*	English Nature
Ms A Gale*	Royal Commission on the Historic Monuments of England
Dr R Leafe*	English Nature
Dr G Radley*	English Nature

* for part of the project duration only

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1 Introduction

1.1 BACKGROUND

Much of the UK coastline suffers from erosion, placing people, property and land at risk. The problem is exacerbated by the age and condition of existing coastal defence structures and by the threat of sea level rise. Sea wall construction costs approximately £5 million per kilometre and it has been estimated that £450 million will be required to be spent over the next 10 years to maintain the present level of coastal protection.

Beach recharge using marine won material offers a soft engineering solution to this problem. Beaches are one of the most effective forms of coastal defence : as well as protecting the coast by the gradual dissipation of wave energy, beaches increase the recreational and amenity value of the coastline without detracting from its natural appearance. The benefits of beach recharge are well known, but if specifications by coastal authorities are identical to concreting aggregate, costs will be high because of competition from the construction industry. At present the specification for material required by the construction industry and for recharge schemes are practically identical. The report will identify material unsuitable or unavailable for use as construction aggregate and assess its potential for beach recharge.

1.2 REPORT OBJECTIVES

The overall objective of this report is to investigate the potential for the use of non-aggregate marine materials for beach recharge.

Detailed objectives are:

- to identify those stretches of the UK coastline where beach recharge may be an option for coastal protection and sea defence, including an assessment of the quantities of material needed and the parameters used
- to assess the availability of non-aggregate marine materials and their properties
- to set out the parameters governing the performance of non-aggregate marine materials used for beach recharge and the response of these materials to their new environment; and to identify the scope for less rigid specifications which would accommodate the wider use of such materials
- to identify the factors which influence the cost of supplying and placing non-aggregate marine materials on the beach and develop an outline cost model
- to indicate the environmental impact factors involved in winning and placing the material
- to indicate possible design approaches
- to prepare recommendations for further work to be carried out under Stage 2 of the CIRIA project.

1.3 DEFINITIONS AND SCOPE

1.3.1 Non-aggregate marine material

For the purposes of this report, *non-aggregate marine material* means deposits not used by the construction industry. This can be because of the material quality or its location.

The general specification for sea dredged aggregate is clean (not containing contaminants such as clays, shell, etc.), with a 60/40 ratio of gravel and sand; although aggregate dredgers are fitted with screens which can remove sand from 30/70 mixtures to produce 60/40 material. Material with a gravel/sand ratio significantly less than 30/70, or material with excessive contaminants is therefore considered non-aggregate.

The zero-effect principle (see below) has generally restricted licensed dredging areas to outside the 18m isobath. If materials within this boundary could be demonstrated to achieve a beneficial effect upon the adjacent beaches, adjustments to the Government View Procedure (see below) may allow it to be made available by the Crown Estate for coast protection users only. Material within the boundary is not available for construction and is therefore considered non-aggregate.

1.3.2 Beach recharge

Beach recharge is the artificial replenishment of an existing beach with imported material. Alternative terms for beach recharge include beach nourishment, beach replenishment and beach feeding.

1.3.3 Beach recycling

Beach recycling describes the works carried out to remove beach material from areas of accretion to areas of beach erosion.

1.3.4 Sand bypassing

Sand bypassing involves the transportation of littoral drift material around an obstruction in the natural hydrodynamic regime.

1.3.5 The zero-effect principle

The criteria set out for the approval of licensing all production areas stipulates that the proposed dredging should not affect the adjacent coastline. This is known as the zero-effect principle.

1.3.6 Government View Procedure

Under the Government View Procedure the Department of the Environment (DoE) coordinates a consultation procedure on extraction licence applications. The Ministry of Agriculture, Fisheries and Food (MAFF), forms a view through consultation and puts its formal comments to DoE under the Government View Procedure.

1.3.7 Aggregate dredgers

Dredgers optimised for winning aggregate are typically fitted with an on-board screening system which enables them to discharge either surplus stone or surplus sand. Thus the natural grading of the seabed material can be improved upon to better meet the required specification. Aggregate dredgers are usually optimised for dry discharge alongside a wharf.

1.3.8 Contract dredgers

Dredgers usually employed in contract work are not normally fitted with on-board screening systems, so the grading of the material dredged does not significantly differ from its natural seabed state. Contract dredgers are usually optimised for pumped discharge through a pipeline and tend to be significantly larger than aggregate dredgers.

1.4 THE NATIONAL SEA DEFENCE SURVEY

The flooding that occurred at Towyn during the storms of February 1990 highlighted the necessity to survey the length, position, condition, effectiveness and ownership of the sea defences around England and Wales. The National Sea Defence Survey (NSDS) was started during the summer of 1990 and will enable the National Rivers Authority (NRA), MAFF, Welsh Office, and other Government departments to determine the state of the sea defences and develop a planning strategy for investment in renewal and improvements for England and Wales. Results of the initial phases of the NSDS are described here as background information before consideration of beach recharge.

1.4.1 Description

The NSDS is being undertaken in four phases.

- Phase One is concerned solely with the sea defences owned or maintained by the NRA or shared by them with others.
- Phase Two is concerned solely with sea defences which are the responsibility of local coastal authorities.
- Phase Three is concerned with sea defences maintained by other bodies such as the Property Services Agency, British Rail, Docks and Harbours, private companies and individuals.
- Phase Four, planned to be carried out during 1991 and 1992, will include a report on the tidal defences excluded during the first three phases which are landward of the Schedule 4 boundaries in the 1949 Coast Protection Act.

The data collected under Phase One (NRA owned or maintained sea defences) included:

- location
- length
- crest level (nominal and effective)
- structures, material and condition
- return period of the sea level corresponding to the effective crest level
- degree of exposure to storm attack
- type of foreshore, height, movement and the degree to which the integrity of the defence depends on the foreshore
- extent of the area at risk of flooding
- land use in the area at risk
- residual life of the defence
- refurbishment priority and urgency

1.4.2 Initial results

Phase One of the survey concluded that the sea defences owned or maintained by the NRA have a total length of 807.13km, of which 29% is fronted by an eroding foreshore. This finding is considered significant by the NRA in their strategic planning and the eventual choice of solutions.
Each element of the defence was given a rating, dependant on the rate of deterioration, to describe its condition. The categories used are:

1. Condition as built

2. Minor works showing some signs of wear, needs to be kept under observation, returnable to as-built condition with simple maintenance

3. Moderate works required, probably limited to a maintenance operation to return condition to as built

4. Significant works needed, capital works probably required in the near future.

Analysis of the data collected showed that 35% of sea defences are in category 1, 51% are in category 2, 12% in category 3, and 2% fell in category 4 (requiring major works). Half of the required works in categories 3 and 4 are related to ancillary structures such as groyne fields. Table 1 summarises the survey results by NRA Region.

Table 1 Analysis of defence elements

	Overall condition (element lengths in km)								
						Residual life		Priority rating	
NRA Region	1	2	3	4	TOTAL	< 2 years	2 to 5 years	1	2
Anglian	107.40	545.56	102.57	3.26	667.79	6.94	41.34	4.01	72.84
Northumbrian	0.71	7.92	1.08	0.12	9.83	0.50	2.56	0.00	0.44
North West	39.41	28.63	5.83	2.60	76.47	4.50	6.55	13.60	6.30
Severn-Trent	30.11	16.10	0.00	0.00	46.21	0.00	6.34	5.75	6.12
Southern	153.38	126.38	46.15	13.88	339.69	32.49	81.34	61.35	67.24
South West	11.41	14.04	2.00	0.50	27.95	0.50	2.00	0.50	9.80
Welsh	126.70	34.31	5.40	0.88	167.29	5.28	27.31	20.37	86.94
Wessex	21.74	26.19	1.42	3.95	53.30	3.95	11.82	0.00	12.19
Yorkshire	2.42	11.08	6.55	2.93	22.98	15.49	1.16	15.74	5.61
TOTAL	493.28	719.11	171.00	28.12	1411.51	69.65	180.42	121.32	267.48
	1212.39								
	86%		12%	2%		5%	13%	8.4%	18.5%

Key:
1 - as constructed
2 - minor works needed
3 - moderate works needed
4 - major works needed

Priority rating 1 - high benefit/cost ratio (urban areas)
Priority rating 2 - lower benefit/cost ratio (mainly rural)

2 Beach recharge

This section provides an overview of the planning, design and implementation of beach recharge schemes and illustrates the processes involved with case studies.

2.1 PLANNING BEACH RECHARGE SCHEMES

Three processes are involved in the planning of a beach recharge scheme:

(a) problem definition
(b) identification of potential solutions
(c) selection of beach recharge.

2.1.1 Problem definition

Erosion of beaches is often the result of a combination of several factors, and assessment of the situation will only be possible if the various erosion processes are identified and quantified to calculate a sediment budget.

The coastline may be naturally unstable due to a shortage of beach material. A classic example of this form of erosion is the Holderness Coast, where rapid erosion of the clay cliffs provides very little material to feed the adjacent beaches.

Another cause of beach erosion is man's activities. For example, where a cliff face has been stabilised by toe protection (or the incursion of the sea has been prevented by the construction of revetments) the source of littoral drift materials is restricted and down drift beaches become denuded. Further examples of man's intervention in the natural coastal regime are development and overuse of dune systems, with sand being permanently lost from the system. The most obvious artificial intrusion into the coastal system is the construction of harbour arms and similar structures creating deflections to the tidal flows close to the shoreline, preventing material reaching the beach from the seaward direction.

2.1.2 Potential solutions

Various solutions are available to provide both sea defence and coast protection and numerous examples exist round the British coastline. Potential solutions include:

- seawalls
- groynes
- revetments
- beach recharge
- offshore breakwaters.

2.1.3 Selection of beach recharge

There are numerous advantages which may be gained by the adoption of beach recharge as a solution to a sea defence or coastal protection problem. Each situation is different, but potential advantages include:

- flexibility
- environmental acceptability
- natural appearance
- added amenity value
- low cost.

Beach recharge offers a flexibility of design because it can be adapted to suit local conditions. It is also flexible with respect to future requirements, as schemes can be adapted at low capital cost.

Compared with hard coastal structures, beach recharge is likely to have a lower environmental impact. In many cases the impact is positive rather than negative. A recharged beach can be designed to blend well with the natural surroundings. Beaches are more aesthetically pleasing than hard structures, and offer additional amenity value.

Beach recharge schemes have already proven to be more cost effective than alternative hard solutions in a number of locations. The use of non-aggregate material for beach recharge could further reduce costs.

The main disadvantage of beach recharge schemes is a lack of design guidance and limited modelling capabilities. Sometimes it is also difficult to persuade the public that a beach recharge scheme provides an effective defence. Little information exists on the environmental impact and amenity value of beaches recharged using non-aggregate materials. These disadvantages could all be overcome through further research.

2.2 DESIGN AND IMPLEMENTATION OF BEACH RECHARGE SCHEMES

The design process involves establishing design conditions and then simultaneously considering design profile and possible sources of recharge material to achieve the optimum solution.

One of the problems with this approach is that much of the necessary information on material sources is held in confidence by the aggregates industry. The use of non-aggregate materials could overcome this problem because information on these would not have such a high commercial value.

2.2.1 Design overview

Having acquired sufficient climatic data it is usual to establish the equilibrium profile of the beach for various return period events by the use of numerical models. Calibration and verification of the models adopted should be carried out where possible, otherwise sensitivity analysis may be required. Predictions of beach movement through both cross-shore and longshore movements should be incorporated in the estimation of the initial design profile to determine the satisfactory performance during the design life.

Details of modelling techniques (including their application for non-aggregate materials) are given in Section 9 of this report. Broad guidelines are given below.

- The nourished beach crest must be at least as high as the run up level on a high spring tide during the design storm condition.

- The beach crest should be sufficiently wide to afford an acceptable residual width during the design storm event. Long term crest and forebeach depletion should also be considered.

- Generally, coarser materials are preferable since the increased permeability will reduce the wave run up and the wave energy will be more effectively dissipated. However, the increase in the median beach grain size may be unacceptable from an amenity aspect or incompatible with the natural beach materials.

2.2.2 Implementation

Having determined various alternative profiles and sources of material, it will be necessary to estimate the cost of the works so that the viability of the scheme can be ascertained. Although some preliminary costing information is included in this report, it may be advisable to refer to dredging contractors for detailed costings. The dredging companies, in providing a budget price for the works, will have to take into consideration the costs incurred through both material and time losses. With this type of work it is usual that there will be an element of intertidal working. With sandy beaches the foreshore is usually gently shelving and dredger access is restricted and hence pumping of the material ashore is required. Exposed sites will require some allowance for downtime due to storm action and this may be compounded by any restrictions applied upon the timing of the project, for instance, to avoid high beach amenity periods. Placement of material without pumping is the exception rather than the rule.

2.3 CASE STUDIES

The purpose of this section is to illustrate the design and implementation processes outlined above using specific examples. Three schemes are described: Portobello, Hunstanton and Seaford. The Portobello scheme was the only one to use non-aggregate quality material. The material used at Seaford was aggregate quality but from a source not commonly exploited by the construction industry. Hunstanton is included because a lot of information is available on its implementation and this makes it possible to speculate on the effects of using non-aggregate material. The Hunstanton scheme is also used to illustrate the detailed design and implementation process.

2.3.1 Portobello

Portobello Beach lies on the south bank of the Firth of Forth approximately 5 miles from Edinburgh City Centre. During the 19th Century the beach provided both amenity facilities for the local population and raw material for the glass and bottle industry located at the western end of the beach.

Problem definition

Although the exact cause of the beach denudation may never be known it has often been assumed that the abstraction of the beach sands to supply the glass making industry may have been the significant factor. The beach levels had been reducing noticeably since the construction of the promenade, to such an extent that by 1926 (30 years after construction) the beach levels had dropped by 2m.

Potential solutions

In 1958 the City Engineer's Department were so concerned about the increased danger of flooding over the promenade that they employed the Hydraulics Research Station to carry out a series of model tests to establish a suitable design for a parapet wall to be added to sections of the promenade. However, it was becoming apparent that major works would be required to ensure the stability of the wall. An initial study of a beach recharge scheme was considered at this stage but no satisfactory method of nourishment could be devised.

Selection of beach recharge

In 1970 the practicality of a beach recharge scheme was considered again. An investigation of the remaining beach indicated that the median grain size of the beach material was 0.2mm and that the beach slope was approximately 1:42. By this time the beach had dropped between 2 and 3m below the promenade level and approximately 1m below the mean high water springs level. The mean spring tide level at Portobello is 5.3m.

Design

It was thought that in order to stand a better chance of success, a coarser sand than that forming the present beach should be utilised. The area is subject to substantial exposure from the north-east winds. Under wave action, coarser sands tend to move close to the bed, and the natural drift as well as the orbital velocities tend to move materials shorewards. Finer materials tend to be entrained into the water column and at these mid-depths the governing transport direction is offshore.

During the period between the first beach appraisal and the 1970 study the City Engineers had the foresight to commission a survey of the offshore deposits. The survey showed considerable deposits of coarse sand 1km offshore of Fisherrow. Borehole samples had indicated that there would be deposits in excess of 600,000 cubic metres of sand with a median size of 0.27mm. Surveys of adjacent beaches had indicated the approximate replenishment profile to be adopted for the Portobello Beach. At Fisherrow and Seton, to the east of Portobello, the beach slopes were approximately 1:12 with median grain sizes between 0.38mm and 0.52mm.

Implementation

The sand replenishment operation started in June 1972. The deposits off Fisherrow were dredged using a bucket dredger, and transferred by self-propelled barges with a capacity of 500m³ to a pumping dredger situated 400m offshore of Portobello Beach. The barges were discharged in the suction head of the pumping dredger and pumped ashore via a 75mm diameter submarine pipeline. On shore the pipeline was bifurcated allowing direct pumping to either side of the beach. The design beach profile was constructed to a slope of 1:20 with a median grain size of 0.27mm.

After 18 months the beach slope had relaxed to 1:23. The actual pumping operation lasted approximately 4 weeks with an estimated cost of about £1.42/m³. Six greenheart timber groynes were included in the design to restrict the movement of the beach material to the west under the action of the NE winds. Monitoring surveys carried out two years after completion of the scheme indicated that there had been no discernable loss of material and after fourteen years approximately 50% of the material is still present.

2.3.2 Hunstanton

The Hunstanton/Heacham sea defences extend 8km along the East Coast of the Wash. In 1953 large areas adjacent to the East Coast of England were inundated by the then highest recorded tidal surge, compounded by storm-force northerly winds. The length of coast between Hunstanton and Snettisham was particularly affected and 15 lives were lost. The whole of the shoreline between Hunstanton and Snettisham is included within a Site of Special Scientific Interest (SSSI). The whole of the Wash is also a Ramsar site (a site of international importance for the protection of migratory birds, particularly water fowl) and a Special Protection Area (SPA) under the European Community Directive on the Protection of Wild Birds. The consent of the Nature Conservancy Council is required for improvements along the shoreline.

Problem definition

Heacham Beach is protected by a shingle bank with an average particle size of less than 10mm. This area suffers from constant erosion both from moderate wave attack and strong tidal currents of up to 4 knots. The construction of three long zig-zag groynes in front of the revetted section to the north had shadowed this section with a consequent depletion of the mobile beach material. Despite having been breached during the 1978 storms, this area had never been the subject of any capital works. At Heacham South Beach a 700m long sleeper retaining wall had been constructed in 1954. This wall, although requiring constant maintenance, had stabilised the position of the shingle ridge. This was evident from the 15m retreat of the unprotected ridge at the southern end of the wall.

The remaining 5km of defence is formed by a shingle ridge, although in sections this has again been protected by sleeper walls, gabions and block revetments. This section is generally thought to be relatively stable, although just south of the Heacham South Beach the shingle ridge was breached during the 1978 storms.

Selection of beach recharge

Beach recharge was considered the most cost effective solution, and was also environmentally beneficial.

Design

The primary engineering parameters are based on tide levels, surge elevations, inshore wave heights, crest elevations, beach response to storm conditions and the volume of the longshore drift potential. The main criteria are listed below:

(a) Tidal Elevations
MHWS + 3.55m ODN
MLWS - 2.85m ODN

(b) Surge Elevations
1 in 10 year event + 5.18m ODN
1 in 50 year event + 5.61m ODN
1 in 100 year event + 5.79m ODN

(c) Inshore Wave Heights
For a 50 year return period the significant wave heights associated with a 1 m 50 year surge elevation vary with location and direction but are generally between 2.9 and 3.9m.

(d) Overtopping
Overtopping was to be reduced from the present volumes for the combined 1 in 100 year event to comply with the permissible guidelines given in Ex 924. This would mean a threefold decrease at Hunstanton and a tenfold decrease at Snettisham.

(e) Longshore Movements
Potential accretion/erosion volumes were determined for various sections based upon the inshore wave data.

(f) Cross-shore response to storm attack
Various profiles and material sizes were extensively modelled to determine the optimum profile. Eventually a bermed embankment was devised which met both the storm response criteria and the overtopping criteria.

Implementation

A contract was let during the latter part of 1990 to include for a two stage operation in which the northern section, Hunstanton to Heacham would be completed during the first campaign (1990) and the remainder would be completed during the second campaign starting in April 1991. The contract involved the dredging of approximately 290,000m^3 of fill material, nominal size 10mm, for transfer to an offshore pumping station which would pump the material through a submerged pipeline to an onshore booster pump and then along a pipeline to the deposition area (approximately 5km). During the tender period MAFF had refused the use of material from the licensed dredging area that had been determined during the detailed design stage and an alternative source of material had to be found. This was because of the existence of *crepidula* within the borrow area and its potential detrimental effects on the inshore shellfish stocks at the site. Two clean sources of material were located, which by careful mixing would comply with the specified grading curve for the fill. Work began in September 1990. On 3rd November 1990, when approximately 100,000m^3 of material had been placed on the beach, the coast was subjected to a storm with a return period in excess of 1 in 10 years which resulted in cliffing of the replenished beach profile of up to 2m. The toe of the cliffing was coincident with the still water level. Although it was shown by extensive modelling that the designed beach would meet the design criteria, it was felt, both by the public and the client (NRA - Anglian Region) that this cliffing was unacceptable and a revised design was requested to minimise this cliffing effect.

Following further modelling, calibrated on the November storm event, a profile was determined to afford the maximum increase in storm stability with the minimum increase in overall cost. The profile consisted of a shingle bank with a crest width of 10m and at a level of +6.7m ODN, a compound beach face with a slope of 1 in 5.5 from the beach crest to +4.7m ODN (1m above spring tides) and then a slope of 1 in 10 to the existing beach. The eventual costs of the works was approximately £6m, involving the placement of approximately 400,000 m^3 of fill material at a unit cost of £13.60/m^3. Although the completed beach has not undergone any severe storm attack, there are some indications that it is able to recover from minor storm deformation during the natural wave regime.

During the design process, consideration was given to a local source of non-aggregate quality material. Although preliminary modelling tests indicated that this fine (150um) material might have been suitable, the time available for implementation did not allow for obtaining a licence to extract it.

2.3.3 Seaford

Problem definition

The Southern Water Authority commissioned a hydrographic survey of the Seaford frontage which revealed that the bay was exceptional in that depletion of material had resulted in deepening of the bay, allowing larger waves to approach the shoreline. This, coupled with exposure to south-westerly gales, resulted in the worst beach conditions in England. HR Wallingford were commissioned to undertake a two year study to determine the physical conditions affecting the beach so that a model could be devised to simulate the existing conditions, predict future regimes and assess alternative solutions. The measurements taken during this study included:

- wave heights - recorded 800m offshore for a period of 16 months
- beach levels - sections were taken at fortnightly intervals and some records showed a loss in beach levels of up to 3m between measurements
- wave direction - radar scans of the wave fronts were recorded during storms
- tidal levels - an existing tide recorder at Newhaven was used to record actual tidal heights.

A physical model of the Seaford frontage was constructed in a large wave tank at HR Wallingford which was used to study the shoreline and to calibrate and verify subsequent mathematic models.

Potential solutions

Various alternatives were considered to maintain the beach levels in front of the old seawalls:

- groynes - constructed from rock due to the large size required
- offshore breakwaters - again constructed of rock, to dissipate energy offshore
- open beach - with one terminal groyne and annual recycling of the beach material.

Selection of beach recharge

Cost analysis demonstrated that the open beach alternative was the most viable, both economically and environmentally.

Design

The beach replenishment profile, a 25m crest with a 1 in 7 slope to the existing beach, required the importation of approximately 1.5 million m^3 of material over the 2.5km length. The specified grading of the material is given below:

BS Sieve Size	% passing (by weight)
20mm	< 70
10mm	< 45
5mm	< 25
150mm	< 5

The grading was similar to that of the existing beach and was representative of known deposits offshore.

Implementation

Certain areas of the scheme were particularly subject to wave damage. As a short-term protective measure five hundred rocks, each weighing between seven and fifteen tonnes were imported from Spain and placed against the seawall. The bolstering of the seawall would also allow time for the natural recycling of the beach during storm events. This work was completed in 1987.

The eventual borrow pit, known as Owers Bank, was situated 16km off Littlehampton and was an existing licensed area. The method involved the use of a 22,000 tonne trailing suction dredger with an operational cycle of 12 hours, delivering 6000-7000m3 material, pumped through a submerged 700mm diameter pipeline from a mooring 700m offshore. This full-time operation was completed in just over 6 months between April and October 1987. The beach was almost immediately subjected to the hurricane force winds that caused so much damage on the south coast on 16 October 1987. The beach withstood the storm well and although the storm coincided with the neap tides, it is not inconceivable that the sea wall would have been breached during this event. Continual monitoring of the beach is carried out with regular surveys being taken to 250m seaward of the wall. From the initial surveys, it was evident that material was moving from east to west and during the first year a total of 57,000m^3 was recycled to compensate for the discontinuity at Buckle.

2.3.4 Summary

The case studies demonstrate the suitability of beach recharge schemes as an option in sea defence and coast protection. The use of non-aggregate material at Portobello Beach has been successful and shows that there is potential for its further use. It has also been demonstrated that the use of non-aggregate material at Hunstanton could have been adopted if the time constraints had allowed for the licensing procedure. The Seaford scheme illustrates the broad advantages, and particularly the low cost, of beach recharge over alternative solutions.

3 Legislation

3.1 ROYALTIES

Under an Act of Parliament (The Crown Estate Act 1961) the Crown Estates Commissioners are charged with the administration of all land and land rights held by the Crown.

The Crown Estate owns approximately 55% of the foreshore (the land between mean high and low water) and most of the territorial sea (within the 12 mile limit). The Crown also owns the rights to explore and exploit natural resources - excluding oil, gas and coal - of the continental shelf.

The main demand for seabed material has been for the construction aggregate industry. Approximately 15% of the aggregates used by the construction industry have been obtained from seabed deposits. Locally this percentage is much higher, and in Greater London, Kent and Sussex constitutes up to 50% of the market. The demand is usually for 60/40 gravel and sand, and in the past the dredged areas have reflected this. It now appears that areas providing this mixture naturally have been fully exploited and screening out of sand at sea is usually necessary.

The second major exploitation of seabed aggregate deposits has been for landfill, land reclamation and other coastal works.

The third main exploitation is the use of marine aggregate for beach recharge. In 1987 the total volume of material used for beach recharge amounted to almost three million tonnes, with the vast majority of this used for two major projects at Seaford for Southern Water.

3.2 LICENSING

The licensing procedure is basically the same whatever the final use of the material. Before considering a licence the Crown Estate Commissioners must be satisfied that the applicant has the resources and the expertise to meet the licensing conditions. The applicant is first required to take a prospecting licence.

A prospecting licence permits the applicant to carry out sampling by seismic survey, side scan sonar and grab and vibrocore samples to determine the consistency and extent of materials within a defined area. In addition, a limited quantity may be taken by dredger sampling. The Crown Estate does not grant prospecting licences within an agreed protection zone (usually 500m) around seabed pipes and cables.

Having carried out the prospecting in accordance with the prospecting licence and identified a viable resource, the applicant then may apply for a production licence.

Other than the navigational requirements set by the Department of Transport, there is no statutory procedure that must be complied with. However, an informal procedure has been agreed under which the Commissioners would grant a licence if, following consultation with relevant Government departments, there is no substantive objection to the application.

To determine the likelihood of dredging work causing damage to the adjacent coastline or coastal regime, the Crown Estate employs HR Wallingford to assess the application. The information required to be submitted to HR Wallingford for assessment includes a chart indicating the proposed production area, details from the prospecting report, and the proposed production; either as an annual rate of extraction (for, say, twenty years) or as a total extraction.

Based on this and other available information, HR Wallingford consider:

- the likelihood of beach drawdown on adjacent beaches
- the possibility of changes to the wave climate due to refraction and hence interference with the existing wave transport regime
- the possible loss of protection to adjacent beaches with the loss of offshore bars dissipating wave energy
- the possible interruption of onshore movement of deposits due to the interference of the dredge area

This initial study is reported to the Crown Estate with a recommendation of the extent and costs of further investigative works (if any) required before a production licence could be granted. The Crown Estate requires the costs of the investigation to be borne by the applicant.

The Crown Estate requires to be assured by HR Wallingford that the proposed dredging licence would have no significant detrimental effect on the coastline - the zero-effect principle. Due to the capabilities of the science, HR Wallingford must err towards caution. However, it may be possible to impose restrictions on the dredging licence that would ensure compliance with the zero-effect principle.

Assuming a satisfactory conclusion to the HR Wallingford investigations, the application, prospecting report and the Crown Estate's summary are submitted to the Department of the Environment Minerals Division for a Government View. The Minerals Division consult all other departments that may be affected by the proposal, such as:

- other Department of the Environment Divisions, for example the Construction Industry Directorate and the Rural Affairs Division
- MAFF
- Department of Transport
- Department of Energy
- Riparian Councils.

Each of these will consult other bodies, such as local authorities and fishery committees.

4 The UK coastline

4.1 EXISTING BEACH RECHARGE SCHEMES

In 1988, Posford Duvivier undertook a survey of beach recharge schemes around the British Isles on behalf of the Crown Estate Commissioners. The survey was carried out in 1988 and 1989, and has not been updated since then. Each coastal authority was requested to complete a questionnaire to provide details of their previous and proposed use of beach recharge. The questionnaire requested information on existing beaches, other structures, volumes, dates, known size, intended use, and sources of recharge material. Although not all authorities replied to the questionnaire it has been possible to reproduce a plan showing the use of sea dredged material by coastal authorities (Figure 1). Table 2 has been copied directly from Posford Duvivier's report and lists the locations of actual or planned beach recharge schemes, the source of material, the frontage length, the quantity of material, and the date of the works. Based on this information it has been possible to produce a graph (Figure 2) indicating the trend in demand for beach recharge material. Figure 2 is based upon the actual volumes of material used and speculates that if the present increasing trend continues then 3,500,000m^3 of sea dredged material will be required during the year 2010.

4.2 POTENTIAL BEACH RECHARGE LOCATIONS

All eroding beaches are potential locations for beach recharge schemes. The presence of an existing hard defence backing an eroding beach does not mean that the beach will not require recharging to maintain or enhance the defences in the future. An eroding beach affects both the stability and performance of seawalls. The loss of passive pressure at the toe of gravity structures such as mass concrete seawalls reduces the factors of safety against overturning and sliding. Recent analysis of existing seawalls, built prior to 1940, indicates that these structures may already have sub-standard factors of safety compared with current codes of practice and British Standards. The loss of beach material in front of sheet pile walls not only increases the bending moments within the wall but also alters the shape of the bending moment diagram and increases the tension in the tie rods.

Phase One of the National Sea Defence Survey reviewed the sea defences managed by the NRA. Of 807km of sea defences, 234km were fronted by eroding foreshores. No detailed analysis of the structural integrity of the sea defences was undertaken in the survey but general observations were made (see Section 1.4). It may be assumed that beach recharge is a remedial works option for the 234km of sea defences with eroding foreshores. On completion of the remaining phases of the survey, the full extent of eroding foreshores adjacent to sea defences should be determined. For the purpose of this report, the results of the 1980 Coast Protection Survey have been superimposed on the NSDS Phase One results, and Figure 3 indicates the extent of eroding foreshores around England and Wales based on the information available. No information was available for the Scottish Coastline.

Many of the sea defences around the British Isles were constructed as a consequence of the extensive flooding along the east coast of England during the 1953 storms. The legacy of these defences not only means that the structures may now require constant maintenance or replacement, but due to the effects of the relative sea level rise, their performance may need to be enhanced. This could be achieved by increased use of beach recharge.

There are various estimates of sea level rise due to the effects of global warming and climate change. The expected sea level rise around the UK Coast will probably be of the order of 20cm by the year 2030, though a rise of as little as 5cm or as much as 40cm is predicted by some models. For the UK the implications of sea level rise must be considered against the trends of land level change. In general the south-east of Britain is sinking at a rate between 1-3mm per year, and the north west is rising due to isostatic rebound following the retreat of glaciers at the end of the ice age. Thus in the south the combined effect of isostasy and eustasy may result in a relative sea level rise of up to 13mm per year. It is therefore likely that southern England will require extensive enhancement of existing sea defences within the foreseeable future. This could be achieved by increased use of beach recharge.

The high demand for materials for beach recharge and the construction industry has already resulted in increasing costs to both industries. The potential demand for beach recharge material is likely to increase further, and alternative material sources and the use of non-aggregate quality material will have to be investigated if this demand is to be met.

	Authority	Qty (cub.m)	Material
1	Anglian W.A.	499,000	Mixture
2	Suffolk Coastal D.C.	140,000	Shingle
3	Tendring D.C.	95,650	Mixture
4	Canterbury City C.	164,280	Shingle
5	Southern W.A.	1,506,000	Shingle
6	Thanet D.C.	10,620	Mixture
7	Shepway D.C	89,000	Shingle
8	Hastings B.C.	225,000	Shingle
9	Eastbourne B.C.	32,810	Shingle
10	Shoreham P.A.	155,000	Shingle
11	Worthing B.C.	2,535	Shingle
12	Arun B.C.	44,300	Shingle
13	Havant B.C.	470,000	Shingle
14	Medina B.C.	10,000	Mixture
15	Bournemouth B.C.	1,618,500	Mixture
16	Wessex W.A.	300,000	Sand
17	Ogwr D.C.	6,110	Sand
18	North West W.A.	21,450	Sand
19	Lothian R.C.	238,250	Sand

Figure 1 *Past use of marine materials for beach recharge*

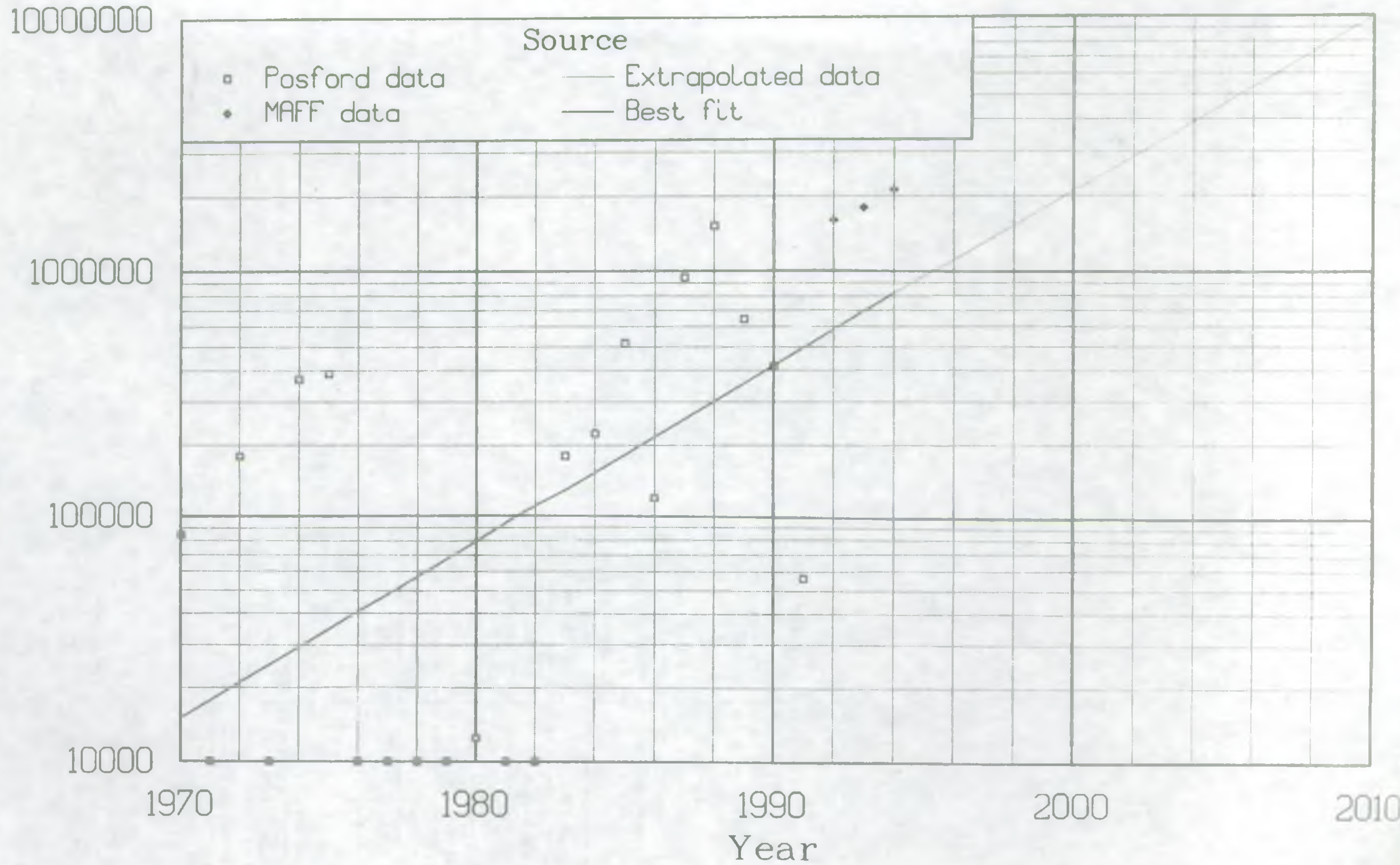


Figure 2 *Volumetric demand trend for marine-based beach recharge materials*

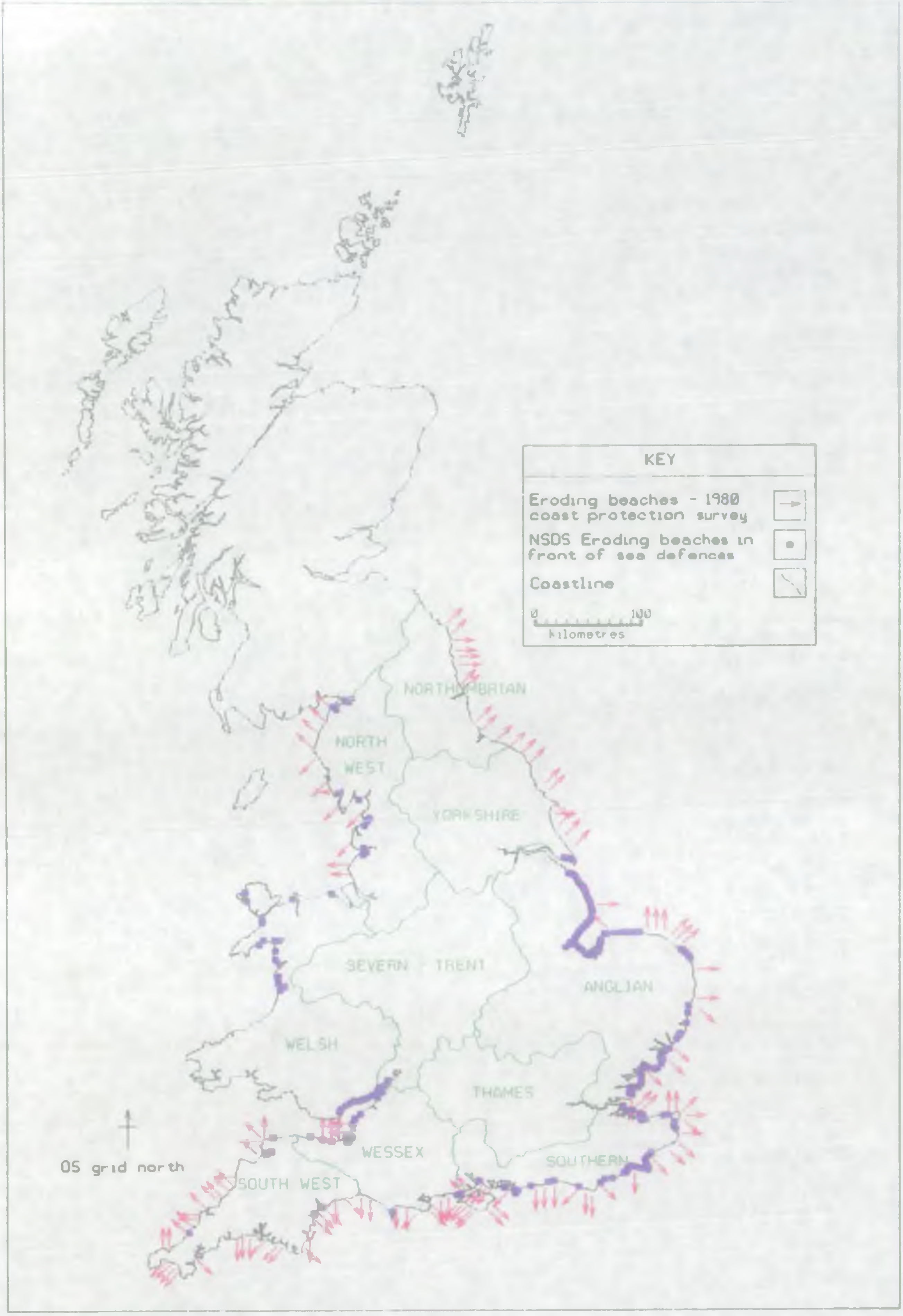


Figure 3 *Eroding beaches in England and Wales*

Table 2 Crown Estates Commissioners' beach recharge questionnaire
Preliminary analysis : locations of actual or planned use

(Listed clockwise from N.E. Coast)

AUTHORITY & LOCATION	FRONTAGE	QUANTITY		DATE		TYPE & SOURCE
BLYTH B.C.						
Blyth Beach	400m	15,000t		1981		Land based sand
Blyth Beach	400m	14,000t		1983		Land based sand
HARTLEPOOL B.C.						
Fish Sand	100m	500t		1983		Land based sand
ANGLIAN W.A.						
Mablethorpe-Huttoft	7km	1,4000,000m³	?	1991-3	?	Unknown
Chapel Point	1.5km	300,000m³	?	1993-4	?	Unknown
Trunch Lane (Chapel St Leonards)	2.5km	500,000m³	?	1993-4	?	Unknown
Ingoldmells Point	2.5km	500,000m³	?	1996-7	?	Unknown
Skegness	3km	600,000m³	?	1997-8	?	Unknown
ANGLIAN W.A.						
Snettisham/Heacham	200m	4,500t		1987-8		Recycled shingle
Snettisham/Heacham	as above	6,000t		1989		Recycled shingle
Hunstanton S. Beach	560m	25,000t		1990-1		Recycled shingle
NORTH NORFOLK D.C.						
Sherringham	90m	12,000t		1988-9		Land based gravel
ANGLIAN W.A.						
Salthouse, Norfolk	1.5km	1,000t		1978		Recycled shingle
East Bavants, Suffolk	500m	1,000t		1987		Recycled shingle
Dunwich, Suffolk	4km	1,000t		1982-7		Recycled shingle
Aldeburgh, Suffolk	500m	10,000t		1982/5/6/7		Recycled shingle
SUFFOLK COASTAL D.C.						
Felixstowe, The Dip	700m	60,000m³		1989		Sea dredged shingle
Felixstowe, Dip to Cobbold's Point	800m	30,000m³		1989		Sea dredged shingle
Felixstowe, Town Frontage	2.7km	50,000m³		1990-1		Sea dredged shingle
Felixstowe, Town Frontage	as above	25,000m³		1990-1		Recycled shingle
HARWICH H.B.						
Landguard Point	600m	10,000m³		1975-88		Recycled sand
TENDRING D.C.						
Holland on Sea	420m	21,650m³		1984		Sea dredged mixture
West Prom. Dovercourt	900m	50,000m³		1984		Sea dredged mixture

Cliff Park Dovercourt	155m	7,500m^3	1985	Sea dredged mixture
West End Dovercourt	145m	4,000m^3	1985	Sea dredged mixture
Orwell Road, Dovercourt	275m	12,500m^3	1989	Sea dredged mixture
Clacton	6km	2,000,000m^3 ?	10 yrs ?	Sea dredged mixture
<u>ANGLIAN W.A.</u>				
Clacton-Jaywick I	1.05km	94,000m^3	1986	Sea dredged mixture
Clacton-Jaywick II	1km	132,000m^3	1987	Sea dredged mixture
Clacton-Jaywick III	1.12km	210,000m^3	1988	Sea dredged mixture
Point Clear Bay	1.22km	63,000m^3	1987	Sea dredged mixture
<u>SOUTHEND ON SEA B.C.</u>				
Various	10km	300t	per annum	Land based gravel
<u>SWALE B.C.</u>				
Minster East	1km	92,000t	1978	Land based shingle
Minster West	600m	35,000t	1987	Land based shingle
Warden Bay	400m	12,000t	1986	Land based shingle
Leysdown	200m	7,000t	1987	Land based shingle
<u>CANTERBURY CITY C.</u>				
Whitstable Central	1.1km	106,500m^3	1988-9	Sea dredged shingle
Tankerton Groynes	400m	4,694^3	1988	Sea dredged shingle
Preston Parade	675m	28,077m^3	1987	Land based gravel
Herne Bay	260m	3,888m^3	1987	Land based shingle
Swalecliff	750m	53,085m^3	1985-6	Sea dredged shingle
<u>SOUTHERN W.A.</u>				
Northern Sea Wall Reculver	?	Unknown	1992-3	Unknown
Margate North Coast	Unknown	Unknown	Unknown	Sea dredged shingle
<u>THANET D.C.</u>				
Ramsgate Eastern Foreshore	400m	2,000t per annum	1983 onwards	Sea dredged mixture
<u>SHEPWAY D.C.</u>				
Folkestone	?	41,000m^3	1990	Sea dredged shingle
Sandgate	?	48,000m^3	1990	Sea dredged shingle
<u>P.S.A.</u>				
Hythe	3km	55,000m^3	1989	Shingle/gravel?
<u>CEGB</u>				
Dungeness	av. 8km	700,000m^3	1965-89	Recycled mixture
<u>HASTINGS B.C.</u>				
Pier to West Marina	2.2km	225,000m^3	1990	Sea dredged shingle
<u>EASTBOURNE B.C.</u>				
Marine Parade	150m	6,000t	1983	Land based gravel
Fishing Station	200m	48,000t	1983	Sea dredged shingle
Marine Parade	80m	4,500t	1985	Sea dredged shingle
Langney Point	1km	3,900t	1987-8	Land based gravel
Marine Parade	80m	3,000t	1989	Unknown

SOUTHERN W.A.				
Seaford	2.5km	1,500,000m³	1987-8	Sea dredged shingle
Lancing	?	6,000m³	1989-90	Unknown
SHOREHAM P.A.				
East of Harbour Entrance	2.95km	25,000m³	1988	Sea dredged shingle
East of Harbour Entrance	as above	30,000m³	1989	Not stated
East of Harbour Entrance	as above	70,000m³	1990	Not stated
East of Harbour Entrance	as above	10-50,000m³ per annum	1991 onwards	Not stated
WORTHING B.C.				
Sea Place, Goring	40m	400m³	1988-9	Sea dredged shingle
Plantation, Goring	100m	800m³	1987-8	Sea dredged shingle
Brooklands Park	50m	335m³	1987-8	Sea dredged shingle
Maintenance	-	1,000m³	1989-90	Sea dredged shingle
ARUN B.C.				
Middleton on Sea I	350m	10,000t	1977	Sea dredged shingle
Middleton on Sea II	400m	13,000t	1978-9	Land based gravel
Rustington	250m	10,000t	1980	Recycled mixture
Bognor Regis I	600m	20,000t	1980	Sea dredged shingle
Aldwick	80m	4,000t	1982	Sea dredged shingle
Middleton-Southdown Close	200m	10,000t	1988	Sea dredged shingle
Bognor Regis II	200m	7,000t	1988	Sea dredged shingle
Felpham	300m	20,000t	1988	Sea dredged shingle
SOUTHERN W.A.				
Elmer Frontage (Bognor Regis)	?	40,000m³	1993-4	Unknown
HAVANT B.C.				
Hayling Island	2.2km	470,000m³	1985	Sea dredged shingle
PORTSMOUTH B.C.				
Clarence Beach (Southsea)	100m	2,000t	1985-8	Recycled shingle
MEDINA B.C.				
St Helens Duver	500m	10,000m³	1989-90	Sea dredged mixture
YARMOUTH H.C.				
Norton Beach	100m	650t	1988	Land based gravel
CHRISTCHURCH B.C.				
Highcliffe on Sea	1km	75,000t	1984	Land based gravel
Highcliffe on Sea	as above	20,000t	1990	Land based gravel
Mudeford	400m	2,000t every third year	1978 onwards	Land based gravel
BOURNEMOUTH B.C.				
Bournemouth West Beach	1.8km	84,500m³	1970	Sea dredged sand
Bournemouth West Beach	as above	106,000m³	1974	Sea dredged sand
Bournemouth Pier Boscombe	2.35km	236,000m³	1974	Sea dredged sand
Bournemouth Pier Solent Bay	4.2km	390,000m³	1975	Sea dredged
Hengesbury Head	1.8km	143,000m³	1988-9	Sea dredged shingle
Bournemouth West Beach	1.47km	187,000m³	1988-9	Sea dredged sand
Bournemouth Boscombe	3.51km	445,000m³	1988-9	Sea dredged sand

<u>TORRIDGE D.C.</u>				
Westward Ho	3km	15,000t per annum	1981-6	Recycled shingle
Westward Ho	as above	5,000 t per annum	1986 onwards	Recycled shingle
<u>WESSEX W.A.</u>				
Sandbay (Weston-Super-Mare)	2km	300,000m³	1983-4	Sea dredged sand
<u>OGWR D.C.</u>				
Town Beach Porthcawl	150m	11,000t	1985	Sea dredged sand
Town Beach Porthcawl	as above	10,000t	1985	Land based gravel
<u>PORT TALBOT B.C.</u>				
FIB Beach	2 km	irregular	1975 onwards	Recycled sand
<u>ARFON B.C.</u>				
Dinas Dinlle	? Unknown	? Unknown	? 1990-5	? Unknown
<u>ABERCONWY B.C.</u>				
Penrhyn Bay	800m	40,000m³	1989-90	Probably land based
West Shore, Llandudno	1.7km	28,000m³	early 1990's	Unknown
North Shore, Llandudno	1.4km	70,000m³	mid 1990's	Unknown
<u>COLWYN B.C.</u>				
Colwyn Bay	3km	300,000m³	1990-1	Land based sand
<u>RHUDDLAN B.C.</u>				
Central Beach Prestatyn	500km	58,500t	1977-85	Land based gravel
<u>WIRRAL B.C.</u>				
New Brighton	800m	60,000m³	1987-8	Recycled sand
<u>SEFTON B.C.</u>				
Crosby	3km	40,000m³	1980-7	Recycled sand
<u>FYLDE B.C.</u>				
Sand Dunes, St Annes	500m	1,000m³	1989-90	Recycled sand
<u>LANCASTER CITY C.</u>				
Morecombe Bay Frontage	41.8km	Unknown	10 years?	Mixture
<u>NORTH WEST W.A.</u>				
Bolton Le Sands	730m	8,750m³	1989	Estuarial sand
Foulsham (Kent Estuary)	1km	12,700m³	1988	Estuarial sand
<u>LOTHIAN R.C.</u>				
Portobello	900m	180,000m³	1972	Sea dredged sand
Portobello	as above	58,250m³	1988	Sea Dredged sand

5 Non-aggregate marine materials

This section describes the properties of aggregate material and contaminants which make material unsuitable for the construction industry. The use of this contaminated (non-aggregate) material for beach recharge is discussed. The second part of the section reviews knowledge of possible sources of non-aggregate material round the UK coast.

5.1 AGGREGATE AND NON-AGGREGATE MATERIALS

Non-aggregate material is that not used for construction either through specification or location. Non-aggregate material therefore includes sands and gravels which are outside the specification requirements of BS882 : *Aggregates from Natural Sources for Concrete*, although the modern aggregate dredger fleet is equipped to modify 30/70 gravel sand mixtures to 60/40 material on board. Silts, clays and coarser deposits such as cobbles are also considered non-aggregate.

BS882 : Part 2 (1973) states that the aggregates shall be hard, durable and clean and shall not contain any deleterious materials in such form or in sufficient quantity to affect adversely the strength at any age or the durability of the concrete. This includes, where applicable, resistance to frost and to corrosion of the reinforcement. Examples of deleterious materials are clay (particularly as an adherent coating); flaky or elongated particles; mica, shale and other laminated materials; coal and other organic impurities; iron pyrites and soluble sulphate salts such as those of calcium, magnesium and sodium.

5.1.1 Sands and gravels

The grading limits for fine and coarse aggregates are given below in Table 3. Deposits of sands and gravels which do not comply or may not be processed to comply with the grading limits or general requirements of BS8110 and BS882 may be available for use as non-aggregate beach recharge material. Although the grading of the granular material may not adversely affect the performance of the beach the amount of fine material (less than 150μm) would have to be considered, as this fraction would tend to wash out during dredging transportation and placing operations and may lead to environmental problems. The inclusion of contaminants would generally be acceptable although excessive quantities of coal or organic material would detract from the amenity value of the beach, and degradable materials such as shales and chalks would probably lead to excessive loss of beach material during prolonged wave action.

5.1.2 Cohesive materials

Cohesive materials are those materials below 60μm grain size and include clays and silts. These materials are generally unacceptable for recharge to amenity beaches, although 370km of the 410km Essex sea defences rely on saltmarshes and high foreshores for wall stability. At Horsey Island and Stone Point it has been proposed to make use of a mixed material containing a high percentage of silts to recharge the eroding foreshore. Harwich Harbour Authority has offered various gradings of pollutant-free dredging to the NRA Anglian Region. It has been proposed that the beach recharge alternative be attempted on a field experiment basis to monitor effects for both flood defence and conservation. If proved successful, such a solution could become a realistic policy for the future.

5.1.3 Cobbles

Cobbles are rarely used as a beach recharge material, although it has been reported by Chillingworth and Nunny (1986) that material has been made available for beach recharge from oversize material (greater than 40mm) screened from the aggregate industry's on-shore processing. There are no known locations where cobbles have been used in extensive beach recharge schemes in the United Kingdom. Galster and Schwartz (1990) report on the use of cobbles for a beach recharge scheme at Ediz Hook, Washington, USA. The erosion control project consisted of the placement of 76,000m^3 of cobbles onto an eroding foreshore. The specification for the material called for gravel and cobble material from 2.5 to 30cm, with 50% larger than 7.5cm and not more than 5% passing the 2.5cm screen.

Table 3 Grading limits for coarse and fine aggregate

Coarse aggregate

Standard sieve (mm)	Nominal size of aggregate 40 to 5mm	20 to 5mm	14 to 5mm
	% passing (by weight)		
50	100		
37.5	90-100	100	
20	35-70	90-100	100
14	-	-	90-100
10	10-40	30-60	50-85
5	0-5	0-10	0-10

Fine aggregate

Standard sieve	Overall limits	Additional limits for grading C	M	F
	% passing by mass			
10mm	100			
5mm	89-100			
2.36mm	60-100	60-100	65-100	80-100
1.18mm	30-100	30-90	45-100	70-100
600μm	15-100	15-54	25-80	55-100
300μm	5-70	5-40	5-48	5-70
150μm	0-15			

5.2 DISTRIBUTION AND AVAILABILITY OF NON-AGGREGATE MARINE MATERIALS

Figure 4 shows the general distribution of seabed deposits around the British coast, and Figure 5 shows the existing licensed dredging areas superimposed onto maps of the seabed sediments. These maps have been simplified and digitised from the British Geological Survey (BGS) maps on a 1:1,000,000 scale, and indicate the distributions of sand, gravel and mud at the seabed, they do not imply the existence of workable reserves of aggregate or non-aggregate marine materials. It should be noted that the maps follow the BGS practice of classifying material as gravel where >30% of the sample is >2 mm.

In the following sections, eight regions of the inner UK continental shelf are considered with regard to aggregates and non-aggregate materials. Only broad regions with less than 50m water depths are considered. These cover the seabed within the present capacity of large dredgers (to c.35m water depths) and small dredgers (to c.25m water depths) and allow for future deeper operations. All units are metric.

To identify the possible range of unconsolidated deposits that might be accessed within a few metres below the seabed, a brief review is given for each region of the Quaternary deposits, which are both pre-glacial and glacial sediments and predominantly form the source material for the present seabed deposits. These latter were generally reworked firstly by coastal erosion during rising sea levels from about 11,000 years

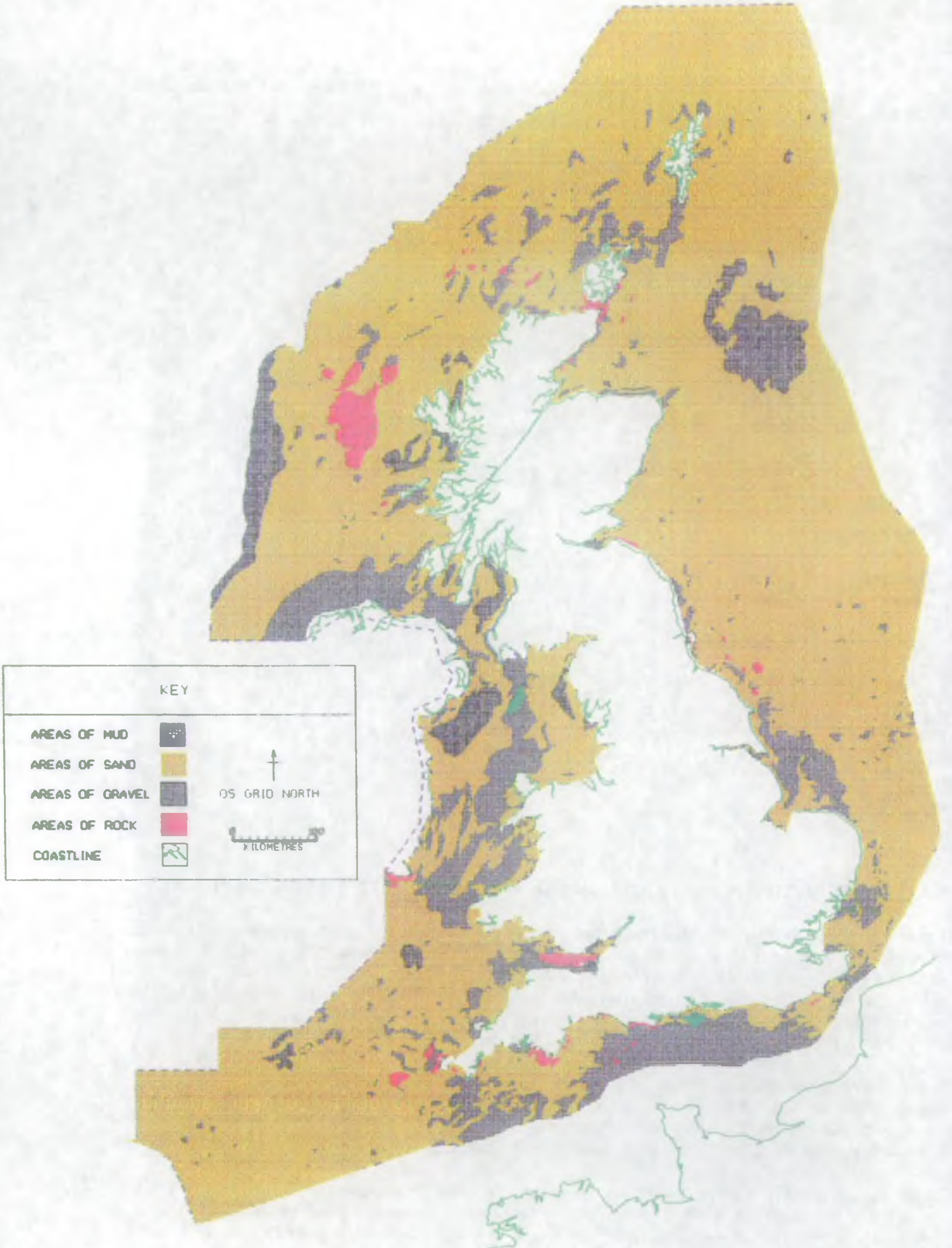


Figure 4 *Seabed sediments around the UK*

REPRODUCED FROM THE BRITISH GEOLOGICAL SURVEY

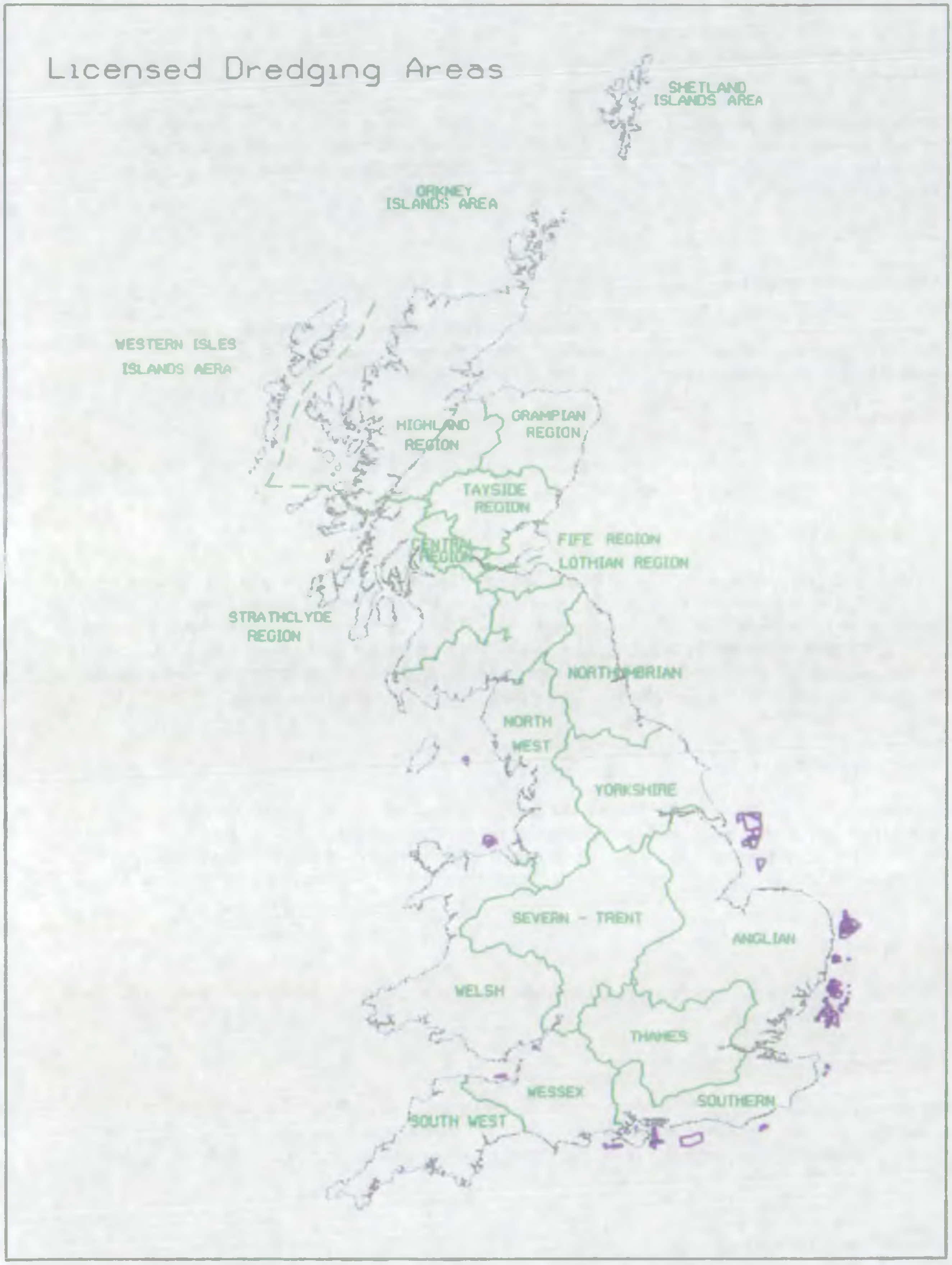


Figure 5 *Licensed dredging areas*

ago, and subsequently by marine processes following submergence. Off the Scottish coasts, where relative sea levels have largely fallen over the last 11,000 years, marine transgression did not occur and the products of coastal erosion are lacking.

Attention is drawn in each region to the lack of systematic survey cover of the inshore zone varying from 1 to 5km or more wide from the shoreline. Most estuaries about the UK coast also lack such surveys. Exceptions to this are the Wash, the Humber and the Severn Estuary/inner Bristol Channel which have detailed British Geological Survey cover.

5.2.1 The Dogger Bank

Geography and bathymetry

The Dogger Bank, despite its name, is not a sandbank. It is an extensive area (roughly equal to that of Wales) of relatively shallow (25 to 40m) depths. Some one-third of its area of 9000km^2 is beyond UK waters. It lies a minimum distance of 90km off the Yorkshire coast.

Tidal and wave regime

The Dogger Bank is very exposed to wave attack from the north. It is in an area of low to medium tidal currents of less than 0.5m/s in the east and less than 1.0m/s in the west.

Quaternary geology

Quaternary deposits underlie the Dogger Bank to in excess of 500m thick. The deposits are predominantly pre-glacial, but those forming the upstanding parts accessible at seabed formed during the last (Devensian) glacial stage and post-glacially. The bank deposits are stiff, glacimarine clays, locally pebbly and to 40m thick. However, in places they are cut by channels to 50m deep and infilled by sandy silts. A number of small open channels or closed depressions to less than 15m deep distinguish the otherwise notably smooth seabed of the Dogger Bank. The channels expose peats up to a few metres thick on their floors and are the subject of present study.

Seabed sediments

The Dogger Bank region was evidently exposed as dry land, and later to coastal wave attack with transgression during late glacial and early postglacial times. The glacial deposits described are planed off by an erosion surface within 1 to 3m below seabed which is overlain by laminated muds and sands, interpreted as tidal flat deposits, and themselves overlain by thin (<0.5m) sands of the present marine regime.

Aggregates

No gravel has been won from the Dogger Bank though prospecting licences were granted in the past. There are strong fishing interests.

Non-aggregate marine material

The seabed sediments are likely to be too thin for consideration. The stiff clays and the silty-sand of the channels are accessible. The considerable minimum depth of water (25m) anywhere on the Dogger Bank and the distances of transport to any coast may render these deposits uneconomic for beach recharge.

Survey requirements

General surveys of the region are complete.

5.2.2 The Wash-Humber and north-east coasts

Geography and bathymetry

South of Flamborough Head the shelf is shallower than 50m except for isolated pits a few kilometres wide and up to 30km long which are up to 90m deep. North of Flamborough Head the slope offshore is steeper, and the 50m isobath is less than 30km off the coast. Two major estuarine complexes run up to 50km inland and provide access to ports.

Tidal and wave regime

On the north-east coast the wave regime is severe from the north and east, but it moderates south of Flamborough Head due to shoaling waters and protection afforded by offshore banks. The Wash is open to seas from the north and east whereas the Humber is sheltered from all quadrants inside Spurn Point. The tidal currents do not attain more than 1.0m/s offshore and only slightly exceed that figure about the coastal headlands, whereas peak velocities up to 1.5m/s are reached exceptionally both in the Wash and the Humber tidal channels.

Glacial geology

Deposits pre-dating the last glaciation are largely absent west of the Greenwich Meridian through Cleethorpes and, though present to the east, they are inaccessible at seabed. The whole area southwards to the north coast of Norfolk and the mid-Wash was overrun by ice in the last (Devensian) glaciation. The ice deposited a mantle of till from 2 to 15m thick and comprising a stiff clay with a variable sand, gravel and cobble content. During deglaciation extensive deposits of outwash sands and gravels to a few (less than five) metres thickness were laid down across the till surface. Locally, meltwaters incised enclosed depressions up to 100m deep and a much shallower (less than 10m deep) network of braided (sandur plain) river channels. The thicker infills of these features comprise predominantly fine-grained lacustrine deposits.

Seabed sediments

The rise of sea level in early post-glacial times produced marine transgression over most of the region's late glacial land surface. The glacial outwash deposits were reworked first by coastal erosion and, following submergence, by marine processes. After submergence, buried ice deposits in some of the larger incised depressions melted to create the elongate pits which in many cases survive as present seabed features due to slow offshore sedimentation rates (e.g. the Inner Silver Pit, Sole Pit, the Well). Tidal currents have fashioned numerous offshore sand banks both parallel to the open coasts and within the estuaries, and deposits of sand, sands with muds, and muds (up to 10m thick as salt marsh deposits), are actively accumulating in the marginal areas of the estuaries. Areas of erosion both offshore and within the estuaries, however, expose extensive, mostly thin (less than half a metre), gravelly deposits, which are locally moulded into gravel waves as forming The Binks, east of Spurn Point.

Aggregates

Most of the better areas of gravelly deposits can be identified by the concentrations of production licences. Prospecting licences issued in the past covered most of the seabed off the Humber approaches and north-east coasts. There is estimated in this region, including licensed areas, to be 120 million tonnes of gravel with sand mixed in commercial proportions. 30 million tonnes of reserves have been refused licences on fishery grounds, and, in one case, on coast protection grounds (Chillingworth and Nunny, 1986).

Non-aggregate marine material

The tidal sand wave areas and tidal sand ridges within the Humber and the Wash, seaward south-east of Flamborough Head and north of Norfolk comprise very large reserves of material. North of Flamborough Head offshore concentrations of sediment are limited. Much colliery waste has been dumped on the County Durham coast, but studies suggest it has been widely redistributed by coastal processes.

Survey requirements

Although the great estuaries of the Wash and the Humber have been surveyed in detail, a considerable proportion of the inshore parts of this region lack systematic cover. The open coasts of the north-east and Holderness have surveys extending inshore to 1 to 3km off the coast, while small estuaries there such as the Lindisfarne area and the Tees also lack cover. Off the coast of Lincolnshire north of the Wash and off the coast of Norfolk east of the Wash shoal waters extend up to 10km offshore and survey cover is far from complete.

5.2.3 The east coast and the Thames estuary

Geography and bathymetry

This region comprises the southern bight of the North Sea opening northwards from Dover Strait. Depths only very locally attain 50m in the deep water channel eastwards along the Median Line between UK waters and those of the Low Countries. In the Thames Estuary is a splay of tidal sand banks with waters 0-7m deep over them and separated by channels seldom deeper than 15m.

Wave and tidal regime

The wave regime is relatively mild but increases to moderate northwards with the lessening protection afforded by the banks north-east of Norfolk. Peak tidal currents mostly exceed 1m/s, and attain 1.5m/s close north-east of Norfolk, but are less than 1.0 m/s in mid-Bight and into the London River.

Quaternary geology

Pre-glacial Quaternary deposits underlie the eastern parts of East Anglia north of Ipswich and thicken to hundreds of metres eastwards under the North Sea. These beds are deltaic deposits of fluvial gravelly sands passing into marine clays. They contain a considerable carbonate content as shelly debris. Glacial Quaternary components are not represented by till deposits offshore though an ice sheet advanced in the Anglian Stage (c.500 thousand years ago) to an east-west limit at 52°30'N through Lowestoft. Depressions to 400m deep, cut by meltwaters at the ice margin and infilled by sand and muds, mark the limit of this advance. The next and last ice to occur locally advanced in the last (Devensian) glaciation to a limit at the northern margin of this region which thus lay south of the ice and suffered little erosion. In consequence a complex series of post-Anglian interglacial and preglacial deposits, laid down variously in on-land, coastal and shallow marine environments are present.

Seabed sediments

The entire presently submarine area of this region was exposed as dry land in late glacial times and has undergone marine transgression. Thus the seabed sediments formed by reworking of pre-existing fluvial and preglacial deposits: first by coastal processes and second by shallow marine processes. Over areas where rock crops out on the seabed, both north of Norfolk and south of the Quaternary limit through Ipswich, there are extensive areas of patchy gravels and flints to some 0.2m thickness. Over the Quaternary deposits east of Norfolk and Suffolk there are sand waves and sand sheets up to a few metres thickness, while, both off north-east Norfolk and throughout the Thames Estuary, approaches are massive tidal sand ridges up to 15m thick, 4km wide 50km long.

Aggregates

Excess sand within gravel deposits is a commercial problem in this region and necessitates on-board screening to produce a cargo of gravel with sand in commercial proportions. Most of the region has been recently prospected. It is estimated that in existing and potential licensed areas there are respectively 200 and 150 million tonnes of such a commercial gravel with sand mix. 18 million tonnes of reserves have been refused licences for fishery, navigational and coast protection reasons (Chillingworth and Nunny, 1986).

Non-aggregate marine material

In the Quaternary areas north of Ipswich, most of the deposits underlying the immediate seabed sediments can be considered. Southwards, similar material might be located in shallow infilled channels beneath the Thames approaches. Sand banks of great size contain large potential reserves through most of the region.

Survey requirements

Present systematic survey cover extends to between 1 and 3km of most coasts, but is lacking inshore. Inclusive of all the creeks and estuaries of the coasts of Suffolk, Essex and Kent, and of the whole Thames estuary west of 1°E; minor areas only are available with inshore surveys off Great Yarmouth, Foulness and a few traverses into the East Anglian shore.

5.2.4 South coast, east of Poole

Geography and bathymetry

The UK designated area along this section of coast of less than 50m water depth varies from 30km wide in the west and south of the Isle of Wight to 20km wide east of Brighton and through Dover Strait. Enclosed deeper waters to 82m deep form 20km long depressions in bedrock as St. Catherine's Deep, 5km south of the Isle of Wight.

Wave and tidal regime

Exposure to the prevailing westerly swell decreases from west to east with the severest wave climates being along west-facing coasts. Peak tidal currents are little over 1.0m/s but run up to 1.5m/s about major headlands. Within the embayments between the Isle of Wight and Beachy Head and between Beachy Head and Dungeness, peak tidal streams less than 1.0m/s occur.

Glacial geology

It is disputed whether ice sheets developed in the English Channel and deposits from this period are thought to be largely the result of periglacial and fluvial processes operating during lower sea levels.

Seabed sediments

The deposits at seabed are generally less than 0.5m thick over bedrock, although thicker deposits occur either as the infills to buried channels (seldom greater than 5m thick and predominantly fine-grained), or as sand and fine gravel waves to less than 6m thick. Deposits inshore may be substantially thicker (to 25m) as both relict and active coastal spit developments (e.g. Dungeness, Hurst Castle spit, Owers Banks). These deposits of former and present coasts comprise a range of sediments from barrier spit gravels and cobbles to lagoonal muds. There are tidal sand ridges in Dover Strait to 10m thick, for example the Varne.

Aggregates

West of a bed-load-parting running south-west from the Isle of Wight are only thin sand ribbons on the gravel rock surface, whereas eastwards there are areas in the bays of continuous sand cover over the gravel/rock surface and local channel infills. The area east of the Isle of Wight has been extensively prospected recently. There is estimated to be 125 million tonnes of gravel and sand in commercial proportions in licensed areas and 100 million tonnes in potential areas. This includes reserves in waters deeper than 25m and consequently inaccessible to the present local aggregate fleet. Licences have been refused for both fishery and coast protection reasons in this area (Chillingworth and Nunny, 1986).

Non-aggregate marine materials

These are probably limited in this area to deposits in the sub-seabed infilled channels and to the deposits found inshore of former coastlines. Gravel banks close inshore are not available to the construction industry and can be considered non-aggregate.

Survey requirements

Current survey cover extends inshore to some 2km off the coast. Only patchy cover exists of Poole Harbour and all the waters north of the Isle of Wight from the Needles to Selsey Bill and the Owers, inclusive of the Solent, Spithead, Southampton Water and Chichester Harbour.

5.2.5 The Bristol Channel and the south-west peninsula

Geography and bathymetry

West of Poole the 50m isobath lies 30km south of the coast until it converges with the coast of Devon at Start Point. Farther west along the south-west peninsula the areas where water depths are below 50m are restricted to less than 20km wide in the larger bays, and less than 5km wide round headlands. The area is of similar width off Dyfed, but broadens eastwards into the Bristol Channel. Most of the Channel east of Swansea is shallower than 50m.

Wave and tidal regime

Wave energies are high along the coast, especially the west-facing coast of Devon and Cornwall. The open sea coasts as far up the English Channel as eastern Lyme Bay have peak tidal streams less than 1.0m/s, and less than 0.5m/s in inner Plymouth and Lyme bays. Peak tidal streams round the exposed headlands of Start Point, the Lizard and the Cape Cornwall - Land's End - Scillies area exceed 1.0m/s, as do streams east of Lundy in the Bristol Channel and east of Portland in the English Channel. Even higher rates, over 2.5m/s, occur off Portland Bill and into the innermost Bristol Channel where they exceed 3.0m/s east of Cardiff.

Glacial geology

Ice is known to have advanced from the north into south Wales and the Bristol Channel area. Farther south only scattered deposits are found, as far as the Scilly Isles, and any glacial or periglacial deposits have probably been removed by erosion and reworking.

Seabed sediments

Across much of this region the cover of superficial sediment is thin (less than 0.3m) and bedrock is exposed at seabed. Locally, within bays and in the lee of headlands, thicker accumulations are found. Around the south-west peninsula there are local patches of sand near the coast, and thicker accumulations, up to about 20m, in a series of infilled submarine valleys. In the Bristol Channel, Carmarthen Bay is infilled with fine-grained sediment and better defined sand banks are developed at the entrance to Swansea Bay and in the centre of the inner Bristol Channel to the east. Muddy sediments occur in the inner parts of the Bristol Channel bays and in the tidal flats about the Severn Estuary.

Aggregates

In this region nearly all the existing licences supply fine aggregate for the construction industry. These aggregate production licences are located mainly on the inner Bristol Channel sand banks, where the licensed reserves are estimated at 55 million tonnes of fine aggregate.

Non-aggregate marine material

Farther up the Bristol Channel, between Cardiff and Bristol, there are extensive thick (over 5m) sand sequences grading down into coarser-grained material. Much of the sand in the Bristol Channel has been considered too fine for aggregate use and some is contaminated with coal particles.

Survey requirements

Systematic survey cover extends to about 2km of the coast in most of this region. Survey cover is lacking of most of the small and medium sized estuaries: Exe, Dart, Salcombe, Plymouth Sound, Fal, Mount's Bay, Padstow, Tor-Torridge and Milford Haven; but both Carmarthen and Swansea bays have considerable cover by university studies and the British Geological Survey have covered the Inner Bristol Channel and Severn Estuary in detail.

5.2.6 South Irish Sea : Cardigan and Caernarfon Bays

Geography and bathymetry

The bights or gulfs, rather than bays, of Cardigan and Caernarfon open westwards to the much deeper waters of St George's Channel. These bights are respectively 90 and 50km wide at their entrances and 50 and 30km deep. Innermost Cardigan Bay is formed by the semi-separate Tremadog Bay isolated by the shoal ridge of Sarn Badrig, while innermost Caernarfon Bay passes inshore of Anglesey as the narrow (less than 1km) Menai Strait. The bights form a platform entirely shallower than 50m water depths.

Wave and tidal regime

Wave conditions are moderate, though the region is noted for persistent south-westerly swell from the Atlantic Ocean. Tidal peak currents are stronger than 1.0m/s in St George's Channel and most of Caernarfon Bay, whereas they are notably less in Cardigan Bay and reach no more than 0.5m/s in the inner two-thirds of the bay.

Glacial geology

Pre-Devensian deposits underlie St George's Channel to over 200m thickness and underlie the outer parts of the bights to lesser thicknesses. Locally these older glacial deposits outcrop in the bights. The whole region was overrun by ice during the Devensian, and a very extensive mantle of sub-glacial till is present from 7 to 55m thick. The deglaciation deposits are discontinuous, but locally to 250m thick: scoured hollows to this depth are cut through the till and older deposits in Tremadog Bay and scattered lesser hollows and channels occur. The upper parts of the hollows and channels are filled, or part filled, by fine-grained sediments, and more extensive sheets of such sediment to less than 10m thick over the till occur in the extreme south-east of Cardigan Bay and in Tremadog Bay. The latest glacial sediments may be boulder deposits which extend as shoals up to 20km long and 3km wide from the coast into inner Cardigan Bay. These shoal ridges (*Welsh: sarnau*) may represent moraines of late Devensian ice or the dissected remains of sandur (outwash plain) sediments from the last mountain glaciers of Snowdonia.

Seabed sediments

Over most of the sea floor of the outer parts of both bights the only seabed sediment is a cobble or gravel lag, with high shell content, which is from a few centimetres to about 0.5m thick. Across this lag are trains of sandy bedforms from a few centimetres to 20m thick, but covering less than a quarter of the area. The thicker sands occur as sand waves seldom more than 6m thick, although the thickest sands form the rare tidal sand ridges as the Bais Bank north-west of St David's Head and banks south-east of Bardsey Island. Sands are present up to a few metres thick as continuous sheets extending up to 20km from the coast in both bights. The latter inshore sands onlap both the boulder ridges of the sarnau and the mud belts of late glacial age.

Aggregates

No aggregate prospecting licences have been applied for in this region.

Non-aggregate marine material

Material of extremely coarse grades could be won from the sarnau. Materials for heavy-armouring have been won from a deposit with similar geology, which comprises the Codling Bank off County Wicklow in Ireland. Fine-grade material is available close to shore from the sand sheets and the mud belts.

Survey requirements

The immediate inshore zone from the high water mark to 1km offshore lacks systematic survey as do the small estuaries off the bights, with the exception of some university studies.

5.2.7 North-east Irish Sea and Liverpool Bay

Geography and bathymetry

The north-west Irish Sea including the North Channel between Scotland and Northern Ireland is of waters deeper than 50m, apart from a narrow shelf along the Irish coast. East of a line between the Mull of Galloway, the south-west Isle of Man and eastern Anglesey, the sea floor of the north-east Irish Sea including all Liverpool Bay southward is shallower than 50m except in small enclosed depressions, such as the Lune Deep off Morecambe Bay. Most this eastern region is shallower than 35m. However, it should be noted that the region includes the economic controlled zone of the Isle of Man to median lines with the surrounding UK and Republic of Ireland waters. Additionally some quarter of the eastern region has less than 15m water depths inclusive of all the great embayments, which have intertidal ground over some 50% of their areas.

Wave and tidal regime

The region is exposed to only moderate wave energy, due to the surrounding lands. Peak tidal currents are less than 0.5m/s between the Isle of Man and Cumbria, but increase north and south to up to 1.0m/s. In the great estuaries eastwards, westwards, north and south of the Isle of Man even higher peak tidal streams occur; reaching more than 1.5m/s between the northern end of Man and the Mull of Galloway, and more than 2.0m/s within the Solway Firth.

Glacial geology

Though pre-Devensian deposits are present locally at depth they are inaccessible at seabed. The whole eastern region was covered by ice during the last glacial stage. A stiff to very hard clay with admixed sand, gravel and boulders formed as a sub-ice deposit and this till is extensive to over 50m thick. The deglaciation sediments comprise a complex sequence of sandur (outwash), glacilacustrine and glacimarine, deposits ranging from a few metres to 200m thick over a locally deeply incised erosion surface over and through the till.

Seabed sediments

The surface of the glacial deposits, including the glacimarine sediments, was exposed above former sea level in early postglacial times; and thereafter suffered coastal, followed by marine reworking with marine transgression. The resulting seabed sediments comprise widespread, thin (less than 0.5m) lag gravels in the west, passing east through gravelly sands and sands up to several metres thick, into an extensive belt of fine-grained deposits ranging from muddy sands to muds. Lag gravels and thicker sands are also found close inshore of the mud belt eastward. Tidal sand ridges up to 25m thick are common in the Solway Firth, Morecambe Bay, south-east Liverpool Bay off the Mersey, in the open sea as the Constable Bank north of Llandudno and as a splay of banks off the north-east Isle of Man.

Aggregates

Much of the region has not been prospected, despite the finding of considerable areas of gravel between Anglesey and the Isle of Man and between the Isle of Man and Scotland by BGS surveys. The majority of these finds lie beneath water deeper than 25 to 35m and are thus outside the range of smaller dredgers. It should be noted that in this region the existing licences supply fine aggregate only for the construction industry. These licences are largely in central Liverpool Bay and reserves of fine aggregate are estimated to be 10 million tonnes. Reserves of 2 million tonnes have been refused licences for coast protection reasons (Chillingworth and Nunny, 1986).

Non-aggregate marine material

The offshore tidal sand banks could widely be considered for beach recharge material.

Survey requirements

Available surveys terminate 1 to 2km offshore of the coasts. There are additional BGS tidal-ground (but not sub-surface) surveys of the Solway Firth, Ribble Estuary and outer Mersey/Dee estuaries. Some studies of Morecambe Bay, Eskmeals Estuary and the Menai Strait have been undertaken by commercial and university workers.

5.2.8 Scotland

Geography and bathymetry

This is a large and diverse area and the notes here cannot give more than a summary picture. With few exceptions, the waters off Scotland shelve to depths in excess of 50m within 20km of the shore. This applies between islands, into most sea lochs and in firths. Only very limited areas of less than 50m depth are found, even in the southern firths of Clyde, Forth and Tay.

Wave and tidal regime

The outer coasts all about Scotland are exposed to very severe wave attack. Some protection is afforded by the islands in the Hebridean area, although exposed areas project far inshore through the North Channel, Firth of Lorne and Minches. On the east coast all the great firths are exposed to wave energies from the North Sea. Fully protected areas tend be small and deep within sea lochs (or semi-landlocked as Sullom Voe or Scapa Flow), with the exception of the extensive Firth of Clyde. Tidal peak rates vary very widely off the coasts. The lowest rates, under 0.5m/s, are in the Moray, Forth and Clyde firths; while enormous rates exceeding 4.0m/s are recorded in some inter-insular localities north of Jura (Gulf of Corryvrechan) and south of the Orkney Islands (Pentland Firth).

Glacial geology

Scotland was the focus of the last (Devensian) ice sheet, with two notable consequences. First, ice-related erosion has led to the removal of almost all pre-Devensian Quaternary deposits. Second, the depression of the Earth's crust caused by the ice (which was up to 1.5km thick) is still rebounding following melting of the ice over 10 thousand years ago. This means that relative sea levels about Scotland have been falling over that period. Thus, unlike the other coasts considered, these are regression coastlines. The glacial deposits are basically sub-glacial till, as very hard clays with sand to boulder sized clasts, overlain by glacimarine deposits as muds passing close-inshore into sandier sediments.

Seabed sediments

The late glacial deposits inshore have been reworked by shallow marine processes leading to a tendency to differentiation into the gravel, sand and mud components.

A number of sand banks distinguish the shallow shelves, generally in the tidal current lee of islands or headlands. Such banks are locally to 5-10m thick and of clean, fine sand.

Aggregates

There are extensive aggregate deposits onshore in Scotland, and offshore resources have not been significantly exploited. Detailed assessment is lacking in many areas. Aggregates have in the past been extracted from the inner parts of the Firths of Clyde and Forth, where significant reserves remain, and also from the inner Moray Firth. There are no present licensed reserves, although three areas containing 11 million tonnes have been rejected for fishery reasons.

Non-aggregate marine material

Non-aggregate materials has been extracted from the Firths of Clyde and Forth for land reclamation and beach recharge. Exploration licences have been issued for deposits of heavy minerals at several localities on the west coast, and extensive reserves of carbonate deposits (shells and shell debris) are known off the north and west coasts among the islands.

Survey requirements

Because of Scotland's intricate coastline of deeply indented mainland and numerous islands, the offshore survey by BGS did not cover considerable areas. Most outlying coasts are surveyed in to 2km offshore, except the shoal ground for up to 10km west of the Outer Hebrides, while interinsular areas are generally only surveyed in broad firths such as the Minches, Sea of the Hebrides, Firth of Lorne and others. Some patchy cover of smaller firths such as the Tay, Beauly and Cromarty Firths are available as university studies.

6 Factors affecting the performance of recharged beaches

The factors which affect beach performance are material grading, length of beach, material volume, placement methods and wave climate. The principles outlined below apply equally to aggregate and non-aggregate quality materials.

6.1 GRADING

The general recommendation of most authorities on beach recharge is that the fill material should be similar or slightly coarser than the endemic beach material. Kramer (1972) states that beach fill material should be coarser than the native beach material in order that excessive losses are not incurred. Newman (1977) states that beach fill material should be 1.5 times coarser than the native material. Other research (Stive and Koster, 1980) concluded that it was impossible to determine the exact requirements of the borrow material, but in general the use of similar or slightly coarser borrow material with a lower uniformity coefficient will be more successful if supplied in sufficient quantities.

Analysis of beach design parameters was carried out on the United States East Coast Barrier Islands. The performance of various beaches with respect to the fill grain size and the natural beach materials was studied and it was concluded that the actual grading of the fill material had little influence on the longevity of the beaches: both finer and coarser recharged beaches had lost 50% of the fill material during the first year (Leonard *et al*, 1990). Despite these conflicting results it is generally accepted that the recharge material should be at least as coarse as the existing beach material.

Figure 6 indicates the equilibrium profile for a recharged beach; assuming constant wave climate and water depths, but varying median grain size. The results are from a beach response model, *Dune*. It can be seen that (according to the model) grain size has a significant effect on the equilibrium profile, and increasing volumes of material are required to afford the same level of protection for diminishing grain size. Vellinga (1984) has derived an erosion profile that can be satisfactorily described by a power curve. After introducing the effect of wave steepness and grain size semi-empiracally, the general expression concludes that the erosion profile is proportional to the fall velocity of the material; which can be related to the median grain size. Table 4, taken from the CUR manual on beach nourishment, indicates the relationship between mean grain size diameter and the mean slope of beaches subject to wave attack. This table is indicative only and is restricted to a mean grain diameter of less than 0.5mm. No data has been found for materials of greater diameter.

Table 4 Mean slope of beaches subject to wave attack

Mean Grain size diameter (mm)	Moderate wave climate		Severe Wave Climate (storm floods)	
	From	To	From	To
0.2	1:50	1:100	1:50	1:100
0.3	1:25	1:50	1:45	1:55
0.4	1:15	1:25	1:40	1:45
0.5	1:10	1:15	1:35	1:40

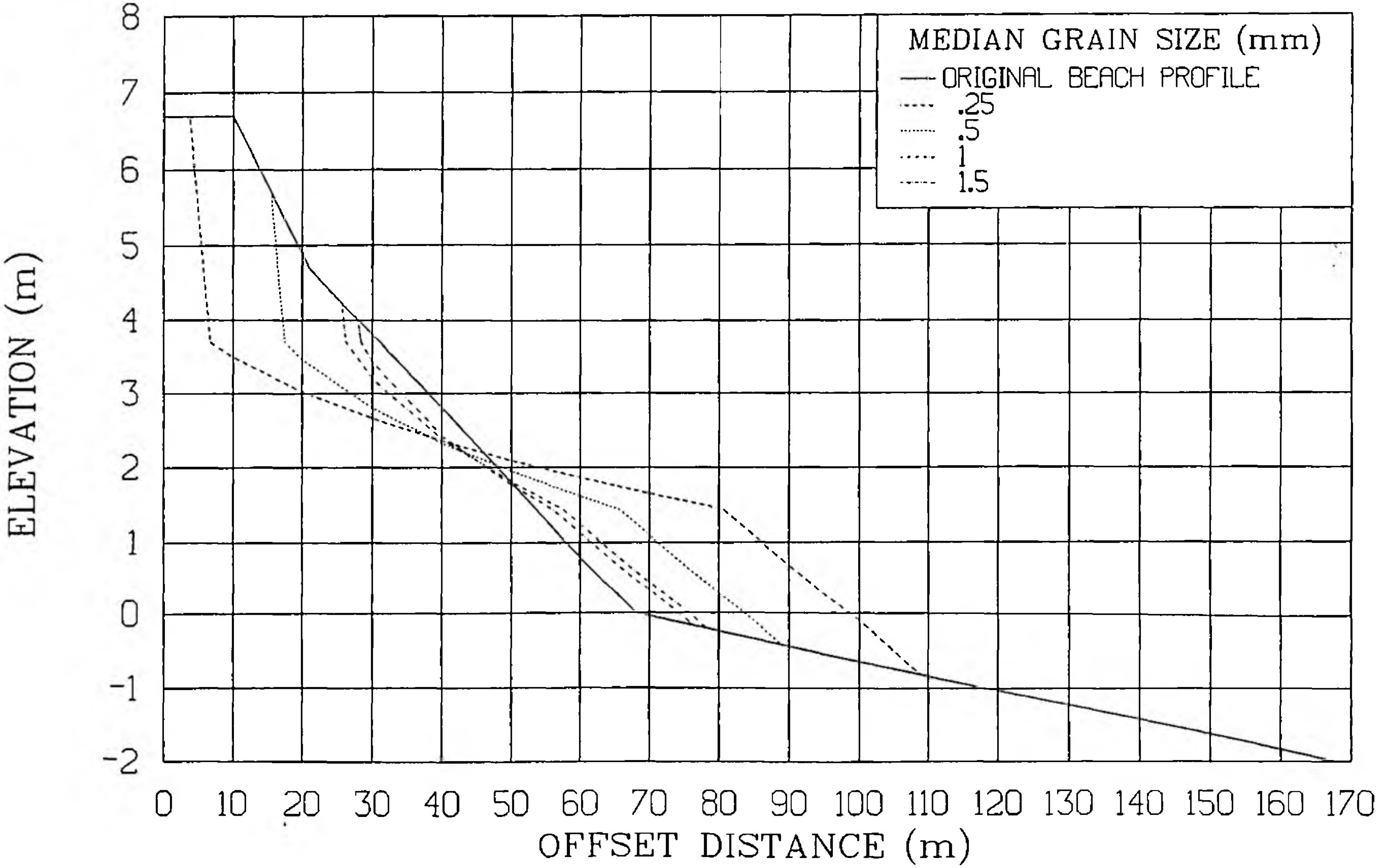


Figure 6 *Erosion profiles - grain size dependency*

6.2 LENGTH OF REPLENISHMENT BEACH

It is generally assumed that the length of the recharged beach is directly proportional to its longevity. For example, Dean (1983) states that doubling the length of the beach would increase longevity by a factor of four. It is implicit in this assumption that the major losses from the beach profile would occur through longshore littoral drift and that only minor losses would occur offshore. Offshore losses during storm events do occur, however, and result in dramatic depletion of beach volumes. It has been documented that over 4 million cubic yards of sand have been removed offshore from Wrightsville Beach, North Carolina, USA.

6.3 VOLUME

It is also assumed that the volume of the fill material will influence the stability of the beach : the greater the volume of replenished fill, the more durable the beach. Recent work by Stauble and Hoel (1986) indicates that at least 150m^3 material per metre run of beach is required for 60% of the replenished fill material to remain after one year. However it is apparent that more than one factor influences the durability of the beach. Figure 7 shows a relationship between volume, durability and wave height. It can be seen that beaches with a predominant maximum wave height less than 3m are generally more stable than beaches with greater wave height, regardless of volume. For comparable densities, durability decreases with increasing wave height.

6.4 PLACEMENT METHODS

Another premise of beach recharge is that hydraulically placed fill will perform better than fill placed dry - presumably because of the hydraulic compaction element of wet placed fill. However, the survey of east coast recharged beaches cannot provide any corroborative evidence to support this theory. Although in the main material is placed on the east coast beaches by hydraulic means, there are a number where land based equipment is adopted. Comparison of the longevity of these two methods, even on the same beach, does not highlight any significant difference in their performance.

6.5 WAVE CLIMATE

It has been proposed that the wave climate parameter should be based on the number of storms during the first year. Information from the United States indicates that the longevity of recharged beaches may be dependent on the number of storms during the first year. Beaches less than one year old experienced two to seventeen storms during the initial year. Beaches with a life span of one to five years experienced between one and four storms, and those with a lifespan greater than five years experienced no storms at all during the first year.

There may also be some correlation between the replenishment, the time of the first storm, and the durability of the beach. Further extrapolation of this theory concludes that the timing of the replenishment would also influence the durability. As the hypothesis resulted in completion dates during winter months, (schemes completed between September to February are less stable than summer completed schemes) the dominant criteria may be the length of the intervening period between beach replenishment and the first storm. This would imply that some form of stabilisation takes place after fill placement. There is no published evidence to support this hypothesis although it may benefit from some further research.

6.6 CONCLUSIONS

Comparative studies have been carried out in the United States on beaches with multiple replenishment. Table 5 indicates the parameters for nine beaches which had multiple replenishment. It would suggest that the dominant parameters determining the longevity of replenished beaches would be volume, hard stabilisation, and storm activity; with grain size and length having only minor influence. Although there must be some doubt about the conclusions of the studies carried out in America, it can be assumed that non-aggregate material would perform in a similar way - influenced by the same factors.

Table 5 Beach durability

Project	Length (m)	Volume (m^3/m)	Grain Size relative to native	Durability Category
Sandy Hook '77	250	22.4	COARSER	< 1 year
Sandy Hook '83	720	2517.3	COARSER	< 1 year
Atlantic City '48	4570	43.12	SAME	< 1 year
Atlantic City '63	1174	444.0	SAME	1-5 years
Atlantic City '70	1160	406.6	SAME	1-5 years
Ocean City '52	1290	575.0	FINER	1-5 years
Ocean City '82	3220	285.0	SAME	< 1 year
Wrightsville '66	2740	89.0	FINER	1-5 years
Wrightsville '70	5780	211.6	FINER	1-5 years
Carolina Beach '65	3000	421.0	SAME	1-5 years
Carolina Beach '71	1200	287.7	SAME	1-5 years
Carolina Beach '82	4270	229.2	COARSER	< 1 year
Hunting Island '68	3050	186.9	SAME	< 1 year
Hunting Island '71	3060	189.0	SAME	< 1 year
Jupiter Island '74	7620	333.0	FINER	1-5 years
Jupiter Island '78	4900	157.4	SAME	1-5 years
Delray Beach '73	4520	274.8	FINER	1-5 years
Delray Beach '78	2740	194.4	FINER	1-5 years
Delray Beach '84	4350	194.4	-	> 3 years
Virginia Key '69	2090	64.4	SAME	< 1 year
Virginia Key '77	2080	184.0	SAME	> 5 years

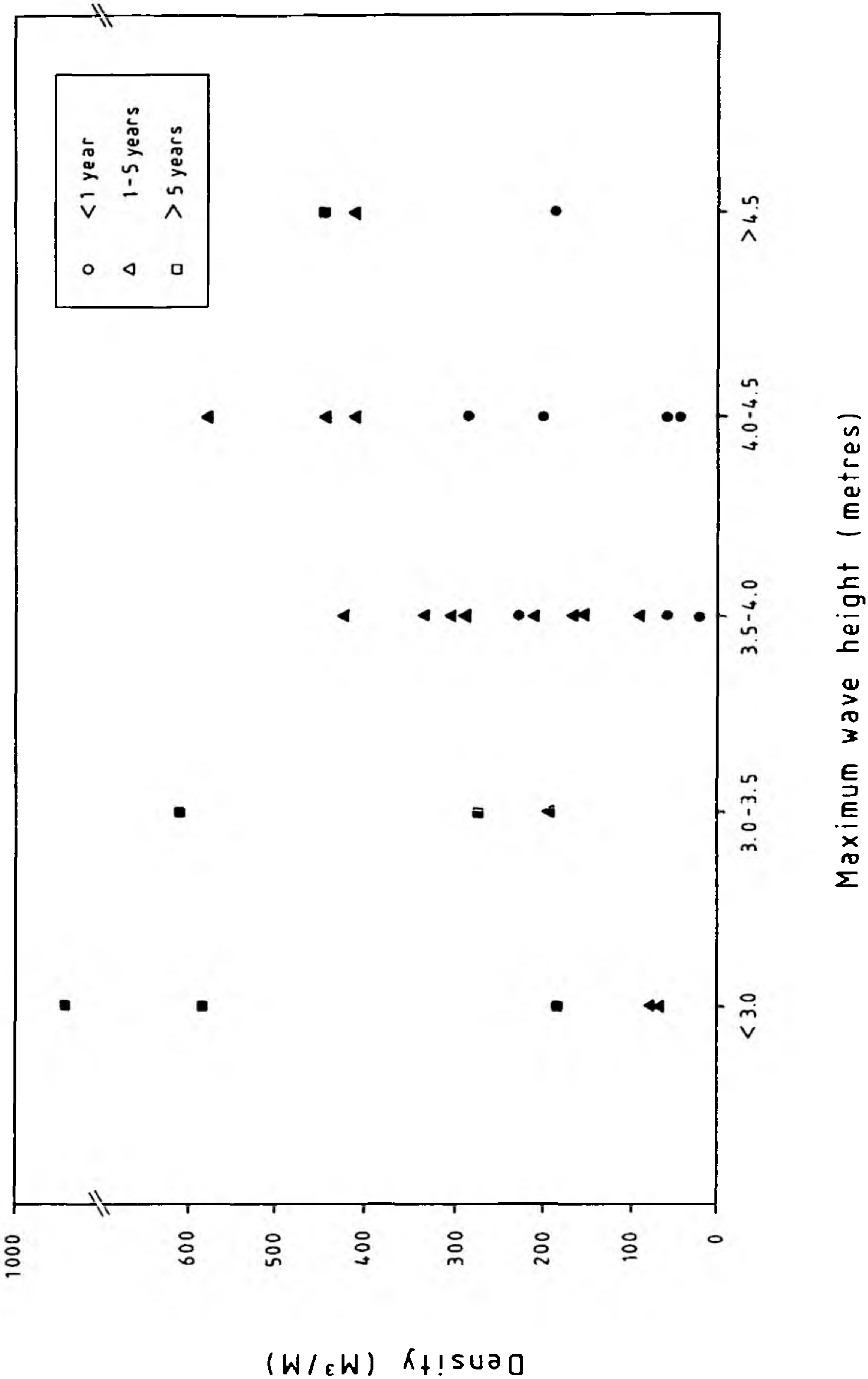


Figure 7 *Relationship between material volume, wave height and durability*

7 Economic considerations

The cost of winning, transporting and placing beach recharge material is governed by:

- site factors
- production factors
- royalties and duties.

Site factors are the most significant and the most variable of the three, as they dictate the plant required to carry out the works. Production factors influence the type of plant required, but have less influence on the overall costs. Royalties and duties are relatively standard charges and no distinction is made between the use of non-aggregate and aggregate materials.

7.1 SITE FACTORS

The distance between the borrow area and the deposition location will determine the viability of direct pumping. As a general rule, 1hp is required to pump $1m^3$ fine sand (300μm) a distance of 1m; and 2.5hp is required to pump gravels (5mm) a similar distance. On larger vessels installed with up to 6500hp, transportation distances of up to 6.5km for fine sands and 2.5km for gravels are achievable.

Where the distance between the borrow area and deposition area precludes the use of direct pumping, minimum water depths may determine alternative methods of delivery. Although shallow draught hopper dredgers may be able to discharge in 4m of water, it is possible for split haul barges to discharge in only 2m of water during very calm conditions.

If both direct pumping and direct discharge are excluded it is possible to relay the material through an offshore booster station and pipeline to shore. Further booster stations may be incorporated within the system as required. Minimum water depths restrict the size of vessel required, and the climatic exposure of the site determines the minimum size of vessel required to be economically viable. Excessive downtime of smaller vessels during minor storm conditions may be more expensive than unutilised production capacity of larger vessels able to operate in most sea states.

The adoption of non-aggregate sources of material would increase the selection of sources available for licensing and production. This would facilitate a wider choice in the balance of costs of production and material placing against the required design profiles and maintenance requirements; so that the optimum financial implications of the works could be achieved.

7.2 PRODUCTION FACTORS

The dimensions and soil characteristics of the borrow area determine the production rate of the dredger. Most dredgers would operate on a 1 to 2m dredge face or thickness of deposit. Thin and inconsistent or discontinuous deposits increase the unit rate of production.

The shipping distance between the borrow pit and the deposition site is one of the prime costs. It is generally accepted that direct pumping is the cheapest form of transportation and deposition of material (Portobello, Edinburgh 1.33p/m^2). Double handling or non production steaming time add to the unit rate cost (Hunstanton £13.60/m^3).

For all materials, the horsepower required for discharge through a pipeline is usually much greater than that required for dredging.

During pumping, excessive damage to the pumps and the pipeline may be expected from coarse material; resulting in downtime for maintenance and repairs. It is usual for the dredging contractor to build this item into his unit rate. Although it has been impossible to determine the actual financial implication from the dredging companies it has been implied that the maintenance on a gravel rock stone pumping pipeline is ten times that for a water pumping pipeline; and a 150 to 400μm material would be approximately two-and-a-half times more expensive to pump than water.

Losses during transportation, delivery and rehandling are accounted for in the unit rate of the material. Losses of between 10 and 15% can be expected for material pumped ashore into settlement lagoons. Where material is either bottom dumped or "rainbow delivered" losses of up to 50% may be expected.

Although unit rates are normally quoted when comparing production costs, it must be remembered that the cost of mobilisation and demobilisation of dredging equipment is very high. The volume of material therefore influences the unit cost.

Compliance with restrictive material specification also attracts premium costs, related to material availability, and built into the unit rate by the dredging contractor. Relaxation of the material specification, if acceptable within the design criteria, would reduce the contractor's losses due to rejection of material and hence reduce the initial unit cost. This would need to be balanced against the difference in the amount of material required.

The main cost components for dredging operations are as follows:

- plant costs

  - depreciation and interest
  - maintenance and repairs
  - insurance
  - mobilisation of the plant

- running costs

  - running costs for plant, labour, materials
  - mobilisation and demobilisation of personnel and services
  - installation on site for plant and labour
  - financial expenditure for bankers and guarantors
  - direct head office expenditure
  - contribution to head office expenditure
  - construction risk insurance
  - third-party liability insurance
  - credit insurance
  - taxes and duties

- profit and risk

  - profit required
  - risks not covered in the plant costs
  - risks not covered in the current costs

Sample costs for dredging, transport and placing of material for a beach recharge scheme have been provided by Posford Duvivier. A medium size vessel (2750m^3), steaming two hours each way with a two-and-a-half hour loading time and and one-and-a-half hour discharge, plus three quarters of an hour mooring and casting off, would produce material costing between £2.75 and £3.75 per m^3 when measured in hopper. Mobilisation and demobilisation costs for the vessel and tug, etc., would cost approximately £60,000 to £90,000. More detailed production and transportation cost information is included in Appendix A.

Typical costs for other contract works could include:

- £40,000 to £80,000 for mobilisation and demobilisation of discharge pipework, dependent on the length of pipework and vessel connection arrangement
- £10,000 to £30,000 per week for supervision of discharge points and moving pipework, depending on size of contract and number of movements of discharge pipework
- £2.50 to £6.00/m^3 for onshore grading of beach and ancillary works, depending on specification and sediment loss from beach during placement.

The above typical costings indicate a range of all-in placed costs for beach recharge material (including onshore work) of £5.00 to £10.00/m^3 for a conventional hopper, dredging and discharging material through a pipeline directly on to the beach being recharged. All the costs exclude prospecting, administrative and royalty charges. Figure 8 gives unit costs for beach recharge material in Holland.

The use of non-aggregate sources of material would allow more flexible use of dredging plant. It is unlikely that sources would be restricted to deposits less than 2m thick unless other economic considerations, such as proximity, dictated otherwise. A relaxation of the specification of the material from a nominal aggregate to a non-aggregate material would reduce the potential rejection of the material and hence the initial costs.

7.3 ROYALTIES, LICENSING AND DUTIES

The Crown Estate bases the royalty charge on market factors, namely competing demands, rates for similar materials, quality of the material and in some cases the final use of the material. It may be possible that the use of non-aggregate material would incur a reduced royalty charge. The licensing procedure may be prolonged. Although there have been no applications made for the licensing of non-aggregate sources it is likely that some factors such as soil sampling would be reduced and that the locations for investigation could be chosen to minimise the environmental impacts and hence the procedures and restrictions that may be applied.

Commercial traffic within a port authority's boundary is subject to a port duty. This duty has been applied to the discharge of material both directly onshore and indirectly through offshore pumping stations. The current average levy is approximately 35p/m^3, although this may vary between 2p and 90p. It is unlikely that use of non-aggregate material would influence the port duty charged.

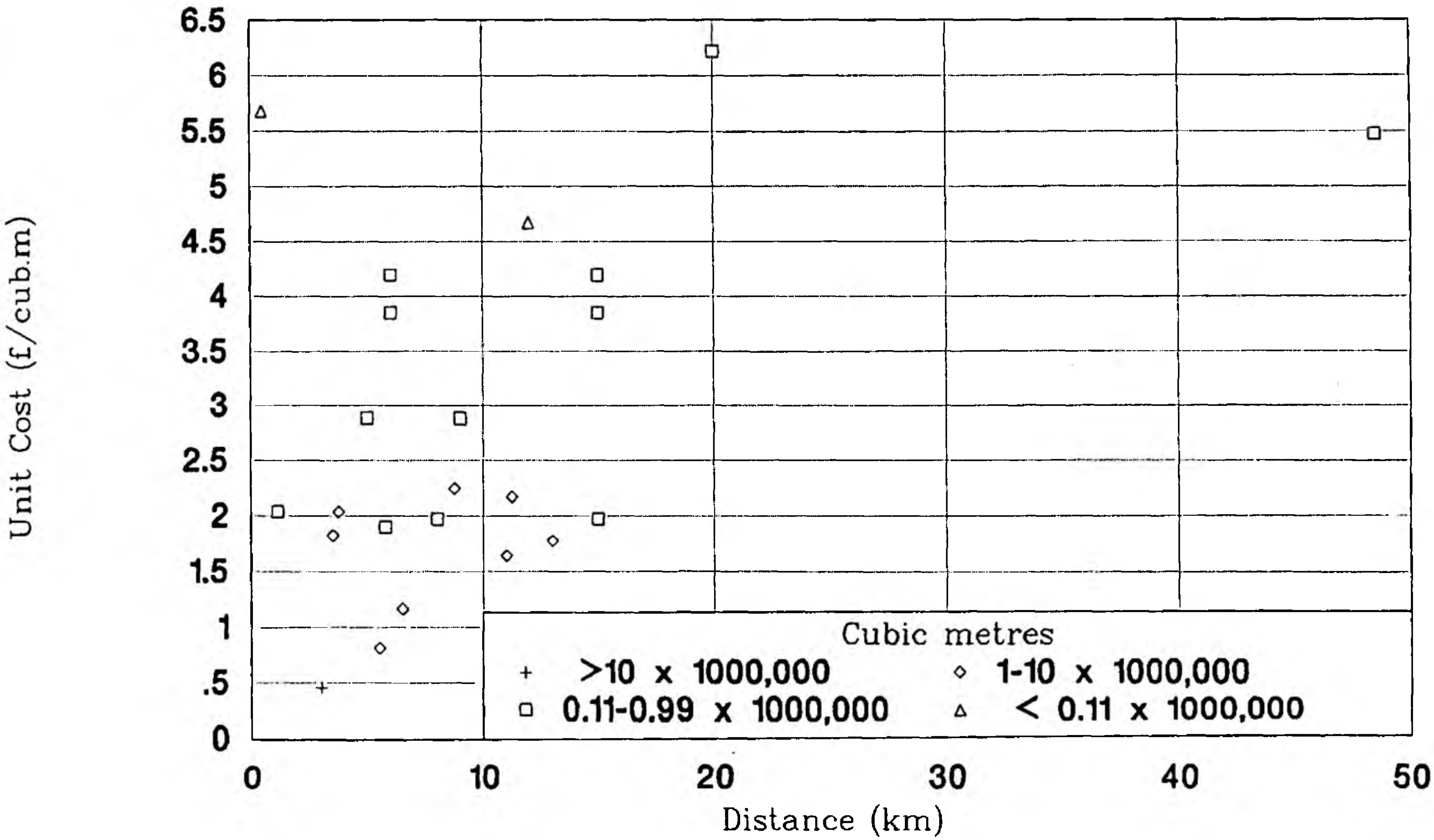


Figure 8 *Rijkswaterstaat cost data on beach nourishment*

8 Environmental issues

During recent decades public interest in the environment has increased considerably. Action groups have focussed attention on the negative environmental effects of all kinds of human (but mostly industrial) activities. To determine the environmental effects of beach recharge, a distinction is made between the three process phases:

- dredging
- transport
- material placing.

It is emphasised that any environmental effect is closely related to local circumstances and a site-specific analysis always has to be made. This exercise may be extensive and is only covered in general terms in this report.

8.1 DREDGING

Noise

Noise caused by dredging activities is a particular nuisance when it occurs near residential areas and at night, especially where a bucket dredger is employed. Bucket dredgers are often replaced by another type, such as a cutter suction dredger, when noise problems are expected; even if the cost is increased.

Wildlife is not thought to be affected by the noise of the equipment, but the increased human activity resulting from dredging can certainly disturb animal life, especially birds and seals.

Noise could be a problem if non-aggregate material was dredged from inshore areas.

Appearance

The appearance of dredging equipment can be a visual nuisance. The digging process can disturb recreational areas or a landscape by the presence of equipment that is felt to be unaesthetic. This could be a problem if inshore material sources were exploited.

Odour

Odours play no significant role during normal dredging practice, and the use of non-aggregate materials is unlikely to change this.

Turbidity

One of the most quoted environmental consequences of dredging is increased turbidity, as fine particles are disturbed and suspended in the water. Coarse particles will settle rapidly, but fine particles remain in suspension for some time. The finer particles may be transported over long distances as a result of their low fall velocity relative to prevailing current velocities.

Suspended material affects the environment in four ways:

- reduction of light penetration
- coverage of certain areas with a layer of spoil material
- disturbance of filter-feeding organisms
- possible damage to the respiratory organs of fish and other animals.

The turbidity problem could be significant if fine non-aggregate material were dredged.

Nutrient release

Natural water sediments are sinks for aquatic nutrients and contain large concentrations of nitrogen and phosphorus compounds. In natural conditions the primary factor controlling release of nutrients is mixing of the sediments with overlying water, and in most cases this natural release is slow.

Dredging operations increase the transfer rates for aquatic nutrients, which can cause localised algal blooms at the dredging sites. On the other hand, an increase in turbidity can limit the growth of algae by reducing light penetration.

Nutrient release as a result of dredging does not appear to be a major problem in the offshore zone, because of dispersal by currents and dilution. However, this can be a problem when fill material is taken from confined areas in the inshore zone.

Biochemical oxygen demand (BOD)

In the underlayer of deep borrow pits, which form a sink for organic material, anaerobic conditions often develop and are maintained by temperature stratification. In such situations, faunal recovery is impossible. The oxygen content of surface water is, among other things, closely related to algal blooming in water. Anaerobic conditions in shallow waters with a high temperature can give rise to diseases like botulism, which has affected thousands of birds in the Netherlands over the past few years.

Although dredging and nourishment operations or projects are not the only (or the most direct) cause of the outbreak of such diseases, a modification of the design or the working method can certainly reduce the risks.

Effects on benthic communities

The benthic community of a dredging site is of course destroyed. Repopulation of the dredged area by benthic animals will depend on the magnitude of the disturbance, the new surface sediment, and the water quality of the borrow site. The borrow site will be re-colonized by migration of organisms from adjacent areas, but the new community may not be the same size or have the diversity of the the original. The stability and bottom sediments at the site after dredging are major factors in determining species re-colonization.

The effects on the benthos are unlikely to be different if the material being dredged is non-aggregate.

Morphology, hydrodynamics and geohydrology

Material can be dredged either from isolated deep borrow pits or from extensive layers of shallow deposits. The advantages and disadvantages of the two methods are summarised below.

Isolated deep pits:

Advantages

- small area affected
- little effect on wave and current patterns

Disadvantages

- great change in geomorphology of the area
- change in sedimentation pattern
- increased possibility of changes in bottom material
- hinder for fisheries
- reduced light penetration

possible disturbances of impermeable layers
stratification problems with anaerobic conditions in the deeper parts of pits
bad conditions for faunal recovery

Extensive dredging area:

Advantages
little change in geomorphology of the area
good conditions for faunal recovery
dredging can be gradual, flora and fauna will be able to follow
bottom material may remain unchanged

Disadvantages
current and wave patterns may be affected
large area affected

Analysis of site specific conditions should indicate which of the two methods to use.

8.2 TRANSPORT

In the transport phase, it is important to consider the impact to recreational and commercial navigation, although other factors may also be of concern. These aspects have a temporary character only. Noise, turbidity, nutrient release, biochemical oxygen demand, effects on benthic communities and mobile animals, and effects on morphology, hydrodynamics and geohydrology are of lesser impact than during dredging.

8.3 MATERIAL PLACING

Noise

Although the actual placing operation does not create excessive noise, the presence of a number of bulldozers and other similar equipment may disturb very quiet areas. This would not alter if non-aggregate material were used.

Appearance

Visual hinder due to the placing operations is of a temporary nature. It may become important, however, if recreation is hampered during placing. Since recreation is mostly seasonal, even the effect of a temporary nuisance may have an important economic and psychological impact. For this reason planning of placing operations should be adapted to reduce the negative effects as much as possible.

Odour

It is unlikely that placing of clean dredgings causes unpleasant odours, but dredged material containing considerable amounts of organic material may cause problems. The only remedy is to select borrow areas where such materials are not present.

Turbidity

Turbidity is only important if the fill material contains a large percentage of fines. When this is the case, settlement of these fines must be expected in large areas around the beach, both offshore and onshore. In both cases it is an undesirable situation, which should be avoided.

Effects on benthic communities

A beach in equilibrium contains benthic organisms which form part of the food chain for other species, mainly birds. The marine bottom communities on most high-energy coastal beaches survive periodic changes related to the natural erosion and accretion cycles and storms. However, nearshore communities are in a more stable environment and are less adaptable to such changes.

Direct dumping of beach recharge material on non-mobile organisms will be generally lethal, while mobile animals may escape.

Recovery of the benthic fauna may occur in one or two seasons, and will depend on the timing of the nourishment operation and the recruitment of larval fauna. Observations in the Netherlands have shown that the original bio-system is restored within one season, as long as the fill material has the same character as the original beach material. The observations have been made, however, in recharge schemes along relatively short stretches of coastline. Extrapolation to extremely long stretches must be done with caution.

Destruction of habitats for fish and shellfish on the recharge site appears to be the major danger.

Morphology, hydrodynamics, geohydrology and landscape

When deciding to carry out a beach recharge project, consideration must be given to the influence on current and wave patterns along the shore and the influence on erosion and sedimentation processes in adjacent locations. The disposal of fill material on the beach by pumping may influence the groundwater regime and salt water intrusion may occur.

8.4 MONITORING

Several authorities have suggested that animal communities be surveyed before, during and after dredging and nourishment. Such studies can be both qualitative and extensive.

As an absolute minimum, a pre-project baseline survey should be made to identify and locate sensitive ecological resources; such as shellfish beds and feeding, spawning and nursery habitats for fish. With these results it is possible to spare potentially sensitive areas.

8.5 CONSULTATION

The extent of the consultation process needed before dredging can take place is indicated in Table 6, which lists some of the organisations which need to be consulted. Although not all are mandatory, the list does indicate the length of the consultation exercise.

Table 7 provides a comprehensive list of Statutory Acts and regulations that may be enforced upon the works prior to consent.

8.6 ENVIRONMENTAL ASSESSMENT

The information gathered for any project should be presented in a concise format which enables important environmental issues to be identified. One way this can be achieved is by using a matrix, which was designed to examine primary and secondary impacts of development on the environment. The method can be applied whether the material is aggregate or non-aggregate.

A matrix has been drawn up to illustrate how this technique can be applied to the placing of beach recharge material (Figure 9). Operational stages or activities during placement of material are listed down the left hand side (1 in the diagram). These activities may cause changes in the existing environmental conditions

Table 6 Dredging consultees

Crown Estates*
Maritime Local Authorities
County Councils
National Rivers Authority*
Water Authorities
Ministry of Agriculture, Fisheries and Food*
Department of Agriculture and Fisheries for Scotland
Ministry of Defence
Department of the Environment*
Department of Trade
Department of Energy
Department of Transport
Harbour Authorities
Nationalised Industries
English Nature*
Nature Conservancy Council for Scotland*
Countryside Council for Wales*
Joint Nature Conservancy Council*
Countryside Commission*
National Trust*
Sea Fisheries Committee
Private Landowners
Police, Customs, Coastguards, and Fishery Protection Services
Joint Nautical Archaeological Policy Committee
The Hydrographic Office
Nuclear Industry
National Radiological Protection Board
Royal Society for the Protection of Birds*
Campaign for the Protection of Rural England
Her Majesty's Inspectorate of Pollution
Barrage Study Groups
Institute of Oceanographic Sciences
Ordnance Survey
Marine Conservation Society*
Country Landowners Association
British Coal
British Geological Survey*
Associated British Ports*
Institute of Terrestrial Ecology
River and Harbour Conservators
Tourist Information Board
Wildlife Trusts
Power Generating Industries
Minerals Companies
Watersports Clubs
Sport and Recreational Council
Diving Clubs
English Heritage

*Statutory consultee

listed along the top of the matrix (2 in the diagram). Each cell in the matrix is studied to determine whether an environmental impact is likely to occur, and if so, the size and type of the primary impact is assessed.

Results are presented in the upper part of the body of the matrix (3 in the diagram). These impacts may themselves lead to other effects, or secondary impacts, examined in the lower part of the matrix (4 in the diagram), in other environmental conditions which are listed on the right hand side of the matrix (5 in the diagram).

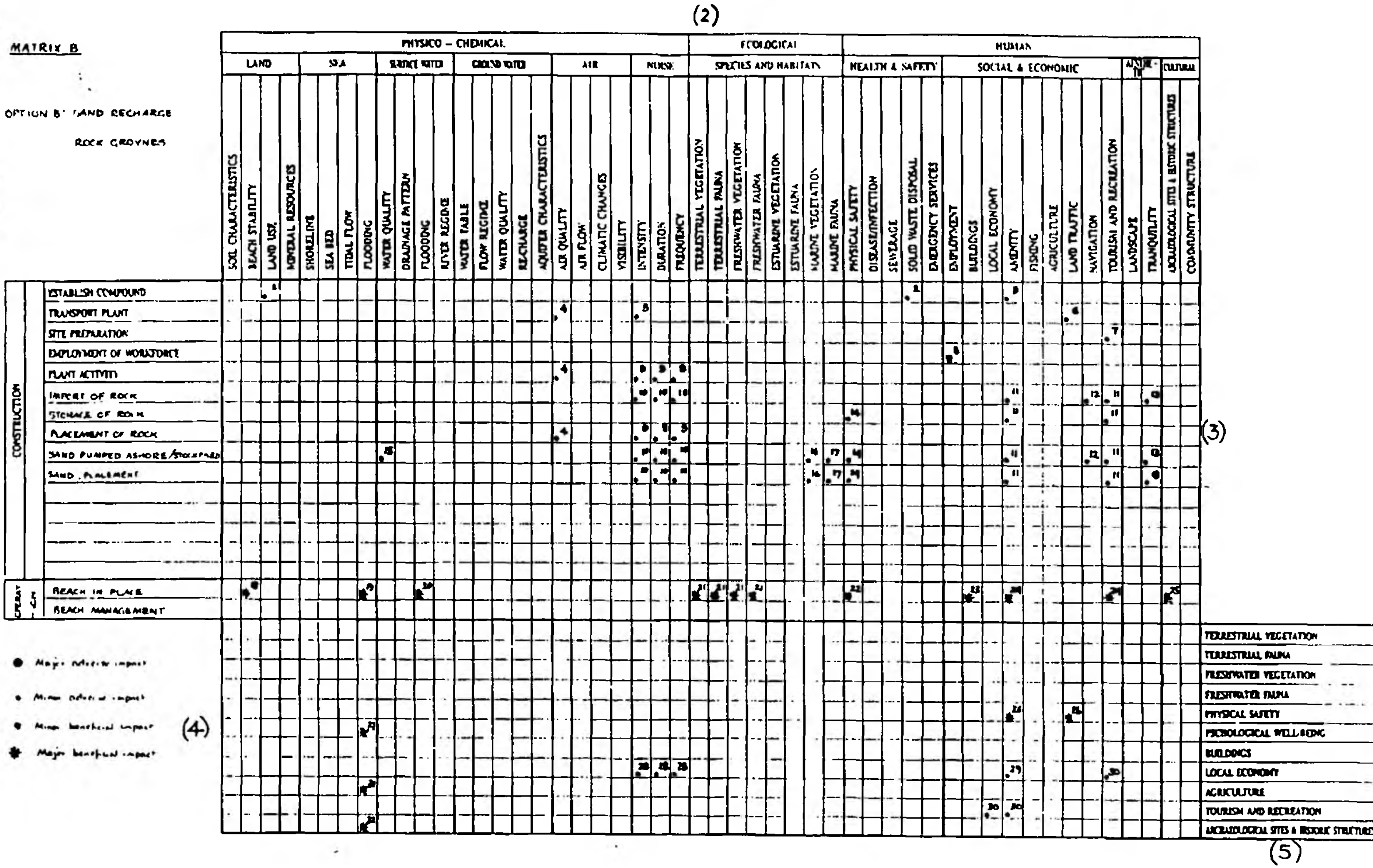
Table 7 Dredging legislation and regulations

National Parks and Access to the Countryside Act 1949
The Countryside Act 1968
The Wildlife and Countryside Act 1981, Amend. 1985
Environmental Protection Act 1990
DoE Circular 27/87 and Welsh Office Circular 52/87 : Nature Conservation
Coast Protection Act 1949 (Prevention of erosion and encroachment by the sea)
Land Drainage Act 1976 (Navigation, sea defences to prevent flooding)
Flood Prevention (Scotland) Act 1961
The Water Act 1989
The Town and Country Planning (Assessment of Environmental Effects) Regulations 1988
Town and Country Planning Act 1990
Planning and Compensation Act 1991
Crown Lands Act 1866 (Mining, quarrying and dredging)
Crown Estate Act 1961
Control of Pollution Act 1974 (Restriction of discharge into coastal waters)
Harbour Works (Assessment of Environmental Effects) Regulations 1988
Harbours Act 1964
Dumping at Sea Act 1974 (Prohibition of dumping in territorial waters)
Prevention of Oil Pollution Act 1971 (Prohibition of discharge of oil in territorial waters)
Highways Act 1959 (Quarrying and navigation)
Customs Act 1952 (Prevention of smuggling)
Sea Fisheries Regulation Act 1966 (Control of fishing industry)
Protection of Wrecks Act 1973
Merchant Shipping Act 1894
Ancient Monuments and Archaeological Areas Act 1979
The Protection of Military Remains Act 1986

Environmental impacts are assessed as either adverse or beneficial, and as either major or minor. Blank cells on a matrix indicate that no impact has been identified. In assessing the significance of each impact the following factors are taken into account:

- *Magnituude* - defined as the probable severity of a potential impact. Will it be irreversible? If reversible, will the area recover quickly? Will the impact preclude the use of the area for other purposes?
- *Prevalence* - defined as the likely eventual extent of an impact, e.g. the cumulative effect of a series of operations and their extent.
- *Duration and frequency* - will the activity be short or long term? Will it allow for recovery during inactive periods?
- *Risk* - defined as the probability of an environmental effect.

Figure 9 *Environmental impact assessment*



- *Importance* - defined as the value attached to an environmental factor as its present state and. in some cases, the number of people deriving benefit from it.

- *Mitigation* - are solutions to problems available? Are they feasible or economic?

The matrix presented here, which examined the impacts of beach recharge using non-aggregate material as a potential option for coastline management, illustrates that 13 minor adverse impacts were likely to occur. Collection of information and screening of "environmental sensitivity" of the area in question enabled the identification of important issues associated with placement of material, and provided an indication of what mitigation measures, if any, could be feasibly drawn up to negate or minimise any adverse impacts. The impacts associated with placement of material are likely to be common to all beach recharge schemes. The example given in Figure 9 identified the following impacts:

- minor degradation of air quality from exhaust fumes of vehicles and plant
- presence of noise during weekday daylight hours
- minor noise during unsociable hours as dictated by tidal conditions
- restricted beach use
- minor interruption of inshore craft
- temporary loss of tranquil environment
- physical safety - a potential risk to children playing on the beach
- increased turbidity
- temporary disturbance to marine fauna and vegetation
- increased noise from construction activity may deter tourists and the associated trade
- loss of amenity may deter recreational use
- decline in tourist numbers may result in loss to local traders.

None of these impacts would occur beyond the working life of the scheme. Careful mitigation measures, public awareness of the necessity for such works, and acceptance of the temporary nature of visual and physical disturbance, allows such schemes to progress efficiently.

Temporary impacts are judged against the benefits which accrue through the provision of works. Awareness of benefits promotes public acceptance and patience. The benefits of recharge as an option for beach management at Dymchurch included:

- a dramatic improvement in beach stability
- the reduced risk of overtopping of existing defences
- a reduced probability of breaching
- reduced threat to areas of conservation importance to the hinterland
- increased level of protection to adjacent properties
- the provision of an improved amenity beach
- enhanced protection of some important archaeological sites, and prevention from damage through tidal inundation
- peace of mind and reduced anxiety among local residents associated with the provision of an enhanced defence standard
- a better level of protection for local agricultural land.

Beach nourishment has an influence on the environment, as it changes the physical and socio-economic aspects of vast areas. Negative effects need to be assessed against environmental and economic benefits. The timing of the works is an important factor when considering environmental impacts. To minimise biological environmental impact, winter is the best time for beach placement. However, in terms of success of performance of placed material, work is most effectively carried out in the summer when the weather is less likely to cause operational difficulties, and long daylight hours allow works to progress in unison with required tidal conditions. This has the unfortunate effect of temporary disturbance and loss of amenity during the tourist season. Public awareness and consultation as part of the procedure for environmental assessment may allow beach recharge to proceed as an environmentally acceptable method of coastline management.

9 Design considerations

This section describes the modelling techniques currently available to the engineer for the design of beach recharge schemes and describes practical considerations associated with their construction. The section also describes the needs for post-placement monitoring. The models, construction methods and monitoring requirements are applicable to all beach recharge schemes whether they use aggregate or non-aggregate material.

9.1 INTRODUCTION TO MODELLING TECHNIQUES

Engineers concerned with the development and management of the coastal zone have traditionally used a combination of experience, field information and physical model studies to assess the impact of wave forces on the existing coast and the future impact of their engineering works. However, during the past ten years the use of mathematical models has gained prominence, for the following reasons:

- availability of cheaper and more powerful computers
- the increasing cost of physical models and awareness of their inherent limitations
- the considerable progress made in the understanding of physical processes involved in the coastal hydrodynamics and related beach response
- the processes which can be modelled are independent of the classification of recharge material as aggregate or non-aggregate. This section therefore describes modelling in general terms.

9.2 NUMERICAL BEACH MODELS

There are numerous beach response models with varying theoretical bases, applications and modelled processes; but they are all generally applied in the same way.

The seabed bathymetry needs to be prepared and its horizontal boundaries determined with at least one boundary taken at the area of offshore wave generation. Offshore wave properties such as the directional spectrum must be measured or estimated using hindcasting techniques. Several well established hindcast models can be used for this purpose such as HINDWAVE, a model developed by HR Wallingford.

To provide a wave climate for the beach models, offshore waves need to be propagated inshore. A number of models can be used to evaluate the associated transformations. The choice of model is made with regard to the complexity of the coast and the input required by the model. For example, the propagation of wind waves (which have a wide spectrum and directional distribution) onto a large open coast can be represented by a refraction model such as OUTRAY, again developed by HR Wallingford.

9.3 MODEL CLASSIFICATION

To make the choice of model for a specific application easier, it is necessary to classify beach response models into certain categories. A number of criteria can be employed which depend upon either the physical processes utilised by these models, the dimensionality they are set to represent or simply the time scales over which the coastal responses are modelled. Typical coastal modelling problems fall into two categories: impact assessment of an existing coastal regime; and impact assessment of engineering works. Early models, which are constantly being improved and are still used today, predict longshore transport and subsequent beach movement.

9.3.1 Longshore models

The assumption of these models is that long term coastal evolution is the result of longshore sediment transport only. Longshore transport is the result of waves breaking at an oblique angle to the shoreline. This assumption greatly simplifies model formulation and in many cases is of sufficient accuracy.

Longshore models can be described as one line, two line or N-line models, depending on the number of lines used to represent the coastline. The waves, either measured or hindcast, are represented by a time series. The beach response in time is then calculated by solving a simple mass conservation equation for each known wave event in the time series, and the corresponding water level.

However, in the cases when this approach is inadequate, more sophisticated models have to be used.

9.3.2 Cross-shore models

Cross-shore models predict the response of a beach profile to storm attack. Both empirical and theoretical applications are available. Input may vary from significant wave height, storm duration, surge level and median grain size to a full description of wave climate, water levels and beach material. However, it must be noted that no model is presently capable of incorporating beach material grading in its prediction. It is normal to run cross-shore models over a design storm event to ensure integrity, and through lesser events to predict future maintenance requirements. With the latest cross-shore models it is possible to represent longshore sediment movement.

9.4 A BRIEF REVIEW OF SOME TYPICAL MODELS

There are a number of well established models for studying long term coast evolution based on the longshore transport concept. HR Wallingford's One Line Model and CERC's GENESIS are among the ones most widely used. These models represent the coast by one line which is usually the MHW or MLW mark. The longshore transport is evaluated using an extended form of the CERC bulk transport formula which takes into account explicitly the effect of longshore variation of wave height. The shoreline movement is then calculated by a simple mass conservation equation. Since these models are computationaly efficient, up to tens of years of wave data can be used.

The cross-shore models based on general hydrodynamic and transport equations have only recently been developed. Among this class of models are the Delft CROSTRAN Model, HR Wallingford and Nairn's NPM Model and Danish Hydraulic Institute's LITCROSS Model. The wave propagation is calculated using the energy flux equation and wave induced currents (undertow) are evaluated using a linear form of the momentum equation. The sediment transport rate is either calculated using a total load transport formula, as in the case of Delft and HR Wallingford models, or is separately determined as a bed load and a transport load in the case of the DHI model. Because the physical processes involved in the sediment transport and the subsequent beach response are all evaluated in detail, these models are robust and generally require less calibration.

Another class of model, developed by Kriebel and Dean, is a schematic. Instead of solving the general hydrodynamic and transport equations, this model assumes that the beach profile will eventually attain a dynamic equilibrium profile for a given water level and wave conditions. The transport rate is calculated in terms of the difference between the actual and equilibrium levels of wave energy dissipation, which is approximately evaluated as a function of local wave height, water depth and beach slope. The model is restricted to the surf zone and has the advantages of computational efficiency and insensitivity to input parameters.

Quasi-3D models have been developed by HR Wallingford, DHI and Delft Hydraulics Laboratory. Apart from being more general and taking into account both longshore and cross-shore transport in the evaluation of beach changes, very few new concepts and mechanisms are involved in such models.

There are also empirical models based upon laboratory or field data results. These models start by defining the beach profile using one or more polynomial lines with a number of free parameters. Extensive experiments are then carried out to determine their values for the free parameters which produce the closest fit to the beach equilibrium profiles formed under specific water level and wave conditions. An example of this type of model is Vellinga's DUNE model for predicting sand dune erosion. More recently, two models were specifically developed for shingle beaches by Powell and Van de Meer. These models assume that longshore transport is uniform. Since these models are easy to use and generally give reasonable predictions of beach response, they are widely used to evaluate the response of a recharged beach during design extreme wave and water level conditions. Under realistic wave conditions the beach experiences constant changes in response to the changing sea states and equilibrium can not be achieved. Since the profiles produced by these models are equilibrium profiles they should be interpreted correctly when compared to actual beach changes during a storm event.

9.5 MODEL SELECTION FOR SPECIFIC APPLICATIONS

A simple model may be approximate but often permits examination of considerably more design options at low cost. Conversely, a sophisticated model gives more detailed and accurate information but would require considerably more accurate input parameters. Hence, in the case where input information is scarce or uncertain, the former may be the better choice. A cost effectiveness factor should also be considered in the model selection. Generally, the more complex the models, the more work is required in the data preparation, model set-up, model execution and finally the interpretation of the results.

9.6 PHYSICAL BEACH MODELLING

Random wave physical models of beaches are usually scaled in accordance with the Froude number, which means some of the less important forces in the model, such as viscosity, surface tension and elasticity must be neglected. Provided the model is operated at a scale sufficiently large to avoid scale effects occurring as a result of this omission, it is unlikely to be important as far as the results of a study are concerned. For 3D beach physical models typical scale range from 1:40 up to 1:90. This generally means that the models are restricted to a maximum coastline coverage of 2km to 2.5km.

The big advantage of most physical models is that a number of distinct problems can be addressed simultaneously. For example, a single model could be used to assess wave disturbance and potential sediment deposition patterns in a harbour; estimate overtopping discharges along adjacent seawalls; optimise the layout and design of breakwater extensions, and finalise the design of a beach re-nourishment scheme. To do this numerically would require the use of three or four models, and pose considerable problems in the interfacing of the various studies.

In order to ensure reliable and accurate results from any physical model it is necessary to ensure that the model satisfies a number of requirements. For littoral transport models these generally centre on the correct reproduction of:

- waves
- bathymetry/topography
- water levels
- currents
- sediment response.

Once the waves have been produced in the model, their subsequent transformation (shoaling, refraction, breaking, etc.) as they travel into shallow water is allowed to occur naturally above any accurately moulded bathymetry. Although the waves in the model are long crested the natural shallow water processes nearly always promote the development of long crested wave at the shoreline.

9.7 CONSTRUCTION METHODS

The design of a beach recharge scheme evolves through consideration of practicable and economic construction.

Dredging can be carried out by various types of dredgers and by a variety of methods. In general there are two types of beach recharge method, hydraulic fill placed on a beach, and material dumped by hopper dredgers or barges in the nearshore zone. Each beach recharge scheme has its own features and local circumstances which lead to the most economical and technically suitable solution for that specific job.

There are two main features which influence the possibilities available for the construction method. These are distance between the borrow area and the recharge site, and the client's requirement for nearshore dumping or beach replenishment. The former determines whether direct pumping from the borrow area to the reclamation site is feasible, while the latter determines whether direct pumping with hopper dredgers or barges is needed.

When fill material is required in the nearshore zone but, due to the wave conditions, it is not feasible to dump in this zone with hopper dredgers or barges, there is still the possibility using the rainbow-system. This entails jetting the sand-water mixture under approximate 45 degrees from a hopper dredger, or from a stationary dredger (equipped if necessary with a flexible floating pipeline and a moored nozzle barge). Distances up to 75m can be reached. However, this system is not favoured because it is difficult to control the dumping process.

Direct dumping in the nearshore zone with hopper dredgers or barges can only be used when sufficient water depth is available to allow loaded shallow draught vessels to enter the area and dump their load. Vessels capable of shallow dumping are those without protruding bottom doors, such as trailing suction hopper dredgers with sliding bottom doors, split hull hopper dredgers, or split hull barges. These vessels move very slowly, head-on to the shore, to the dumping spot, and then they start slowly moving backwards while dumping their load. Some trailing suction hopper dredgers are equipped with a stern winch, which makes it possible to proceed till the vessel runs aground, after which the cargo can be unloaded while moving backwards, if necessary assisted by the winch.

Good weather conditions are required during this kind of operation. Important information needed during such a job are relevant tidal data, and sufficient soundings throughout the dumping zone. By using shallow draught hopper dredgers it is possible to dump in a minimum of 4m water depth; however, when sea conditions allow the use of split-hull barges, this can be decreased to 2m water depth. The production level achieved with a trailing suction hopper dredger will mainly be influenced by the sailing distance, soil characteristics, and local circumstances, and will be approximately 300,000m^3 per week at the most. The maximum production rate using barges will depend upon the production level of the sand winning dredger.

Trailing suction hopper dredgers directly pumping through a pipeline to the beach is one of the favoured methods when a mobile system is required with various discharge points on the beach. Advantages of trailing suction dredgers are that they can span large borrow areas or use more than one borrow area or even use material from capital dredging work. The longer the sailing distance, the more economical it becomes to use larger trailing suction hopper dredgers. This results in greater water depth requirements at the mooring points, and consequently, a longer pipeline to the beach. The type of mooring point selected and the pipeline connection with the beach depend on the local wave, tide, current and weather conditions. Under calm conditions it will be possible to use a riser pontoon anchored or fixed with spuds, on the seaward side of a submerged pipeline. This can be connected to the hopper dredger by means of a flexible floating pipeline and a quick-coupling over the bow. When long pumping distances are required, for instance for more than 2500m for a large self-unloading trailing suction hopper dredger with say, 300μm sand and no reduction of production is permitted, the riser pontoon can then be replaced by a floating booster station. This distance also depends on soil and pump characteristics and production levels. Maximum achievable production rates for large self-unloading trailing suction hopper dredgers will be approximately 250,000 cubic metres per week per dredger.

Dredger pumping directly through a pipeline to the beach zone is commonly used when the borrow area is relatively close to the reclamation site. The kind of sandwinning dredger used, such as cutter, dustpan, and stationary suction dredgers, is dependent upon the restrictions and dimensions of the borrow area. Cutter or dustpan dredgers are favoured because they can dredge a relatively thin layer from the borrow area, and therefore can be safely operated closer to the beach zone. By planning several borrow areas along the coast, pumping distances can be reduced. The disadvantage of this direct pumping method can be that all the fines from the borrow site end up in the reclamation area, which will result in undesirable settlement of fines in that area.

Trailing suction hopper dredger pumping via nozzle placed on the bow (rainbow system) entails pumping through a nozzle on the bow of a trailing suction hopper dredger. This system, which can only be exploited during a calm weather period, requires regular surveying to monitor the replenishment progress. To be able to approach the foreshore as closely as possible, shallow draught hopper dredgers are preferred. The combination of small hopper dredgers and high sand losses, makes this method relatively expensive. Adding to this the low efficiency, expressed in the ratio between material in place and material delivered, has as a result that this system will only be used to replenish areas difficult to be reached by pipelines. The rainbow distance will depend on wind force and direction, pumping capacity, and the unloading production. Distances will range from 25 to 75m. The profiling of the beach would be carried out by land based equipment and careful planning of the works must be carried out to minimise the amount of double handling. Locations of stockpiles of material should minimise the transport by dump trucks and where pumping material ashore is carried out the pipeline should be extended as the works progress.

It may be necessary to construct a haul road along the recharge frontage in order to minimise intertidal working. Where the recharge material permits this should be constructed within the design profile to minimise abortive working.

The profiling of the beach would be carried out by land based equipment and careful planning of the works must be carried out to minimise the amount of double handling. Locations of stockpiles of material should minimise the transport by dump trucks and where pumping material ashore is carried out the pipeline should be progressed as the works progress.

9.8 MONITORING

Due to the flexible nature of beach recharge and the expected deformation of the profile during the design life, regular monitoring of the beach will be necessary to ensure the integrity of the defences and to plan any recycling or re-nourishment operations. In order to ensure that these operations can be carried out economically it will be necessary to survey cross-sections at regular intervals, perhaps as close as 100 m. Volumetric calculations may then be carried out to determine the locations that require replenishment to the original profile and locations that offer a source of material. During normal climatic periods these surveys may be carried out at intervals of 6 months spanning the winter period. In areas of extensive longshore movement samples should be taken of the beach materials during the level survey to ensure that segregation of a graded material does not result in deposition of predominantly finer material in any particular area.

The response of the beach to wave attack should be monitored to verify or otherwise the assumptions made in the initial design stages. In order that a critical analysis of the response can be made not only will an accurate topographical plan be produced, but accurate information of still water levels and incident wave climates must be obtained. This may involve the deployment of recording apparatus such as wave rider buoys and tide gauges. Should the results of the analysis contradict the predictions of the original design, the information will enable the re-calibration of the model.

10 Conclusions

10.1 GENERAL

The amount of data available on non-aggregate marine material and its use for beach recharge is limited. Consideration of the data available indicates that there is potential for the use of such material for beach recharge.

10.2 POTENTIAL DEMAND

In England and Wales over one quarter of beaches considered important for coast protection and sea defence are eroding. There may be other eroding beaches (without a significant role in coast protection or sea defence) of concern for environmental or amenity reasons. All of these are potential sites for recharge schemes (Section 1.4).

Areas of particular concern in England and Wales are the East Anglian and Lincolnshire coasts and the South coast between Dover and Poole Harbour. Although these coastlines are significantly different both have utilised beach recharge successfully (Section 1.4).

Almost 6 million cubic metres of recharge material has been placed on UK beaches since 1970. The quantity of shingle and shingle/sand mixtures is about ten times the quantity of sand placed. Virtually all recharge schemes have made use of existing licensed dredging areas (Section 4).

Based on historical information, it is estimated that a further 1.3 million cubic metres of material per year will be needed for beach recharge in the UK between now and the end of the century. MAFF estimate that a short-term peak demand of 3 million cubic metres per year will occur during this period.

10.3 AVAILABILITY OF MATERIAL

All aspects of obtaining aggregate quality marine material can be difficult and time-consuming. It is not yet possible to assess the ease with which non-aggregate quality marine material could be obtained because this has rarely been attempted.

There is a dearth of information on quantities and properties of nearshore deposits, which are classed as non-aggregate because they are not available to the construction industry (Section 5.2).

Information exists on quantities and properties of offshore materials, but has generally been collected under a prospecting licence and is confidential to the owner of the information and the Crown Estate (Sections 3 and 5).

10.4 BEACH PERFORMANCE

There is scope for a more flexible approach to the specification of materials for beach recharge but the required parameters are difficult to quantify because non-aggregate quality materials have rarely been investigated (Section 6).

No theoretical information exists on the performance of non-uniformly graded recharged beaches.

No information has been found on the performance of beaches recharged using contaminated and soft material (such as chalk).

Little information exists on the mechanism of outwashing from non-uniformly graded and contaminated beaches.

10.5 ECONOMIC FACTORS

The cost of a beach recharge scheme is a critical factor in determining whether or not it will go ahead (Section 7).

The major factors influencing material costs have been identified as the distance of the deposits from the recharge site, the methods of extraction, transportation and deposition and the competing demand for materials for the aggregate industry. Outline costs have been quoted which indicate the potential costs of using non-aggregate material (Section 7 and Appendix A).

The low availability and high cost of material from licensed areas is related to aggregate companies' need to safeguard supplies for their long-term regular market. Costs are therefore likely to be lower for non-aggregate material (Section 7).

The cost of any recharge scheme is determined by the balance of material availability, quantity required and recharge frequency. All of these need to be taken into consideration (Section 7).

10.6 ENVIRONMENTAL FACTORS

Environmental impacts in their broadest sense are seen to be a controlling factor in the decision-making process which can lead to a beach recharge scheme.

The large number of environmental consultees (statutory and voluntary) at the production licence application stage is one of the reasons why issue of licences can take several years (Sections 3 and 8).

Little information exists on the public acceptability of beaches recharged with material dissimilar to the original material.

No standard procedure or established guidelines exist for the assessment of the environmental impacts of beach recharge (Section 3).

10.7 DESIGN APPROACHES

Various design approaches have been developed for beach recharge. These do not accurately predict all of the observed phenomena but this does not appear to have compromised overall scheme performance (Sections 2.3 and 9).

Observations of schemes using non-aggregate quality material are very limited and it is therefore not possible to refer to previous experience with confidence (Section 2).

Gaps in existing knowledge of beach performance (see above) are reflected in the capabilities of modelling tools. These may be more significant for modelling some non-aggregate quality materials (see Section 9).

There are no accepted standard procedures or guidelines for designing beach recharge schemes.

11 Recommendations

It is clear from the conclusions listed in Section 10 that a great deal of further work is needed to establish the availability of non-aggregate materials and to be confident about the use of such materials for coast protection. This work must be given the highest priority so that results are available to engineers responsible for the many beach recharge schemes likely to be required in the next few years.

The areas in which further work is needed range from laboratory studies to provide basic process information to re-examination of Government procedures so that beach recharge material can be more readily and economically obtained. Each area is of critical importance to the success of beach recharge schemes: there is little point in producing numerical models for beach design if the materials needed are not available; and there is little point in providing information on the supply of suitable recharge materials to engineers who lack the design knowledge needed to use them. A coordinated approach is therefore needed in which all aspects are addressed in parallel, working to a common objective, and it is this approach which forms the main recommendation of this report.

The need for research into coastal processes has already been recognised by research-funding organisations and many projects have started or are planned to start in the next two years. These projects are extremely diverse, and although many are relevant to beach recharge they have not necessarily been developed with this application in mind. To obtain maximum benefit for beach recharge from existing projects, it is important that they are supplemented and coordinated into an integrated programme of research designed to provide the information needed for the successful future application of beach recharge.

11.1 OUTLINE RECOMMENDATION FOR STAGE 2

The recommendations of this report are based on the concept of a programme of research comprising current projects, planned projects which are already funded, extensions to current and planned research and new projects to supplement existing work. One of the options for implementing such a programme is for CIRIA to manage the research as Stage 2 of the current project, with the following overall objectives:

> *To co-ordinate existing research and initiate new projects in areas where additional work is needed to increase theoretical and practical knowledge of all aspects of beach recharge, including the availability of non-aggregate marine materials.*
>
> *To use this knowledge to produce practical guidance for engineers on the availability, use in design, placing and subsequent monitoring of non-aggregate marine materials in beach recharge schemes.*

The outline structure of the Stage 2 Programme is illustrated in Figure 10. The Programme is made up of individual projects to address the areas needing further study which were identified in Section 10, and recommendations for these projects are listed in Section 11.3.

The final output of the Programme is a Beach Recharge Design Manual. Because of the urgent need for practical guidance on beach recharge before completion of an authoritative Manual would be possible, interim guidance notes on various aspects of beach recharge would be produced throughout the study.

To develop the structure further, an appreciation of current and planned research is needed. This is considered in the following Section.

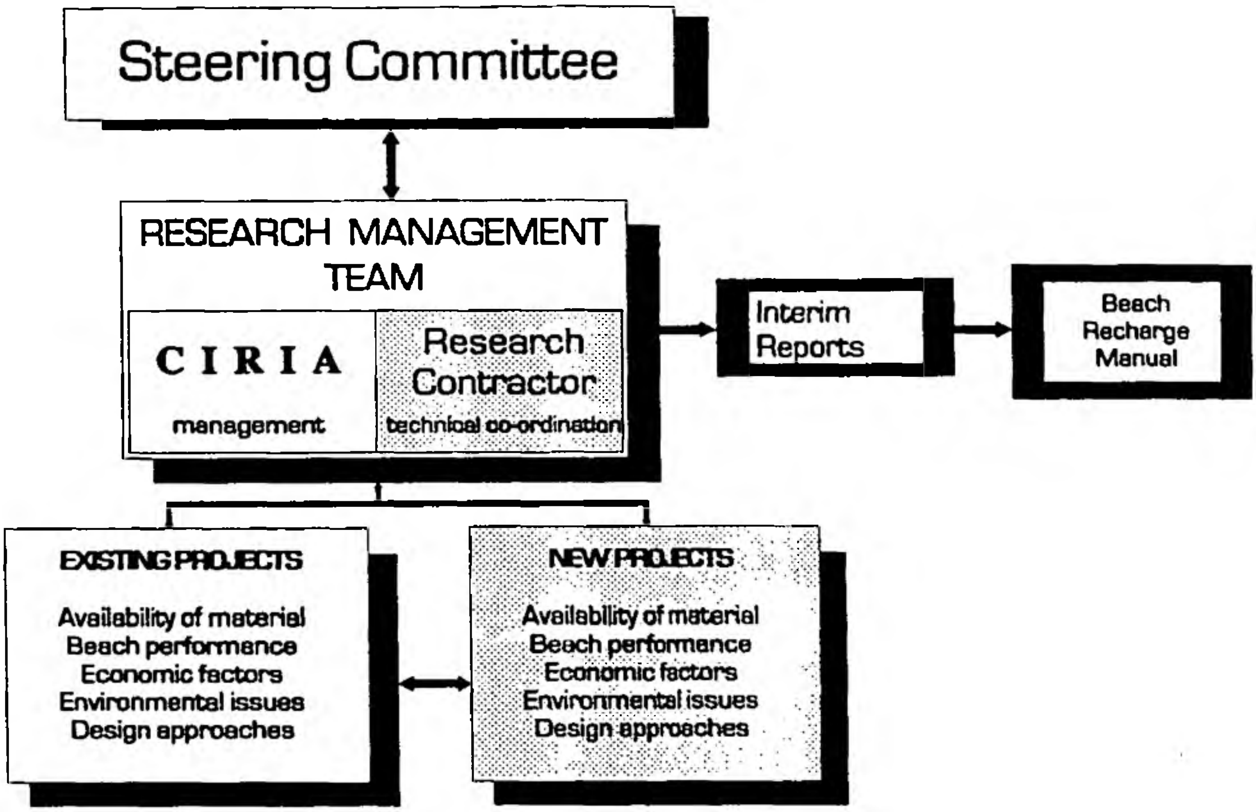


Figure 10 *Outline Structure of CIRIA Stage 2 project*

11.2 CURRENT AND PLANNED RESEARCH

Four major research programmes currently include projects relevant to beach recharge in the UK:

(a) MAFF Flood Defence Division R & D Programme for 1992/93.

(b) The European Community Marine Science and Technology Programme (MAST-1).

(c) The SERC Coastal Research Programme.

(d) The NRA Flood Defence R & D Programme.

A brief description of these programmes is given below and a summary of the projects of most interest to the Stage 2 Programme is given in Table 8.

11.2.1 MAFF R & D Programme

MAFF is the Government department with policy responsibility for flood and coastal defence in England. MAFF undertakes applied research with strategic aims, to complement basic research funded by the research councils and applied research carried out by the NRA. Since 1985, the MAFF research strategy has been guided by a report produced by a committee of experts under the Chairmanship of Professor

Wolfe. In 1991, a new committee was set up to update this strategy, under the Chairmanship of Peter Ackers. The Ackers Report, published in 1992, reviews the whole field of Flood and Coastal Defence research and will guide MAFF research strategy for the next five years.

MAFF currently spends £2.5m per annum on research and development and has a comprehensive programme of projects including many which are relevant to beach recharge. Many of these have started, or are due to start in April 1992, at HR Wallingford.

11.2.2 EC MAST-1 Programme

The MAST-1 Programme includes a cluster of projects on Coastal Morphodynamics led by the "Group of six" (G6) European hydraulic laboratories involved in coastal research. The G6-M objective is an agreed, validated and balanced modelling concept for morphological problems in coastal areas. G6-M consists of five technical projects, undertaking process research and model conceptualisation for random sea waves, coastal water motion, non-cohesive and cohesive sediment transport, and the morphological behaviour of the coast. The present contract is due to end in June 1992. The results of these projects will provide basic process information rather than software design tools, which will be developed later.

11.2.3 The SERC Coastal Research Programme

SERC has just launched a Coastal Research Programme which includes waves, currents, sediments and pollution in the surf zone, nearshore zone, estuaries and around structures. A Management Committee has been formed to oversee the Programme, with representation from other research funders. The Management Committee encourages academic researchers to submit proposals for projects covering theoretical development, 2D laboratory flume tests, 3D wave basin facility tests and field data measurements.

Current projects of particular interest include: *Modelling of fluid mud, Coastal morphodynamics* and *Bottom shear stresses under waves and currents crossing at arbitrary angles*. The first two of these include development of numerical models, and the third will produce data for model calibration and a direct means of measuring bottom shear stresses under waves.

With a few exceptions SERC-funded projects provide understanding of basic principles and processes, and the results require further work to produce practical tools for the coastal industry.

11.2.4 The NRA Flood Defence R & D Programme

The NRA R & D Programme is designed to serve the practical needs of NRA engineers and scientists. NRA R & D Topic C6, *Coastal and tidal processes and design* is made up of applied research projects with specific aims, such as the production of Manuals. The NRA will spend £0.25m on coastal engineering research in 1992/93. Proposed new projects for 1992/93 include the development of probabilistic design procedures and a beach management manual. The latter would describe current best practice on beach management and beach recharge, and could be produced as an early Stage 2 interim report.

Table 8 Summary of current and planned research projects

Funder	Project title *Research objective*	Contractor	Start	Finish	Ref.
MAFF	Study of shingle beaches *To study changes over the past two winters so as to assess the minimum beach profiles, and, where applicable, modifications to seawalls on the South Coast.*	HR Wallingford	Jan 1991	Oct 1992	A
MAFF	Assessment of alongshore drift variability *To compare the trend in longshore drift with that experienced in the winter of 1989/90 at points along the South Coast.*	HR Wallingford	Jul 1991	Nov 1991	B
MAFF	Behaviour of replenished beaches *To provide a data set covering site specific influences on shingle beach behaviour and long term development of the beach.*	HR Wallingford	1992/93		C
MAFF	Coastal cell maps *To prepare maps of coastal zones which can be considered as self contained between well defined promontories in that movement inside a cell is independent of any movement outside that cell.*	HR Wallingford	1992/93		D
MAFF	Model sediment transport in wave/current flow *To enhance understanding of the processes of sand suspension by combined waves and currents, and thereby to improve prediction methods for sediment transport and erosion/accretion on coastlines - mathematical modelling*	University College North Wales	1992/93		E
MAFF	Shingle movement in coastal waters *To measure in situ wave/current movements and threshold of shingle movement at sea bed. To derive empirical formulae for rate and direction of shingle movement. To identify parameters to be monitored for improved design and management of shingle.*	University of Southampton	Aug 1990	Jul 1993	F
MAFF	Beach replenishment using dissimilar materials *To optimise the design of beach replenishment schemes using material with a size and grading dissimilar to that occurring naturally.*	HR Wallingford	Jan 1991	May 1992	G
MAFF	Beach profile management *To provide advice based on examples and theory on the merits of different methods of artificially modifying beach profiles.*	HR Wallingford	1992/93		H
MAFF	Management of muddy foreshores and saltmarshes *To review methods of managing foreshores and saltmarshes to preserve or enhance their role in coastal defence while maintaining their environmental value, to provide guidelines for managers.*	HR Wallingford	1992/93		I
MAFF	Financial performance of coastal defence schemes *To investigate and develop methods of assessing how well a coast defence scheme has performed against a background of natural variation in the coastal environment.*	HR Wallingford	1993/94		J
MAFF	Sea defence standards *To develop a new and reliable design standard for allowable wave overtopping which will be applicable to the whole of the UK.*	HR Wallingford	1993/94		K
SERC	Bottom shear stresses under waves and currents crossing at arbitrary angles *To produce test data against which to calibrate numerical models of waves and currents crossing at arbitrary angles, specifically shear stresses, mean velocities and turbulence. To establish a UK test facility for measuring waves and currents in coastal waters. To develop a shear plate for direct measurement of bottom shear stresses under waves.*	Dr R R Simons & Dr A J Grass, University College, London	Oct 1989	Dec 1991	L
SERC	Modelling of fluid mud *To advance ongoing research into formation and transport of fluid mud. To study the effects of wave action, currents and the mechanism of entrainment. Numerical modelling of cohesive sediment transport.*	Dr K H M Ali & Prof. B A O'Connor, Liverpool University	Nov 1991	Nov 1994	M

Table 8 continued

Funder	Project title *Research Objective*	Contractor	Start	Finish	Ref.
SERC	Coastal morphodynamics *To examine the philosophy of existing n-line models. To develop new methodology. To examine reflectivity of structures with existing IWP models. To test new approach against laboratory/field data.*	Prof. B A O'Connor & Mr T S Hedges, Liverpool University	Oct 1991	Sept 1993	N
NRA	Development of probabilistic design procedures *To define and indicate the use of procedures for probabilistic design of sea and tidal defence.*	Not known	1992/93	1993/94	O
NRA	Beach management manual *To produce a practical manual incorporating best practice information on planning/design/management of beaches and beach recharge.*	Not known	1992/93	1993/94	P
NRA	Saltmarsh processes *To examine saltmarsh processes such as wave energy dissipation, role of creeks and erosion/deposition relating to mudflats/saltmarshes.*	Not known	1992/93	1993/94	Q
NRA	Saltmarsh guidelines *Practical guidelines arising from ref. Q and a second NRA project on estuary morphology and saltmarsh deterioration.*	Not known	1992/93	1993/94	R

11.3 RECOMMENDATIONS FOR STAGE 2 PROJECTS

The following recommendations are for Stage 2 Projects which would lead to the production of an authoritative Beach Recharge Design Manual. Where applicable, the recommendations refer to current and planned research projects in Table 8. It is stressed that the existence of current research does not necessarily satisfy the recommendations; in some cases the existing research has not been developed with beach recharge in mind, so might not go far enough, or might have a different emphasis. This is in no way intended as a criticism of current research programmes, which have simply been developed with a different focus. The precise relevance of existing research to the production of a beach recharge manual would be determined as part of the co-ordination exercise in Stage 2.

The recommendations are grouped under the headings used to list the conclusions in Section 10. All the projects listed are of high priority. The suggested Stage 2 framework including these projects is illustrated in Figure 11.

11.3.1 Availability of material (AM)

AM1 A map should be produced showing those areas round the UK coast which are most likely to be a useful source of beach recharge material.

This would provide information on materials in the coastal zone which could be used immediately to indicate areas in which detailed surveys would be worthwhile. No such information is available at present and none of the projects listed in Table 8 will produce it. The need for this information has been recognised by MAFF and a similar recommendation appears in the Ackers Report (MAFF, 1992).

AM2 The dredging activities of ports and other commercial enterprises should be collated and mounted on a database for comparison with other information.

This would provide information on the suitability and availability of dredged spoil. The usefulness of such material has been studied by Posford Duvivier Environment for English Nature and this work would be reviewed. None of the projects listed in Table 8 are investigating this source of recharge material. This source of material for beach recharge has also been recognised by MAFF in the Ackers Report (MAFF, 1992).

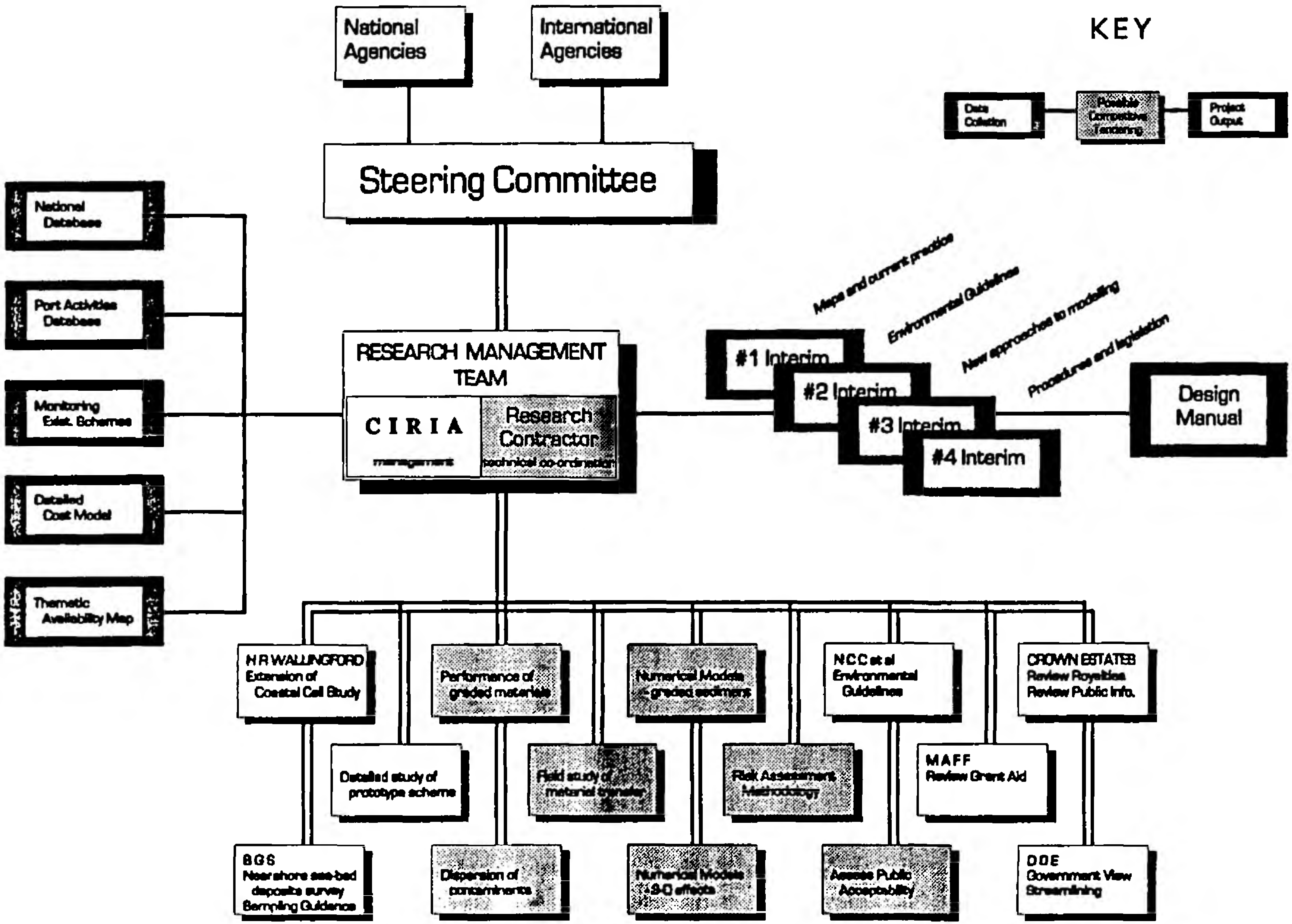


Figure 11 *Suggested framework for CIRIA Stage 2 Project*

AM3 The British Geological Survey should extend its assessment of sea-bed deposits to provide comprehensive cover of the nearshore zone.

This would provide detailed information on materials which are not generally available to the aggregate industry but might be suitable for beach recharge. Existing BGS maps do not cover inshore and near offshore areas.

AM4 Guidance should be produced on methods of sampling seabed deposits to provide information on the quality and quantity of materials for beach recharge.

This would guide coastal engineers through the technical and administrative procedures involved in assessing the suitability of materials identified by projects AM1 and AM3. Current practice for establishing the nature and extent of surface seabed deposits is adequate, but guidance may be needed on aspects of particular importance to beach recharge.

AM5 A study of measures necessary to make confidential information on seabed deposits publicly available should be undertaken.

This would investigate the release of information on non-aggregate quality material currently considered confidential to aggregate companies. None of the projects listed in Table 8 are addressing this issue.

AM6 Discussion should be initiated with the Department of the Environment on streamlining of procedures to speed up the consultation process leading to issue of production licences for beach recharge material.

This would reduce the time taken to obtain production licences for recharge material. None of the projects listed in Table 8 are addressing this issue.

11.3.2 Beach performance (BP)

BP1 Research into the performance of beaches recharged using material contaminated with non-hazardous fines and soft material should be undertaken to provide basic design information.

Much of this work is covered by existing MAFF, MAST and SERC projects; including Refs. C, E, G, I, M, and Q in Table 8. These would need to be investigated in detail and possibly extended to provide the required focus. A similar recommendation is made in the Ackers Report (MAFF, 1992).

BP2 A National Beach Database for storage and retrieval of beach monitoring data should be set up. Discussions should be held with the NRA, MAFF and other relevant authorities to decide who is best placed to design and maintain such a database.

This would partially rely on information collected under BP3 and BP6. Other relevant research which would provide data includes refs. A, B, C and D in Table 8.

BP3 The monitoring of existing beach recharge schemes should be intensified to provide calibration data for numerical models.

Some monitoring is already being funded by MAFF (ref. C in Table 8). This might need to be supplemented to provide information on a wider range of conditions. MAFF (1992) have already recognised the need for increased monitoring.

BP4 Liaison between the UK and Holland should be continued through CIRIA's existing agreement with CUR. This would increase UK knowledge on the performance of beach recharge schemes using fine-grained materials.

Such liaison would provide valuable information for a Manual of Current Best Practice (see below), using Dutch beach recharge expertise.

BP5 HR Wallingford's coastal cell study should be extended to include accreting foreshores and to identify gaps in monitoring data.

The existing study will produce Coastal Cell maps in 92/93 under a one-year MAFF project (ref. D in Table 8).

BP6 Detailed monitoring of a beach recharge scheme using non-aggregate materials should be undertaken. The proposed use of Harwich Harbour dredgings in Essex would be suitable for this purpose, but would only provide information on fine material and sheltered recharge areas.

This could be carried out as an extension to Project BP3. No such monitoring has been carried out to date and none of the projects listed in Table 8 will monitor beaches recharged with non-aggregate material.

11.3.3 Economic factors (EC)

EC1 A detailed cost model should be developed which fully incorporates the effects of varying material types and differing locations.

Some work has already been carried out by WRc using Dutch cost information. None of the projects listed in Table 8 are addressing this issue.

EC2 The Ministry of Agriculture Fisheries and Food should consider extending its grant-aid policy to cover monitoring and periodic restoration of recharged beaches.

This is already under active consideration by MAFF.

EC3 Discussion should be initiated with The Crown Estate to develop a policy on royalty payments for materials for sea defence or coast protection purposes.

Royalties for beach recharge schemes are agreed with marine aggregate extraction licence holders or directly with the Crown Estate where appropriate for individual schemes. A more long term policy for beach recharge material would be desirable.

11.3.4 Environmental factors (EN)

EN1 Discussion should be initiated with statutory conservation agencies with the objective of establishing guidelines for the environmental assessment of beach recharge schemes.

Some such work has already been carried out by Posford Duvivier Environment for English Nature, but only one sand fraction has been considered. This work would be reviewed and possibly extended.

EN2 The public acceptability of beaches recharged using material dissimilar to the original material should be assessed.

No other studies in this area are proposed, although there are plans to carry out work on the design of beaches using dissimilar materials (ref. G in Table 8).

EN3 Discussion should be initiated with the Department of the Environment on changes to the Government View procedure. In particular, the question of whether the *zero effect principle* could be relaxed to a *net benefit principle* where material was required for beach recharge should be addressed.

None of the research projects listed in Table 8 are directly related to this recommendation, but coastal cell maps (ref. D) and advances in numerical models (refs. E, F, M, and N) will impact on it.

EN4 Fieldwork should be undertaken to assist in the determination of the processes involved in the interchange of material between beaches and offshore banks. The results of such work may have a profound effect on the Government View Procedure.

MAFF-funded projects E and F in Table 8 are investigating sediment transport and would be reviewed and, if necessary, extended.

11.3.5 Design approaches (DA)

DA1 Practical guidelines should be developed for the design engineer on the supply, placing and subsequent monitoring of non-aggregate marine materials in beach recharge schemes.

This should be tackled on two levels. The first would provide Current Best Practice information in the short term (ref. P in Table 8). The second would produce an authoritative Design Manual. All the other recommendations and associated current and planned research described in this report would provide information for the authoritative Manual, and in particular refs. C, H, I, Q and R in Table 8. The development of improved beach design methods has been identified by MAFF (1992) as a priority area for research.

DA2 Research into the hydraulic characteristics of graded materials under wave and current action should be encouraged to support model development.

Some of this work might be covered indirectly by the current MAFF and MAST programmes. These should be investigated in detail to determine whether any additional work is needed.

DA3 Numerical models capable of simulating graded sediment transport should be reviewed and future development tailored to meet future needs.

Models for review could be identified through current MAFF, SERC and MAST programmes, many of which will produce conceptual or numerical models. Model development has been identified in the Ackers Report for MAFF (1992) as a research need.

DA4 A review of 3-dimensional coastal area models should be made and future developments directed for application to beach recharge.

Models for review could be identified through current MAFF, SERC and MAST programmes.

DA5 The risks associated with the use of beach recharge should be defined and a method for assessing these risks developed.

There is no current research which is specifically looking at the risks associated with beach recharge, but there is some overlap with refs. J, K and O in Table 8.

11.4 RECOMMENDED ACTIONS

A Working Group should be set up to consider the recommendations of this report in conjunction with the identified research needs of the NRA and MAFF. The Working Group should include funders of current and planned work, potential funders for Stage 2 of the CIRIA project, researchers, and coastal engineers responsible for beach recharge schemes. Organisations which could be represented are:

- Ministry of Agriculture, Fisheries and Food (coastal engineering and environmental protection functions)
- Department of the Environment (coastal zone planning and minerals functions)
- National Rivers Authority
- The Crown Estate
- Coastal authorities
- British Geological Survey
- SERC
- Academic researchers
- Ports and Harbours
- English Nature
- Joint Nature Conservation Committee
- HR Wallingford
- Federation of Dredging Contractors
- Consulting engineers
- CIRIA

11.4.1 Working Group objectives

a) To confirm the need for a coordinated approach to producing guidance on the supply, placing and subsequent monitoring of non-aggregate marine materials in beach recharge schemes.

b) To agree the priorities for further work on beach recharge and identify projects which could start immediately under Stage 2 of the CIRIA project, such as a Manual of Current Best Practice.

c) To agree a programme of research for the remainder of the CIRIA Stage 2 project, based on the recommendations of this report and leading to the production of an authoritative Beach Recharge Manual.

d) To establish an approximate order of costs for the various parts of Stage 2 of the CIRIA project, split into annual increments; and establish the likely degree of benefit to each potential funder.

e) To establish and obtain a committment for an appropriate level of contribution from potential funders for Stage 2 of the CIRIA project.

11.4.2 Suggested method for planning the CIRIA Stage 2 project

A study including the following steps is suggested as a method for planning the CIRIA Stage 2 project. Work which could start immediately, such as a Manual of Best Practice, should already have been identified.

a) Review in detail all relevant current and planned research, including timescales, and assess the degree to which this satisfies the requirements for an authoritative Beach Recharge Manual.

b) Identify gaps in current and planned research which would need to be filled before an authoritative Beach Recharge Manual could be produced.

c) Design costed projects to fill the gaps identified in b) and secure funding for these.

d) Set up a coordination framework for the Stage 2 project to include current and planned research as well as new projects. This should make full use of all existing coordination mechanisms such as the SERC Coastal Research Management Committee and the NRA's proposed Coastal Research Steering Group.

e) Produce a detailed schedule for the Stage 2 programme, taking into account existing research timescales and outputs as well as those of new projects.

f) Form a Steering Committee for the Stage 2 project to oversee the work.

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Appendix A Budget prices

1. The dredging industry was asked to supply budget estimate costs for various production and transportation options.

2. **ASSUMPTIONS**

2.1 The prices are based upon the use of a 2500 m^3 trailer suction dredger with a loaded draft of 7.0 m and above to discharge a maximum distance of 500 m.

2.2 The material to be dredged in the borrow area shall consist of loose to dense sand and/or gravel, both with a low content of fines. The borrow area has a minimum water depth of 7.0 m.

2.3 The quoted unit rates per m^3 are measured as placed on the beach but do not allow for any losses during transportation and placement. In general these losses may vary between 15 and 30% subject to the site location and material specification.

2.4 The quotations are based upon the assumption that the dredger will be able to work 7 days per week, 24 hours per day. There is no allowance for down time due to climatic conditions which may vary seasonally and by location.

2.5 The units rates have not included for any royalties, harbour duties, pilotage, conservancy charges etc.

3. **SCOPE OF WORK**

3.1 The unit costs will include for the following procedures where applicable:

- dredging, transportation and pumping ashore by hopper;
- additional land booster for pumping ashore of coastal materials;
- direct pumping of fill to the beach, i.e. no land based transport;
- spreading and levelling of the reclaimed material;
- handling of pipelines;
- survey and positioning;
- free drain off of the return water.

4. **PARAMETERS**

4.1 Material Types

(a) d_{50} = 250 - 350 micron.
(b) d_{50} = 750 - 1250 micron.
(c) d_{50} = 2000 - 5000 micron.

4.2 Dredging Depths

(a) 10 - 15 m water depth
20 - 25 m water depth.

4.3 Transportation Sailing Distances

(a) Over 5 nautical miles.
(b) 10 - 15 nautical miles.
(c) 15 - 20 nautical miles.
(d) Greater than 20 nautical miles.

4.4 Pumping Distances

Material	250-350 μm	750-1250 μm	2-5 mm
Max. pumping distances (m)			
Hopper only	1800 m	800 m	na
Hopper plus land booster	na	1600 m	1000 m

The above table includes the 500 m from the hopper dredger to the booster station and therefore the maximum length of beach recharge possible without the relocation of the land-based booster pump would be:-

Material	250-350 μm	750-1250 μm	2-5 mm
Effective beach length (m)			
Hopper only	2600 m	600 m	na
Hopper with land based booster pump	na	2200 m	1000 m

5. COSTS

5.1 Material with d_{50} = 250 - 350 μu

(a) Hopper dredger (effective beach length 2600 m)

Sailing Distance	Dredging Depth	
	10 - 15 m	20 - 25 m
5 nm	£1.70/m³	£1.90/m³
10 nm	£2.10/m³	£2.30/m³
15 nm	£2.55/m³	£2.70/m³
20 nm	£3.00/m³	£3.15/m³

(b) Hopper dredger with 200 Kw land based booster

Not used for the purpose of this budget estimate because of the relatively high mobilisation costs of land based discharge pipelines.

5.2 Material with d_{50} = 750 - 1250 μm

(a) Hopper dredger (effective beach length 600 m)

Sailing Distance	Dredging Depth	
	10 - 15 m	20 - 25 m
5 nm	£2.10/m^3	£2.30/m^3
10 nm	£2.50/m^3	£2.70/m^3
15 nm	£2.90/m^3	£3.10/m^3
20 nm	£3.30/m^3	£3.50/m^3

(b) Hopper dredger with 2000 Kv land based booster (effective beach length 2200 m)

Sailing Distance	Dredging Depth	
	10 - 15 m	20 - 25 m
5 nm	£2.60/m^3	£2.80/m^3
10 nm	£3.10/m^3	£3.30/m^3
15 nm	£3.60/m^3	£3.80/m^3
20 nm	£4.15/m^3	£4.35/m^3

5.3 Material with d_{50} = 2000 - 5000 μm

(a) Hopper dredger

Not applicable.

(b) Hopper dredger with 2000 Kv land based booster

Sailing Distance	Dredging Depth	
	10 - 15 m	20 - 25 m
5 nm	£3.30/m^3	£3.80/m^3
10 nm	£3.80/m^3	£4.30/m^3
15 nm	£4.30/m^3	£4.80/m^3
20 nm	£4.80/m^3	£5.30/m^3

5.4 Mobilisation and Demobilisation Costs

(a) Mobilisation hopper dredger floating submerged and land based pipelines — £130,000

(b) Intermediate relocation of floating submerged and land based pipelines — £50,000

(c) Demobilisation hopper dredger floating submerged and land based pipelines — £100,000

(d)	Mobilisation land based booster and pipeline	£60,000
(e)	Intermediate relocation of booster station	£25,000
(f)	Demobilisation land based booster and pipeline	£50,000

5.5 The above budget estimates do not include for value added tax and should only be used as an initial guidance only. For a more accurate estimate relative to a specific location it may be necessary to consult the dredging industry.