# Soft engineering techniques for high and low energy coasts

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## Introduction

Whilst hard coastal defences (solid structures which prevent land:sea interaction) effectively fight wave energy, soft defences aim to dissipate it using natural coastal processes. In this way, coastal defence works in sympathy with natural processes of sediment erosion, storage and transport, (known as the sediment budget, not against them. This results in a low maintenance coastal system which is able to respond to external forcing factors such as storms and sea level rise. Wide beaches and mudflats dissipate wave energy, as do coastal wetlands, hence, their creation can effectively protect the coast from erosion and flooding without the need for large concrete sea walls.

Coasts and estuaries contain a series of morphological features (Beaches, sand dunes, spits and bars, cliffs, intertidal flats, salt marshes). Soft engineering solutions to coastal erosion reflect the natural behaviour of these morphological types and manage them so as to achieve coastal protection. The main engineering options are:

- Beach management
- Dune restoration
- Cliff stabilisation
- Mud flat recharge
- Polders
- Salt marsh creation
- Abandonment

### 1.1 Sediment budget

All coastlines continuously receive and lose sediment by processes of long shore drift and on/offshore sediment movement. Such sediment movement can be calculated in the form of a budget, where inputs (from erosion) count as plusses, and outputs count as negatives. The successful management of any coast requires a knowledge of where sediments enter the coastal system (plusses), where they leave it (negatives), and where they are stored within it. Areas of storage are typically referred to by other names, such as beaches, dunes, mud flats, etc. In order to survive, coastal features (stores) need to receive at least as much sediment as they lose, otherwise they will experience net erosion. Soft engineering, therefore, has to adopt an holistic approach, and needs to know details of sediment inputs sediment transport pathways, areas of sediment storage and sediment losses from the system.

#### 1.1.1 Sediment inputs

- the reworking of sediment from a sediment store into the sediment budget.

These may be cliffs, beaches, offshore sources, but in a world-wide context, predominantly from rivers. In areas where inputs exceed outputs, there will be a net sediment gain, and accretion will result. Where sediment losses exceed inputs, there will be a net sediment loss and erosion will result. Hard defences, such as sea walls, are one of the main methods by which sediment inputs are reduced and coastal erosion initiated. In rivers, a prime cause of input reduction is river bank protection and dam construction.

Where sediment inputs are particularly low, they can be augmented by human actions, such as beach feeding or mudflat recharge.

#### 1.1.2 Sediment transport pathways

- the route taken by sediment from source to store

Once eroded, sediment is moved from its source, along shore until it is deposited in a sediment store. This movement occurs by tide and wave generated currents and may be by near shore (longshore drift), or offshore currents. On some coasts, wind also plays an important role in transferring sand to the high beach (supra-tidal zone), where it forms sand dunes.

Hard defences, such as groynes (spelt groins in the U.S.A.) or jetties interrupt this long shore movement and prevent the supply of sediment to downdrift beaches. This results in sediment starvation and net erosion of these areas. The area up-drift of the groyne or jetty traps this sediment, which is why groynes are frequently used on coasts to promote local beach accretion.

##### 1.1.2.1. Further information

Title: Impact of groynes on beach sediment

Type: Web site
URL: http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1617/toc.htm
Organisation: The U.S. Army Corps of Engineers (USACE) is the primary group in the US responsible for coastal defence construction and research. Many of their engineering report and manuals are held within the public domain and can be found through the above URL
Abstract: The document refers to the use and design of groyne and jetty structures and their impact on beach sediment accretion patterns.

**1.1.3 Sediment stores**

- any area on the coastline where sediment is deposited.

Any sediment deposit (beach, sand dune, salt marsh, mudflat, cliff, etc) may be regarded as a store because they represent sediment which has the potential to be moved by waves at some later date. These stores are not permanent but occur because the sediment they contain is surplus to the sediment budget at the present time. When needed, this sediment is reworked and transported (eroded). Cliffs may be regarded as a special case because they represent a long-term sediment store. Initially the sediment contained within the store was laid down over geological time scales, and only now are these stores being utilised.

Soft engineering attempts to maintain these stores as accessible features, and does not isolate them from the sea by means of walls or other structure.

**1.1.4 Sediment losses**

- the removal of sediment from the coastal system

Material may be lost from the system by either leaving at the downdrift end of a section of coastline, being transported offshore during storms to a point beyond normal wave base, or by being locked up behind hard defence structures. Either way, this represents a deficit to the sediment budget, which needs to be compensated for by increased inputs if a net balance is to be maintained.

## 2 Beaches

- gently seaward sloping store of sediment between low and high water. In its strictest sense this term is independent of grain size, although common misusage has led to its adoption mainly in the context of sands and shingle features.

Beaches are mobile features which respond to changes in wave energy by changing shape and profile length. The equilibrium beach is one where sediment inputs equal sediment losses, although many beaches experience a dominance in one or the other and are thus not in equilibrium.

Beaches, along with mudflats and salt marshes are the most efficient method of dissipating wave energy due to the friction caused when water (wave) flows across the beach (sediment) surface. The wider the beach, the greater this level of dissipation will be, and the less need for upper beach defences (sea walls).

Title: Impact of sea walls on beaches
Type: Web site
URL: http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1204/toc.htm
Organisation: The U.S. Army Corps of Engineers (USACE) is the primary group in the US responsible for coastal defence construction and research. Many of their engineering report and manuals are held within the public domain and can be found through the above URL
Abstract: This manual covers important environmental considerations relevant to the construction of hard sea defences. Issues include studies of different structures and their impacts on beach levels.

Where sediment input to beaches is less than the volume of material removal, a situation of net erosion results, meaning the beach will become less effective in wave energy dissipation, and the hinterland will receive greater amounts of wave energy. There are three main ways of overcoming this problem:

- Add more sediment to compensate for reduced input, and to at least equate for the imbalance in inputs and losses. This method is known as beach feeding, but is also referred to as beach recharge or beach nourishment.
- Artificially change the profile of the beach by moving material from the low beach area back to the high beach, thus increasing the volume of material available for beach draw down by waves. This method is known as beach scraping
- Beach erosion is also related to level of the beach water table. By lowering this, sediment stability increases and erosion is reduced. This may be achieved by beach drainage.

### 2.1 Beach feeding

Where beaches experience net sediment loss, the artificial increase of beach volumes will serve to make good this budget deficit (see Caioba example from Brazil). With adequate sediment added, the beach will continue to serve as efficient storm protection (see also mudflat recharge). The majority of situations where feeding is necessary are those where sediment input from updrift has been reduced by the construction of hard defences.

There are three main techniques for beach feeding:

- Direct placement of sediment on the beach
- Trickle charging
- Pumping

Beach feeding has become one of the most popular approaches to soft coastal engineering over the past decade or so, and many regard it as the ultimate response to beach degradation. However, beach processes and, by inference, the technique itself is still not fully understood and not all experiences have been favourable.

Key factors which need to taken into consideration when planning recharge include:

- The recharged profile
- Grain-size of recharge material
- Recharge volume

In addition to these planning considerations, there are other factors which are also of importance:

- Permanence

- Source of recharge sediment
- Environmental impacts

### 2.1.1 Further information on beach feeding: The Caioba example

Title: Caioba Beach, Brazil
Type: Web site
URL: http://www.netpar.com.br/lindroth/caiobain.htm
Abstract: This study demonstrates the use of beach feeding in one area of Brazil, and highlights the problems and background details necessary for beach feeding techniques to be employed.

### 2.1.2 Direct placement

- importing large volumes of sediment from either land-based sources or from down drift on the same beach.

Where no economically viable offshore sources are available (see trickle charge and rainbow pumping, land-based sources or the down drift end of the beach itself can be used to source sediment recharge. Typical sources to be considered include:

- Down drift sediment accumulations, particularly in association with sediment trapping by jetties.
- Quarried stone (crushed to suitable 'grain size')
- Inland sand sources (e.g. poorly cemented sandstone)
- Quarry waste (e.g. residual quartz from china clay extraction)
- Mine waste

All sources listed have been used to feed beaches in locations world-wide, although problems of permanence and unsuitable grain-size properties have occurred. Sediment recycling from down drift is perhaps the most suitable because it reuses littoral sediment which has been sorted according to the wave and tidal climate of the area. Other sediment sources may experience rapid initial profile and volume adjustments because they represent sediment alien to the environment in which they are placed.

Delivery to the beach is normally by road and profiling is carried out by heavy plant. The shape of the profile can be calculated according to research-derived equations (see profile).

To make effective the use of sediment sources, certain criteria need to be met:

- Adequate infrastructure to allow lorry access to both source and beach.
- Source material to be close enough to recharge site to make process cost-effective.
- Quarry or mine waste needs to be suitably 'clean' and free from contaminants.
- Sediment grain size, roundness, sphericity and specific gravity need to reflect those naturally occurring on the beach if an acceptable level of permanence is to be achieved.
- No detrimental impacts on source area

Clearly, the most ideal source of sediment is that which comes from the littoral environment. This means that offshore sources are the most favoured and should be considered first as possible sediment supplies.

### 2.1.3 Trickle charging

- the slow recharging of beaches by the placing of sediment at either a single point, or series of points on the beach and allowing either longshore or onshore currents (depending on location of sediment placement) to move and distribute sediment across the beach.

Typical locations for placement are;

- Offshore above normal wave base. For coasts with strong onshore currents. Sediment will be brought up the beach and distributed as a natural profile. The position of sediment placing is critical. In particular is the relationship to closure depth. Sediment placed above closure depth tends to disperse and move rapidly onto the beach. Sediment placed below closure depth will move shorewards only under certain conditions, and shoreward transfer is not certain.
- Low water mark. Similar processes involved as above.

- Up drift end of degraded beach. For coasts with strong longshore currents. Sediment will be moved naturally along the beach, mimicking natural coastal processes.

In order to determine the most appropriate method, a detailed understanding of longshore and onshore currents is vital. The advantage of this approach is that the resulting beach profile forms naturally, and so will become an integral part of the coast:beach system. The disadvantage is that the recharge process is slow when compared to pumping.

Dredging is the most frequent means by which to obtain sediment. Typical source areas to be considered are:

- Offshore berms or shoals
- Other suitable areas of sea floor sediments
- Maintenance dredging in ports and harbours
- Capital dredging schemes as one-off sources
- Recycling from down-drift accumulations

Delivery to the site will be by barge or pumping into the sites from which sediment will be naturally moved.

### 2.1.4 Pumping

- the rapid recharging of extensive beach areas by pumping sediment directly onto the beach and artificially profiling using heavy plant.

This is the most rapid way to recharge a beach but does require a modelling approach to obtain the final profile. This will subsequently undergo adjustment by waves following recharge. Sources of sediment are the same as those listed above but instead of being dumped in discrete piles, the material is pumped onshore via a pipeline. Two approaches can be used:

- Pumping via a pipeline which runs up the beach from the dredger moored off the coast, potentially over the dredge site. Sediment is pumped into discrete areas, often delineated by bunds to pond up water and allow slow seawards drainage. Because sediment is delivered by pipeline, large dredgers can moor offshore and deliver large volumes of material to extensive areas, and over relatively short time periods, thus making the method suitable for large recharge schemes.
- Spraying from the dredger (rainbow pumping) which is moored close inshore, to cover the whole beach. This method can be most effectively used along coastlines with low tidal ranges and low wave energy. The need to get close inshore does have disadvantages, in that the dredger draft is limited, thus restricting the size of the vessel. This restriction means that the spraying technique is often restricted to small recharge schemes.

The processes involved in this approach to beach feeding impart additional requirements and restrictions on its application. In particular:

- In order to be pumped, the sediment needs to be in a fluid state, which is achieved by mixing it with 10% water. This water will then drain back seawards with the potential of carrying sediment with it unless ponded.
- The use of long pipelines between dredger and beach mean that operations may only occur in calm weather
- On gently shelving coasts where the dredger needs to moor some distance offshore, intermediate pumping stations need to be installed to maintain pumping pressure.

Such issues are not, however, the main concern of the coastal engineer, as licensed dredging companies provide plenty of experience in such operations.

### 2.1.5 Beach nourishment as a coastal management tool

Title: Beach nourishment as a coastal management tool
Type: Scientific publication
Authors: Davison A.T., Nichols R.J. & Leatherman S.P. (1992)
Reference: Journal of coastal research 8(4): 984-1022
Abstract: An annotated bibliography of on developments associated with the artificial renourishment of beaches. The paper provides an overview of issues pertaining to beach feeding covering the methods outlined in 2.1.2 – 2.1.4. The text is exemplified with many case studies and methodological details relating to a wide range of experiences world-wide.
Language: English

### 2.1.6 Importance of profile

Beach profiles vary according to grain-size, wave climate, tidal range, and storminess. Because of this wide variability in forcing factors, estimating profile shape for recharged beaches is difficult. The general rule is that the recharged profile should reflect that of a natural concave beach. Once recharge is completed, the beach will naturally adjust to the ambient conditions until it reaches a situation of dynamic equilibrium. The trick is to make this period of adjustment as short and as ‘undramatic’ as possible. Two main scenarios should be avoided:

- A beach which is over-steep will become reflective and encourage sediment draw down, possibly leading to erosion.
- A beach which is too shallow may stick out too far into the surf zone and actually act as a barrier top longshore sediment movement (aka groynes and jetties). In addition, its construction will require excessive amounts of sediment and increase its cost.

The issues of estimating profiles occur only with rainbow charging methods, as trickle charging allows the natural processes to form their own profile. The process of predicting the recharge profile can be carried out using one of two approaches:

- A knowledge of natural beach profiles. The immediate pre-recharge beach is not a good model for this as it is degraded and not in dynamic equilibrium. The Dutch method is to estimate how much sediment has been lost through erosion and to estimate recharge volumes and placement locations from this.
- By using a mathematical model which allows predictions to be made. A simple model is provided by Dean (1991)

$$h(y) = Ay$$

where:
h = water depth
y = seaward distance from a fixed point
A = scaling parameter related to sediment grain size

Given that the elevation of high water is known, water depths can be calculated along a shore normal profile, allowing a stable profile to be constructed by survey methods. Although simplistic, the results from this equation compare favourably with non-recharged, stable beach profiles.

#### 2.1.6.1 Equilibrium beach profiles: Characteristics and applications

Title: The importance of profile in recharged beaches
Type: Scientific publication
Author: Dean R.G. (1991)
Reference: Journal of coastal research 7(1): 53-84
Abstract: By understanding equilibrium beach profiles, a valuable insight can be gained into the engineering of beaches. The equation detailed above forms the basis of the mathematical solutions to the form and shape of the required profile. Different profile types and their importance is discussed in detail, outlining the importance in getting the recharged beach shape correct if adequate wave attenuation is to be achieved.
Language: English

### 2.1.7 Importance of grain-size

Beach profiles get shallower as sediment grain-size decreases. Clearly, to maintain a ‘natural’ beach profile for any section of coastline, it is important to use the correct grain-size of sediment. If this is miscalculated, one of two things could occur:

- If sediment is to fine, it will be unstable in the wave climate and wave energy will rapidly wash material offshore, producing rapid beach degradation.
- If sediment is too coarse, waves will be unable to move sediment around, producing an un-responsive, over-steep beach which may become reflective and induce erosion.

This latter point may be developed to the planner’s advantage. Considering beach loss is due to currents removing sediment, material slightly coarser than that originally present can be used to reduce the amount of sediment lost and thus increase beach stability. On sandy beaches, a grain-size of 1.5 times the original is recommended to increase permanence.

### 2.1.8 Importance of recharge volumes

The volume of the healthy beach, minus the volume of the degraded beach equals the volume of sediment needed to recharge the profile. Not all recharge sediment will remain on the beach because the grain size distribution is generally greater than that of the natural sediment, and initial losses can be great. The beach will also need to undergo profile adjustments to achieve an equilibrium profile. It is important, therefore, to over-charge a beach to cover these initial losses. These losses normally occur within a year or two of recharge and should be expected. Estimates of excess volumes required range from 20% to 40% depending on grain-size.

In addition, the following have implications for beach volume calculations:

- Storm frequency and severity (to estimate draw down volumes)
- Wave climate
- Wind climate
- Longshore and on/off shore transport rates
- Natural profiles
- How the beaches have behaved historically.

It is important to realise that following recharge, sediment will also be lost over the medium to long term due to ongoing longshore and on/off shore movements (i.e. the original cause of the beach degradation problem – beach feeding does not treat the cause, just the symptoms). This issue relates to the permanence of the recharge scheme.

### 2.1.9 The issue of permanence

No beach recharge scheme will offer a permanent solution to the problem of beach erosion, it will only provide a temporary solution to the loss of beach sediment. The permanence reflects how long will it be before more sediment needs to be added to the beach to feed it again.

Measures used include:

- Recharge lifetime – how long the sediment lasts
- Beach half life – time taken for recharge volume to drop by half
- Critical beach level (CBL) – beach level at which the beach is no longer able to offer effective wave attenuation and hinterland protection. Due to sea level rise, the CBL increases over time, thus successive fills need to involve larger volumes.

As erosion rates can be measured, the point at which the CBL will be reached can be estimated, therefore allowing subsequent recharges to be planned and budgeted for. Some examples of time taken to reach CBL are:

- Bournemouth ca. 13 years
- East coast, USA ca. 5 years
- Westerland, Germany ca. 6 years

The time period relates to the physical processes operating on the beach (waves, tides, storms, natural sediment supply, etc). Each CBL, therefore, needs to be calculated for each individual site. Each repeated recharge, however, involves cost, and therefore these repeat costs need to be built into original planning estimates for recharge schemes.

#### 2.1.9.1 Beach replenishment: implications for sources and longevity form results of the Bournemouth schemes.

Title: Beach nourishment longevity
Type: Chapter from coastal management publication
Authors: Cooper N.J. & Harlow D.A.
Full reference: pp163 – 177 in Hooke J. (editor) (1998) Coastal defence and earth science conservation. The geological society, London. ISBN 1-897799-96-9
Abstract: With effective beach profile monitoring it is possible to determine the loss of recharge material, both in the initial stages following feeding, but also in the longer term, as a result of continued long-shore drift. Using these records, net beach volume can be plotted and these can be used to estimate the time to reach CBL, and hence, the time when further recharge will be needed.
Language: English

### 2.1.10 The source problem

An important consideration for any recharge is the material source. Given that the popularity of the method is increasing, not just for coastal protection but also for tourism, there is an important issue here – *Where will all the sediment come from?*

With 70% of the world's beaches eroding, it is predicted that demand for sediment will outstrip supply in the near future. There are a series of potential sources:

- Quarries
- Reworking quarry and mine waste
- Reworking 'fossilised' beach deposits
- Reworking from down drift
- Port and harbour dredging
- Lagoons and barrier island coasts
- Rivers
- Offshore

Each of these have their own degree of suitability associated with them. Offshore sources, dredgings, and reworking of existing beaches are to some degree 'sustainable' because they continuously accrete. However, the rate of accretion may not match the rate of extraction and so they may not replace themselves over suitable time periods. Beach sediment may become a tradable commodity in the future.

### 2.1.11 Environmental issues

Any coastal defence scheme will have a series of associated environmental issues. With recharge these impacts are less than other methods, because we are, in effect, replacing what the waves have removed. However, beach feeding adds large volumes of material to an environment in which it would not naturally be. The main impacts are:

- Beach compaction during reworking of placed material may reduce swash infiltration and increase surface runoff, thus enhancing beach erosion.
- Seaward drainage of water used in sediment pumping can cause intertidal scouring. Also, seaward transport of fines may clog pore spaces and thus reduce swash infiltration.
- Impact on source area. Offshore berms may be acting as natural wave breaks, for example. Dredging should not over-deepen the near shore area as this will allow large waves to penetrate further inland. Increased turbidity may also occur during dredging.
- Impacts on infauna which needs to adjust its vertical position in the beach. During rapid placement of sediment, they may not be able to do this quickly enough.
- Impacts on other fauna, such as beach-nesting turtles and some bird species, where sediment may not have the same drainage or thermal properties to encourage successful hatching.
- Impacts of sediment loss through draw-down and post recharge profile adjustment (especially on coral reefs)

### 2.1.12 Summary of benefits

- Increased beach levels provide improved coastal protection through more efficient wave attenuation and ability to respond to storms
- Better beach development for amenity usage encourages economic development (see also 2.1.13)
- Increased socio-economic stability for coastal communities
- Maintenance and possible enhancement of natural coastal processes and sediment transport
- Maintains coastal dynamics largely intact

### 2.1.13 Summary of problems

- Increased turbidity around dredge and backwash areas may impact on benthic or nektonic communities
- Enhanced amenity usage may encourage coastal development, thus causing a greater commitment to coastal defences in future. Not acceptable under many sea level rise scenarios
- Short longevity of many schemes meaning the frequency of repeat recharge is high, coupled with costing of such.
- Impacts on beach infauna
- Inability to function as 'natural' beaches. Not dealt with in detail here, but recharge beaches do not, overall, function in the same way as natural beaches

- Identification of future sources, given increased popularity of the method

**2.1.14 Recommended usage**

- To protect and enhance beach development in areas of sediment starvation due to hard defences and source deficits
- To increase and protect amenity usage, providing increased security for coastal development. Care should be taken, however, that development is not encouraged by the method's usage, as the fact remains that the coastal erosion issue has not been solved.
- Where the maintenance of 'naturalness' is important, such as on heritage coasts or other important conservation sites.
- Where the coastal sediment budget is already is severe deficit, and new supplies of sand would serve an important function not just around fill area, but down drift.
- To supplement other defence structures.

**2.1.15 Further expertise**

Title: Engineering and Design - Design of Beach Fills
Type: WWW document/engineering manual
Organization: U.A. Army Corps of Engineers
Link: http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-3301/toc.htm
Abstract: This USACE document covers key aspects of this technique, notably site characteristics, borrow site characteristics, design and stabilisation of the recharged profile, scheme planning, performance monitoring, and an operations and maintenance manual.

**2.2 Beach Scraping**

- to restore the beach profile by redistributing existing beach sediment (often following storms).

Where sediment losses are not severe enough to warrant the importation of large volumes of sediment (see beach feeding 2.1]), it is possible to increase beach stability by artificially re-profiling the beach. This may be important following large scale storms which produce excessive draw down of sediment.

Beach scraping (also known as beach re-profiling), involves moving sediment around on the beach to increase its wave dissipation effectiveness.

**2.2.1 Methods**

A simple technique involving the physical relocation of sediment using heavy plant. Typically, sediment is pushed up the beach from the source area and fashioned into the desired profile.

The depth of scraping will effect the success and longevity of the scheme. Depending on the grain-size of the beach sediment, it is argued that only between 0.2m (fine sediment) and 0.5m (coarser shingle) depth should be scraped.

**2.2.1.1 Beach scraping – is it damaging to beach stability?**

Title: Beach scraping
Type: Scientific paper
Author: Bruun P. (1983)
Reference: Coastal Engineering 7(2): 167-173
Abstract: Discusses the field criteria necessary for successful project implementation and the correct sourcing of sediment. By acknowledging criticism from other sources, the text also explains the potential pitfalls of the method.
Language: English

**2.2.2 Sourcing sediment**

The beach itself is the source of sediment for the scraping. Normal source areas are the beach ridges which typically form at the top of the up-rush zone (see 2.3.1 [see 2.3.1]). These should be well developed when material is taken, normally around the spring and summer.

### 2.2.3 Importance of beach profile

As with any beach, the resulting profile should be sympathetic to the physical processes which operate along the coastline in question. See section 2.1.6.

### 2.2.4 Longevity

There are no permanence problems associated with the introduction of sediment, etc as occurs with beach feeding. In this situation, the profile will last until the next major storm causes large-scale beach adjustments, at which time the reprofiling will need to be repeated. This is often as an emergency measure.

### 2.2.5 Scientific validity

Although many local authorities and defence agencies carry out this approach to beach protection, there is some scientific scepticism as to its effectiveness. However, comparative studies in the USA have shown that scraped beaches responded more favourably to storms than unscraped beaches. In a similar study, other factors were seen to be important in stability, such as wind direction. This is because beaches naturally align themselves to the predominant swash wave direction, and are generally unstable with waves from another direction.

### 2.2.6 Environmental issues

- Sediment compaction due to heavy plant affecting swash infiltration and surface runoff.
- Possible impacts on infauna
- Possible impacts associated with the removal of berms.

### 2.2.7 Summary of benefits

- Increased defence effectiveness of the beach without expense of importing large sand volumes
- No importation of ‘foreign’ sediment
- Removes the need for hard structures
- Relatively quick method, ideal emergency measure following storm damage. This does mean that the method is also a good ‘stop gap’ measure to afford protection prior to more permanent measures being undertaken.

### 2.2.8 Summary of problems

- Short-term measure. Due to the recycling of beach sand, no replacement of lost material occurs, thus deficits increase over time.
- Profile estimation
- Relatively unresearched method

### 2.2.9 Recommended usage

- Emergency situations where immediate action is essential
- Where sediment input deficits are not too severe to warrant increased sediment provision.
- For amenity usage, to accelerate summer profile formation at the start of holiday season.

## 2.3 Beach drainage

- to decrease the volume of surface water during backwash, thus reducing the seaward movement of sediment.

Sediment deposition on beaches is a function of swash deposition/erosion, and backwash deposition/erosion. Swash mobilises sediment and moves it up the beach, backwash mobilises sediment down the beach. Therefore, if the severity of backwash can be reduced, there will be an increased swash dominance.

### 2.3.1 Role of swash and backwash in sediment movement

As waves rush up the beach (swash) their velocity decreases as a function of their momentum, angle of beach face, water depth, sediment roughness, and the degree of infiltration into the sediment. On ‘dry’ beaches (where the water table is low) water can percolate rapidly, reducing water depth and up-rush velocity. As velocity decreases, flow regime changes from turbulent to laminar and deposition occurs, producing a thick lens of sand at the top of the uprush zone. During the backwash, this flow pattern is reversed, changing from laminar to turbulent, at which point, erosion occurs and sediment is transferred seawards.

Backwash erosion can, therefore, be reduced by delaying the change from laminar to turbulent flow. This may be achieved by increasing the non-surface flow routes, such as sediment through flow. In order to achieve this, the beach water table needs to be lowered. If this occurs, more infiltration occurs and less water returns via surface flow, reducing erosion and enhancing net accretion.

#### 2.3.1.1 Influence of the water table on beach aggradation and degradation

Title: Beach accretion and water table position
Type: Scientific publication
Author: Grant U.S. (1948).
Reference: Journal of Marine Research 7: 655-660
Abstract: This paper provides details relating to the physical process of swash and backwash infiltration and velocities. It stems from classical research into the topic and although the reference is dated, the matter discussed still holds today.
Language: English

### 2.3.2 Methods of lowering the beach water table

There are two main ways of achieving a lower beach water table.

- Gravity dewatering. Pipe drains or routes of easier flow (such as gabions of coarser sediment) are installed on the beach, allowing rapid infiltration and primary internal flow routes back to the sea. Such a scheme in Australia resulted in a drop of beach water table by 0.3m.
- Pumped drainage. Installation of a pipe system buried in the sand, with water collecting at a central point, from where it is pumped. In Denmark, pumping rates of up to 400 $m^3$ $hour^{-1}$ have been achieved, whilst in Florida, a drop in water table of 1.0m has been recorded.

#### 2.3.2.1 Sources of further information

Because there are several methods of carrying out beach dewatering, it is important to decide which is more suited to any particular situation. The various techniques are described in detail in the following source:

Title: Coastal defence: processes, problems and solutions
Type: Scientific text book
Author: French P.W.
Source: Routledge, London
Language: English

### 2.3.3 Impacts on beach accretion

Lowering of water tables has been frequently followed by reduced erosion or marked sediment accretion, although this is not always the case. Whilst increased erosion is rare, some schemes have shown no statistical difference from control sites, suggesting other environmental factors may be of greater importance in some areas.

The example of a pumping rate of 400 $m^3$ $hour^{-1}$ from Denmark was reduced by 60% after just 6 months due to the volume of sediment accreted on the beach. In effect, the pipe system suffered decreased efficiency due to the net increase in burial depth.

#### 2.3.3.1 The influence of beach porosity on wave uprush and backwash

Title: Beach porosity and waves
Type: Scientific paper
Author: Packwood A.R. (1983)
Reference:  Coastal Engineering 7(1): 29-40
Abstract: Using modelling studies related to field situations, this work demonstrates and explains how increased beach permeability will attenuate swash wave energy and lead to increased sedimentation on the beach surface.
Language: English

### 2.3.4 Environmental issues

This technique offers a method of increasing beach elevations without any net input of sand by the operator. Sedimentation is often increased although issues of infauna survival are still of concern (see 2.1.11. Similarly, impacts on nesting fauna may also be problematical, a pumping scheme in Florida was suspended during the nesting season due to its impact on nesting turtles.

### 2.3.5 Summary of benefits

- Increased beach levels and width without importing sediment
- Greater wave attenuation benefits
- Availability of pumped water for other uses
- 'Natural' beach sediment accretion, fashioned by wave activity, leading to natural profile
- Still lacks fundamental research

### 2.3.6 Summary of problems

- Impacts on infauna and nesting species
- Enhanced removal of sand from the coastal sediment budget may deprive down drift beaches of their sources, therefore transferring the beach erosion issue.
- Accretion will cause reduced effectiveness of the dewatering system, although this could be used as a regulatory function to reduce sediment starvation impact down drift.

### 2.3.7 Recommended usage

- In locations where sediment sources for beach feeding are limited
- Where hard structures are intrusive
- Where impacts of sediment starvation downdrift are minimal
- In areas where plenty of sediment occurs in the budget, but wave energy is particularly high

### 3 Dune restoration

- dunes represent wind-blown accumulations of drifted sand located in the supratidal zone, but which supply the beach with sand during stormy periods.

Dunes are unique among coastal landforms for two reasons. Firstly they are the only landform formed by wind rather than moving water, and secondly, they are the only coastal sediment store formed beyond the normal limit of waves and tides. They are vital for coastal defence not only for the store of sediment and beach inputs, but also in the natural barrier between sea and hinterland.

Dunes are very vulnerable to damage. For example, over the period of a month:

- 10 passes can reduce vegetation height by 66%
- 40 passes can reduce vegetation height by 75%
- 80 passes will start to produce bare ground
- 150 passes will produce 50% vegetation loss

  where a 'pass' represents the passage of one person over the ground. (for original source, see section 3.3.3.

Loss of vegetation is critical for dune stability and their long-term survival and effectiveness. Because of this vulnerability, dune degradation can range from minor to serious depending on the degree of impact. Management therefore, varies accordingly:

- Complete reconstruction of heavily degraded dunes
- Encouraging sediment deposition to repair eroded dune fronts
- Stabilisation of bare sand by vegetation planting [see 3.5] or artificial methods
- Managing visitor impact to protect lightly damaged areas

#### 3.1 Further information

Title: the importance of dunes in beach stability
Type: Web document
URL: http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1204/toc.htm
Organisation: The U.S. Army Corps of Engineers (USACE) is the primary group in the US responsible for coastal defence construction and research. Many of their engineering report and manuals are held within the public domain and can be found through the above URL
Abstract: The report covers details of the complex interactions between the supratidal dune area and their interaction with the beach.

#### 3.2 Importance of dunes in coastal stability

Not only do dunes represent a physical barrier between land and sea (i.e. as does a sea wall), they are dynamic features, supplying sand to the beach at times of need, and storing it in times of plenty. In effect, dunes are sea walls which can carry out their own beach recharge.

During stormy periods, dune faces experience erosion. In the short term, this is not a management issue but part of the natural sediment cycling between dune and beach. During clam periods, wind blows sediment back into the dunes. Monitoring should be undertaken to verify that erosion is offset by increased deposition during non-stormy periods.

For sediment transfer to dunes to occur, several factors are critical:

- A wide fronting beach to provide the sediment.
- Wind speeds of 4 – 5 $ms^{-1}$ are needed to initiate sand movement. Velocities over 20 $ms^{-1}$ are needed for rapid transport.
- Beach sand needs to dry rapidly. Wet sand is much more cohesive than dry sand, and therefore harder to move
- The sand grain-size. Wind speed needed to move grains is a function of the square root of grain diameter.

On coasts with healthy dunes, all these conditions are favourable and dune:beach interactions continue in dynamic equilibrium. Where external pressures occur (typically human-induced, but also natural forces, such as sea level rise) repair may be needed. There are four key factors vital for successful dune management:

- Interaction – dunes need to be able to interact with natural processes
- Vegetation – essential for stability, but over vegetation can prevent sand reworking and lead to dune 'fixing'
- Migration – need to be mobile (particularly important on coasts experiencing sea level rise)
- Sediment supply – to recharge the dunes during calm periods

### 3.3 Dune reconstruction

- the physical placement of sand in front of severely degraded dunes to facilitate their reconstruction, and to trigger natural processes of sand movement and dune formation.

#### 3.3.1 Methods

The key factor here is to get the required sediment into the desired location. Two methods are often used:

- Feeding the upper beach area from external sources, as is done for beach feeding. This method would be needed if fronting beach levels are low. If this is the case, serious consideration would need to be given as to whether the resulting dunes could be maintained in the long term from wind blown beach sand.
- Pushing sediment into the upper beach area from low beach berms, as in beach scraping. Where there is adequate sediment available, such as where large-scale dune damage has resulted from severe storm activity and sediment has been drawn down onto the lower beach area, dune repair can be encouraged by pushing sand back up to the high beach where it can dry more rapidly and be blown landwards.

Either of these methods could provide adequate sand for large-scale dune repair. This will then be fashioned using heave plant into embryo dune areas. These may need to be vegetated to increase stability.

Dune reconstruction will not provide the perfect dune morphology. This will only be obtained by wind which will shape the sand forms into dynamically stable systems.

#### 3.3.2 Sediment sources

The two options outlined above rely on different source areas. The first depends on sediment brought in from external sources (see section 2.1), whilst the second relies on the existing beach (see section 2.2). Both of these source areas have already been discussed.

#### 3.3.3 Sources of additional information

Information covering the last two sections is adequately summarised in the following source:

Type: Management manual
Author: Ranwell D.S. and Boar R. (1986)
Title: Coastal dune management guide.
Publishers: Institute of Terrestrial Ecology, N.E.R.C. , Huntingdon
Abstract: This source covers all the major aspects of dune regeneration and can be used to support much of the information in this section.
Language: English

#### 3.3.4 Additional contact

Title: Coastal dune regeneration and management
Type: Service (Research and advisory body)
Organisation: Institute of terrestrial ecology
Purpose: The role of ITE is diverse and covers many aspects of ecology. In this context it has extensive experience in dune management.
URL: http://www.nmw.ac.uk/ite/
Languages: English
Spatial coverage: UK
Telephone: +44 (0)1487 773 381

### 3.4 Encouraging sediment deposition

- the encouragement of new sediment accumulation in front of degrading dunes.

This technique can also repair dune fronts which have been subject to excessive storm damage. It may not be effective if erosion is the result of long-term retreat caused by changes in wave climate or sea level rise.

### 3.4.1 Intercepting aeolian sediment

Most of the sand transferred into dunes is moved by saltation and rarely reaches further than 1m off the ground (During particularly high winds, dust clouds can form to heights well in excess of this). The most common way of encouraging sand deposition is to impede this saltated flow by placing an obstacle in its path to reduce wind velocity, thus encouraging sediment to settle out. Although this principle is simple, there are a series of methods by which it can be achieved.

### 3.4.2 Methods

Management of dune sedimentation is normally carried out by using porous fences to encourage the formation and growth of fore dunes.  Single fences are often used, although on high wind coasts, double fences encourage faster accretion. Materials typically used include:

- Wire mesh
- Brushwood fencing
- Geotextile
- Old Christmas trees
- Various sticks/canes etc interwoven

Organic material is the most preferable, as on burial by sand, this will decay and supplement organic matter.

The critical point about the material used is that it should be porous and allow wind to pass through. Through flow of wind is sufficient to decrease velocities enough for coarser sediment to settle, whilst still allowing the finer material to pass through into the higher dune area. This avoids sediment starvation in the inner dune areas, and the possible initiation of a new set of dune degradation problems.

The effect of fences on sedimentation can be dramatic, with noticeable accretion of sand occurring for up to 8m behind a 1m high structure. Sediment will also settle in front of fences by surface creep. In some instances, it is possible to get complete burial of the fence.

### 3.4.3 Importance of fence porosity

There has been considerable attention paid to design of fences and their effectiveness on sediment accretion. In one test using fern frond fencing, split bamboo, bamboo canes, wooden slat fencing, the most effective for sediment accretion was the fern fronds, and the least successful the wooden slats. This variation was linked to the porosity of the structure, with fences less than 50% porosity being detrimental to accretion.

### 3.4.4 Importance of fence angle to prevailing wind

Angle to prevailing wind direction is also important, although it is linked directly with fence porosity. The rationale is that as wind veers from normal to the structure (90 degrees), the effective porosity of the fence is reduced.

The ideal situation is that fences should be placed at right angles to the prevailing wind. Clearly, wind direction does vary and so the net effectiveness of the fencing will depend on the duration that the wind is blowing from the optimum direction.

## 3.5 Vegetation stabilisation

On dunes which are largely in tact, but have experienced vegetation loss, repair may simply be a case of replacing vegetation. Similarly, this may also apply as a secondary measure in both the preceding cases to stabilise dunes once they have become established. Many projects combining fences and vegetation planting have been carried out successfully in a range of situations. The type of vegetation is important here, as it needs to reflect the stage and maturity of the dunes to be stabilised.

### 3.4.1 Role of vegetation

Vegetation will colonise dunes once they have become established. Typically, the type of vegetation will form a landward succession, reflecting the maturity of dunes and the degree of soil formation. The successful colonisation, and maintenance of vegetation is vital in the long term stability of sand dunes.

Vegetation plays two key roles:

- Roots bind sediment, making it more resistant to wind erosion, thus increasing the stability of the dunes
- Leaves interrupt wind flow and encourage sediment deposition, thus enhancing dune growth (c.f. methods of encouraging sediment deposition.

### 3.5.2 Vegetation type

Most frequently, sediment to be stabilised is in the fore dune area and the species most commonly used is marram and sand couch grass. Different strains of the species are found at different geographic locations, and so careful selection is necessary.

Repair of trampled areas elsewhere in the dune complex should be with species common to the plant community present. In heavily used areas, consideration should be given to using boardwalks or other forms of dedicated pathway, in order to channel people movement.

### 3.5.3 Planting strategies

Detailed planting recommendations are available, but general guidelines exist:

- Planting to a depth of 15-20cm in domino-5 pattern
- Inter-plant spacing between 0.3-0.9m. Closer spacings in exposed or steep slopes, and more distant spacing on less exposed and flatter slopes.
- Large, bare areas are best filled with marram, as these rapidly spread and check erosion.
- Best planting time is late winter and spring, to avoid drought risk.
- Plant from the top of a slope to the bottom

#### 3.5.3.1 Further details

Type: Management manual
Author: Ranwell D.S. and Boar R. (1986)
Title: Coastal dune management guide.
Publishers: Institute of Terrestrial Ecology, N.E.R.C., Huntingdon
Abstract: This source covers all the major aspects of dune regeneration and can be used to support much of the information in this section.
Language: English

## 3.6 Other methods of sand stabilisation

Sand slopes above 33% are difficult to stabilise with vegetation planting. In these cases artificial stabilisation can be used. This takes several forms:

- Surface netting – pinning fine mesh directly to the sediment surface to reduce sand erosion from the surface
- Thatching – brushwood stems is wired together and pinned to the surface. Also encourages sand entrapment and breaks down over time to increase organic content of soil.
- Binding – use of chemical binding agents to stabilise sediments. May be used in conjunction with plantings although the possible detrimental effects on plants is not adequately determined.

### 3.6.1 Further information

Type: Management manual
Author: Ranwell D.S. and Boar R. (1986)
Title: Coastal dune management guide.
Publishers: Institute of Terrestrial Ecology, N.E.R.C., Huntingdon
Abstract: This source covers all the major aspects of dune regeneration and can be used to support much of the information in this section.
Language: English

### 3.7 Visitor management

In slightly damaged dune areas, it may be just a question of implementing people management strategies rather than large scale dune management. Techniques include:

- Provision of boardwalks or surfaced paths. People generally prefer the easiest possible route, and will avoid soft sand if they can walk on a solid surface.
- Fence off fragile areas. This can be effective but trials have shown that provision of public information boards to inform visitors of the reasons for access restrictions make them more acceptable and less vulnerable to trespass and vandalism.

### 3.8 Environmental issues

Dunes are fragile ecosystems and because of this there is a tendency to over-manage. This can be disastrous for such a dynamic system, and can lead to fixing and long-term damage. A fixed dune coast will behave like one backed by a sea wall, with no sediment interchange with the beach, and no landward transfer with the hinterland.

Dune management must be carried out with due consideration of coastal processes, and the importance of the dune in sediment interchange with the beach.

Dunes are important sediment stores yet key problems concern this sediment supply. Because dunes occur on sandy coasts, many conflicting issues to successful coastal management can occur. These include:

- Sand extraction (for building or beach recharge)
- Conversion to agricultural land
- Conversion to forestry
- Golf courses
- Development
- Sediment starvation due to coastal defence construction updrift

Holistic management is vital to balance these various pressures. There is no basic blueprint for dune management and strategies need to be location specific, incorporating local coastal processes with human demands on the system.

### 3.9 Summary of benefits

- Dynamic coastal defence structure which can naturally respond to short term changes in coastal processes
- Once management strategies completed, the dunes can continue to function in this natural manner
- Techniques are not visually intrusive, and if successful, will either disappear (fences/thatching/ netting) or become part of the natural system (planting).
- Provides important conservation areas
- Protects and maintains an important local sediment store.

### 3.10 Summary of problems

- Over management is easy and common, but will make the system non-functioning and, eventually, lead to instability.
- Potential to lock up too much sand and prevent exchange with beach system
- Tendency to increase public perception of security, leading to inappropriate hinterland development which will, eventually prevent landward movement of the dune system under sea level rise.

### 3.11 Recommended usage

- Dune maintenance should be encouraged wherever possible to maintain this dynamic coastal sediment store.
- To maintain and protect an effective line of coastal defence.
- Wherever it is possible to prevent methods which reduce dune mobility.

## 4 Cliff Stabilisation

- steeply inclined or vertical rock/sediment faces along the coastline subject to marine erosion leading to input to the coastal sediment budget.

One of the key things about cliffs is that the erosion problem and failure mechanism can be manifest in a number of ways depending on the composition of the cliff itself. Such factors include:

- Composition or rock type
- Geologic structure (joints/faults/etc)
- Wave energy
- Development of fronting beach
- Climate

Cliffed coasts are traditionally managed in a variety of ways, most typically by hard defence methods, as these are the main ways in which cliff recession can be halted. However, soft defences can be used to reduce retreat and also, in some circumstances, to stop it. Soft engineering approaches include;

- Cliff drainage – where water lubrication of planes of weakness encourages sliding and slipping.
- Cliff profiling – where gravity failure is important. Reducing the angle of repose dilutes gravitational force.
- Rock pinning – where seawards dipping strata slide easily. Bolting thin rock layers together increases overall strength.
- Vegetating cliff faces – in unconsolidated material where failure occurs in surface layers
- Cliff toe protection – where wave undercutting and rotational slides are common.
- Beach feeding – where fronting beach degradation is relevant to increasing wave energy at cliff base.
- Creation of stable bays – where overall wave energy along a length of coastline is the problem (experimental)
- Do nothing where contribution of cliff erosion to sediment budget is critical in downdrift beach stability.

The effectiveness of the methods depends on the processes involved in cliff erosion:

- Undercutting by waves leading to gravity failure
- Lubrication of planes of weakness (joints/bedding/faults/etc) by groundwater leading to slide failure
- Infiltration of surface water at cliff top leading to toppling failure
- Direction of dip of planes of weakness (seawards or landwards)
- Sediment type and tendency to flow (clay cliffs and slumping/mud flows)

Each of these failure processes implies a different approach to defence. Furthermore, this huge variety of failure mechanisms means that a full assessment of the cliff area needs to be undertaken before any defence strategy can be adopted.

### 4.1 Additional information:

Title: Sea cliff management handbook for Great Britain
Type: Management manual
Author: Mitchley J. & Malloch A.J.C. (1991)
Publisher: Institute of Environmental & Biological Science, University of Lancaster
Abstract: Reviews main issues relating to cliff stability and the different management approaches which can be applied.
Language: English

### 4.2 The importance of rock type in cliff stability

Different rock types have different hardnesses and resistance to erosion. Some typical retreat rates include:

| | | |
|---|---|---|
| Granite | 0.1 | cm $a^{-1}$ |
| Limestone | 0.1 – 1.0 | cm $a^{-1}$ |
| Shale | 1.0 | cm $a^{-1}$ |
| Chalk | 1.0 – 10.0 | cm $a^{-1}$ |
| Sandstone | 1.0 – 10.0 | cm $a^{-1}$ |
| Till | 10.0-100 + | cm $a^{-1}$ |

All cliff erosion leads to sediment input, and it can be inferred from the table that some rock types lead to greater inputs than others. This is critical for the health of the sediment budget, with cliff protection providing one of the main ways in which sediment deficits in this budget can occur. Sandy beaches may rely on inputs from sandstone cliffs to remain stable. Shingle beaches may rely on inputs from chalk or till cliffs for stability. Therefore, such considerations are imperative before defence decisions are taken. There may need to be a trade off between protecting cliff top properties and protecting healthy beaches for coastal defence down drift (see 'Do nothing' 4.11 and 'Environmental Issues' 4.12.2).

Key factors relating to cliff failure and sediment type include:

- Clays fail by slumping and flowing
- Limestones, igneous or metamorphic rocks often fail along planes of weakness, producing large blocks which are generally immobile as far as normal wave conditions are concerned
- Chalk often produces valuable flint shingle, although the chalk itself is useless in beach building
- Sandstones may desegregate if poorly cemented, producing valuable beach sand
- Tills and other poorly consolidated sediments yield valuable sands and silts.

### 4.3 The importance of geologic structure in cliff stability

Cliffs are only as strong as their weakest part. These weak links are often joint or bedding planes, along which water can flow or, if inclined, along which gravity can induce failure. Cliffs with seawards dipping strata are more likely to fail than cliffs with landwards dipping strata. Similarly, cliffs containing different rock types will often fail along rock boundaries.

An understanding of these relationships between rock types and structure is vital for an understanding of how cliffs fail, and how defence may address the issues.

### 4.4 Cliff drainage

- where water seepage along planes of weakness facilitates rock sliding, or where liquefaction of sediments results in slides and mud flows

Water within cliffs can induce several modes of failure, from sliding due to lubrication of planes of weakness, particularly in the case of seawards dipping strata, by increasing pore water pressure, or by mixing with sediments to produce material flow.

#### 4.4.1 Role of pore pressure in cliff failure

One of the prime reasons for cliff failure is the presence of water. Different rock types manifest this problem in different ways:

- In clay cliffs, increased pore pressure can increase the formation of tension cracks and failure planes which can develop into larger slump planes or slide surfaces.
- In jointed and bedded rocks, increased pore pressure can force water along existing planes of weakness (bedding planes/joints), causing lubrication and slip surface formation.

By reducing pore pressure therefore, these two processes can be reduced and cliff stability increased. This can be done by getting water out of the cliff faster, so pore pressures cannot build up to critical failure levels.

##### 4.4.1.1 Further information

Title: Stabilisation and control of local rock falls and degrading rock slopes
Type: Scientific publication
Author: Fookes P.G. & Sweeney M. (1976)
Reference: Quarterly Journal of Engineering Geology 9: 37-55
Abstract: The paper describes the design and methods used in the stabilisation of cliff failure, as well as the processes responsible for them.
Language: English

#### 4.4.2 Methods

Draining of cliffs is the easiest way of achieving these pore water reductions. There are several approaches to the problem, although the principle is the same -–removal of water in as shorter time as possible.

- Agricultural drains to pipe water out of the cliff, preventing accumulation at rock boundaries, thus reducing the potential of bedding plane lubrication.
- Provision of lines of easy flow, such as gravel trenches. This method removes water from the surface before it has time to seep into the cliff.
- Alteration of cliff-top drainage, especially soak aways to reduce the volume of water entering the cliff
- Where water content only involves near surface sediments (such as soils) plants may extract enough water to decrease water content sufficiently to increase stability.

The method used will by governed by the failure issue. Alternating strata my require internal drainage methods to avoid the build up of water in the cliff which facilitates sliding. Clay cliffs may require surface drainage to prevent water entering surface cracks.

### 4.5 Cliff profiling

- the changing of cliff face angle to increase stability be dilution of gravitational pull. Also referred to as grading.

Cliffs fall under the influence of gravity. The steeper the slope, the greater the risk of falls occurring. Thus, by reducing the angle of the cliff face (dilution of slope) collapse frequency will be reduced.

The angle at which cliffs become stable (natural angle of repose) is a function of rock type, geologic structure, water content.

There are three different methods of cliff profiling :

- Cut and fill – taking material from the top of the cliff and placing it at the base, pushing the high water mark seawards and the cliff top landwards.
- Fill only – importing material and placing against the cliff face, pushing high water mark seawards but maintaining the line of cliff top.
- Cut only – grading the cliff face back inland and exporting the cut material, maintaining the existing high water mark.

#### 4.5.1 Natural angle of repose and cliff stability

- the slope angle at which, given an equilibrium environment, the cliff would be stable.

This angle varies considerably, and the potential of achieving it will depend on the degree of cliff top development. The methods which exist to profile cliffs can introduce some flexibility into this.

Typical slop values are:

Clay cliffs with high water content – 40% (2 in 5 or 22 degrees)
Clay cliffs with low water contend – 100% (1 in 1 or 45 degrees)
Hard rock cliffs (e.g. granites) – vertical

A further factor in achieving cliff stability would be a combination of techniques. From the above, reducing the water content of the cliffs (see drainage) would decrease the effort involved in reducing the cliff to a stable angle.

#### 4.5.2 Methods

Three basic methods to artificially reduce the cliff face to a stable angle:

- Cut and fill – removes material from the top half of the cliff (cut) and places it at the base (fill) to produce an overall cliff face angle which is stable. This method will involve loss of cliff top land, and also the seawards movement of mean high water level and so may not be suitable for areas of high land value, rapid sea level rise, of high energy wave climates. This is the most common approach to profiling and has been used successfully in a range of cliff types and rock/structure combinations. It is often necessary to protect the fill with toe protection.
- Cut only – removes material from the cliff and exports it from the system. This method removes considerable cliff top land but maintains the position of mean high water.
- Fill only – maintains the cliff top in tact without land loss, but can involve considerable seawards movement of mean high water mark. This can have detrimental impacts on long shore sediment movement (see 4.14 Summary of problems). The method involves the importation of a large volume

of material which may be costly. In addition, this material should be free draining otherwise water build up may induce slumping, leading to further stability measures, such as drainage.

#### 4.5.2.1 Further information

Additional information may be sought from civil engineering companies and also local coastal authorities which experience cliff management problems. Additional details occur in:

Title: Coastal defence: processes, problems and solutions
Type: Scientific text book
Author: French P.W.
Abstract: Reviews the main problems and controls over cliff failure, and the methods available for management and prevention.
Language: English

## 4.6 Rock pinning

- prevention of slippage in seawards dipping rocks by bolting layers together to increase cohesion and stability

By using large bolts which are inserted normal to bedding direction, individual rock layers can be bolted together to increase their cohesion and stability. This technique was mainly developed for stabilising road cuttings, but has been increasingly seen as a means of preventing coastal cliff failure, particularly in association with safe amenity usage of beaches.

This method does not prevent wave attack at the base of the cliff, but does reduce the threat of mass movement and thus reduce net erosion rates.

### 4.6.1 Problems of seawards dip

Seawards dipping rocks tend to be very unstable and can prevent safe amenity usage of the beach. Where failure is mainly gravity induced, pinning can reduce this by bolting rock layers together. In other circumstances where lubrication is also a factor, pinning may need to be used in conjunction with drainage.

In clay cliffs where rotational slips are common, pinning can reduce the incidence of large rotational slide movement.

### 4.6.2 Methods

In engineering terms, a straight forward technique of inserting metal rods into the cliff normal to bedding or planes of weakness. Whilst bedding planes are normally obvious, it is important to carry out geological survey work to accurately determine all joint directions, and to identify key stress directions.

It is often necessary to carry out in conjunction with other methods, such as drainage or to treat the surface after pinning with netting or vegetation. In some examples, such as in Dover, UK, profiling and grouting were also used.

#### 4.6.2.1 Further information

Additional information may be sought from civil engineering companies and also local coastal authorities which experience cliff management problems. Additional details occur in:

Title: Coastal defence: processes, problems and solutions
Type: Scientific text book
Author: French P.W.
Abstract: Reviews the main problems and controls over cliff failure, and the methods available for management and prevention.
Language: English

## 4.7 Vegetating cliff faces

- to increase the cohesion of surface sediments/soil on cliff slopes to prevent downhill slumping and sliding.

This technique to solely concerned with shallow slumping and soil movement. It will not be a solution to deep seated failures.

#### 4.7.1 Vegetation and increased stability

Vegetation can increase slope stability in three ways:

- Plant roots bind sediment together and increase its resistance to erosion and slumping (see also the role of vegetation in dune stability [see 3.5.1].
- The planting of slopes also increases stability due to the removal of water by the plants. This may well also serve to overcome problems of cliff drainage if this only involves near surface sediments.
- Planting can reduce the quantity of, and slow the rate of, surface runoff. This will reduce gulleying and down slope sediment movement.

#### 4.7.2 Methods

The use of vegetation for slope stability is increasing. Many quarry companies use vegetation to stabilise waste tips, whilst civil engineers are developing seed sprays to stabilise road cuttings.

Application is simple, but may be labour intensive.

- Direct planting of plants on the slope, working from top down (cf. vegetation of sand dunes 3.5.1].
- Spraying onto cliff face, incorporating a seed mixture, binding agent, growing medium, and fertiliser.

##### 4.7.2.1 Further information

Additional information may be sought from civil engineering companies and also local coastal authorities which experience cliff management problems. Additional details occur in:

Title: Coastal defence: processes, problems and solutions
Type: Scientific text book
Author: French P.W.
Abstract: Reviews the main problems and controls over cliff failure, and the methods available for management and prevention.
Language: English

### 4.8 Cliff toe protection

- to protect the base of the cliff from undercutting by waves, or to stabilise rotational slides.

In some circumstances, this approach may be considered a hard method, but when used in conjunction with rotational slides, it can reduce the rate of cliff failure. Rotational slides represent a cliff failure in which the cliff face slips seawards as a single unit along an inclined failure surface. Placing blocks at the foot of this slide may be sufficient to prevent this rotational movement and hold the block in place.

This method is not suitable for very liquid movement, such as mud flows, as the material will merely over ride the protection. To be effective, the flow needs coherence and internal strength.

#### 4.8.1 Methods

The most frequent approach is to use large boulders placed at the foot of the slide plain. This serves two purposes:

- Reduces the rate of erosion of the slide
- Reduces the rate of seaward movement

The material used should be resistant to erosion itself. Common materials include crystalline limestone, metamorphosed rocks, or some igneous rocks. It is rare that local rock are suitable because this is the material which is comprising the failing cliffs.

#### 4.8.2 Further information

Additional information may be sought from civil engineering companies and also local coastal authorities which experience cliff management problems. Additional details occur in:

Title: Coastal defence: processes, problems and solutions
Type: Scientific text book
Author: French P.W.

Abstract: Reviews the main problems and controls over cliff failure, and the methods available for management and prevention.
Language: English

**4.9 Beach feeding**

- to protect the cliff base by the provision of a healthy fronting beach

Healthy beaches protect the cliff base due to effective attenuation of wave energy. Considering that waves erode cliffs because of surplus energy, a pile of sediment (beach) fronting a cliff will provide the erodable material, whilst preserving the cliff.

Full details of this technique are given in section 2.1

**4.10 Creation of stable bays (largely theoretical)**

- where wave energy per unit length of coastline is sufficient to cause erosion, by increasing the length of coastline, wave energy per unit length can be reduced.

This still largely theoretical approach involves the creation of coastal embayments by allowing some parts of the coast to erode, but protecting others.

**4.10.1 Rationale behind coastal length and wave energy**

Coastal erosion is caused by wave energy. Many techniques, such as beach feeding, reduce this energy by attenuation methods. The creation of stable bays will (theoretically) reduce energy by dilution, spreading it over a greater length of coastline.

Along any length of coast, if the effective length of that coast were to be increased, and the amount of wave energy remains the same, the amount of wave energy per unit length of coast will decrease.

Although theoretical in concept, the technique has been practised but by other means. Considering piecemeal protection of coasts, where individual properties have been protected whilst the areas between have not, this effectively amounts to the same approach. In these cases, erosion continues between areas of protection, leading to the formation of embayments. The shape of the embayment depends on:

- Wave regime
- Angle of wave approach
- Spacing between hard points.

**4.10.2 Methods**

This method uses a combination of hard and soft defence technology. Hard defences, typically cliff toe protection [see 4.8] are used to protect parts of the cliff, whilst the areas between are left to erode (see do-nothing 4.11).

**4.10.3 Problems with predictability**

This is largely experimental, although circumstantial evidence can be drawn from many practical field situations.

Two main areas of unpredictability concern this method:

- Natural bays form with a characteristic offshore bathymetry which is closely linked to the coastal processes (ie waves, currents, sediments, etc) of a particular area, and produces the typical wave refraction and wave focusing patterns seen on embayed coastlines. With artificial bays, no such bathymetry occurs, and so the modification of wave behaviour is uncertain.
- Once initiated, the exact morphology of the embayments is at the mercy of the sea. In natural situations, bays enlarge until their outline mirrors the refracted wave pattern, at which point they are said to be stable. With no developing wave refraction, the point of stability may not be reachable. Additionally, bays potentially coalesce to form larger bays, isolating the hard points as stacks.

## 4.11 Do nothing

- soft engineering at its extreme. Allowing an eroding cliff to retreat at will until it reaches its own natural angle of repose.

This should always be the preferred solution because to it is the most natural coastal management technique. It should also be used as the baseline with which to compare all other methods during the defence planning stage.

### 4.11.1 Relevance to cliffs

Cliffs form and erode because they are unstable landforms. Allowing them to continue to erode allows them to achieve dynamic equilibrium. This is a bit simplistic, perhaps, because this point of stability can only be reached if the baseline to which they are adjusting remains stable. In many situations, this base line (sea level) is constantly changing (see section 9).

An important question to ask is whether it is worth defending a cliff which has a land value less than cost of defences. This is a difficult issue and one which no coastal manager is keen to address. Several points to consider:

- How much will defences cost?
- How much is the land, and its use worth?
- How much would it cost to relocate land use activities/infrastructure?
- How much is a person's attachment to their property worth?
- How much is the social structure of a small hamlet worth, if it is to be abandoned?

These are all important questions and not easy ones to answer. If this approach is taken, it is normally on the basis of cost benefit analysis. Some aspects are easy to cost, others aren't.

Environmentally it is sound because it allows maintenance of sediment inputs and natural coastal processes to operate. Socially, it can be a mine field.

### 4.11.2 Important management issues

The rationale behind this approach is sound, but a series of considerations need to be made.

- The technique is only suitable if cliff top development is small scale (i.e., the land is 'low value')
- How are issues of compensation addressed for land and property owners?
- How important is the sediment from cliff erosion for the sediment budget ?

The bottom line is that where the land value is less than defence costs, defences will not normally be built.

## 4.12 Environmental issues

Protecting a cliffed coastline needs to offset erosion problems with sediment supply. One key argument is that if defences stop erosion and, therefore sediment input, will this impact on beaches downstream?

### 4.12.1 Sediment budget deficits

The sediment budget is perhaps the most fundamental consideration in soft engineering. All erosion feeds some part of this budget, and so by preventing a cliff from eroding, this may represent a significant component. Any sediment deficit will need to be made up from other sources, most probably adjacent beaches or from other cliffs at the end of the protected cliff.

An example from Fairlight Cove, Sussex, where an offshore breakwater was built to reduce wave activity on the cliff.

Length of cliff affected = 500m
Average cliff height = 25m
Rate of erosion before construction = 1.14m $a^{-1}$
Rate of erosion after construction = 0.36m $a^{-1}$

Therefore:

Pre-construction sediment budget contribution = 14250 $m^3\ a^{-1}$
Post-construction sediment budget contribution = 4500 $m^3\ a^{-1}$

Total budget deficit as a result of this scheme = 9750 $m^3\ a^{-1}$

Not all cliff sediment is incorporated into the coastal sediment budget. Coasts are high energy systems, and so beaches tend to be sands and shingle. Clay cliffs are composed of silts and clays, and so this sediment will not be of use to beach build-up, but could be important in adjacent estuaries or back-bar areas. For this reason, where a coast contains clay cliffs, it is vital to understand fine sediment transport pathways so as to prevent secondary impacts occurring elsewhere (possibly some distance away).

#### 4.12.1.1 Further information on the Fairlight cove scheme

This scheme was overseen by the local authority. Details are:

Title: Post-project appraisal and design details of the Fairlight Cove sill scheme
Type: Service
Organisation: Rother District Council
Telephone: +44 (0)1424 787 815
Fax: +44 (0)1424 787 879

### 4.12.2 Property vs. Beaches

Each set of site specific circumstances must be given full consideration before a decision to defend is made. There is a need to balance:

a) value of land use, value of infrastructure and property, social welfare, coastal history

with

b) contribution of eroded sediment, beach welfare, cost of defences, other ways of maintaining the sediment budget.

Only with a full consideration of all of these can a decision to protect cliffs be made.

## 4.13 Summary of benefits

- Increased security for cliff-top development
- Increased security for beach users
- Increased economic security for coastal resorts

## 4.14 Summary of problems

- Reduction in sediment supply to sediment budget, with associated implications for areas down drift.
- Implications for fronting beach longevity
- Reduced exposure for scientific study (geology/palaeontology/etc)

## 4.15 Recommended usage

- In areas where cliff-top land values are high
- Where alternative sediment supplies are available to compensate for loss of sediment input. (e.g. beach feeding [see section 2.1])
- Where continuous mudlfows block long shore drift and lead to sediment starvation.

## 5 Mudflat recharge

In many ways, this technique is similar to beach feeding [see 2.1] but with one major difference. Beach feeding deals with coarse, non-cohesive sediments, whilst mudflat recharge deals with finer, cohesive sediments. This difference means adaptations to those techniques mentioned in this earlier context.

One main issue is the time required for these particles to settle. A typical clay particle of 2µm has a settling velocity of 0.00024 cm $s^{-1}$. As soon as the currents fall enough to allow such particles to settle, they will start to fall through the water column. For particles of this size, currents only fall low enough for a short time around slack water. However, in a 1m depth of water, such particles will take 58 hours to settle. Clearly, this will not be able to occur unaided, and so artificial methods may be needed for such fine sediment.

There are three main approaches to recharging mudflats:

- Trickle charging
- Rainbow charging
- Polders

Direct placement, as used in beach feeding, is not a suitable method on mudflats because of their soft nature, and the inability of heavy plant to cross them.

An important issue for consideration is that a mudflat is very ecologically diverse, and may support important wildfowl communities, often reflected in conservation designations. In such situations, no actions should be undertaken which may threaten these communities (see 'Environmental Issues' 5.5).

### 5.1 Trickle charge

The methods used in this approach are the same as those for beach feeding. The benefits of this method are also seen in areas of high biodiversity, as the slow rate of recharge allows infauna to survive in tact.

### 5.2 Rainbow charging

The methods used in this approach are the same as those for beach feeding.

### 5.3 Polders

In situations where there is plenty of fine sediment in suspension, it is possible to encourage its settling out by increasing the time of still water. By constructing a series of bunds on the mudflat, these are filled at high water and during ebb tides, this water slowly drains out through porous sides, leaving sediment trapped in the bund.

There are two main ways in which this can be achieved:

- Brushwood groynes
- Wave baffles

#### 5.3.1 Brushwood groynes

Permeable structures composed of brushwood or similar material, such as bracken or old Christmas trees, will allow water to pass through, but impede its passage sufficiently to allow sediment to settle and increase mudflat level. These structures have been used in an increasing complexity of design.

- Simple, shore-normal, permeable groynes. In cases of strong long-shore currents, simple shore normal structures will be sufficient to trap fine sediment moving along the coast, whilst allowing water to pass through, albeit at a reduced velocity.
- Shore normal groynes plus shore parallel structures to form sedimentation fields. Where these is also a significant onshore/offshore component to sediment movement, making the groynes into 'box' like structures will pond water up for longer than the normal tidal cycle, allowing increased sediment deposition and reduced re-suspension on the ebb tide.
- Combinations of sediment fields into larger arrays, often incorporating modifications to mudflat elevation, to increase ponding and sediment deposition. Such elaborate approaches are often referred to as the Schleswig-Holstein technique, after the location where it was first developed.

#### 5.3.1.1 Further information

Title: Consultancy and advice on estuarine structures
Type: Service
Organisation: H.R. Wallingford
Abstract: HR Wallingford is one of the leading research institutes involved in original and consultancy research linked to many aspects of coastal science. They are pleased to offer advice on a range of coastal defence issues.
Purpose: To provide support and advice in planning of coastal defence structures.
URL: http://www.hrwallingford.co.uk/
Telephone: +44 (0)1491 825381
Fax: +44 (0)1491 832233

### 5.3.2. Wave baffles

If sediment is prevented from settling out due to shore normal currents, protection from these currents may be sufficient to allow sediment to settle. Offshore wave baffles may be employed to protect the mudflat from waves, creating a quiet area to landward in which sediment can settle. This may be compared to a sedimentation field but without the ‘groyne’ component.

Methods of construction have employed;

- Offshore reefs of old car tyres
- Old barges sunk offshore
- Geotextile tubes
- Brushwood structures

#### 5.3.2.1 Further information

Title: Consultancy and advice on estuarine structures
Type: Service
Organisation: H.R. Wallingford
Abstract: HR Wallingford is one of the leading research institutes involved in original and consultancy research linked to many aspects of coastal science. They are pleased to offer advice on a range of coastal defence issues.
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## 5.4 Material sources

For trickle and rainbow charging, sediment sources are external to the site. Polder schemes utilise sediment currently in suspension but which hasn’t the chance of settling out due to shore normal and shore parallel currents.

Sediment may be derived from;

- Utilising dredgings from other activities, such as maintenance dredging of ports and harbours. These need to be suitably clean and free of contaminants.
- Dredging offshore mud banks

### 5.4.1 Further information

Title: Dredging
Type: Web-based manual
URL: http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-5026/toc.htm
Organisation: The U.S. Army Corps of Engineers (USACE) is the primary group in the US responsible for coastal defence construction and research. Many of their engineering report and manuals are held within the public domain and can be found through the above URL
Abstract: The manual provides key information on the dredging of offshore material to use in mudflat recharge. Important aspects are covered concerning dredge quality, impacts and methods.

## 5.5 Environmental issues

Because of the recent, and in some cases, ongoing development of some techniques, a full assessment of impacts of mudflat building is not possible. However, there are areas where care should be taken.

### 5.5.1 Burying of infauna

As with beach feeding, infauna can only move upwards through the sediment column at certain rates. Increased depth of burial beyond this may result in mortality. In mudflats, this is increasingly important because of the reliance of other species on infauna for food. Many large intertidal areas are important International over-wintering grounds, and infauna population crashes would have major implications.

In areas of important wildfowl usage, slow accretion, such as trickle charge [see 5.1], is more suitable. In some estuaries, even polder schemes may result in accretion rates above that tolerable to infauna.

### 5.5.2 Potential contamination

When using dredged material, the most frequent source is maintenance dredgings from harbours. These are also the areas of greatest potential contamination. Surfaces of clay grains are key sites for metals and other contaminants to bond, and such sediments often scavenge and store pollutants. Introduction of such contaminated sediments to a mudflat may seriously impact on infauna, and subsequently, wildfowl.

### 5.5.3 Suitability for colonisation

Many mudflats are precursors to salt marshes, in that when of suitable elevation relative to the tidal frame, they will become colonised by pioneer flora (see Marsh Creation [see 6]). It is important that the material used is of suitable composition for this to occur. (see also Marsh Creation: Environmental Issues: 6.4])

## 5.6 Summary of benefits

- Increased wave attenuation and coastal protection
- Increased protection for marsh edge
- Facilitation of future marsh development
- Increased habitat for conservation interests
- Increased wildlife potential for estuaries
- Useful employment of dredgings (if suitably clean)

## 5.7 Summary of problems

- Potential for infauna burial and mortality of sedimentation rates too high
- Possibility of aesthetic intrusion
- Possible modification of infaunal community structure

## 5.8 Recommended usage

- To protect eroding marsh edges from wave exposure
- Where abundant fine sediments already exist.
- In areas where landward coastal realignment [see 7] is not possible

## 6 Marsh creation

Following on from mudflat recharging, once the level of sediments is high enough, relative to the tidal frame, vegetation will colonise. This is important for three reasons:

- Vegetation increases the stability of sediment due to the binding effect of the roots, increasing shear strength and decreasing erodability. Research has demonstrated increases in shear strength of up to 300% compared to unvegetated areas.
- The leaves and stems provide a wave baffle increasing wave attenuation. Wave attenuation is a function of wave height, distance travelled through the marsh, water depth, and plant spacing. Typically, up to 50% of wave energy and 40% of wave height will be lost in the first 2.5m of marsh.
- The wave baffling increases sedimentation and so increases the rate of mudflat accretion. A positive correlation between vertical accretion rate and vegetation height has been noted from many areas, and also with plant density.

(see also the U.S. Environment Protection Agency fact sheets on wetland importance [see http://www.epa.gov/owow/wetlands/facts/fact2.html])

Rather than await natural colonisation, increased sediment stability and wave attenuation ability, may be achieved by artificially encouraging the growth of salt marsh plants. This may be achieved in two ways;

- Planting of mudflats with pioneer marsh species, such as S*partina sp.* This method pushes the line of salt marsh seawards, whilst leaving the landwards limit in tact.
- Allowing the landward spread of high marsh flora by allowing the marsh to spread inland by realigning the sea defences. This method pushes the line of salt marsh landwards, whilst leaving the seawards limit in tact.

Each of these methods serves a different purpose and is a solution to a different problem.

### 6.1 Further information

Title: The importance of wetlands in coastal defence
Type: Web site
URL: http://www.epa.gov/owow/wetlands/facts/fact2.html
Organisation: U.S. Environmental Protection Agency
Abstract: Covers the importance of wetlands in defence and as an ecological system. The fact sheet discusses the various roles which wetlands play in coastal functioning, including habitat, coastal defence, and pollutant buffering

### 6.2 Vegetation planting

- to colonise and increase the stability of accreting mudflats, either seaward of an existing marsh or to create a new marsh.

#### 6.2.1 Important considerations for marsh planting

As with any coastal defence method, the development of a salt marsh by vegetation planting is site specific and should only be used in sites where conditions are favourable. Such conditions include:

- Is their a history of marsh growth? This will prove that marshes can grow in the area, but will also provide a seed supply for marsh succession and development.
- Is the coastline experiencing rapid erosion? If so, a planted marsh may not survive long and landward realignment may be a better option.
- Is the mudflat to be planted of a suitable elevation? Existing marshes will help in determining at what elevation pioneer vegetation first appears.
- Is the mudflat slope suitable for marsh succession to develop?
- Is the salinity, hydrology, substrate suitable?

#### 6.2.2 Suitable species

With marsh development on mudflats, it is necessary to use pioneer species. Most commonly, this will be *Spartina sp.* , a species which has been used for this purpose since the late 19th century. This species is particularly suitable because:

- It is invasive. Sometimes a problem, but when rapid marsh formation is wanted, the rapid lateral spread will cover the surface as rapidly as is possible. Rates of lateral advance of planted marsh of 4 m $a^{-1}$ , and areal spread of $3600m^2$ $a^{-1}$ have been recorded.
- It is hardy
- Its foliage is effective in sediment trapping. Rates of 7mm $a^{-1}$ have been recorded.

#### 6.2.3 Planting methods

Certain criteria should be adopted when planting mudflats.

- Plants should, ideally, be sourced locally. This should be from existing marsh areas or from cultivated beds.
- Planting is best carried out be hand. Machinery on the mudflat surface would cause unnecessary damage and compaction.
- Spacing of plants is important. A rapid, maximum coverage is important, but cost needs to be considered. On exposed sites, spacings of between 45 – 60cm are adequate, whilst on sheltered sites, up to 1m has provided complete plant coverage after 1 year.
- Post planting maintenance may be necessary, and areas of die back replanted.

##### 6.2.3.1 Further information

Title: Salt marsh planting
Type: Web site
Organisation: Delft Hydraulics
Site address: http://www.ihe.nl/he/dicea/clm33/clm3301.htm
Telephone: +31-15-2151715
Fax: +31-15-2122921

#### 6.2.4 Post-planting issues

The planted marsh should develop as a natural system and ultimately behave in a similar manner. This will not happen immediately because:

- Plants have not grown from seed in situe, and so rapid post-planting modifications may occur. Trials have been carried out using direct seeding, but this has only achieved any notable success on high elevation, sheltered marsh areas. Its use, therefore, is limited.
- Marsh soils will take time to form. This is the case if mudflat recharge has been used, and particularly so if dredged spoil is used.

#### 6.2.5. Alternatives to natural vegetation

There are other possibilities other than using natural plants, to increase mudflat stability:

- Increased stability has been obtained using mussels. Areas have been seeded and successful colonies of mussels have established. Most success has been found where attachment points are present.
- Artificial sea weeds. Attachment of such to netting, fixed to mud surfaces, can behave in the same way as plant leaves. Although no root binding occurs, the presence of the netting and attachment points provides sediment stability.

##### 6.2.5.1 Further information

Title: Artificial seaweed for erosion control
Type: Scientific publication
Author: Rogers, S.M. (1987)
Reference: Shore & Beach 55(1): 19-29
Abstract: With the importance of vegetation established in the role of wave energy attenuation, attention has turned to the development of synthetic materials to use as substitutes. This paper studies outcomes of this research and the various methodologies tested.
Language: English

### 6.3 Managed realignment

- increasing the amount of marsh be landward realignment of coastal defences. May also be referred to as *managed retreat* or *set back*

In this case, where it is not possible to push the marsh seawards because the criteria of the area do not meet the considerations necessary for planting, the only alternative way of increasing marsh width is to allow its development landwards. This typically involves relocating the line of defence and allowing the controlled marine inundation of the hinterland .

This area of soft coastal management is perhaps the most important contemporary issue in coastal management and receiving much attention. Estuary locations are the prime target and some practitioners regard realignment as the way forward for estuarine management, as beach feeding is to open coasts. It is important to be aware of the relevant environmental issues. Constant additions are being made to the information base and it is advisable that interested practitioners seek further updates from sources such as English Nature or DEFRA.

Managed realignment is favoured because:

- It returns land to the sea which has been previously claimed, This serves to re-establish the natural 'shape' of estuaries, whilst increasing intertidal area and reducing flood risk.
- The method mimics the coast's natural response to sea level rise, in that landward migration is facilitated.
- It is comparatively cheap. In Essex, one realignment scheme cost £22,000, whereas to maintain the existing defence would cost between £30,000 and £55,000, excluding future maintenance costs.
- Changes in agricultural practices mean a lot of land is available through set aside and stewardship schemes.
- It increases marsh width which increases wave attenuation and thus, hinterland security.
- It increases the conservation potential of an estuary.
- It increases intertidal area which can offset impacts of sea level rise.

### 6.3.1 Methods

Estuaries have a typical 'funnel' shape, and retreat schemes should aim to regain this form. The means of achieving this are relatively straight forward.

- Removing all or part of a seawall to allow the tide to flood previously protected areas.
- Constrain this flooding by means of natural relief or newly constructed embankments inland of the original.

There are a series of further considerations, however, which should be incorporated into planning. Due thought of all factors will allow a greater chance of scheme success. These are detailed and full discussion is not possible here. Further consultation is advisable:

#### 6.3.1.1 Additional sources: DEFRA

Title: Managed realignment
Type: Advisory service
Organisation: DEFRA Flood and coastal defence
Purpose: To support and advise on flood and coastal defence projects
URL: http://www.defra.gov.uk/environ/fcd/setback3.htm

#### 6.3.1.2 Additional sources: IHE Delft

Title: Managed realignment
Type: Advisory service
Organisation: IHE Delft
Purpose: To support and advise on flood and coastal defence projects
Information URL: http://www.ihe.nl/he/dicea/clm01/clm0102.htm
Advisory service URL: http://www.ihe.nl/ihe/advisory.htm

#### 6.3.1.3 Additional sources: HR Wallingford

Title: Managed realignment
Type: Advisory service
Organisation: HR Wallingford
Purpose: To support and advise on flood and coastal defence projects
URL: http://www.hrwallingford.co.uk/

### 6.3.2 Further considerations

Additional factors to be considered are:

- Tidal prism – the volume of water entering and leaving the estuary on each tidal cycle. This will be modified by increasing intertidal area and may have implications for the net accretion/erosion status of the estuary.
- Morphology – returning the estuary to a natural shape to allow processes to function 'naturally'.
- Site history – was the area originally salt marsh? A history of salt marsh growth will mean that conditions favourable to such, exist in the estuary.
- Soils – How modified are the original marsh soils. Ongoing research is suggesting that land-use history is important in marsh generation success.
- Surface elevation – is the site high enough for vegetation to survive. Following initial claim, land often sinks due to compaction and dewatering. Land which has been cut off from the sea for long periods of time may well be lower than the limit of vegetation colonisation.
- Surface gradient – marsh zonation from pioneer to upper communities rely on a seawards slope
- Sediments – all marshes are fine grained, although some degree of variation exists. Increased coarser sediment due to land use practices may mean drainage is too great.
- Creek networks – natural creeks are complex structures. Some debate exists as to whether to artificially create these with machinery, or allow them to develop naturally.
- Tidal hydraulics – main ebb/flood channels and current velocities. This factor will control the required width of the breach
- Breach location – it is important to avoid breaches open to predominant wave direction, as these can lead to scour and erosion.
- Sediment budget – is there enough sediment available for marshes to grow and develop, without detrimental impacts on the rest of the estuary (see Environmental Issues [6.4]).

There is a wide range of factors to consider. The implications of some are not completely understood at the present time, and are still the subject of scientific research.

## 6.4 Environmental Issues

The idea of managed realignment, in particular raises several issues. There is a large social debate regarding the giving of land to the sea. It is often cited as 'giving in' and retreating in the face of the enemy (the sea). However, in counter to that, retreat from one battle may win the war!

Perhaps of greater importance is the idea of losing land which has an alternative use. Typically, the land involved is farmland and farmers may well receive compensation through a stewardship scheme. One key issue remains, however. Schemes carried out so far have been largely piecemeal, involving small pockets of land which happen to be available. If we are to equate the need for holistic management and realign estuaries to a natural funnel shape, the needs for compulsory land acquisition needs to be addressed.

Another issue is that we are still in the realms of experimentation. Much research is ongoing and best practices have been developed. There are still no definite guidelines in place which have been tried and tested. As a result, all retreat schemes are adding to our knowledge of the process.

The planting of newly created mudflats is less contentious, but the practice has to be carried out in appropriate situations. Steep gradients on exposed estuaries are not suitable, even though marsh loss is acute.

## 6.5 Summary of benefits

- Increased intertidal width and wave attenuation capabilities
- Increased conservation potential
- Improved protection against sea level rise, particularly in the case of managed realignment
- Increased naturalness of estuaries
- Increased habitat for conservation interests

## 6.6 Summary of problems

- Increased sediment trapping by vegetation may impart an imbalance into the sediment budget, having implications for other areas in the estuary.
- Opening up of parts of the sea wall for managed retreat may cause major changes to accretion/erosion dynamics of the flood/ebb tide cycle
- Uncertainties of estuarine response (particularly with managed realignment).
- Novelty of the technique and the amount of 'unknowns' (particularly with managed realignment).

- Complexity of potential compensation issues (particularly with managed realignment).

**6.7 Recommended usage**

**6.7.1 Vegetation planting**

- On coasts where the intertidal flat slopes gently and has accreted (or been built up) to the appropriate level.
- Not for use on exposed coasts where marsh retreat is rapid, as the chances of survival are low (such coastlines should be considered for managed realignment).
- Where increased wave attenuation would benefit coastal defences
- Where landward movement of the defence line is not possible
- Where marshes once existed but have been lost through drowning or slow erosion/die-back
- To increase conservation potential though low mash flora.

**6.7.2 Managed realignment**

- To increase intertidal width in areas of rapid marsh retreat
- In estuaries with over-steep intertidal profiles, where seaward marsh advance is not possible
- To regain natural estuary functioning
- To offset the impacts of sea level rise by increasing intertidal area (cf. floodlands).

## 7 Abandonment

- having identified a coastal erosion problem, to do nothing about it and let the coast retreat un-hindered

Many previous methods of soft engineering maintain a ‘natural’ coastline with the addition of sediment, or the creation of new intertidal areas. The ethos of soft defence is to maintain and promote naturalness and so the ultimate scenario for this is to allow the coast to continue to erode without intervention.

The advantage is that a coastline will find its natural form by evolving at a rate determined by process. To do this, it will have no regard for any structure or land use which gets in the way. This, therefore, distinguishes it from managed realignment [see 6.3] which allows natural erosion but only to pre-determined lines

### 7.1 The rationale behind non-intervention policies

Any coastal defence initiative, as part of the planning process has to adopt a baseline scenario. In most cases, this is the ‘do-nothing’ position, ie, comparing each potential strategy with what would happen if nothing was done. This means that this approach is already commonly considered.

Where hinterland values are high, this method cannot be adopted. Where values are lower, it may be better policy to allow land to erode, in order to get the benefits of erosion (such as sediment input [see 1.1.1]). Such policies have been adopted in several areas, notably Holderness and Suffolk.

### 7.2 Management issues associated with abandonment

As with cliffs [see 4.11], the decision to abandon land is emotive and not one to be taken lightly. Discussion of the issues can be found in section 4.11 [see 4.11]. In general, several key issues need to be considered:

- What are the land uses involved?
- How has the coastline behaved in the past?
- Can the future behaviour be modelled/predicted?

### 7.3 When to intervene – the use of set-back lines

It would be dangerous to adopt a decision which says that the coastline will never be defended. Using predictive tools, it is better policy to predict the limit of acceptable erosion. This may be by predicting the coastline position for a series of time intervals (say 10, 20, 30 years), and identifying at which point the threat to property is so great that defence may become a suitable alternative. When this point is reached, the management strategy can be reconsidered. Such limits are known as ‘set-back’ lines.

The defence situation can also be improved by not allowing any new development seaward of the set-back line, and not allowing any re-development of existing properties as they reach the end of their useful lives.

### 7.4 Environmental issues

There are a series of key issues which need to be considered:

- Ownership of the land which is being left to erode, and possible compensation.
- The importance of the eroded sediment in the coastal sediment budget. A coastline which relies heavily on such sources will have a strong case for the non-intervention policy. The Holderness coast in eastern England is such a case, with eroded sediment supplying beaches in the UK and also Germany and the Netherlands.
- The socio-economic issues of affected communities.

### 7.5 Summary of benefits

- Increased naturalness of coastlines
- Increased conservation potential of habitats
- Improved protection against sea level rise
- Cheap
- Maintains inputs to sediment budget

### 7.6 Summary of problems

- Loss or property and livelihoods on affected land
- Compensation issues
- Social and cultural implications
- Predictability of modelling in terms of set-back lines
- Reliability of coastal behaviour models

### 7.7 Recommended usage

- Areas of low land values
- Where other defence alternatives are cost-prohibitive
- Where sediment input from coastal erosion is fundamental to coastal stability

## 8 Environmental Benefits of soft engineering

There are a variety of techniques for achieving soft coastal engineering. The main environmental benefits are:

- Increased coastal protection without hard structure construction
- Maintenance (as much as possible) of coastal processes
- Provision for proper functioning of the sediment budget
- Holistic appreciation of coastal processes
- An understanding of the impacts of human actions.

Techniques can be classified into three groups, depending on how they interact with the coastline:

| Retreat landwards | Hold the existing line | Advance seawards |
|---|---|---|
| Dune restoration<br>Managed realignment<br>Abandonment | Beach feeding<br>Beach scraping<br>Beach drainage<br>Dune restoration<br>Cliff stabilisation<br>Mudflat recharge<br>Vegetation planting | Beach feeding<br>Mudflat recharge<br>Vegetation planting |

Some appear in more than one group, as their impact relates to the situation, and the approach used, to carry them out.

### 8.1 Criteria for adoption

Each of the methods has been outlined previously, and recommended usage listed. It may be beneficial to consider the decision making process.

#### 8.1.1 Retreat landwards

- On coasts where wave energy is high and erosion a major problem
- Rapid retreat of landforms has occurred and the coastline is degraded.
- On coasts with low land use value and undeveloped hinterland

#### 8.1.2 Hold the line

- On coasts with high hinterland values
- As a supplement to hard defences (such as sea walls)
- Where one-off events (i.e. storms) have reduced beach levels
- As emergency measures
- Where sediment budget deficits have occurred due to other coastal defence works

#### 8.1.3 Advance seawards

- Where wave erosion is minimal
- To increase wave attenuation capabilities of the beach/marsh structure
- Where sediment supply is suitable for medium/long-term maintenance

### 8.2 The importance of an holistic approach

For soft engineering to be successful, it is important to consider the following when planning engineering:

- What are the sources of sediment to the sediment budget, and does the proposed scheme reduce/increase sediment provision?
- What is the main sediment movement mechanism – long shore or on/off shore?
- Are there likely to be impacts down drift of the operations?
- Can future problems be reduced by land-based measures?
- Is abandonment a practical option?

## 9 Soft engineering and sea level rise

All sea defence types are planned with reference to base level conditions. For many coasts, this base level is changing because of sea level rise. Sea level rise is a multi-faceted problem, but for coastal defences, the key problems are:

- High tides become higher
- Wave base comes further inshore, increasing near-shore wave base and wave exposure.
- Marsh vegetation may become unstable
- Coastal squeeze will become a real threat.

Hence, for any sea defence project, the following must be considered:

- How will wave conditions change with rises in sea level?
- Will beach sediments remain stable or will they be lost offshore?
- Will current erosion rates increase?
- Will flood risk be increased and how will this be dealt with?

One important consideration – coasts erode because they are unstable. Will soft engineering be able to force the coastline into stability? If not, then should the coast be left to erode?

### 9.1 Further information and data

Title: Permanent Service for Mean Sea Level
Type: web site and data archive
URL: http://www.pol.ac.uk/psmsl/psmsl.info.html
Organisation: Bidston Observatory, Proudman Oceanographic Laboratory
Language: English
Scope: Mainly UK ports
Abstract: Provides data sets from tide gauges around the UK coastline. Also provides some analysis and links to further information sources.
Tel: +44 (0)151 653 8633
Fax: +44(0)151 653 6269
Telex: 628591 OCEANB G
Email: psmsl@pol.ac.uk

### 9.2 What is sea level rise and what does it mean?

In simplest terms: a rise in sea level relative to the land. There are two components:

- Rising water (sea) levels
- Falling land levels

From a coastal defence point of view, two things can happen:

- Increased instability of undefended (soft) coasts with adjustment to new sea levels according to the Bruun rule [see 9.2.1]. This will involve the movement of coastlines inland and associated loss of habitat.
- Increased coastal squeeze on coasts with hard defences will increase instability and impact on fronting beaches and marshes. With time, these problems will increase and become more expensive.

#### 9.2.1 The Bruun rule

As sea levels rise, coasts respond by migrating to a new position such that their location, relative to the tidal frame, remains the same. Typically, this movement is landwards and upwards. Material is eroded from the shore face and transferred onto the sea floor. By this method, wave base, mean high and low water and each point on the profile remain at the same water depth.

Mathematically, we can cite the Bruun rule as:

$$S' = \{(zR)/x\}.\{1+(r/100)\}.\{1+(c/100)\}$$

Where:

S' = sea level rise

x = width of profile
z = depth of profile
R = landward movement of shoreline (erosion)
{1+(r/100)} = constant expressing sediment composition
{1+(c/100)} = constant expressing losses from the system (offshore or long shore transport)

#### 9.2.2: Further information

Title: Sea level rise as a cause of shore erosion
Type: Scientific paper
Author: Bruun P. (1962)
Reference: Journal of Waterways and Harbours Division A.S.C.E. 88: 117-130
Abstract: Discusses the formulation of the Bruun rule for sea level rise
Language: English

### 9.3 Impact of sea level rise on coastlines

Each type of coastline will respond in its own way to sea level rise. We can assume that the best way of managing coasts would be to not interfere and allow natural adjustment. However, given that this situation is rare, coastal engineers need to be aware of these responses and plan accordingly.

#### 9.3.1 Beaches and mud flats

Increasing water depths will increase wave activity near the coast, which will lead to increased sediment movement. The main habitat to experience this problem are the beaches and mudflats. Increased wave energy will increase current activity and sediment movement, potentially increasing beach scour and beach lowering. Immediate responses to this will be to decrease erosion by hard methods, or preferably by drainage [see 2.3]. Rapid changes due to storms can be repaired by scraping [see 2.2], whilst in the longer term, sediment losses may be compensated for by feeding [see 2.1] or by increased sediment provision by natural means, such as by accelerated cliff erosion [see 9.3.3]. Problems of sourcing beach feeding need [see 2.1.10] to be considered, particularly in the light of potential increased demand. Ultimately, consideration may be given to moving hinterland infrastructure or allowing inland migration by beach roll-over.

Beaches may also be protected in other ways not considered here, such as by offshore breakwater construction, which prevents direct wave attack on the beaches.

#### 9.3.2 Dunes

Sand dunes represents the landward extension of beaches on wind-dominated coastlines, and so many factors pertain to both. Landward transfer is essential for long term stability and so management would involve several processes;

- Hinterland usage which does not restrict landward migration
- Removal of plantations which restrict sand mobility

Given the above, dunes can easily react to sea level rise, and also continue to serve a dynamic role in beach level preservation.

Fixing of dunes will lead to rapid removal and increased flood risk to the hinterland. In addition, increased sea level will raise the water table which could increase plant instability and threaten survival.

#### 9.3.3 Cliffs

It is difficult to predict cliff reaction to sea level rise because of the many structural and sedimentological controls on their behaviour. However, typically, cliffs will retreat landwards but the rate at which this will increase may not be linear across all cliff types. For example:

- Increased undercutting by increased wave action will accelerate the rate of gravity collapse.
- Slumping in clay cliffs may accelerate more because of increased water tables and corresponding increased pore water pressure in failure surfaces. This may lead to large-scale reactivation of dormant slide planes in some circumstances.
- Hard rock cliffs may not respond at all.

It is argued that increased cliff erosion may offset some beach erosion problems. Increased sediment from erosion will increase the provision of supply to beaches down drift and may offset increased erosion problems. Important to note, however, that this needs to be of the right grain-size.

### 9.3.4 Salt marshes

Salt marshes backed by sea walls will experience coastal squeeze, and may revert to lower marsh species as the frequency and depth of inundation increases. Ultimately, this could result in reversion to mudflat. It is essential for marsh survival that depth of water be prevented from becoming too deep because instability will result. Hence, where sea level rise is rapid, seaward movement by planting will not prevent problems of marsh reversion, unless vertical accretion can keep pace with rising water levels.

The ability of marshes to keep pace with sea level rise is critical. Vertical accretion is a function of sediment supply and vegetation present. Using a formula derived by Allen (1997), it is possible to investigate marsh behaviour during sea level rise scenarios:

$$\Delta E = \Delta S_{min} + \Delta S_{org} - \Delta M$$

where:
$\Delta E$ = change in marsh surface elevation
$\Delta S_{min}$ = thickness of minerogenic (inorganic) sediment added to marsh surface
$\Delta S_{org}$ = thickness of organic matter added to marsh
$\Delta M$ = change in relative sea level

#### 9.3.4.1 Further information

Title: Simulation models of salt marsh morphodynamics: some implications for high intertidal sediment couplets related to sea level change
Type: Scientific paper
Author: Allen J.R.L. (1997)
Reference: Sedimentary Geology 113: 211-223
Abstract: Discusses the importance of sediment supply in the ability of salt marshes to keep pace with rising sea levels, and the ways in which this sediment is obtained.
Language: English

## 10 DEFRA guidelines for shoreline management in the UK

In the U.K. the leading authority on coastal management and defence construction is the Department of the Environment, Farming and Rural Affairs (DEFRA) (Flood and Coastal Defence Division). All consents are given through this agency, as well as most of the necessary funding.

Title: DEFRA
Type: Advisory service
Organisation: DEFRA Flood and coastal defence
Purpose: To support and advise on flood and coastal defence projects
URL: http://www.defra.gov.uk/

One of the main areas of importance to the successful implementation of coastal defences is the provision of an holistic management plan, covering all parts of the coastline and integrating all aspects of the sediment budget [see 1.1]. This is achieved by the construction of shoreline management plans (SMP's).

### 10.1The role of SMP's in coastal management

An SMP is a document detailing the management strategy for a length of coastline. It includes details of natural processes, including sediment budget considerations [see 1.1], and also to existing land-use and defence structures. It is intended to operate as a advisory document at times when changes in defence or coastal problems occur, and should provide guidance on hte most sustainable management of a stretch of coastline.

SMP's are non-statutory initiatives designed to inform decisions relating to local and regional development plans, and to coastal defence construction scenarios. They are normally prepared by local authorities as a means of informing policy on vulnerable areas, or areas of high conservation potential. DEFRA publish guidelines on the production of SMP's for both coastal defence authorities [see 10.1.1] and managers and decision makers [see 10.1.2]. The key issues pertaining to these documents will be reviewed here.

#### 10.1.1 Further information

Title: Shoreline Management Plans: A Guide for Coastal defence Authorities
Type: Guidance manual
Authors: MAFF, Welsh Office, Association of District Councils, English Nature NRA
Abstract: This guide acts as an advisory document on the development of management plans for the coastline of England and Wales, although its advice will be relevant to a wider range of coastal users and managers.
Language; English

#### 10.1.2 Further information

Title: Coastal Defence and the Environment: A strategic guide for manager's and decision makers in the National Rivers Authority, local authorities, and other bodies with coastal responsibilities.
Type: Guidance Manual
Authors: MAFF
Abstract: This manual provides a step-by-step guide to the implementation of coastal defence works, covering all aspects of the project from full consideration of the alternatives, to design of the structure, and also any environmental considerations.
Language: English

### 10.2 Important considerations

The reason for developing an SMP is to manage the coastline effectively and sustainable. In order to do this, it is imperative to develop an understanding of the following:

- How coastal processes interact with the landforms to produce the sediment sources, transport, and depositional areas which comprise the sediment budget [see 1.1]
- How the coast has behaved historically
- From  this, how the coast may behave in the future
- Areas of the coastline which may be adversely affected by any coastal changes.

Hence, when developing an SMP, some important areas need to be considered:

- Coastal processes [see 10.2.1]

- Existing defences [see 10.2.2]
- Land-use [see 10.2.3]
- Natural environment [see 10.2.4]

**10.2.1 Coastal processes**

In effect, how the coastline under study functions. It is important to understand the sediment budget [see 1.1] as well as waves and tides which produce currents which move this sediment around. In addition, this knowledge should extend back in time to determine the historical perspective of coastline evolution. This is important considering the present coastline is but a snapshot in time, and part of an ongoing evolutionary process. This knowledge will ten enable a prediction of likely future trends, given scenarios such as sea level rise [see 9.3].

**10.2.2 Existing defences**

The defences which currently exist on a coastline are likely to be having a major influence on it already, particularly if these defences are 'hard' rather than 'soft'. It is important to determine what defences are present and how effective they are in protecting the coastline and allowing the free movement of sediment.

Given that all defences have a limited life span, if the remaining 'life' of each defence can be determined, then this will allow forward planning to occur, the identification of potential alternative strategies, such as the replacement of a sea wall with a more 'soft' approach.

**10.2.3 Land-use**

Any future defence provision will ultimately depend on the value of the land in question. Only be determining land-use and its worth can strategies such as 'do nothing' [see 7] or managed realignment [see 6.7.2] be assessed. Clearly, high value land, such as urban or industrial centres will need to have their protection maintained, but for lower value land this may not be the case, and alternative strategies could be adopted.

**10.2.4 Natural environment**

Many coastlines contain environmentally and ecologically important areas, often reflected in some form of designation. Such protection needs to be acknowledged and any management plan take this into account so as not to impact detrimentally upon it. Each plan will need to make provision for the maintenance of such sites, and may also need to take the holistic viewpoint, in that external factors may well have the potential for negative impact, such as a sea defence elsewhere on the coast which leads to a decrease in available sediment.

Each SMP should also provide for the increased provision of coastal habitats, especially considering the problems of sea level rise and coastal squeeze [see 9]. Mudflats [see 5], salt marshes [see 6] and coastal dunes [see 3] are particularly vulnerable to sea level rise and to development, and so the identification of areas for such habitats to be re-created may be possible.

**10.3 Guidance on the procedure for constructing a shoreline management plan**

There are two stages in the collection of an SMP:

- Data collection**,** data analysis and setting the plan's objectives
- Preparing and implementing the plan

Ideally, the delineation of the management area should coincide with coastal cell boundaries (A coastal cell is defined as a length of coastline within which coarse sediment movement (sand and shingle) are relatively self contained).

**10.3.1 Consultation**

An important point is that of consultation with local people and coastal users. All SMP's are advisory only, and so by achieving agreement and consensus at an early stage will make the eventual plan more workable and acceptable by local people. The local population and users should never have the impression of being forced into something by a group of outsiders. High priorities are:

- Establish links with local authority and all user groups, and to maintain these links throughout the process
- To identify areas of conflict at an early stage and overcome them by reasoned negotiation

- To use local knowledge in the gathering of data [see 10.3.2] and information on how the coastline works
- To gather local opinion to potential problem areas and needs, and to develop key parts of the plan

As well as local groups, regional and national bodies, such as conservation agencies and river authorities should also be included in this stage.

### 10.3.2 Gathering and analysing data

To understand how a coastline works, and how waves and tides interact to produce coastal landforms, it is necessary to gather scientific information on which to base an interpretation. Unfortunately, whilst some coasts have been relatively well studied, many have not and so there may be a lack of information on which to base this phase. If this is the case, there is no alternative but to adopt one of the following:

- Develop a monitoring strategy to fill in gaps in knowledge. Often only of limited use as the length of time necessary to build such a detailed knowledge is prohibitive and not possible.
- Continue with the plan on the basis of what information you have, bearing in mind the potential weak links in any predictions made.

Key areas of knowledge which may be investigated for the necessary information include:

- Local knowledge (residents, fishermen, harbour authorities)
- Local bodies (natural history groups, local societies)
- Regional bodies (planning authorities, regulatory authorities)
- National bodies (conservation groups, defence agencies)
- Searches of the scientific literature

It is important to gather information on the following areas:

- history of the coastline in question
- landscape and landscape evolution
- contemporary processes
- rates of erosion and accretion
- rates of sea level rise
- areas at risk of flooding from storms and sea level changes
- sediment movement (onshore and offshore)
- status of sea defences (responsibility/ownership)
- sediment sources
- land protection designations
- land-use and management
- commercial activities
- current planning guidelines, development plans and restrictions
- areas of high scientific importance (ecological, geological, archaeological)

Based on such knowledge, it will be possible to develop guidelines relating to key areas which the plan needs to address. These may be the protection of important habitats, increased provision of flood defences, land-use zonation.

### 10.3.3 Preparing an SMP

Once the key information is gathered and analysed (bearing in mind the potential gaps due to lack of knowledge), the plan can be prepared. The first decision to make will be to divide the management area into manageable units (sub-cells). MAFF guidelines [see 10.1.1] state that these should be

> *'... a length of shoreline with coherent characteristics in terms of both coastal processes and land-use'*

Having done this, each management unit should be discussed in the SMP in relation to its sustainable management and usage. Recommendations should be included relating to land-use, environmental protection, future defence provision, and any potential user conflict. In the case of defence provision, it is important that each section of coastline has a recommendation for future management policy to be adopted when existing defences need repair or renewal. Possibilities include:

- Do nothing [see 7]

- Hold the existing line - i.e. maintain the current position of defences due to high land values. Under this category, possibilities should include repair or renewal of existing structures, beach feeding [see 2], habitat restoration [see 3], protecting existing habitats such as dunes [see 3] or cliffs [see 4].
- Advance the line of defence seawards - i.e. force the high water mark away from the land. Methods could include beach feeding [see 2] or marsh creation [see to 6.2]
- Retreating landwards to new defences - i.e. increase intertidal width by giving up land. Such methods include managed realignment [see 6.3].

Making such decisions [see 10.4] is itself a complex task, and is considered below. By undertaking such informed decisions at this stage, the future of each bit of the coastline can be projected, such that areas highlighted from managed realignment or abandonment will not receive any future planning consent, whilst areas where the line of defence is to be held or advanced seawards, may also be earmarked for future development.

**10.3.4 Post implementation monitoring and review**

The plan may have been formulated but given that it may contain a number of assumptions due to the lack of information on which to base initial decision, it is important to constantly monitor and review the plan. All SMP's should be considered as working documents, in that they need revision and updating. Such a timetable for updates should also be included in the plan when published.

At the time of updating, each decision and recommendation should be 'revisited' to establish whether the criteria on which that decision was based are still valid. If this is the case. Such recommendations can be carried forward into the second draft, but where predictions have not been as expected, revisions or even changes in recommendation may be necessary, and should not necessarily be taken as failures on behalf of the original plan compilers.

**10.4 The SMP and coastal defence recommendations**

In order for the SMP to recommend which coastal defence strategy to adopt, it is necessary to consider each section of coastline with respect to accretion/erosion, habitats, land-use, sediment budget, and natural processes. With such consideration, it will be possible to determine how best to protect each section of coastline in the future.

There are a series of steps by which to make such decisions [see 10.1.2]

- Preliminary considerations [see 10.4.1]
- Appraising all coastal defence options (hard and soft) [see 10.4.2]
- Choosing a preferred option [see 10.4.3]
- Design of the scheme and identification of potential environmental impacts [see 10.4.4]
- Operation of the scheme [see 10.4.5]
- Post project review and appraisal [see 10.4.6]

**10.4.1 Preliminary considerations**

When deciding which defence type is best suited to a coast, it is important to consider all aspects of a coastline which will be affected [see 10.3.2]. Some issues are more important than others, such as reducing the risk to life, protecting high value areas from flooding/erosion. Other considerations, however, are also important, such as the natural environment, and other areas which may suffer as a result of any scheme. Where defences already exist, these should be treated in the same way.

Consideration should also be given to disruption during the construction of the scheme, including any vulnerable areas which may be affected.

As with constructing an SMP [see 10.3], consultation with user groups, local interest groups, and other interested parties with local knowledge should be made at this stage. Once there is a knowledge of the area, different possibilities can be considered [see 10.4.2]

**10.4.2 Appraising different options**

All possibilities for defending the coast should be considered. Initially, this appraisal should consider:

- Do nothing [see 7]. Adopt a policy of non-intervention and let the coastline continue to erode. This policy is important because it will also provide a base line with which to compare all other possibilities.

- Risk management. Consider the possibility that it may be better to manage the problem (such as flooding) in ways other than structural. Possibilities include introducing flood warning systems to facilitate evacuation.
- Maintain the current defences. Repair the existing defences of carry out works to make good any sediment losses (beach feeding [see 2.1).
- Change. Where existing defences are inadequate, or where no defences exist, new structures or methods need to be adopted. Here we should also consider such possibilities as holding the line, moving landwards, or moving seawards

Work from the construction of the SMP [see 10.3] may also be incorporated at this stage, including information relating to environmental designations, and input from national, regional and local authorities.

Some possibilities may be ruled out at this stage, such as managed realignment if the area is highly developed. Those remaining should then be subject to an informal environmental impact assessment, to include an assessment of:

- Assessing input from local groups, consultants, national/regional bodies, etc
- Assessing impacts on sediments and coastal processes which may impact on the adjacent coastline
- Consider vulnerable and sensitive areas
- Consider impacts of construction
- Identify ways of reducing and environmental impacts identified
- Consider ways of enhancing the environment

Further to this exercise, some other schemes may now be ruled out on the base id impacts on the environment. This will leave a list of possibilities which are environmentally viable.

**10.4.3 Choosing the preferred option**

At this stage, necessary legal and policy requirements need to be met, such as formal Environmental Impact Assessments and possible, cost benefit analysis. These need to be carried out for all of the remaining possibilities.

The outcome will be a ranking of all remaining possibilities on the basis of environmental acceptability and cost. If the preferred option on the environmental list is the same as that on the cost benefit list, that will be the adopted method. Should they be different, then the final decision will be a matter of judgement, part of which will be the choice between the importance of environment or cost. It is for this reason that it is important to consider all environmental implications at an early stage.

**10.4.3.1 Further information on project selection**

Title: DEFRA
Type: Advisory service
Organisation: DEFRA Flood and coastal defence
Purpose: To support and advise on flood and coastal defence projects
URL: http://www.defra.gov.uk/

**10.4.4 Designing the scheme**

Once the preferred option has been decided, formal planning can proceed. This design should consider all environmental implications, such as the sediment budget, natural processes, and coastal usage (accessibility etc). It may also be possible to design a scheme which offers environmental enhancement. Main areas of consideration regarding this include:

- Protection/enhancement of areas of special interest or value
- Protection of species/habitats
- Protection of landscape/coastal features/archaeological/or geological exposures
- Choice of materials so as to reduce physical and aesthetic impacts
- Provision of access (Note, in some situations of important habitat value, prevention of access may also be desirable)
- Construction methods so as to reduce impacts

**10.4.5 Operation of the scheme**

When implementing a defence scheme, consideration should be given to the following:

- Timing of construction in environmentally vulnerable or tourist areas. It is advisable to avoid flowering or nesting seasons, as well as major tourist seasons.
- Confine work-related activities into designated areas to avoid unnecessary compaction of beaches [see 2.3], or trampling [see 3]
- Informing contractors as to the importance of the above measures
- Adopt emergency procedures to clear up spills
- Adopt a policy for cleaning up the construction site following completion

**10.4.6 Post-project appraisal**

Many of the criteria used in making the decision of which method of defence to adopt has been based on prediction. Monitoring of the scheme will allow these predictions to be validated, and increase the accuracy of future predictions. Any adverse impacts should be rectified with remedial measures. This is particularly important with respect to:

- Sediment levels on fronting beaches (particularly if hard defences are used)
- Stability of adjacent habitats
- Any modification of coastal processes.

**Key references**

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**12 Some Key Internet sites**

Key links are provided in the text. The general links below will take the reader to additional, more general sites

DEFRA home page - http://www.defra.gov.uk/

Bidston observatory (for data relating to sea level rise) http://www.pol.ac.uk/psmsl/psmsl.info.html

U.S. Army corps of Engineers (for on-line reports relating to many areas of coastal defence). - http://www.usace.army.mil/inet/usace-docs/eng-manuals/cecw.htm

Links to coastal/wetland engineering sites around the world - http://www.geog.ucl.ac.uk/~jthompso/worldwet.html