Department for Environment Food & Rural Affairs

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Environment Agency

delivering benefits through evidence

Cost estimation for coastal protection – summary of evidence

Report –SC080039/R7

Flood and Coastal Erosion Risk Management Research and Development Programme

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We cannot do this alone. We work closely with a wide range of partners including government, business, local authorities, other agencies, civil society groups and the communities we serve.

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Miranda Kavanagh

Director of Evidence

Executive summary

This summary of evidence provides indicative costs and guidance for coastal erosion and flood management activities. Coastal environments are often very dynamic and are highly variable in terms of the severity of exposure to natural conditions. Producing collated cost information is therefore challenging.

Coastal		
Key cost components	Key cost components are likely to be the enabling costs (procurement, planning and design), capital construction costs and post construction monitoring and maintenance costs.	
Key asset types	• Walls • Revetments/coastal embankments • Groynes • Beach recycling and recharging or nourishment • Dune, shingle, beach management • Managed realignment discussed separately (see below)	
Data reviewed in specific guidance	Key datasets include: • Environment Agency Unit Cost Database (capital costs). • Various other case studies and examples	
Other relevant data	Local or proxy records such as data from Environment Agency SAMPs and local authority information	
Relative cost importance	Enabling costs	Costs may be higher than other measures due to the level of consultation, design and preliminary assessments required.
	Capital costs	Variable costs depending on type of assets and management methods, asset length and size, associated structures and site conditions, but typically much higher than the fluvial equivalent. Dune, shingle and beach management are more likely to have significantly lower costs, but often higher maintenance costs.
	Maintenance costs	Variable. Walls may offer a very low maintenance burden, but revetments and particularly beach recycling/nourishment schemes can have high ongoing costs.
	Other cost considerations	May include environmental costs, habitat creation and decommissioning costs.

Cost estimation methodology	Initial concept/national appraisal	Approximate unit rates for the completed asset available
	Strategic, regional, or conceptual design	Approximate unit rates for the completed asset available. Costs for some asset types not available and specialist advice likely to be required.
	Preliminary feasibility/design	No specific cost information provided. Guidance on data availability and procedures provided.
Design life information	Data provided by Environment Agency asset deterioration reports are provided for guidance associated with embankment design lives. Some additional design life references are also provided.	
Quality of data	Coordinated, readily available information is relatively absent for coastal erosion and protection measures, although some example unit costs are available for a number of different asset types. Coordinated recording of actual out-turn costs for these assets is limited, but some case studies and very generic costs from literature are provided to assist appraisers on the scale of costs for broad scale, early cost estimates. The scale of information is fairly broad and useful only for very high level strategic, national or very early stage cost assessments. Insufficient information is available to derive cost curve data to support tool development. Available information and guidance on the key aspects is provided to support practitioners undertaking high level costs estimates.	
Additional guidance	Checklist of factors likely to influence capital and maintenance costs, and key factors to consider for detailed costs estimation List of R&D and general design guidance Case studies of recent schemes	

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1 Long term costing - coastal flood protection

Coastal management in the UK has evolved significantly in design and execution over the last 20–30 years from building structures to reduce shoreline erosion and prevent flooding of the hinterland to working with tidal and wave processes.

A coastal protection system consists of a combination of the beach and backshore elements such as cliffs, beaches, dunes and/or artificial defences that contribute to flood protection and coastal erosion prevention.

1.1 Forms of coastal defence operations

There are a number of forms of coastal defences from natural beach and dune defences from structural flood defence walls and revetments that limit tidal overtopping, through to breakwaters and groynes designed to reduce longshore sediment transport and reduce wave heights.

The method of protection and form of defence may be linked to the value of the hinterland being protected but also to specific exposure conditions, the hydraulic performance required, environmental considerations, beach usage (amenity, tourism and so on) as well as cost.

1.1.1 Natural defences

Natural defences are preferable to hard flood defences as they allow coastal zones to adapt to natural processes and reduce the need for long-term intervention. Natural defences may include cliffs, sand dunes, shingle banks or sand beaches. The successful management of these natural defences can negate the need for more costly intervention options.

Management methods may include artificial improvement of beach levels/profiles, or beach nourishment or recharge where beaches are eroding. Beach recycling is the mechanical shifting of sand, shingle or even boulders from an area of accretion to an area of erosion. Normally recycling would be undertaken at a local level, with sediment being taken from an accreting ridge, the lower beach or an estuary bar, and transported a short distance to an eroding foreshore. Alternatively the donor area may be to landward if sand is blown onto roads or other areas where it is not wanted and from where it can be recovered.

Recycling sand or shingle can be carried out to repair minor erosion problems, or it can be used to rebuild long lengths of upper beach. Use of boulders is usually restricted to relocating small numbers up the beach face to provide temporary armouring of short lengths of dune face suffering minor erosion.

If material is imported from a source not related to the eroding site the approach is known as beach nourishment or recharging. Beach recharge may require the use of groynes or breakwaters or recirculation (transporting material from a downdrift location to the updrift end on a regular basis) to maintain levels and/or slow beach losses.

1.1.2 Seawalls

There are many types of seawall, reflected in both the varying physical forces they have to withstand, and location-specific aspects (for example, local climate, coastal position, wave regime and value of land protected). Seawalls may be constructed from a range of materials (for example, concrete, masonry, sheet piles or gabions) and are constructed in a range of profiles (for example, vertical, sloped or stepped). Seawall sub-options include permeable or impermeable facings.

These hard defences are constructed directly on the landforms of the coast with the primary purpose of reducing the impacts of tides and waves. In many cases these are costly defences but ensure people, property, conservation, leisure and economic activities are protected from the effects of erosion and/or flooding.

Seawalls are constantly subjected to impacts of the sea – accentuated by climate change. Therefore ongoing monitoring, maintenance and eventually replacement are requirements if seawalls are to provide effective long-term defences.

Seawall designs must take account of surrounding environment including landforms, wave climate and so on They can be standalone structures or form part of a combined structure with other assets, for example, wave walls along the crest of revetments.

1.1.3 Revetments

Revetment is a generic term used when an armouring layer is applied to a sloping surface of an embankment or shoreline. There are two main types of revetments: permeable and impermeable revetments.

The function of permeable revetments is to reduce the erosive power of the waves by means of wave energy dissipation in the interstices of the revetment. Permeable revetments can be built from rock armour, timber, gabions and concrete armour units. Where frequent wave attack is anticipated, the revetment may be topped by a vertical or re-curved wall to reduce overtopping.

The cladding or facing layer of revetments may include rock armour, concrete block matting, precast concrete units, gabion mattresses, asphalt or in situ concrete slabbing/steps. Options other than rock are generally used where there are over-riding aesthetic requirements, health and safety issues, or where rock armour is difficult or too expensive to obtain.

Impermeable revetments are continuous sloping defence structures of concrete or stone blockwork or mass concrete, and are used to provide a fixed line of defence for frontages with high value backshore assets or specific amenity requirements. Intended to withstand storm wave attack over a life expectancy of 30–50 years, amenity facilities such as promenades, slipways and beach access steps can be built into this type of revetment. An example is Blackpool Council’s Central Area coastal defences (2005-2010).

Wire mesh baskets filled with cobbles or crushed rock, gabions are filled in situ, often with locally available material and therefore have a relatively low capital cost. Gabion revetments can provide a short term (5–10 years) alternative to rock armour structures in areas where large rocks are not available at an acceptable cost, or where long-term protection is not appropriate. Gabions may also be valid choice of defence in less exposed locations where the expected design life can be much higher.

Timber revetments have been historically used in the UK for coast protection, particularly on the south and east coasts, where the costs or impacts of a seawall may have been unacceptable. Construction flexibility allows timber revetments to serve various purposes. They can provide a partial barrier to wave energy when built as a permeable ‘fence’ along the upper beach. Alternatively they can form a final wave protection wall when built as an impermeable vertical breastwork along the upper shore line.

Asphalt faced revetments are widely used in Europe – the Netherlands and Germany in particular, but less so in the UK.

1.1.4 Breakwaters

Offshore breakwaters are typically built parallel to the shore, either singly to protect a specific coastal location (for example, at Rhos-on-Sea in north Wales) or in series to provide protection to longer frontages (for example, Happisburgh to Winterton on the Norfolk coast). Breakwaters are usually constructed from rock or precast concrete units. Rock armour facing may be used to minimise wave reflection. In some instances composite precast unit and rock structures are used to mimic the behaviour of natural reefs.

Breakwaters are primarily designed to reduce wave energy and wave heights reaching the shore, but also benefit from reducing longshore transport and encouraging beach formation in their lee.

1.1.5 Groynes

Groynes are cross-shore structures designed to reduce longshore transport on open beaches or to deflect nearshore currents away from the shoreline. On an open beach they are normally built as a series to influence a long section of shoreline that has been nourished or is managed by recycling. In an estuary they may be single structures.

Rock is now often favoured as the construction material; in the past timber was favoured but is now considered less sustainable. Alternative construction materials include sheet piles, concrete, open stone asphalt, cribwork and plastic.

Groynes can be used in combination with revetments to provide a high level of erosion protection.

Groynes can be permeable or impermeable. Impermeable groynes are solid and are designed to intercept all material arriving on the updrift side. Permeable groynes allow some sediment to pass through.

Rock groynes have the advantages of simple construction, long-term durability and ability to absorb some wave energy due to their semi-permeable nature. Wooden groynes can be less durable (dependant on the specific conditions and beach sediment they are retaining) and tend to reflect, rather than absorb, energy. Gabions can be useful as temporary groynes but have a short life expectancy.

1.1.6 Dune management

Low-cost, short-term management practices for beach/dune/shingle barriers often consist of groynes and beach recycling, but may also include complimentary low-cost options such as dune grass planting, dune fencing and dune thatching (SNH 2000).

Dune grass planting

Dune grass planting encourages dune growth as the vegetation traps and stabilises blown sand. Natural dune grasses act to reduce wind speeds across the surface of the dunes, thereby trapping and holding sand. They grow both vertically and horizontally as the sand accumulates. Marram grass is particularly effective as it positively thrives on growing dunes and is perhaps the easiest to transplant.

Transplanting can also be used to enhance the appearance and effectiveness of built erosion defences. Rock, timber or gabion structures can provide a fixed defence line but are incongruous along a natural dune coast. Partial burial of these structures using recycled sand, followed by transplanting, will create a more natural dune appearance if conditions are favourable.

Dune thatching

Thatching of exposed dunes faces or blowouts using waste cuttings from forestry management, or other low cost materials, is a traditional way of stabilising sand, reducing trampling and protecting vegetation. Materials are low-cost if locally available and no machinery or skilled labour is required to achieve success, but continual maintenance is important. The approach is normally carried out with dune grass planting to encourage dune stability.

Dune fencing

Construction of semi-permeable fences along the seaward face of dunes will encourage the deposition of wind-blown sand, reduce trampling by people and livestock, and protect existing or transplanted vegetation. A variety of fencing materials can be used successfully to enhance natural recovery. Fencing can also be used in conjunction with other management schemes to encourage dune stabilisation and reduce environmental impacts.

Access control

Dune erosion can be exacerbated by uncontrolled access that destroys vegetation growth and makes the sand more susceptible to aeolian forces. The provision of boardwalks in association with fencing controls access and provides improved conditions for dune stabilisation.

1.2 Key cost requirements

Whole life costing is the analysis of all relevant and identifiable financial cashflows relating to the acquisition and use of an asset. The following cost components may be required, but the importance of each will depend on the type or combination of measures used.

To compile whole life costs the following parameters may need to be considered:

- procurement and design costs
- capital construction costs
- operation and maintenance costs

- monitoring costs
- replacement or decommissioning costs

More detailed cost elements are provided in Table 1.1.

Table 1.1 Typical elements of the cost of beach control works (CIRIA 2010)

Subject	Costs to be included
Preliminaries	• Project coordination, management and administration
Planning and design	• Survey, data collecting and observations • Model studies • Design and contract preparation • Statutory procedures and licences • Economic appraisal • Environmental impact assessment and licences • Safety planning supervision
Construction	• Contract payments including adjustments, claims and so on • Supervision (including safety) and administration costs • Ancillary works for environmental improvement, amenity of services
Land or property	• Purchase or lease of land either as part of the works or for construction • Compensation payments to affected owners
Operation and maintenance	• Operational activities • Monitoring and maintenance including replacement of elements having a shorter life than the overall scheme • Repairs

Source: CIRIA (2010a)

1.3 Enabling costs

Initial enabling costs for coastal works can be high due to the level of initial scoping, design, management and partnership negotiation required. The most important enabling cost considerations can be split into preliminaries and approvals. Each of these depends on the approach to coastal protection and the many other variables discussed below.

In general, coastal works involving over-water working such as breakwaters are more costly than land-based techniques. This is due to the higher mobilisation cost involved with using specialist floating plant and the difficulties associated with working over water. The costs of schemes largely depend on the physical conditions at the site and the sensitivity of the scheme to these factors.

1.3.1 Preliminaries

Preliminaries include a number of activities critical to the initial development of a scheme such as:

- partnership negotiation
- contract management
- procurement
- project management

Partnership negotiation of objectives, governance and funders at the start of the scheme can take a significant amount of specialist staff time and can have significant impact on costs in the preliminary development of a scheme. A guidance and lessons learnt report was prepared on behalf of Defra and the Environment Agency as part of project FD2635 to help exchange best practice and knowledge between stakeholders involved in coastal schemes (Defra and Environment Agency 2011). This report derived guidance from case study evidence from around England and Wales. It gives the advantages of partnership working as:

- informed objective setting
- multiple skills and wider range of knowledge introduced into projects
- increased capacity to deliver
- improved stakeholder and community consultation and engagement
- shared risks, responsibilities, accountability, issues and problems
- improved cooperation and coordination
- helping to secure funding and approvals
- raising the scheme's profile and improving chances of some form of government intervention or support
- helping to manage the complex approvals process
- helping to meet wider organisational policy requirements across partners

Although there are many advantages, experience has shown that there are commonly barriers and constraints which can result in the requirement for additional specialist input and thus an increase in costs. The case studies from the FD2635 research suggest that the following are crucial barriers and constraints:

- public reaction
- political support
- timescales
- conflicts
- risk sharing

To manage adverse public reaction, recognition is needed that different approaches are required to address the different perspectives of stakeholders. Examples of successfully tested approaches and tools can be found in *Working with Others, Building Trust with Communities* (Environment Agency 2004).

Political as well as stakeholder support, particularly in the early stages of projects, can impact on progress. In the Parrett Estuary Strategy (Defra and Environment Agency 2011, Case Study 9), an evidence base (‘Parrett Tidal Flood Defence Report’) and engagement strategies such as the use of an independent chairperson for meetings, successfully achieved political and stakeholder support for the tidal barrier option.

Costs of preliminaries

The costs incurred for preliminary works is difficult to estimate as they depend on many variables including:

- size of partnership
- objectives
- funding arrangement
- roles and responsibilities
- staff involved in negotiations

Only through experience can preliminary costs be estimated accurately. The case studies from the FD2635 research give examples of costs and he timescales required for effective partnership working and consultation.

1.3.2 Approvals

The process of obtaining the approvals and consents necessary to implement a flood and coastal defence scheme is a further factor which must be considered when calculating whole life scheme costs.

Planning and design

Planning and design approvals may include the following cost considerations or risks:

Planning approval

This is granted by the local planning authority and can take 13 weeks if the scheme is unusually large or complex. Most applications are decided within eight weeks. However, the planning authority can request the applicant’s written consent to extend this period up to 13 weeks. The planning authority can either grant or refuse an application or grant it subject to conditions which must be met by the applicant. There are a number of grounds for appeal, but appealing can be a timely and expensive option and agreement can often be reached by a process of discussion with the planning authority and the submission of revised proposals. This aspect should usually be included within the risk aspect of a cost estimate during the early stages of a project.

Environmental Impact Assessment (EIA) or Strategic Environmental Assessment (SEA)

Where statutory EIA or SEA (for plans and strategies) is required this can be a costly and time-consuming process which needs to be included within the whole life costs for schemes. An initial screening opinion must be sought from the local authority to determine the need for EIA or SEA. An Appropriate Assessment may also be required under the Habitats Regulations to ensure that a project will not have adverse effects on the integrity of sites designated under the Habitats Directive.

Where the local planning authority determines that a statutory EIA or SEA is required it must then approve the scope of the EIA. The scope must be appropriate to the range and scale of environmental impacts predicted. Depending on the sensitivity of the site, costs for an EIA may be considerable and can result in programme delays if requirements are not assessed early within the project planning process. One example is the requirement for specialist species surveys which can only be carried out at certain times of year. In sensitive locations English Nature's requirements for species surveys can be extensive and can add 6–12 months to the project programme.

Statutory approvals

There are a number of statutory licensing approvals which may be required for coastal protection schemes. Experience based on FD2635 research indicates that the preparation and approvals of these can take time. Where statutory nature conservation approvals are required English Nature can be a valuable project partner.

Consents for all coastal protection schemes may be require the following:

- consents under Section 5 (approval to carry out works) and Section 34 (navigation requirements) of the Coast Protection Act 1949 (CPA)
- Food and Environmental Protection (FEPA) licences – required for the deposits of substances or articles in the sea or under the seabed including disposal at sea of dredged material, or where construction work which involves deposition of materials below the high water mean spring tide
- land drainage consent if applicable under the Land Drainage Act 1991 amended by Flood and Water Management Act 2010

Until recently FEPA licences had to be obtained before construction could commence. The process took a statutory 12 weeks to turn around with a full submission being required if an extension of time was needed. FEPA licences were granted by non-technical staff members, which caused problems, particularly when communicating engineering matters.

The FEPA and CPA licensing has now been replaced by the New Marine Licensing System, introduced under the Marine and Coastal Access Act 2009, which came into force in April 2011. Further information on the new system can be found in:

- *Factsheet – New Marine Licensing System* (Defra 2010)
- guidance from the Marine Management Organisation (MMO 2011)

Non-statutory internal approvals

On multi-partner schemes, internal and non-statutory approval processes must be considered in project programming. As part of the Weston-super-Mare scheme, a project appraisal report was developed by North Somerset Council which required approval by the Environment Agency's National Review Group (NRG). The council was the first local authority nationally to go through the NRG process – eight iterations were needed, and there were long delays due to the size of scheme, approval taking nine months to be finally granted in July 2007.

Non-statutory approvals include:

- landowner agreements
- memorandum of understanding

Funding approvals

The majority of funding for flood and coastal erosion schemes is derived from Defra Flood Defence Grant in Aid (FDGiA), an approval process which takes around 6–9 months.

However, there is evidence that non-FDGiA (funding or contributions) can be secured. Examples include:

- local authority maintenance budgets such as highways departments to protect local infrastructure
- Regional Development Agencies – such as the 'Civic Pride' initiative
- European Union funding programmes such as the European Regional Development Fund or Interreg
- Commission for Architecture and the Built Environment
- Heritage Lottery Fund

Further detail on funding, including information on external contributions, is given below. Additional information can be found in Defra and Environment Agency (2011).

1.4 Generic capital cost ranges

For appraisers looking at cost estimates and unit costs for early stage appraisal processes where site-specific information is not yet available, previous similar projects in the same geographical area should be considered and out-turn costs reviewed where available to help determine relative costs.

For the purpose of this report, very generic capital costs are provided by two sources that may be applicable to very early stage projects or national level assessments. These are:

- *Flood Risk Management Estimating Guide* (Environment Agency 2007)
- *A Guide to Managing Coastal Erosion in Beach/Dune Systems* (SNH 2000)

Indicative costs obtained from these two reports are summarised in Table 1.2. These provide an indicative assessment of the importance of key cost considerations for coastal assets. Additional detail and further guidance on some of these measures where more specific or up-to-date information is available is discussed further below.

Table 1.1 Indicative costs associated with the cost of coastal protection

Option	Significance			Indicative cost (£/m)	
	Enabling costs	Capital costs	Maintenance costs	Scottish Natural Heritage	Environment Agency UCD
Beach recharge and breakwater	Medium	High	Medium	–	2,700–7,300
Beach recharge and groynes	Medium	High	Medium	–	1,600–4,700
Rock armour	Medium	High	Low	–	1,350–6,000
Impermeable revetments and seawalls	Medium	High	Low	2,000–5,000	700–5,400
Timber revetments	Medium	Medium	Medium	20–500	–
Rock revetments	Medium	High	Low	1,000–3,000	650–2,850
Groynes	Medium	Medium	Medium	10,000 to 100,000 per structure	–
Nearshore breakwaters	Medium	Medium	Low	400–1,000	1,750-4,300
Artificial rock dune protection	Low	Medium	Low	200–600	–
Gabion revetments	Medium	Medium	Medium	50–500	–
Beach nourishment	Medium	Medium	Medium	50–2,000	350–6,450
Shingle recycling/ re-profiling	Low	Low	Low	10–200	15–120
Dune fencing	Negligible	Low	Low	4–20	–
Dune thatching	Negligible	Low	Low	2–20	–

Notes: The Scottish Natural Heritage (SNH) costs relate to a 2000 cost base and the Environment Agency costs relate to a 2007 cost base. An allowance for inflation using a suitable index is required to update these values to present day costs.

1.5 Capital costs

Construction costs for coastal protection works are highly variable due to the varied nature of works required, site conditions and the costs, availability and source of materials used. Important cost considerations for all coastal works include those listed in Table 1.3.

Table 1.2 Key cost considerations for coastal works

Consideration	Comments
Availability of materials	Choice of size, gradation, armouring, structure shape and design slopes will influence costs.
Source of materials	Haulage and transport of materials will influence costs. Use of lower quality local resources may reduce costs but require alternative design/sizing and maintenance costs.
Use of materials	Use of lower cost materials for parts of a structure, requirements for armouring and designing to optimise the use of higher cost materials.
Access limitations and ease of construction	Tidal range, ground conditions and access points will affect costs. Winter working may also influence costs.
Type of plant	Depends on size of material, but maximum reach of plant and construction from land/water will influence costs.
Impact of environmental designations on choice of construction techniques and material delivery	

Detailed costs at the detailed design stage will need to be developed using specialist advice, standard rates and a bill of quantities. Guidance on detailed costs is provided in standard price estimating books such as SPONS (Davis Langdon 2011) and the Institution of Chemical Engineer's CESMM price database (ICE 2012).

The sections below provide indicative costs and guidance on whole life cost estimation for coastal flood protection measures. The information given is suitable for early stage appraisals, national level assessments or outline design stage only. While the unit rates provided are suitable at the outline design stage, a bill of quantities will be more appropriate at the detailed design stage.

Estimated capital costs for various coastal elements are available in the *Flood Risk Management Estimating Guide* (Environment Agency 2010) – also known as the Unit Cost Database (UCD). The costs available are based on out-turn costs from a large number of projects to install defences or coastal erosion for the purposes of flood risk management in England and Wales. The costs include all associated works, temporary works and any contractor variations, compensation events/delay costs.

The UCD costs are broken down into the key asset types including walls, revetments and beach recycling/recharging/nourishment. Other cost information for groynes has been collated from a number of other sources.

1.5.1 Beach recycling and recharging or nourishment

The capital costs of recycling and recharge are typically considered to be moderate to high due to the initial planning and capital costs of undertaking the work and the requirement for ongoing maintenance and repeat works.

Costs for these schemes will depend on a number of crucial variables such as:

- physical process conditions and beach movement behaviour
- type of material required
- source of material
- transport methods and distances to transport
- expected scheme life before topping up (controlled by the longshore drift regime)
- volumes required
- need for beach control structures (groynes, breakwaters and so on) or minor works to enhance the beach system

Delivery of material from the sea is less damaging, but cost-effectiveness depends on the economies of scale and the source of the material. For example, dredging for recharge can have very high mobilisation costs, particularly if carried out as a standalone operation.

The indicative costs in the previous section are provided as examples of the relative unit costs associated with beach recharge, but may be misleading for anything other than very early stage feasibility or national level assessments. Additional detailed costs should be determined by specialists for more detailed design estimates.

The first edition of the *Beach Management Manual* (CIRIA 1996) and the Environment Agency Unit Cost Database (2007 version) include the following example unit rates. NB The 2007 version of the Unit Cost Database includes some examples not updated or referred to in the 2010 version.

The first edition of the *Beach Management Manual* (CIRIA 1996) included a number of case studies for 20 shingle beach recharge projects carried out between 1979 and 1992 with details of on fill volumes and unit costs. Unit costs (unadjusted for inflation) ranged from £3 to £17/m^3. However, methodologies and techniques may have advanced since the time of these works.

The second edition (CIRIA 2010a) suggests that shingle recycling operations will vary between £1.50/m^3 to £20/m^3 (2008 costs) depending on the haulage distance, fuel and plant costs.

The Environment Agency's Unit Cost Database (2007 version) included a cost curve for the cost per cubic m for beach recharge against the volume of sand/shingle recharge that varied from £8 to £21/m^3 in 2007 prices.

The 2010 version (Environment Agency 2010) provides cost data on a number of beach recharge schemes which are summarised in Table 1.4. These costs for sand/shingle recharge are based on out-turn costs of completed projects in the Unit

Cost Database. These costs are provided for information and as reference projects. Appraisers are recommended to review these schemes before using the information to ensure that the costs are applicable if applied to similar proposed projects.

Cost estimation for beach recharge is a very complex process and requires specialist consultants/contractor involvement for detailed cost estimates.

Table 1.3 Example costs from the Environment Agency Unit Cost Database associated with beach recycling/recharge

Scheme	Description	Length (m)	Volume (m^3)	Total cost (£k)	Cost (£/m)	Cost (£/m^3)
West Clacton – Jaywick Sea Defences (1999)	Beach nourishment, 500,000 m^3 sand from Long Sands, plus 100,000 tonnes of rock	3,250	689,000	6,276	1,931	9
Happisburgh to Winterton Sea Defences Intermediate Works – Phase 3 (2000)	Beach recharge	4,300		8,888	2,067	
Happisburgh to Winterton Sea Defences – Phase 3 (2002)	Beach recharge	2,000	438,000	5,889	2,945	13
Shoreham and Lancing Beach Defences – Phase 1 (2002-2003)	Beach recharge		28,000	891		32
Seaford Bulk Recycling Scheme (2002-2003)	Shingle recycling, maximum 2 km haul		360,000	451		1
Pett Sea Defences (2005-2006)	Beach recharge		50,000	745		15

1.5.2 Walls

In addition to physical size (length, depth) of the walls, the most important issues that will affect the cost of the completed structure are as follows:

- access constraints – distance to work site, ease of movement along site length, need for temporary access and so on
- weather – winter working will have an influence on productivity and therefore likely higher costs than working during the summer

- quality of materials for building, facing and finishing the structures (such as coping stones)
- economies of scale – whether the wall is a short, isolated section with high mobilisations costs or a long length of uniform construction type
- precast or in situ construction

The Unit Cost Database (2010 version) provides unit costs for a range of wall types, typically used in the fluvial environment (retaining and with cut-off and piled foundations). These costs are included in the fluvial flood defence evidence summary. A number of more relevant coastal projects are also provided, although the number and type of projects are limited and therefore only provide example historical data and reference projects to assist appraisers in cost estimation.

Table 1.5 summarises the unit costs for these coastal assets. It highlights the wide range in costs and emphasises the need for site-specific consideration for more detailed design estimates.

Table 1.4 Example costs from the Environment Agency Unit Cost Database associated with coastal walls

Type	Description	Length (m)	Height (m)	Total cost (£k)	Cost (£/m)	Cost (£/m²)
Raising	Raise and modify existing wall	3,000		1,704	568	
	Concrete retaining wall, clad both sides with stone, tie to existing	100	1.0	149	1,490	1,490
Wave/ retaining wall	Sea defence wall – brick clad, granite coping	300	0.5	395	1,317	2,633
	Seawall	450	0.4	861	1,913	5,467
	Sea defences	1,190	3.8	2,456	2,064	543
	Reinforced concrete wave return wall	75	2.0	472	6,293	3,147
	Tidal sea defence – seawall, stone clad	370	1.5	1,488	4,022	2,681
	Wave return wall	822	1.8	1,237	1,505	836
	Wave return wall and crest slab	515		442	858	
Quay wall	Reinforced concrete quay wall – masonry facing, including water cavity to rear, some piled, counter walls	300	6.5	3,277	10,923	1,681
Piling	Piling to quay wall	30	14.0	95	3,167	226
	Piling to slipway	70		48	687	

1.5.3 Revetments

For rock armour or rip-rap revetments, construction costs depend on:

- dimensions of the structure (required crest and toe levels, gradient and so on)
- availability of suitable material
- transport distances and methods
- requirement for additional works such as accesses

As a result of these factors, capital costs for these schemes will vary significantly. Due to the non-standard design, arrangement, duties and materials used in revetments, the provision of the indicative costs may be misleading for anything other than very early stage feasibility or national level assessments. Additional detailed costs should be determined by specialists for more detailed design estimates.

Costs cited in a Geocases case study of Norfolk sea defences[1] suggest costs of £1,000–3,000/m using rock as toe armour. Typical capital costs of £2,000–5,000/m are typical for a large-scale rock revetment where there are nearby sources of suitable rock available. Accordingly costs vary geographically in the UK, with historically schemes on the south and east coasts being generally more expensive.

The Environment Agency's Unit Cost Database (2010 version) provides cost data on a number of rock/stone revetment schemes (Table 1.6). These costs are based on out-turn costs of completed projects in the Unit Cost Database and are provided to assist appraisers through the provision of historical data and reference projects. The table illustrates the wide range in costs and highlights the need for specialists for more detailed design estimates.

Table 1.5 Example costs from the Environment Agency Unit Cost Database associated with revetments

Scheme	Description	Length (m)	Volume (m^3)	Total cost (£k)	Cost (£/m)	Cost (£/m^3)
Happisburgh to Winterton Sea Defences	Rock armour – land and sea placement	35	2,180	1,019	29,114	467
South Felixstowe Flood Alleviation Scheme	Rock armour on beach		24,117	1,730		72
Minsmere Tidal Sluice Outfall Improvement Works	Rock/stone revetment works	25		57	2,280	
Happisburgh to Winterton Sea Defences – Phase 1 Intermediate	Revetment protection works	1,700	16,320	311	183	19

[1] http://www.geocases1.co.uk/printable/Coastal%20defences%20in%20Norfolk.htm

Scheme	Description	Length (m)	Volume (m^3)	Total cost (£k)	Cost (£/m)	Cost (£/m^3)
Works						
Tendring and Hollane Tidal Defences	3-5t Rock armour	650	24,375	1,017	1,564	42
West Clacton – Jaywick Sea Defences	Rock armour	1,000	257,000	2,380	2,380	9
High Knocke to Dymchurch Sea Defences	Rock armour	1,256	54,501	5,840	4,649	107
Alkborough Tidal Defence Scheme	Rock armour erosion protection	83	8,330	1,457	17,554	175

There is currently very little information available for impermeable or other types of revetments other than that provided by the Environment Agency Unit Cost Database in Table 1.6. Additional research or collation of this information is recommended to ensure these data are made available and reviewed in the future.

1.5.4 Breakwaters

Offshore breakwaters generally have a length similar to their distance offshore, which is typically 200–300 m. Structures may be placed either singly to protect a specific coastal location, or as a series to provide protection to longer frontages. Breakwaters may be constructed as a standalone element or as part of a wider coastal management strategy, for example, in combination with groynes or as part of a beach recharge scheme. The design may therefore consider a certain applicable deterioration or damage to the breakwater structure that will not result in catastrophic failure or failure to the overall scheme purpose.

Appraisers should determine the issues most likely to influence costs and consider these with specialists during the design phase. The most important aspects influencing offshore breakwaters are fully described in the report by Crossman et al. (2003) and summarised below.

- **Geometry of the breakwater**. Costs will depend on the sizing, slope, complexity and design of the structures.
- **Materials type and source**. Costs will depend on the cost of the rock, accessibility of the site, delivery methods and distance to the quarry or local source material. Design of the structure can be adapted to a particular or local source material. Costs may also depend on the grading and proportion of the rock that can be used and the degree of excess material. Armour sizing will also influence plant requirements and costs.
- **Construction methods**. These influence plant equipment and access requirements. Requirements for foundation, excavation and toe protection works will often require different and more costly marine plant to be used.

- **Timing of construction.** Summer months may have a lower risk of downtime and delays, but may not be possible due to public amenity pressures.

Due to the number of factors that contribute to the costs associated with these structures it is not possible to quantify the impact of different issues on cost within this document. Future recording of construction costs may lead to different unit rates for breakwaters, but current information on out-turn costs is limited for these structures.

The Environment Agency Unit Cost Database (2007 version) included two examples of offshore breakwater projects with unit costs that varied from £1,750 to £3,304 per metre.

1.5.5 Groynes

Important factors to consider when costing groyne schemes include:

- functional design –length, spacing, height, depth of groynes
- materials to be used to construct the groynes
- length of beach requiring protection
- beach exposure conditions
- tidal range, geomorphology of the beach deposits and the depth of the bedrock if piles are to be driven

The beach material is also important as groyne's design life depends on abrasion rates under different exposure and sediment size conditions (more abrasion and a reduced design life have been recorded for shingle beaches).

Timber groynes

Design guidance on timber groynes is provided by Crossman and Simm (2004). A number of case studies and examples of timber groyne costs are provided below to illustrate the range of typical costs.

- Within the Environment Agency asset deterioration guidance document (Environment Agency 2009), Bournemouth Borough Council cited costs of around £200,000 per timber groyne in 2004.
- A case study of coastal defences in Norfolk from the Geocases website suggests costs for rocks of £40–50/m^3 with a rock groyne typically costing £125,000.[2]
- Bournemouth Borough Council's rolling groyne reconstruction programme cited costs of £200,000 per timber groyne (Crossman and Simm 2004). However, this high cost was in part due to the small tidal range and length of the groynes necessitating considerable temporary works and hard underlying strata which required pre-boring for the piles with high-pressure water lances.
- Worthing Borough Council reported within the Environment Agency asset deterioration guidance document (Environment Agency 2009) that typical costs for a 70 m long softwood timber groyne were now £100,000.

[2] http://www.geocases1.co.uk/printable/Coastal%20defences%20in%20Norfolk.htm

- The Norfolk Coastal Defences case study (Environment Agency 2009) suggests costs of £1,000/m for timber groynes. Assuming a typical groyne length of 100 m, that is £100,000 per groyne.
- Eastbourne's coastal protection scheme included 94 timber groynes (65–110 m in length) at a total cost of £30 million (£320,000 per groyne) (Suffolk Coastal District Council 2009).
- Waveney District Council developed a £7 million scheme at Southwold to construct both rock and timber groynes. The timber groynes (45 m in length with a 110 m spacing) were constructed at a cost of approximately £105,000 per groyne (Suffolk Coastal District Council 2009).
- A cost benefit analysis in 2004 estimated timber groyne costs of £1,330/m for the groynes in Swanage (Suffolk Coastal District Council 2009).

Rock groynes

The construction costs of rock groynes will depend on the scope and complexity of the site and design of the groynes. Site accessibility may also influence the design and ability to construct or top up rock groyne structures.

The Environment Agency's Unit Cost Database (2010 version) provides cost data on a number of rock groyne schemes (Table 1.7). These costs are based on out-turn costs of completed projects in the Unit Cost Database.

Table 1.6 Example costs from the Environment Agency Unit Cost Database associated with rock groynes

Scheme	Description	Length (m)	Volume (m^3)	Total cost (£k)	Cost (£/m^3)
Felixstowe Ferry Sea Defences	Groynes – rock	Unknown	2,290	220	96
South Felixstowe Flood Alleviation Scheme	Groynes – rock	Unknown	27,344	1,713	63

A number of case studies and examples of timber groyne costs are provided below to illustrate the range of typical costs.

- Waveney District Council developed a £7 million scheme at Southwold to construct a field of rock groynes (45 m in length with a 70–80 m spacing) at a cost of approximately £200,000 per groyne (Suffolk Coastal District Council 2009).
- A cost benefit analysis in 2004 for the Swanage frontage estimated rock groyne costs of £2,410/m for the 30–50 m long groynes and £3,930/m for 175 m long groynes (Suffolk Coastal District Council 2009).
- An example of the use of rock groynes is provided in the CIRIA Rock Manual (CIRIA 2010b). A 4 km length of shoreline was protected using a combination of 33 (70 m long) rock groynes and breach recharge. The total cost was £12 million.

Groyne cost curves

Variations in costs for timber and rock groynes for different heights of groynes are presented in Crossman and Simm (2002), which suggests approximate unit rates (Table 1.8). This indicates that below a groyne height of 4 m the construction cost per linear metre ratio is lower for rock groynes compared with timber groynes.

These costs may be useful to help determine whole life costs if adjusted for inflation and once other factors such as groyne design and materials are taken into account.

Table 1.7 Estimated groyne construction costs (£/m)

Height (m)	Timber groyne	Rock groyne
1	400	150
2	800	550
3	1,200	1,100
4	1,550	1,700
5	1,950	2,500

Source: Crossman and Simm (2002)

1.6 Operation and maintenance costs

All structures must be maintained. This is particularly true of coastal erosion management and flood risk structures operating in ‘harsh environments’. Therefore maintenance should be addressed at both the design stage and throughout the operational life of the structure.

Frequent and intermittent maintenance and inspection works will need a defined maintenance and replacement programme as part of a scheme appraisal. Post-storm, seasonal or annual inspections will be required, followed by appropriate maintenance and repair work. This commitment must be costed and programmed from the outset if maintenance is to be managed effectively.

Other more substantial schemes, which are likely to have much higher initial construction costs, may require a much lower level of long-term maintenance commitment. However, they will have to be monitored to ensure ongoing effectiveness as at many sites foreshore erosion will be an ongoing process and may cause local scour or general beach level reduction, resulting in structural instability. The *Beach Management Manual* (CIRIA 2010a) details elements that should be considered in relation to the future maintenance of works and the factors influencing maintenance requirements such as exposure conditions.

1.6.1 Maintenance operations and costs

Costs associated with maintenance works for coastal defences are not widely recorded and cost information for these aspects is not readily available. While the requirements for coastal defence operation and maintenance (O&M) will vary from those used in the fluvial environment, it is suggested that annual O&M costs for embankments, concrete and steel walls provided in the fluvial flood defence evidence summary are used. These costs may not be directly applicable to coastal environments and so an allowance needs to be made for this in the weighting and scoring methodology proposed.

Coastal defence inspections activities may include a number of aspects such as visual inspections at low tide, aerial surveys, beach profile surveys and diver surveys.

Typical maintenance activities are described in the *Beach Management Manual* (CIRIA 2010a). These include

- beach management/recycling
- concrete defence element repairs (abraded, spalled and corroded sections)
- joint/crack repairs/sealant replacement to concrete structures
- repairs or extension to toe protection (concrete, rock and so on)
- replacement of fixings and/or damaged/rotten piles/planks or walings to timber elements
- addition or removal of timber planks to groynes (dependant on beach behaviour)
- replacement of damaged/dislodged stones/armour blocks
- re-coating protection to pile structures
- replacement/re-painting of fences or railings
- drainage and flap valve maintenance/replacement

Additional detailed information on maintenance activities associated with concrete assets in the coastal environment is given in CIRIA report C674 report (CIRIA 2010b).

The maintenance activities listed above generally intermittent maintenance activities. Annual maintenance activities are less likely other than for beach recycling operations, but larger scale maintenance nay be required at a lesser frequency. Costs of maintenance activities will therefore depend on the frequency of replacement or repair works required. These are highly correlated with exposure conditions at the site and typical fluvial maintenance frequencies are unlikely to be relevant for coastal environments.

Table 1.9 suggests frequencies for a number of maintenance activities associated with fluvial environments that may be relevant in the absence of more specific site information for an initial appreciation of the requirement for repeat works.

Table 1.8 Environment Agency suggested maintenance frequencies

Maintenance activity	Frequency
Embankment grass control	1–3 times per year
Embankment tree work	Once a year to every two years
Embankment vermin control	Once a year to every two years
Wall vegetation clearance	Once every 2–5 years
Wall minor concrete repair	Once every 2–20 years
Wall repair works	Once every 2–20 years

1.6.2 Seawalls

Guidance for rock structure maintenance activities and armourstone degradation are covered in the *Rock Manual* (CIRIA 2007).

Costs associated with O&M activities for seawalls are not widely recorded or available. It is recommended that appraisers review the maintenance costs associated with walls covered within the fluvial linear defences evidence summary.

1.6.3 Revetments

No records of any readily available cost information associated with the intermittent costs for revetment protection measures were available at the time of writing. Further information or records from local authorities or the Environment Agency should be sought to provide guidance for this protection measure.

1.6.4 Breakwaters

The *Rock Manual* (CIRIA 2007) suggests the following range of repair and upgrading requirements for breakwaters:

- simple maintenance that does not require removal and handling of a substantial volume of material
- repair involving heavy work and even reconstruction of one of more parts of the structure (carried out when the structure is at risk of further deterioration or has suffered damage that diminishes the performance of the structure)
- preventative rehabilitation and reconstruction of a significant part of the structure (topping up breakwaters with additional rock may require considerable dismantling work to ensure interlocking of individual rocks can be achieved)
- reconstruction or replacement of the entire length of a breakwater

The design and evaluation procedure for breakwaters typically attempts to minimise whole life costs by the selection of design conditions that balance the initial capital costs and any longer term O&M costs. This process aims to determine an accepted level of damage for which the structure is designed that will ultimately influence the frequency of maintenance works and the whole life costs associated with these structures.

1.6.5 Groynes

Typically, timber elements have relatively short design lives and structures have significant monitoring and maintenance obligations. This may not be practical where access is difficult or dangerous and this is often cited as a disadvantage. Rock groynes have less maintenance requirements and lower long-term maintenance costs. Rock groynes are unlikely to require annual maintenance costs, but may require intermittent maintenance as for other rock structures.

The need to maintain or replace individual structures may provide opportunities for modification or adaptation during the scheme life and, in some circumstances such as a large groyne field, the individual structures can be replaced on a rolling programme of approximately the same duration as the structure life. This enables expenditure to be maintained at a relatively steady level while facilitating a long-term relationship with external contractors, evolution of design and construction practices, and continuity of knowledge and experience.

Timber groyne maintenance activities are recorded in Crossman and Simm (2004) and may include the following specific activities:

- replacement of damaged or degraded elements
- adjustments to structure profile or configuration
- repairs to ensure public safety
- preventative action to avoid further damage – may include replacement of pile protection or replacement of loose planking

Available costs of timber groyne maintenance are limited, although some specific information from the Defra/Environment Agency asset deterioration report (Environment Agency 2009) is provided below.

- Bournemouth Borough Council cited maintenance costs of around £500 per groyne per year.
- Canterbury Borough Council reported annual inspection and plant replacement costs of £3,000–5,000 to maintain about 430 groynes (excludes cost of timber).

The costs of timber groyne maintenance recorded by Suffolk Coastal District Council (Suffolk Coastal District Council 2009) suggested the following examples:

- Dover coastal defence maintenance cost per groyne is approximately £700 per groyne
- estimated repair work to Great Yarmouth timber groynes is approximately £1,000–2,000 per year per timber groyne
- Waveney District Council estimated maintenance costs for timber groynes is £1,500 per year per groyne for the first 10 years and then reducing

As part of the Southern Coastal Group, New Forest District Council has developed some innovative solutions to timber groyne management so as to reduce costs, simplify the maintenance, provide a more sustainable solution and improve the condition and performance of the groynes at two sites – Calshot and Milford-on-Sea.

Due to the coarse beach material at Milford-on-Sea, shingle abrasion was a major issue with lifespan of piles of typically 3–5 years. Poor quality mild steel fixings had also been used and were severely corroded creating weak connections and beach material was being lost as some piles were too short and also unstable. The solutions developed included the use of timber pile protection which can be replaced when worn and costs four times less than pile replacement (an annual saving of £13,000 has been made). Use of stainless steel fixings which do not corrode and can be reused has created further savings. The depth and length of the groynes have been increased which, combined with beach recharge, has helped to reduce future large-scale losses (Southern Coastal Group 2010).

1.6.6 Coastal dune and vegetated shingle management

The costs of dune erosion management can vary from almost nothing to several million pounds per kilometre, although management costs are more usually towards the lower end of this range. Major cost elements are labour and materials for initial works, with secondary elements being preliminary investigations, consultant's fees, pre- and post-project monitoring, site equipment, site access, permissions and ongoing maintenance.

Small dune grass transplanting or thatching schemes can be carried out by unskilled volunteer labour using locally available materials. As the consequences of inappropriate implementation are minimal, there is be no need to perform significant preliminary investigations, involve consultants or establish any rigorous monitoring programmes. Costs would be very low, but the life of the scheme may be short and the benefits very localised.

The main costs of managing coastal sand dunes relate to habitat management and restoration typically include costs for scrub clearance, dune grass planting, dune fencing and protective stock fencing. The UK Biodiversity Action Plan (UKBAP) costing report cites agri-environment payments of costs of £140/ha for dune management in England and £50/ha for dune management in Wales (UKBAP 2006a).

Maintenance of vegetated shingle habitats does not generally require intensive management, but depends on protecting sites and species from disturbance or damage from human activities. Thus the principal cost involves protecting sites and alleviating human pressure through the installation and maintenance of fencing and/or through wardening of shingle sites. Some sites may require low level grazing to prevent the invasion of scrub. Examples and costs are provided in the UKBAP Costings Annex report (UKBAP 2006b) with indicative costs similar to dune management at £50 per hectare per year.

1.7 Coastal monitoring

Coastal monitoring provides a sound scientific base to inform all levels of strategic coastal management, including high level Shoreline Management Plans, Coastal Strategies and local beach management activities, as well as providing a basis to inform future decision-making.

This growing data resource is helping the Environment Agency and other organisations to understand how the coast changes over time, after storm events, and how human intervention affects the surrounding coast.

Long-term repetitive monitoring and data collection underpins all flood and coastal erosion risk management activities. It highlights where beaches are eroding and accreting, and therefore how they should be managed for best effect and for best value for money.

To improve the consistency of approach, a national coastal monitoring programme was set up to steer the five regional monitoring programmes in England from 2011 (Environment Agency 2010).

Costs associated with coastal monitoring are likely to be low compared with the acquisition and capital costs associated with new schemes, and may not need to be included within an appraisal type study. However, different spatial and temporal scales of beach management works require different amounts of information from monitoring programmes to inform them. Table 1.10 provides a summary of the types of data required to inform different beach management works, including who is most likely to use the information.

Table 1.9 Summary of potential monitoring data requirements

Beach management activity	Monitoring information required	Purpose	Likely audience
Event management	Post-storm beach profile	Post-storm survey to record changes in beach level in relation to crisis and alarm levels	Beach managers, coastal scientists and engineers, coastal ecologists, general public
	Wave and water level conditions during event	Data recorded at time of event to inform appraisal of event in relation to standard protection, particularly when combined with post-storm profile survey	
Operational maintenance	Beach profiles	Profile surveys over a period of time (for example, a year) used to inform routine maintenance works such as recycling and re-profiling, to guide where to move sediment from/to along the shoreline (or if more material needs to be brought to site)	Beach managers, coastal scientists and engineers
	Structural inspections	Undertaken periodically to inform timing of maintenance works to structures (for example, seawalls or groynes) and inform residual life assessments	
Strategic planning to scheme development	Beach profiles	Repeat profile surveys over a period of time provides appraisal of longer term trends in beach movement	Beach managers, coastal scientists and engineers, coastal ecologists, geomorphologists, general public
	Post-storm beach profile	Provides detail of short-term beach response to storm events – most useful when combined with event wave and water level data (refer to event management).	
	Hydraulic conditions	Waves, tide levels and currents affecting the beach over the same period of time as the profile data (provides the 'forcing' conditions that affect the observed beach profiles)	
	LIDAR/	Repeated surveys over a	

Beach management activity	Monitoring information required	Purpose	Likely audience
	detailed topographic data	period of time allows difference plots to be created, showing net accretion and erosion patterns over the beach. Can provide crest level information for defences to assist in defining standards of protection being provided	
	Bathymetric survey	Repeated surveys over a period of time allows difference plots to be created, showing net accretion and erosion patterns within the nearshore subtidal zone.	
	Sediment sampling data	Repeated surveys aids understanding of where sediment is moving to both along the shoreline and on/offshore.	
	Natural environment data	Ecological survey data helps to inform potential impacts of management options on the natural environment and in particular designated habitats and species.	
	Aerial Photography	Provides data to identify changes in morphological features for example, banks and channels and changes in boundaries of coastal habitats for example, dunes, marsh and so on.	
Strategic planning to scheme development	Human environment data	Includes historic environmental features (archaeology), public rights of way, and beach use patterns. All of these need to be considered when developing beach management options.	Beach managers, coastal scientists and engineers, coastal ecologists, general public
Performance assessment	Beach profiles	Repeat profile surveys over a period of time provide appraisal of management approach in relation to the	Beach managers, coastal scientists and engineers, coastal ecologists,

Beach management activity	Monitoring information required	Purpose	Likely audience
		longer term trends.	geomorphologists
	Post-storm beach profile	Provides details of short-term beach response to storm events – most useful when combined with event wave and water level data (refer to event management) to assess impact of storm event on the Standard of Protection designed for.	
	Environmental data	Includes appraisal of impacts on flora and fauna, as well as bathing water quality and beach use.	

General costs associated with coastal monitoring will vary depending on the type of monitoring works undertaken. Average costs suggested by the strategic regional coastal monitoring programmes (2011-2016) indicated that the proposed funding of ongoing national monitoring could be approximately £1,558 per km per year, though there is regional variability (£960–1,955 per km per year) that reflects local risks and assets (Southern Coastal Group 2010a).

1.7.1 Walls

Following structure completion, there should be regular monitoring to ensure the structure continues to perform satisfactorily. Environmental monitoring should take place such as:

- beach/seabed levels adjacent to the structure
- wave, wind and tidal climate at the site

Regular monitoring is important to plan for maintenance. Generally the frequency should be immediately after construction, after extreme storm events, annually and every five years for submerged elements. Monitoring methods for modified seawalls include (CIRIA 2010a):

- visual inspection at low tide
- general, fixed aspect and aerial photography
- profile surveys of structure and foreshore
- inspection of voids

Erosion of the toe is a common problem and is the mechanism most likely to cause structural failure. Monitoring of the toe is therefore vital.

1.7.2 Revetments

Revetment design must anticipate ongoing erosion which may result in toe scour, over topping or outflanking, and may cause partial structural failure. Monitoring methods for revetments typically include:

- visual inspection at low tide
- general, fixed aspect and aerial photography
- profile surveys of structure and foreshore
- inspection of voids

Inspection requirements as defined by the *Rock Manual* (CIRIA 2007) for rock structures suggests planned monitoring and inspection intervals of 6–12 months for basic inspection and structure surveys, with submerged diving or other survey techniques for submerged structures carried out on a five-year interval. It may be necessary to consider a higher inspection frequency after construction to ensure a satisfactory performance. Post-storm surveys to a structure should be carried out on an event basis to check for damage or the need for repair works.

1.7.3 Groynes

Post-project monitoring should be carried out at least bi-annually to assess the beach–dune evolution and the success of the scheme relative to its objectives. Monitoring must include adjacent shorelines as well as those immediately within the groyne scheme.

Groyne heights, lengths and profiles can be modified if monitoring indicates that the initial layout is not achieving the required objectives. Modification is easier to achieve with timber rock structures than with rock.

Monitoring methods for groynes typically include:

- visual inspection at low tide
- general, fixed aspect and aerial photography

1.7.4 Beach recycling and recharging or nourishment

Monitoring of beach recycling and nourishment schemes will require detailed modelling, calibration and analysis prior to the works being undertaken. Notwithstanding this, there are significant uncertainties that cannot be predicted such as the timing of future wind and wave or surge conditions that will influence local processes and beach movements and require ongoing measurements and observations to determine replenishment rates.

Post-project monitoring should be carried out at least bi-annually to assess the beach–dune evolution and the success of the scheme relative to its objectives. Typically intensive monitoring is required initially following scheme completion, which can then be fine-tuned and the frequency reduced into the future, subject to analysis of results.

Appendix 2 of *A Guide to Managing Coastal Erosion in Beach/Dune Systems* (SNH 2000) provides further monitoring guidelines.

1.8 Design life and asset deterioration

Design life is defined as the minimum length of time that a scheme or structure is required to perform its intended function. While the design life of a scheme will be influenced by initial construction and longer term operation and maintenance costs, coastal defences will also be heavily dependent on the durability of the materials and their resistance to anticipated loadings.

Understanding and quantifying deterioration rates of the common materials and components in flood risk management assets is important for estimating and planning programmes of maintenance that contribute to an asset's whole life costs and for day-to-day maintenance and renewal intervention activities. It is also important to understand how deterioration interacts with asset condition and performance under service conditions

Within the Environment Agency asset deterioration guidance (Environment Agency 2009) a table of deterioration rates to different condition grades (1–5) sets out different asset types and exposures with and without a typical regime of maintenance. The following information has been extracted from this table to illustrate the deterioration times for different types of vertical coastal walls. Information on the best estimate of deterioration rates is summarised below. Additional upper and lower estimates can be found in the asset deterioration guidance.

1.8.1 Walls

Deterioration rates for walls within the coastal environment depend in part on their construction materials and on the degree to which they are exposed. Table 1.11 provides best estimates for deterioration (in years) from condition Grade 1 (very good) to each consecutive grade for different materials. For example, it takes 15 years for a Grade 1 brick and masonry defence to deteriorate to a Grade 2 (good) condition and 75 years to deteriorate to a Grade 4 condition (poor).

Table 1.10 Deterioration rates for different materials in coastal environments

Material	Maintenance	Best estimate deterioration rates (years)				
		Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Brick and masonry walls	No difference	0	15	45	75	90
Concrete walls	No	0	10	30	60	75
	Yes	0	10	30	65	80
Sheet piles	No	0	8	30	43	50
	Yes	0	8	30	53	60

Source: Environment Agency (2009)

1.8.2 Revetments

Impermeable revetments are generally intended to withstand storm wave attack over a life expectancy of 30–50 years. Rock structures are likely to degrade over time depending on the location of the defence and the physical characteristics of the rock used.

There are currently few long-term data for rock structures that have been in service for over 50 years with which to determine appropriate longer term design life estimates. However, some structures that have been in service for between 30 and 50 years are showing little obvious signs of rock degradation (Williams A, personal communication).

Table 1.12 provides best estimates for deterioration (in years) from condition Grade 1 (very good) to each consecutive grade for permeable and impermeable revetments.

Table 1.11 Deterioration rates for revetments in coastal environments

Material	Maintenance	Best estimate deterioration rates (years)				
		Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Permeable revetments	No	0	9	19	31	38
	Yes	0	13	25	42	50
Impermeable revetments	No	0	9	19	31	38
	Yes	0	13	25	42	50

Source: Environment Agency (2009)

1.8.3 Groynes

The design life of a timber groyne will depend on a number of factors but particularly:

- biological attack – fungal decay, marine borers and insect attack
- abrasion – which is linked to sediment characteristics and can lead to faster deterioration of timbers and consequent reduction in life expectancy)
- wave climate – more aggressive wave climate will reduce life expectancy

Within the second edition of the *Beach Management Manual* (CIRIA 2010a), Case Study 15.1 Coastal Defences at Whitstable Kent contains detailed information on the design issues affecting the cost of this timber groyne and beach recharge project. With respect to whole life costing the local authority client required a design life of 80 years (before total renewal) with an allowance for major maintenance after 40 years. Following tests it was concluded that, for coastal defence structures, tropical hardwoods were the only type of timber that met this requirement.

Further research on the performance of different types of timber has been carried out by Bournemouth Borough Council. Greenheart, Purple Heart and Ekki have been tested at a demonstration site and to date Ekki has been most successful. The Purple Heart timber planks were found to be heavily infested with gribble (marine borers) after a very short period of time.

Timber groynes have a typical life expectancy of 10–25 years but life expectancy depends on the species of timber used. In tests, Canterbury Council found that non-tropical hardwoods (oak and Douglas fir) lasted between 5 and 10 years before decay affected the structure. The types of tropical hardwoods used in groynes (Greenheart and Ekki) have strengths twice that of non-tropical European hardwoods such as oak. Timbers of lesser strengths would have to be increased in section to meet the design stresses, with consequential increases in cost and timber usage (CIRIA 2010a).

In schemes requiring large quantities of tropical hardwoods, evidence of a legal and sustainably managed source will usually be required. The Whitstable scheme was able to make a substantial cost saving by removing purchase of the timber from the main contract and purchasing on a shipment basis direct from the country of origin (CIRIA 2010a).

The average design life of rock groynes is anticipated to be higher – in the region of 50 years – but will depend on the local conditions and design of the structures (as discussed above).

Gabion groynes are generally not recommended due to the short design life associated with these structures. The design life may be in the region of 1–5 years, but will depend heavily on the local conditions and shoreline exposure.

1.8.4 Beach recycling and recharging or nourishment

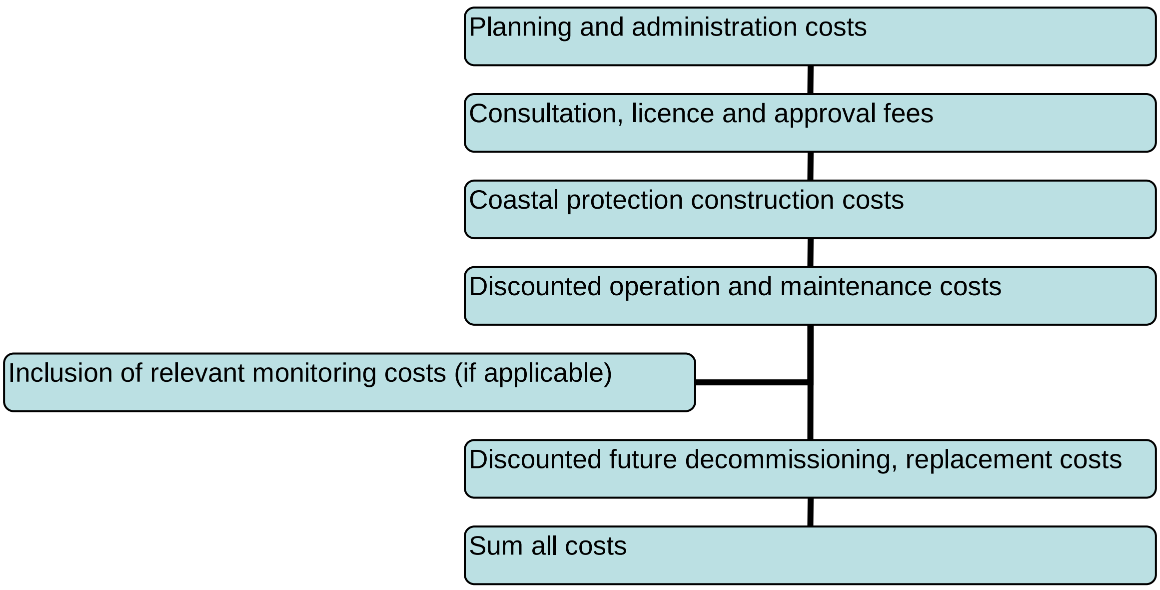
Beach recharge or recycling for coastal defence is normally required to improve beach levels to improve the level of protection. Groynes are used to assist in control of the beach and thereby influence the need/frequency for recycling/further replenishment.

The replenishment frequency will need to be estimated to consider the whole life costs for this option. This will need a detailed understanding (and modelling) of the longshore drift to determine the frequency of recycling. The resulting significant uncertainty associated with this aspect will need consideration and sensitivity/scenario testing as part of the cost estimate and economic appraisal.

1.9 Cost estimation methodology

Figure 1.1 shows the key aspects required to generate a whole life cost for a coastal flood defence to include all relevant capital and O&M costs.

Figure 1.1 Flow diagram for coastal whole life costs



1.10 Case studies

1.10.1 East Lane, Bawdsey

East Lane is situated on the Suffolk coast. It is subject to severe coastal erosion and flood risk. Unable to receive grant-in-aid, a trust was formed supported by Suffolk Coastal District Council to protect a scheduled ancient monument and residential properties. The scheme involved a hard rock armour revetment providing a 50-year Standard of Protection. Before this scheme and after the first Shoreline Management Plan had been produced in the 1990s, an emergency scheme with an estimated 10-year life was constructed to hold the line in the short term to allow appropriate management actions to be defined.

A partnership group was set up due to the disagreements and conflicting interests of stakeholders, each having different interests (statutory/non statutory) in relation to the management of East Head. The partnership's objective is to achieve a common way of working for the best and most sustainable evolution of the coastline. The agreement over the appropriate management policies for East Head took over seven years of meetings and partnership working.

From the initial formation of the trust in 2004 it took four years for the East Lane scheme to be developed with a planning application being submitted and approved during 2007. Following the approval, works on-site began in late 2008 and were completed in summer 2009 with the final north-end tie-in being completed in spring 2010.

Erosion of a flood defence embankment in 2004 at East Lane is shown in Figure 1.2 and an aerial photograph of the completed scheme in Figure 1.3.

Figure 1.2 Erosion of Environment Agency flood defence embankment, November 2004 (source: Terry Oakes Associates Limited)

Figure 1.3 Completed East Lane, Bawdsey Coast Protection and Flood Defence Scheme (source: M Page)

1.10.2 Lyme Regis, Dorset

Lyme Regis is a coastal town in west Dorset, often referred to as 'The Pearl of Dorset', and is a World Heritage Site heavily reliant on tourism. To tackle its long history of coastal erosion problems, a five-phase coastal defence programme of projects began in the 1990s. There are a number of contributing partners including South West Water.

In the early 1990s, the Lyme Regis Voluntary Advisory Panel was formed including anglers, retired engineers, town councillors and geologists. This developed over time to form the Lyme Regis Coastal Forum. The Forum is used as a mechanism to consult with the public. It is felt that significant improvements have been made to the scheme by engaging with local people.

During the design and construction of Phase II, the project team held regular meetings with local advisory groups including the highway authority and emergency services, residents, traders and the town council. During the lead in work for Phase IV, the Environment Agency, Natural England and Dorset County Council ecologists and World Heritage Site staff attended regular progress meetings with West Dorset District Council (WDCC) and its consultants.

To illustrate the time taken to develop just one phase of this scheme, preliminary designs for Phase IV received conditional planning consent in April 2010. Following this approval, the Environment Agency's project appraisal report was submitted later that year and given technical approval. Working in partnership with Dorset County Council, WDDC started work on the appointment of consultants and contractors. Subject to receiving financial approval following receipt of tenders, the main contract was expected to commence in spring 2013 and to take approximately two years to complete. Approved pre-construction costs for Phase IV are currently £1,346,000 relative to construction costs of £13,077,000.

An example of coastal erosion at Lyme Regis in 1062 is shown in Figure 1.4 and the completed seawall with the beach and jetties in Figure 1.5.

Figure 1.4 Coastal erosion, 1962 (image courtesy of Environment Agency)

Figure 1.5 Completed seawall, beach and jetties (image courtesy of Environment Agency)

1.10.3 Alkborough Flats Tidal Defence Scheme, Humber Estuary

This scheme, the largest managed realignment scheme in the UK, was completed in 2006 at cost of £10.2 million and is located on the south bank of the Humber Estuary. The Humber is internationally important for habitat and biodiversity interests, with 400,000 people living on its floodplain. It is also internationally important for navigation. Climate change could raise sea levels in the Humber by 1.2 m by 2100. The project was led by a partnership including the Environment Agency, English Nature (Natural England), Associated British Ports, North Lincolnshire Council and supported by RSPB, parish councils and local landowners. The project attracted substantial external funding from a wide range of sources.

Figure 1.6 Alkborough Flats managed realignment – breach to the right (copyright: Environment Agency)

As part of the Alkborough scheme, a management group was set up that included senior representatives from all the key partners. The management group was supported by a stakeholder steering group with representatives from around 15 stakeholder organisations as well as local people. In total more than 60 people regularly provided input to all aspects of the project. Project public consultation and communication took place for two years (2002-2004) prior to land purchase agreements being reached with the landowners. Site purchase was completed in early 2005. The final breach in the floodbank and completion of the project was made in 2006 (see Figure 1.6) – seven years since its inception in 1999.

1.11 Checklist

Use the checklist to:

- identify the key cost elements required for watercourses
- ensure all relevant whole life costs are incorporated into the cost estimate

Whole life cost estimate checklist for coastal protection

Item	Description	Frequency	Comments
Planning and design costs			
Professional fees	Initial appraisal, planning and design costs, options appraisal and design development	One-off	
Consultation	Including planning, management , public consultation, stakeholder engagement, partnership working and agreements	One-off	
Feasibility studies	Undertake feasibility studies	One-off	
Surveys	Undertake baseline surveys and all environmental/engineering surveys.	One-off	
Licences and consents	Planning permission, statutory or non-statutory EIA, Appropriate Assessments (if required), marine licences	One-off	Can have programme implications.
Capital			
Enabling works	Site set-up, procurement of specialist materials or dredging for beach recharge	One-off	
Construction costs	Asset construction costs	One-off	
Inspections			
Monitoring programme	Development and review of monitoring programme	Ongoing	
Operational and public safety inspections	Cost of regular inspections including visual inspection at low tide, general, fixed aspect and aerial photography, profile surveys of structure and foreshore and inspection of voids	Ongoing	
Maintenance			
Maintenance	Costs of maintenance and intermittent refurbishment works associated with new structures	Ongoing	
Replacement costs	Costs of replacing temporary defence or erosion control	Ongoing	

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