SALTMARSH MANAGEMENT TECHNIQUES

A REVIEW

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1 INTRODUCTION

New Forest District Council is working in partnership with the Environment Agency, English Nature, Lymington Harbour Commissioners, Hampshire County Council, the Hampshire Wildlife Trust and other interested stakeholders to develop a sustainable coastal strategy to safeguard the long-term future of the Lymington-Keyhaven saltmarshes. This is likely to require innovative saltmarsh management techniques.

This report is the result of a desk-based review of the ‘soft’ engineering techniques available for saltmarsh and mudflat management. Examples of field trials and site experiments from the UK, the US and in Europe are shown in Table 3, 4 and 5, respectively.

Many of the techniques which have been successfully employed in the US and Europe have not been implemented in the UK, as of yet. These innovative techniques may provide potential sustainable saltmarsh management options to coastal zone managers in the UK. Small-scale field trials need to be conducted and further developed, which may result in the techniques being more-widely applicable and implemented on a larger scale.

2 Saltmarsh Management Options

2.1 'Hard' Engineering Techniques

'Hard' engineered coast protection works, fixed structures such as sea walls and revetments, may not provide cost-effective and environmentally acceptable solutions to prevent saltmarsh erosion. Such techniques often conflict with natural processes, and require expensive repairs and regular maintenance, in order to provide an adequate level of coast and flood protection from the effects associated with climate change, sea level rise.

In many locations, for example the coastal and flood defences between Lymington and Keyhaven, structures are designed on the basis of saltmarshes and mudflats remaining in front of them. If these saltmarshes and mudflats decrease in area or disappear completely as a result of 'coastal' squeeze, their ability to absorb and dissipate wave energy from storms will reduce accordingly. The structures may well need to be redesigned or upgraded.

2.2 'Soft' Engineering Techniques

Factors that influence and adversely affect coastal processes and ecological conditions, such as sea level rise, may necessitate management of the environment to produce a more appropriate regime. This may be achieved through the selective use of 'soft' engineering management techniques, for example re-cycling dredged material and inter-tidal recharge, which manipulates natural processes rather than confining them.

There is limited experience of the application of soft engineering techniques in sensitive estuarine saltmarsh and mudflat environments in the UK. Such techniques are largely unproven and require careful development before large-scale implementation. They could provide the potential to allow the coast to evolve more naturally, and may be more cost-effective to implement. Appropriate shore protection techniques should be screened based on the criteria set out in Table 1.

Criteria	**The selected alternative should:**
Compatibility	Not be radically different from existing shore protection schemes in nearby areas.
Effects on Coastal Processes	Not adversely influence the regional coastal processes
Effects on shoreline use	Not severely restrict the current or planned shoreline use
Environmental effects	Have minimal adverse environmental impacts
Management implications	Not mandate a drastic change in the coastal management policy
Construction schedule	Have a construction timetable within appropriate environmental windows
Project costs	Be cost-effective and sustainable

Table 1 Criteria for Shore Protection Techniques

Decisions need to be made concerning the relative value of existing habitat types, and the need for creation or restoration of different habitat types. These decisions must be made on a case-by-case basis and could vary temporally and spatially. It is worth noting that saltmarsh restoration does not provide immediate solutions to sea defence problems, often involving long periods of continued maintenance before the new or restored marsh can be considered stable.

Whilst sentiment might favour restoration of the most valuable sites or the most threatened sites, in practice it is recommended that investment must be prioritised for the most easily restored/created sites, where the likelihood of success is greatest.

Coastal sediments, including dredged material, need to be viewed as an asset and managed as a resource on the basis of a sound understanding of the natural system and its susceptibility to external changes. DEFRA consider all dredged material to be a potential resource rather than a waste product. English nature will promote the use of navigational dredging schemes, which retain capital and maintenance dredged sediment within the active estuarine sediment budget, especially where the dredged sediments are of good environmental quality.

3 Saltmarsh Stabilisation Experiment trialed at Lymington

3.1 Fibre Rolls

A small-scale trial of staked coir fibre rolls was carried out in the Lymington River in 1994, at a site that was subject to typical hydrodynamic conditions and a significant level of commercial and recreational boat traffic. The aims of the trial were to:

(a) reduce saltmarsh erosion rates,
(b) provide a stable growing medium at the edge of the channel and
(c) protect the establishing vegetation from boat wash and wave action

It was envisaged that by protecting the edge of the saltmarsh in this way, further loss could be prevented while regenerative techniques are given a chance to work within the saltings themselves.

Subsequent monitoring of this trial site demonstrated that this technique was ineffective. The saltmarsh edge behind the constructed fence line has continued to retreat at 1m/year. The area of mudflat has therefore increased, which may provide ecological benefits to feeding wildfowl and waders.

Pre-construction monitoring details have not been available for subsequent analysis and comparison to more recent datasets.

3.2 Wave Screens

The wave screens positioned either side of the main navigation channel were constructed in the early 1990s. These wave screens have been successful in terms of providing flood protection for the harbour from wave attack from the south east and contributing towards safer conditions for the many marine users within the harbour.

A notable impact has been the change in inter-tidal foreshore gradient north of the eastern screen. The gradient has lowered significantly which has improved the wave energy dissipation characteristics of this saltmarsh frontage.

Documentation for the design of the structures, pre-construction monitoring details and reports have been particularly limited.

3.3 Spartina Transplantation

Another field experiment that was trialed was the transplanting of a species of *Spartina* from Lindisfarne. This trial was extremely small-scale, the planting was in a relatively high energy environment and proved ineffective. Again, documentation for the design of the structures, any monitoring details and reports have been particularly limited.

4 Description of Proposed Techniques

Many innovative 'soft engineering' techniques, are largely unproven in the UK and require careful development before large-scale implementation. Technical considerations include measures to:
(a) reduce or reverse the rate of retreat of managed coastal habitats;
(b) mitigate estuarine sediment deficits;
(c) restore the engineering and ecological functions of inter-tidal flats and saltmarshes;
(d) reduce wave energy, control the tidal velocities and to encourage deposition of the fine-grained sediment fraction;
(e) manage and control the rate of either naturally induced, or artificially-enhanced, sedimentation;
(f) transform low and concave eroding muddy foreshores into high and convex accreting shores; and
(g) ideally extend the saltmarsh seawards.

The following soft engineering techniques aim to produce environmental conditions, which enhance inter-tidal and saltmarsh habitats (Table 2).

Increased Sediment Supply	Inter-tidal recharge or foreshore renourishment	• Direct pipeline discharge ▪ Trickle charge ▪ Rainbowing material onto marsh ▪ Bottom dumping ▪ Agitation dredging
Retention and Stabilisation of Sediment	Geotextile 'structure'	▪ Biodegradable geotextile 'geotubes' and meshes; ▪ jute; coco and straw mats
	Wavebreaks	▪ Chenier enhancement ▪ Inter-tidal coarse-grained bunds ▪ 'baffle fencing structures' ▪ sand bags ▪ used tyres
	Vegetation protection	▪ hydro-seeded vegetative cellular confining blankets; ▪ planting / transplanting; and ▪ water velocity reducers
Managed Realignment		

Table 2 Soft Engineering Techniques for Saltmarsh–Mudflat Enhancement

4.1 Increased Sediment Supply

The physical characteristics of the sediment used for habitat restoration relate to the successful colonisation of wetland vegetation. Typically fine-grained dredged material (silts and clays) is more desirable for wetland vegetation restoration than sandy materials.

Beneficially 'recycling' dredged sediments as a fill or substrate for habitat restoration or enhancement schemes, and retaining the material within the estuarine system may increase the supply of sediment available for sedimentation processes, and may generate substantial local and regional socio-economic and environmental benefits. Various techniques for the beneficial use of dredge material include:

- Applying dredged material in thin layers to bring degraded wetlands up to an inter-tidal elevation;
- Restore the width of the inter-tidal zone, and stabilize eroding natural wetland shorelines to provide spatial opportunities for the coastal habitat regeneration;
- Sub-tidal placement of sediment to reduce the tendency for erosion of adjacent inter-tidal margins;
- Inter-tidal foreshore placement of sediment to increase the dissipation of wave energy, reduce erosion and/or trickle-feed sediment back into the wider estuarine system;
- Using dewatered dredged material to construct erosion barriers and other structures that stabilise and restore degraded wetland.

However, coastal morphological profiles must be regarded as whole units; modifying the upper part of the profile and neglecting the inter- and sub-tidal zones would not promote natural processes, enhance coastal stability, or increase the integrity of defended foreshores.

4.1.1 Inter-tidal Recharge

Inter-tidal recharge is the term used to describe the artificial raising of inter-tidal and sub-tidal areas with imported sediment, such as dredged ('waste spoil') material, to a threshold elevation above which vegetation can naturally gain a foothold.

Inter-tidal recharge is still an experimental technique that makes beneficial use of densified, low-contaminated (clean or treated), low-cost maintenance-dredged sediment. The general aim of inter-tidal recharge is to recreate self-sustaining soft sediment shorelines in eroding areas. Financial, logistical, and resource constraints would limit options for many environmental enhancements if dredged sediment resources were not available.

Mudflats, because they are cohesive, respond at different rates, and so it is not as critical for the stability of the foreshore to maintain the prototype grain size distribution. Fine-grained sediments do not develop an equilibrium immediately, but need time to dewater and consolidate, and develop an infauna of microorganisms. It is only after such processes that the full cohesive strength is attained. Muddy, low-contaminated, dredged spoil will need to go through a densification process to achieve the stability necessary for placement on the eroding tidal flat. This means that mudflat recharge is not a rapid process, because it is necessary to protect the recharge sediment from waves and tides while they are settling and dewatering. Trailing suction hopper dredgers and cutter suction dredgers are best suited for foreshore recharge.

4.1.2 Direct placement of Dredged Material

The aim of direct placement of muddy sediment onto the existing saltmarsh-mudflat profile is to modify the morphology and to make additional sediment available for recycling within the saltmarsh system.

4.1.2.1 Placement via Pipeline Discharge

Direct placement of marina maintenance dredged material via pipeline discharge over relatively short distances may be a potentially cost-effective option, involving no rehandling costs, storage of material or transportation to site by vessel. However, pumping distances and the potential disruption to navigation may restrict this option.
To sustainably re-nourish the entire inter-tidal and saltmarsh profile, pipelines would need to be permanently laid within the saltmarsh system or repeatedly mobilised and removed.

Advantages of discharging the sediment via a pipe include the potential to control the volume, rate and location of discharged material with some degree of accuracy. Material discharged via a pipeline is geotechnically weaker and therefore, more readily resuspended than bottom-dumped material, and would need time to dewater and consolidate. If the sediment was discharged through permeable materials, such as straw bales, this may aid the dewatering process.

4.1.2.2 Placement via Rainbow Dispersal

An alternative direct 'placement' technique would be to spray ('rainbow') muddy slurry on to the upper foreshore, from a shallow-draft hopper, using a mud-cannon. By jetting the slurry at slack low water (to maximise the onshore sediment transport), the sediment can be 'placed' high on the foreshore, or behind wavebreaks, which protect the recharge while it is dewaters (Figure 1).

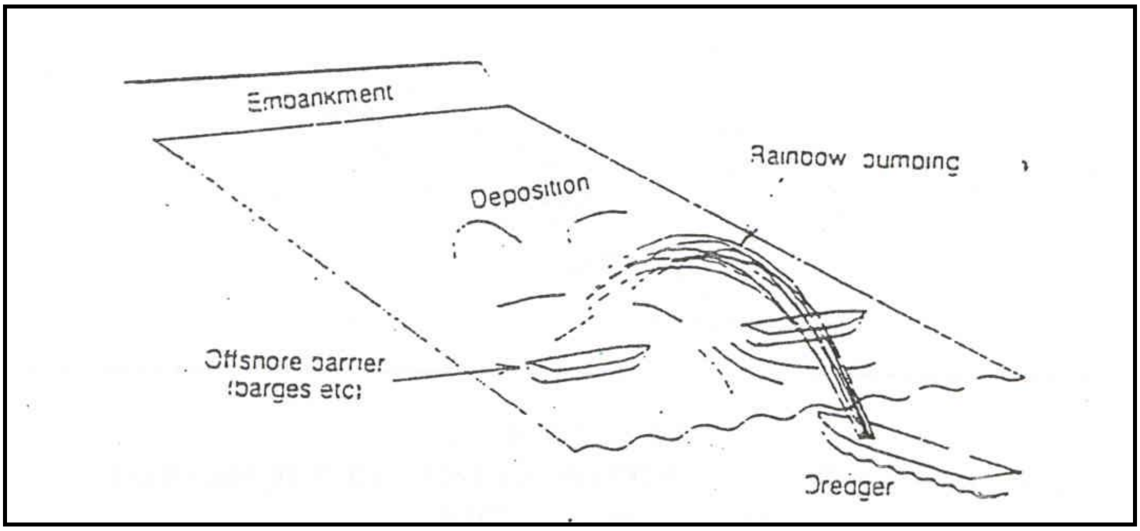


Figure 1. Foreshore Recharge with Cohesive Sediments : Pumping From A Dredger. Source: MAFF (1993).

Vessel access and operation capability may depend on the nearshore bathymetry, and gradient of the inter-tidal foreshore; the sediment-water mix ratio may determine the distance over which the material can be rainbowed.

4.1.3 Trickle Charge

The concept of trickle charge is to increase the availability of source material by using the energy of the natural system to redistribute the dredged material.

4.1.3.1 Inter-tidal Trickle Charge

Inter-tidal trickle charge requires the strategic placement of small quantities of sediment in sacrificial ‘mud mounds’, at the appropriate level on the inter-tidal zone, to disperse naturally. Alternatively, a bank of sediment may be deposited from split hopper barges on the spring tide at approximately low water mark (Figure 2).

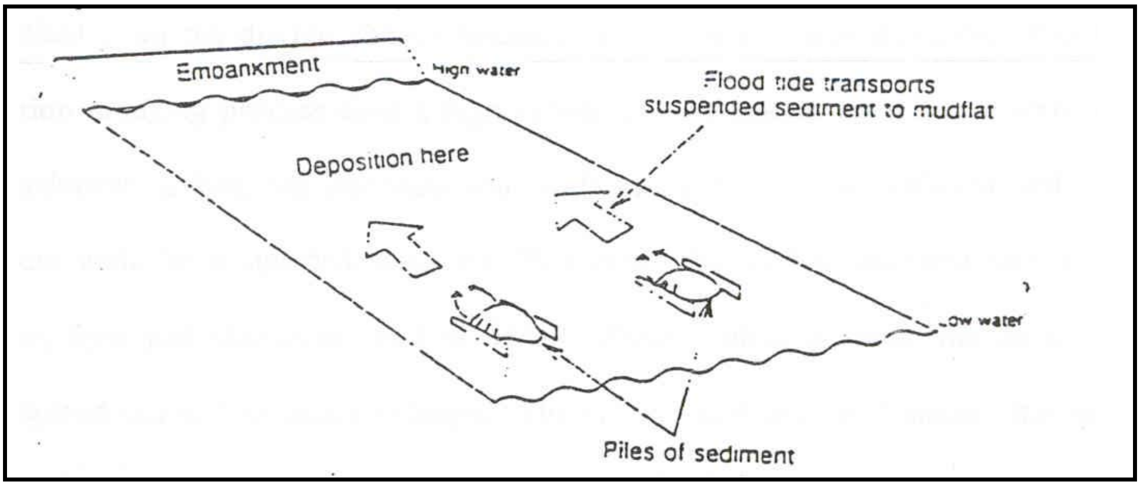


Figure 2. Foreshore Recharge with Cohesive Sediments : Trickle Charging. Source: MAFF (1993).

The natural movement of the sediment to the required areas is promoted, which allows the foreshore to respond naturally to physical processes. This results in increased suspended sediment concentration in the inter-tidal zone, and forms an equilibrium morphology without the necessity for artificial periods of consolidation. Sedimentation is wholly dependent on natural processes. The shallow water depths, low current velocities, and dissipation of current and wave energy over the saltmarsh due to vegetation are other factors that enhance potential sedimentation.

4.1.3.2 Trickle Charge via the Water Column.

An alternative to this technique is trickle charge via the water column. In this method the dredged material is discharged into the water column at such a rate and dilution that the moving water column is able to carry the recharged material away from the site of introduction.

A variation on this technique is agitation dredging, currently not licensed but under review by DEFRA. The basic aim of agitation dredging is that material is mobilised from the dredge site by hydraulic action (e.g. water injection). The water injection dredging process aims a high-volume, low-pressure water jet directly above the sediment surface; the jet-stream will erode and penetrate the sediment and form a mixture with the suspended sediment. This raises the muddy sediment into a turbid density layer just above the seabed. Unless retained, the density layer will spread out and decrease in height.

The natural tidal regime disperses the agitated dredged material from the dredge site. The fine-grained sediment would settle out as a thin layer over a wide area, through the deposition and subsequent re-suspension of the sediment within tidal cycles.

4.2 Stabilisation & Retention of Sediment

Increasing the period of sedimentation during a tidal cycle may be achieved by decreasing transport velocities. This may be achieved by traditional fine-grained sediment-deposition (‘warping’) methods where high tide waters are impounded and sediments allowed to settle, before draining the waters off (‘dewatering’) via a sluice gate, or as tide falls. The rate of deposition is controlled largely by the interaction between tidal current velocities and vegetation cover.

Techniques to decrease the transport velocities include:

- the provision of sedimentation polders or the use of baffle fences;
- the use of wave-energy reducing geotextile structures;
- the ‘construction’ of coarse-grained bunds seaward of the eroding frontage;
- vegetation planting / transplanting.

4.2.1 Sedimentation Polders

The poor settlement characteristics of both natural, and dredged fine-grained material, requires the construction of large sediment fields, or polders, to permit sufficient time for the fine-grained sediment to settle out (Figure 3 & Plates 1 & 2).

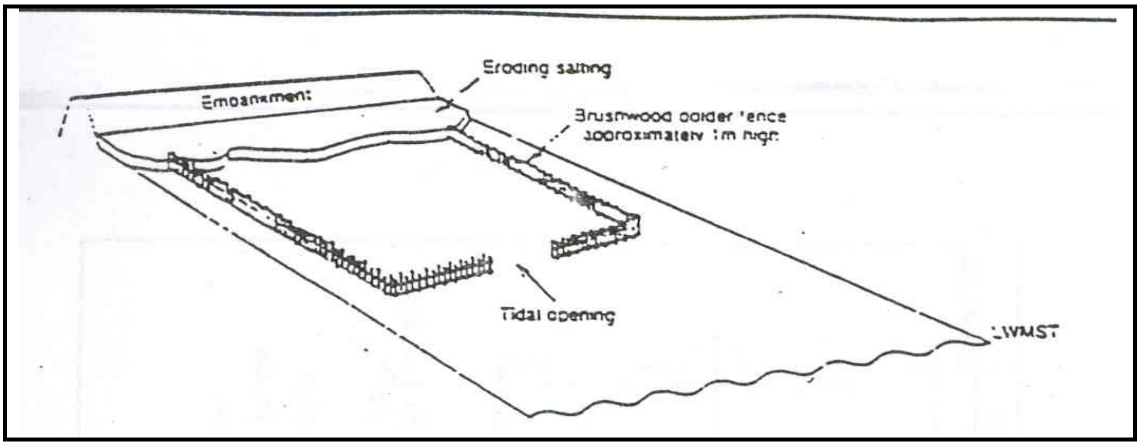


Figure 3. Sedimentation Polders.
Source: MAFF (1993).

The ‘Schleswig-Holstein method’, established in the Netherlands and Germany, encloses a width of mature upper marsh, together with a similar width of mudflat seaward of the marsh, by the construction of a perimeter fence (Figure 4). Ditches are dug in a regular pattern across the polder to collect the warp (layer of deposited fine-grained sediment) which is cleared and piled on the banks between the ditches. The aim is to develop a new area of salting, which will protect the reclaimed or regenerating area, and which is subdivided into several enclosures or polders. Gaps in the fencing along the seaward line of each enclosure allow the tidal inflow into a series of channels within the area; these are maintained to control the flow and hence the sediment distribution. The main ditches are dug perpendicular to the coast while other trenches (‘grips’) are dug parallel with it. The main trenches direct the waters of the flooding tide onto the upper areas, sufficiently rapidly for them to carry the sediment towards the shore, instead of depositing it further offshore.

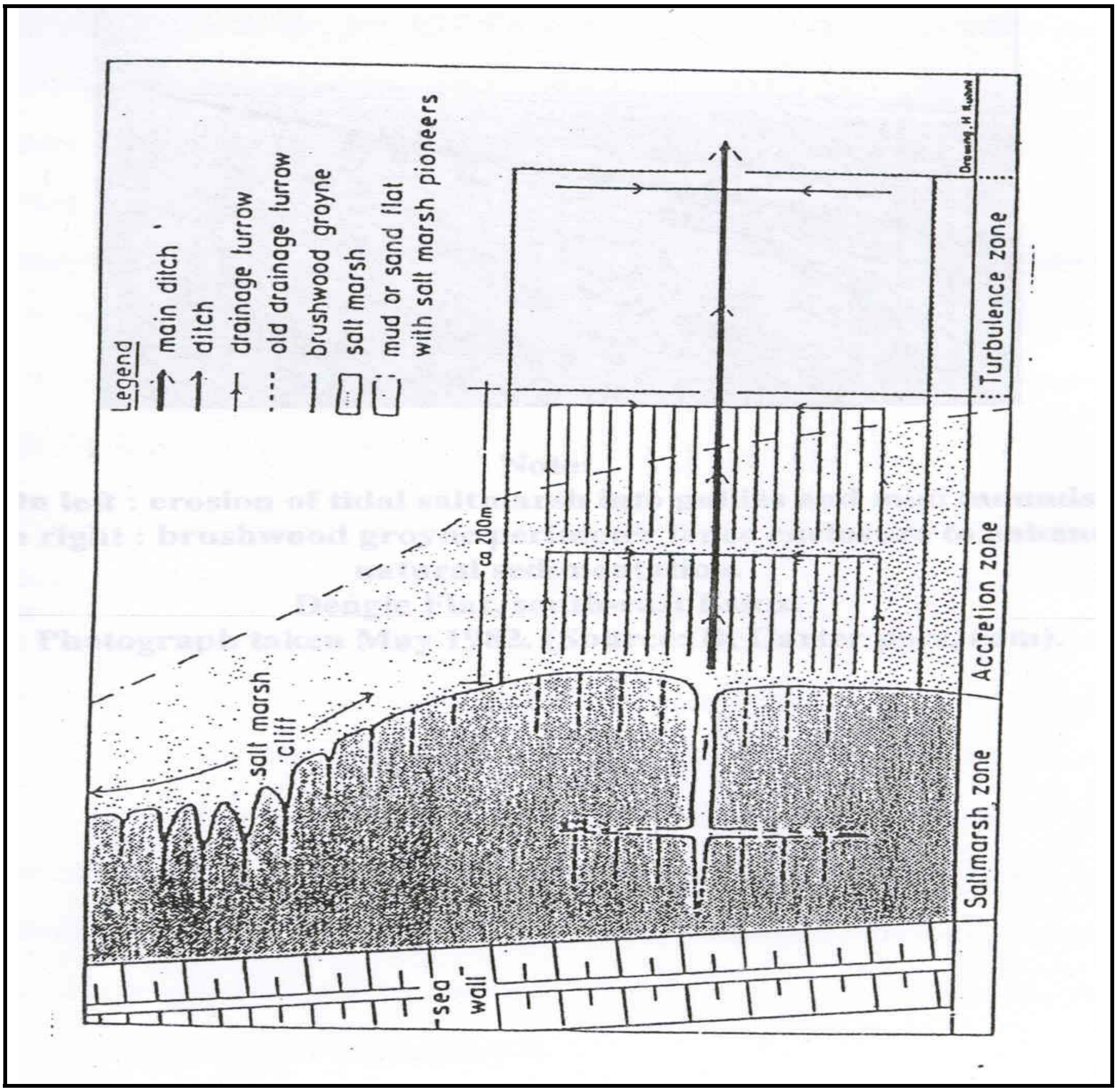


Figure 4. Design For Sedimentation Polder.
Source: Hofstede (1995).

4.2.2 Brushwood Groyne Fencing

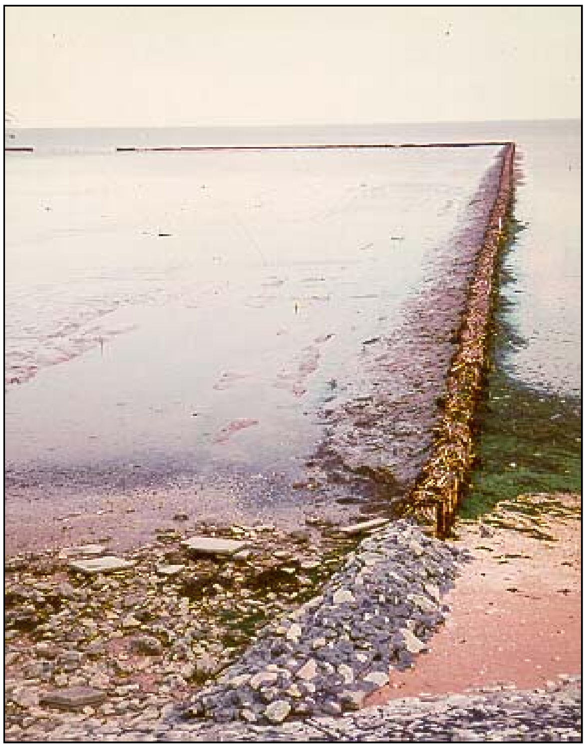
Brushwood fences consist generally of a double row of wooden stakes driven well into the mudflat. They minimise wave action, slow currents and promote sedimentation, and to some extent delay the departure of the ebb tide. Tidal velocities are reduced by the ponding effect and the erosive effects of wave and tide-generated shear stress are diminished, thus allowing the fine-grained fraction of the sediment to settle out. As a result, the sedimentation of suspended matter is enhanced, both behind the groynes and in front of the saltmarsh edge. Monitoring the effectiveness of the brushwood fencing is essential.

A combination of techniques is often used to restore and enhance saltmarsh systems. A method of foreshore accretion and artificial creation of a saltmarsh, developed from Dutch experiences, can typically be divided into three phases. During the first phase, a groyne field is built in order to reduce turbulence and to improve sedimentation, When the elevation of this field is high enough, a system of drainage furrows is dredged in order to improve aeration and to initiate the growth of pioneer vegetation. At the same time, a second groyne field is built in front of the first and takes over the function of the first (second phase). If the development is successful, a saltmarsh will be generated. If necessary, this saltmarsh can then be protected by a third groyne field (phase 3).

Plate 1 Sedimentation Polder, Dengie Marshes, Essex

On left : erosion of tidal saltmarsh into gullies and mud mounds.
On right : brushwood perimeter fence enclosure to enhance natural sedimentation. Photograph taken May 1982. (Source: D. Carter, University of Portsmouth).

Plate 2 Brushwood Fencing used in Polder Construction



Brushwood groyne fencing erected in 1981 to encourage sedimentation on eroding saltmarshes, Dengie Flat, Essex. Photograph taken May 1982. (Source: D. Carter, University of Portsmouth.)

4.2.3 Geotextile 'Structures'

Where traditional construction techniques are ill-suited or cost-prohibitive, geotextile 'structures', such as geotubes™ are simple to place and construct, are cost-effective and have minimal impact on the environment. Efforts to protect, reclaim, or increase wetland areas can be enhanced by designing and constructing longitudinal geotextile elements for containment. To ensure retention of fine-grained dredged material behind these structures until it consolidates, an additional tube may be placed on top of the primary tubes to raise the elevation.

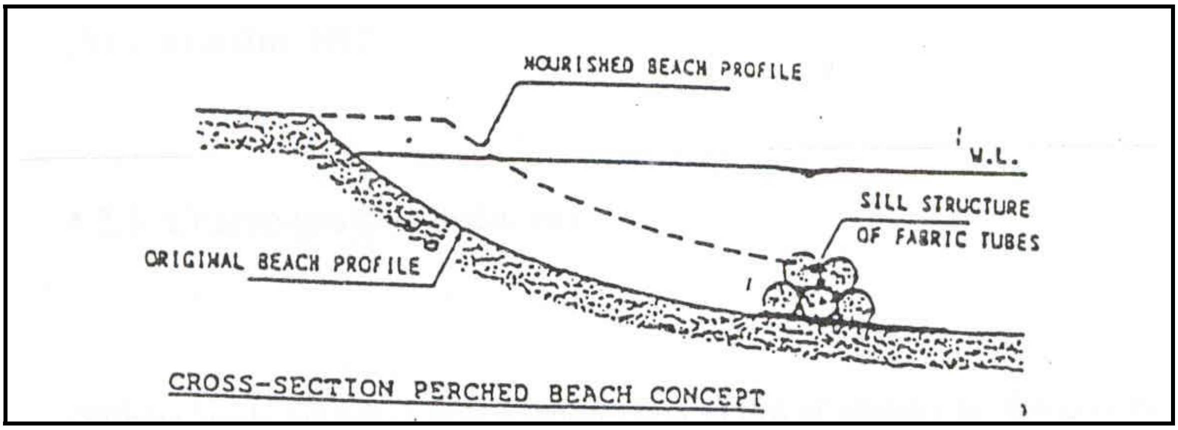


Figure 5. Foreshore Reclamation Using Geotextile Containers. Source: Fowler And Sprague (1993).

The hot-dog-shaped geotubes™ consists of an inner tube and an outer 'master' tube that can be hydraulically and mechanically filled with dredged material, and laid directly on the existing substrate. The half-life of both types of geotubes™ is expected to be roughly 20 years. The outer geotubes™ may be made of polyester covered with a polypropylene shroud, which protects them from the harmful effects of ultraviolet light, which otherwise would deteriorate them.

The bio-degradable geo-textiles comprise of polyethylene or woven geotextiles usually in open mesh form. The fill material may be impregnated with seedlings or vegetation planted through the outer geotextile layer. These structures could be applied to raise inter-tidal elevations, enhance the stability of the retained sediment by decreasing the tidal current velocities, and generate vegetation growth at the same time.

4.2.4 Coarse-grained Sediment Inter-tidal Bund

The placement of gravel ridges on the inter-tidal foreshore could be achieved through bottom discharging over high water spring tides, if the nearshore bathymetry allowed.

The fully submerged coarse-grained bund or ridge could be placed by bottom discharge from hoppers over high water spring tides at the low water mark, which would stabilise and retain the fine-grained sediments higher up the inter-tidal profile. The practicality of placing the dredged material in the required position will depend on prevailing conditions and the type of dredger available.

4.2.5 Vegetation Planting

The influence of plant roots increases the tensile strength of marsh soil and prevents marsh cliff instability and erosion. Vegetation density is critical, as it influences root complex densities and over-marsh currents on high water spring tides. Root densities alone are not as important in sediment binding as the actual distribution or configuration of the roots. The tangle of marsh plant roots and stems helps to:

- stabilise the substrate beneath the sediment-water interface;
- promote accumulation of cohesive sediments, to trap debris and dissolved nutrients introduced by each tidal cycle; and
- improve the shear strength of marsh soils.

Accretion is critically dependent upon the cumulative stabilising and sediment trapping efficiency effect of halophytic species. Marsh erosion may be enhanced where substrate stabilisers (such as halophytes) will not grow or where adverse ecological conditions cause temporary denudation of the marsh surface. Where more rapid progress is required at a marsh front, transplanting vegetation species from within the saltmarsh system is a potentially sustainable stabilisation technique. It is important that the correct elevation for the chosen plant species is established, and sufficient protection from erosion is in place.

Through deliberate vegetation planting, particularly *Spartina* species, erosive tidal flows can be dissipated by the plant stems with the resultant effects of a decrease in current velocity, increased sediment deposition, and raising the level of the mudflats and marshes. An alternative method, proposed by LRDC in 1993, was the use of pre-planted pallets anchored to the marsh, in order to secure young plants in fresh mud whilst they become established.

In more sheltered higher marsh zones, seeding of the discharged material may further enhance sediment stability, preferably using locally collected seed material from similar elevations. The marsh channel network, often dendritic in nature, is a key component in the functioning of saltmarshes, bringing in and removing sediments, water and nutrients. Trenching of the marsh would aid accretionary processes by increasing the distance water that can enter the saltmarsh channel network.

4.3 Managed Realignment

Another strategic option would be to reposition the defence line further landward, to provide space for the estuary and therefore, the saltmarsh and mudflat systems to migrate inland in response to climate change and sea level rise. Managed realignment may be defined as the deliberate process of setting back a defence line or allowing a coastline to recede to a new line of defence (natural or manmade) accompanied by measures to encourage the development of an environmentally beneficial habitat. This may involve retreating inland from the existing line of flood or coastal defence, or allowing the natural erosion of the coastline in areas where expenditure on coastal defences cannot be justified, and/or where such defences would have an unacceptable environmental impact.

Management doesn’t necessarily entail intervention, e.g. ‘hard’ engineering works, but implies monitoring and provides an opportunity to intervene if appropriate. Managed realignment (or ‘set-back’) in low-lying areas involves the maintenance of a defence but along a new line further inland. It is particularly applicable to locations where the fronting saltmarsh and mudflat is eroding and the presence of a defence structure is prohibiting a compensatory movement landwards. Set-back involves the construction of a secondary, usually less expensive inner line of defence; breaching of the old defence; management of the land between the old and new defences promoting the creation of saltmarsh; and finally removing the front sea wall either wholly or partially. Forms of managed retreat, that approximate to setback or to controlled abandonment are most likely to produce mid to low-level saltmarsh and / or inter-tidal flat.

Managed realignment may not be viable in many coastal areas, due to residential and commercial development, transport route networks, and nature conservation designations.

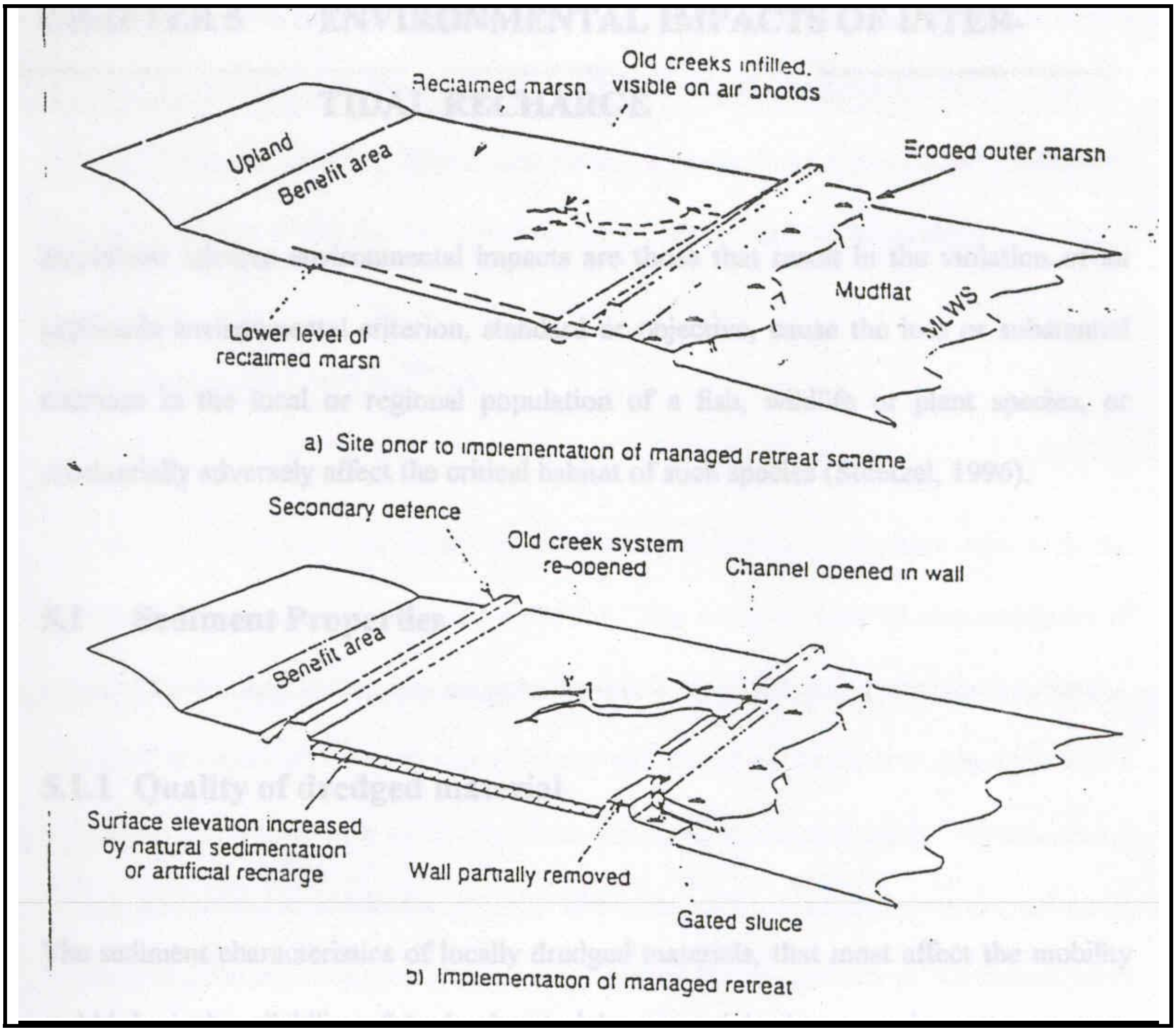


Figure 6. Managed Realignment in Low-lying Areas.
Source: MAFF (1993).

4.4 The 'Do Nothing' Option

An important aspect for saltmarsh systems management is that erosion of the saltmarsh and inter-tidal foreshore represents a natural response to sea-level rise and climate change. The natural transformation of habitats may not necessarily be an adverse impact of saltmarsh erosion. Saltmarsh and inter-tidal mudflats are of equal importance in terms of biodiversity and nature conservation. Loss of saltmarsh may reduce high water roosting or nesting sites, but may create larger areas of inter-tidal flats suitable for wader feeding, or creating isolated islands of saltmarsh / cheniers for nesting.

The long-term development of saltmarsh systems will require the existing environment to evolve. This includes loss or change in habitat and ecosystems. The development of a saltmarsh is dependent on the existence of a mudflat, which is capable of reducing wave and tidal energy sufficiently to allow sedimentation and salt-tolerant plants to colonise bare inter-tidal mud or sediment. Erosion and significant loss of inter-tidal flat areas will ultimately impact upon the saltmarsh; this results in exposure of the shoreline and sea defences to wave action, and threatens the long-term survival of the inter-tidal system.

Any attempts to protect the saltmarsh edge will mean that the mudflat section of the inter-tidal zone will be prevented from adjusting to the new energy conditions. The fine-grained suspended sediments resulting from saltmarsh and inter-tidal erosion are transported into the inter- and sub-tidal zones and offshore, out of the estuarine system; exacerbating the lack of sediment within the estuarine system.

The impact of accelerated sea-level rise emphasises the potential conflict between conservationists, seeking to maintain the areal extent of inter-tidal habitats, and engineering requirements to stabilise the present shoreline and/or maintain levels of flood protection.

The saltmarshes provide natural flood protection to the coastline between Keyhaven and Lymington. Historical maps and recent aerial photography show 734 hectares of saltmarsh in 1921, but only 297 hectares in 1994. Long-term monitoring and analysis by NFDC has shown that the seaward edges of the saltmarshes are eroding on average at 3m per year. The rates of saltmarsh and mudflat erosion are likely to increase due to the effects of global climate change and sea level rise.

If nothing is done the saltmarshes will provide a decreasing amount of protection to the harbours and seawalls for perhaps another 50 years, and will have completely disappeared by the end of this century, or sooner.

As a saltmarsh erodes, ecological benefits may be gained through the creation of a mudflat, which provide particularly valuable feeding sites for over-wintering birds. However, these mudflats may only be temporary features within an evolving estuary. If the saltmarshes and mudflats were to disappear, it would have devastating implications on internationally important bird populations, and for the overall health of plant and marine life.

With the saltmarsh disappearing, unprotected shorelines would be more vulnerable to erosion and the risk of flooding would increase. The existing coastal and flood defence between Keyhaven and Lymington were designed on the basis of a saltmarsh fronting them If there were no saltmarshes to absorb the wave energy from storms, these defences would require extremely costly repairs and regular maintenance. Increased wave exposure reaching further into the estuaries has already affected the number and position of yacht moorings, and safety within marine recreation activities. If conditions within the harbour continue to deteriorate it could damage tourism and commercial activities. The vibrancy, prosperity and character of the local town will become threatened if appropriate action to save the saltmarshes and mudflats is not taken.

5 Monitoring

Extensive research and accurate, flexible and cost-effective monitoring for any of the proposed inter-tidal recharge techniques is critical to any saltmarsh and inter-tidal foreshore management strategy, as it is for all coast defence research. Information exchange, data transfer and dissemination are fundamental tools for the viability of any saltmarsh restoration plan, both to underpin and justify management and measure change. Results from monitoring will provide important scientific input to the development of ideas, concerning methods for assessing environmental resources. Historically, there has been very little monitoring of inter-tidal wetland extent. Data collection is normally carried out by maritime authorities, the Environment Agency, or SMP Coastal Groups.

Owing to the high natural spatial and temporal variability in complex estuarine ecological systems, there is a need to establish good ‘baseline conditions’ and an understanding of natural processes, followed by regular surveys to identify natural and enhanced rates of coastal morphological changes. For example, a combination of baseline field surveys and analysis of topography, nearshore and offshore bathymetry, vegetation (composition, productivity), geotechnical attributes, seabed sediment types, concentrations and budgets, hydrodynamics (wind, wave condition, tidal level and climate), and sediment transport may be required. Much of this programme is already in place at NFDC. A long-term time series of comparative photographs is updated, maintained and stored by the Lymington Harbour Commissioners. This clearly shows the plan shape morphological changes of the saltmarsh edges in a number of locations in and around the Lymington saltmarsh system.

Detailed, site-specific and generic environmental appraisals and hydrodynamic assessments may also be required prior to field trials or larger scheme being implemented. Pre-, interim and post- construction monitoring of a defence should ensure more effective management.

Access for monitoring could pose logistical problems if the areas enclosed were highly fragmented and included saltmarsh islands and creek networks. Remote sensing techniques, such as CASI, ATM, and LIDAR, are potentially cost-effective methods of mapping saltmarshes in terms of vegetation and elevation, respectively. They are, however, relatively recent innovations, and currently undergoing development and evaluation. Remote sensing of this type gives good spatial data but it must also be balanced with ground-based data coverage of similar temporal resolution.

A ground survey relating saltmarsh and mudflat plant communities to elevation, may enable generic and predictive models of plant community change to be applied to the site. Surveys of bird populations, especially breeding and overwintering birds, using count data and biotope maps and linkage of substrate type to bird-carrying capacity of the existing regime is essential. Monitoring of the engineering performance of the regenerated tidal flat should be accompanied by parallel studies of invertebrate colonisation and bird acceptance.

Location (UK)	Saltmarsh management techniques trialed	Area	Purpose of scheme
Cob Marsh, Essex	15,000m^3 of material trickle charge post-bottom dumping	Not known	Chenier enhancement
Deal Hall, Dengie marshes, Essex	Schleswig-Holstein method of Polder brush wood fencing & Thames lighter barges sunk to act as breakwaters	<400m^2 sediment fields	Saltmarsh creation and stabilisation
Foulton Hall & Stone Point, Hamford Water, Essex	Low water dumping of material & brush wood fencing	Not known	Saltmarsh creation & restoration
Horsey Island, Hamford Water, Essex	Inter-tidal recharge by rainbowing, in combination with sunken Thames lighter barges	Not known	Saltmarsh creation
Hythe marshes, Southampton Water	Inter-tidal recharge	~1 acres or 4000m^2	Saltmarsh creation
Northey Island, & Fambridge and Wallasea Island, Essex	Managed retreat	~0.3 acre	Saltmarsh re-creation
Orplands, Blackwater estuary, Essex	Coastal realignment, breaching of sea wall	16 acres	Saltmarsh re-creation
Peewit Island, Hamford Water, Essex	Piped sediment	Not known	Saltmarsh creation
Shotley foreshore in the lower Orwell estuary & Ports of Harwich and Felixstowe	dredged sediment pumped directly behind a gravel bund	~8 acres or 30,000m^2	Saltmarsh restoration
Tollesbury, Blackwater estuary, Essex	Managed retreat, breaching of sea wall	0.4 acres	Saltmarsh re-creation
Trimley marshes, Orwell estuary, Essex	Direct pumping of clay, sand and gravel in front of seawall & brushwood fencing	Not known	Shoreline stabilisation

Table 3 Saltmarsh Management Techniques Trialed in UK

Location (USA)	Saltmarsh management techniques trialed	Area	Purpose of scheme
Allan Harbour, Rhode Island	Wetland buffer strips, rip-rap	Not known	Saltmarsh stabilisation
Apalachiola Bay, Florida	Inter-tidal recharge (trickle charge using wave energy) and bioengineering (planting) to stabilise shore of, and to fill, existing island	<10 acres	Wetland restoration
Aransas National Wildlife Refuge Texas	Combinations of geotextiles, stones and bioengineering structures were used to retain dredged material	>50 acres	Shoreline stabilisation
Barren Island, Texas	Marsh and seabird nesting island created Shell material increased elevation of nesting ridge Geotextile tubes subsequently placed 2-300 ft from shoreline for added protection	~100 acres	Land creation
Bolivar Peninsula, Galveston Bay, Texas	Inter-tidal recharge (trickle charge using wave energy) Geotextile tubes, floating tyre breakwater, and plant rolls	3 sites of 10 acres - includes control site	Saltmarsh creation
Drakes Creek, Tennessee	Geotubes filled with dredged sediment used in levee construction, gravel bunds	~7 acres	Shoreline stabilisation
Eastern Neck National Wildlife refuge, Maryland	Inter-tidal recharge (trickle charge using wave energy) Detached rip-rap breakwaters and geotextile tubes retained dredged material until consolidated	10 acres	Wetland restoration
Galveston Bay, Texas	Geotubes - 13,500 linear feet of large (30ft in diameter, 100ft long) and 15,000 linear feet of smaller geotubes (7-15ft in diameter) Some geotubes seeded.	Not known	Reduce marsh erosion, habitat creation
Kenilworth, Maryland	Geotextile tubes retained dredged material until consolidated and bioengineering (planting)	32 acres	Wetland restoration
Middle Ground Island, Winyah Bay, Carolina	Inter-tidal recharge (trickle charge using tidal currents) No retention structures	>150 acres	Marsh creation and restoration
Muzzi Marsh, California	Inter-tidal recharge (trickle charge using wave energy) Breaching of existing dike	>50 acres	Saltmarsh restoration
Queen Bess Island, California	Inter-tidal recharge (trickle charge using wind-wave energy)	8 acres	Marsh and nesting island creation

San Francisco Bay Salt Pond, California	Inter-tidal recharge (trickle charge using wave and tidal currents) and bioengineering (planting)	111 acres	Saltmarsh restoration
Sonoma Baylands, California	Inter-tidal recharge and bioengineering (planting)	>100 acres	Marsh restoration
St. Johns River, Florida	Inter-tidal recharge (trickle charge using river and tidal currents)	Several 100 acres	Marsh creation
West Bay, Texas	Inter-tidal recharge (trickle charge using wind-wave energy), Bioengineering (planting and plant rolls), and geotextiles	40 acres test site	Shoreline and wetland stabilisation

Table 4 Saltmarsh Management Techniques Trialed in USA

Location (Europe)	**Saltmarsh management techniques trialed**	**Area**	**Purpose of scheme**
Anna Jacoba site, Oosterschelde, Netherlands	Trickle charge / bottom dumping of sediment	200m frontage	Saltmarsh stabilisation
Eastern Scheldt, south-west Netherlands	Bioengineering – hydro-seeded slopes, confining blankets, biodegradeable rolls and meshes, jute, coco and straw mats, water velocity reducers	Not known	Shoreline stabilisation
Zuidgors, Westerschelde, Netherlands	willow and brush wood fence / groynes	Not known	Saltmarsh stabilisation

Table 5 Saltmarsh Management Techniques Trialed in Europe

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