



SID 5 **Research Project Final Report**

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1. Defra Project code

2. Project title

3. Contractor organisation(s)

4. Total Defra project costs (agreed fixed price)

5. Project: start date

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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

Barrier beaches around the UK are important, not only in terms of defences against flooding but also in their own right as important coastal geomorphological features. A lack of detailed understanding of how these beaches evolve and of models to predict their performance as flood defences, together with constraints on acceptable methods of intervention, make the successful and cost-efficient management of barrier beaches a challenging task for coastal managers. The need for better management of such beaches as both flood defences and natural heritage areas will inevitably increase in the face of rising sea-levels.

The essential feature of a "barrier beach" is that it has a distinct crest separating the seaward beach face and a well-developed back-slope. In many cases, such beaches have (or once had) an area of water on their landward side, whether an estuary, lagoon or brackish-water. Beaches with these characteristics may be further sub-divided into "barrier islands", "spits" and "barrier beaches", depending on whether they have none, one, or both of their ends attached to a land mass. Distinctions such as this, however, can become blurred although this may not be particularly important from the viewpoint of managing such features, as opposed to the geomorphological approach to describing and classifying them.

Barrier beaches often form a natural flood defence to low-lying land behind them. However, man's chosen land-use, e.g. for residential and business properties, can often mean that the natural standard of defence afforded by the barrier is inadequate. Barrier beaches are often overtopped by large waves, they leak, can roll-back landward, and ultimately may breach. All of these events can give rise to unacceptably high flood-risks, and are likely to become more frequent as sea levels rise further. These flood-risks can justify intervention to improve the standard of protection that barrier beaches provide, but the natural heritage interests of such barrier beaches can constrain what type of intervention is acceptable.

At present there is scant guidance available which enables a balance between intervention and natural heritage interests to be achieved, and coastal managers are sometimes left to struggle through on a trial and error basis when seeking solutions.

This study has provided justification and scope for further research into the performance of barrier beaches as flood defences. The Performance-based Asset Management Systems (PAMS) research programme, funded by Defra and the Environment Agency, has furthered performance-based flood-risk assessment through, for example, the concepts of fragility, resilience and deterioration. PAMS is specifically designed for the identification and prioritising of works needed to manage existing flood defences. Part of the reason for the lack of management guidelines for barrier beaches is our relatively

poor understanding of the processes driving their short-term morphology and long-term evolution. The recommendations for further research, and the further research itself, will be embedded in the Environment Agency's Sustainable Asset Management theme. As such, the proposed research, whilst still firmly and unavoidably centred upon improved process understanding, is placed into the context of performance-based flood-defence management. Ultimately, the research is expected to provide the framework for the evolution of a "Best Practice" guide.

The main outputs of this study, centred around the production of the R&D Technical Report FD1924/TR include:

- A review of scientific literature and of existing predictive process methods for overtopping, through-flow and morphological change of barrier beaches has been carried out.
- A review of barrier beach management methods has been carried out in consultation with individuals responsible for management of the beaches. This review includes discussion on monitoring and appropriate analysis. Case histories detailing state-of-the-art at 12 selected sites have been presented.
- A catalogue providing site-specific information on barrier beaches around England and Wales, including an on-line GIS database that provides information relating to these beaches. Details such as description, location, dimensions, current management practice, photographic record and links to further information, are consequently held on one publicly available website www.barrierbeaches.org.uk. This web-site is also used to disseminate the findings of this scoping study.
- Recommendations for a future phased-research programme within the Environment Agency's Sustainable Asset Management theme have been made. This programme is designed to enhance our knowledge and understanding together with our predictive capabilities. It will include monitoring their condition, performance and the flood-defence standard that they offer, as well as develop predictive tools. Ultimately a "Best-Practice" guidance for cost-effective and environmentally acceptable management of barrier beaches as natural flood defences will be produced.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Transfer).

Background context

Barrier beaches are wide spread around the coast of the UK. They are subject to rapid and large-scale changes in morphology, during episodic extreme storm events. Overtopping and overwashing may occur in such events, resulting in large scale flooding. Limited flood forecasting techniques are available to aid their management, yet these are often high-risk structures in context with flooding (Plates 1 and 2).



Plate 1 Salthouse flooding 1996 (Steve Harris)



Plate 2 Chesil beach overwashing at Chiswell 1979
<http://www.swgfl.org.uk/jurassic/chiswell.htm>

Barrier beaches have an important role as geomorphological features in their own right; they are often part of a coupled system, providing natural protection to extensive areas of wetlands. In some instances large scale rollback of the barrier can occur (Plate 3) with displacements of 80-100m occurring in a single storm event. This can cause instantaneous loss of large areas of environmentally important intertidal areas and may also have a dramatic impact on built infra-structure (Plate 4).



Plate 3 Hurst spit roll back 1989 (AP Bradbury)



Plate 4 Erosion of Slapton coast road - 1999 (Peter Wagstaff)

<http://www.saveslaptoncoastroad.co.uk>

Occasionally, the formation of a permanent or semi permanent tidal breach may occur when the barrier reaches a stage of breakdown; this may cause significant changes to the morphological and ecological evolution of the area to landwards.

A wide variety of management techniques are used including recharge, recycling, beach scraping (Plate 5) and hard structures.



Plate 5 Beach scraping at Medmerry (Environment Agency)

Objectives

The objectives of this project are set out in contract CSA 6932 and are repeated below:

- To undertake a scoping study to assemble and assess current understanding of barrier beach design.
- To define the need for further research.

In particular, the research has specifically addressed the following:

- threshold conditions for overwashing;
- causes of breaching;
- through-flow;
- prediction of the profile development of the beach following the onset of overwashing;
- processes that may result in the natural rebuilding of the crest;
- quantification of overtopping rates;
- quantifiable modification of the crest and back barrier by overtopping and overwashing; and
- review field performance of a range of key sites.

In addition, the project was expected to:

- gather information on and report current management methods;
- estimate costs of current barrier beach management practice; and
- understand and report constraints on management.

The work has also established a framework of studies to support better-informed and more effective management of barrier beaches.

During the course of this study, it was proven very difficult to estimate the costs of current barrier beach management practice. Coastal managers were generally unwilling, or perhaps unable, to contribute cost estimates to the scoping study. Because of this, that particular aim was not achieved.

It was recognised at an early stage in this scoping study that our general understanding of the performance and condition of sandy beaches (and barrier beaches) is far greater than our understanding of the performance and condition of mixed sediment and shingle beaches. Because of this, a strong emphasis was placed on the scoping of knowledge and application of techniques to mixed and shingle barrier beaches. Until such a balance of understanding is achieved, or close to being achieved, it is recommended that effort be concentrated in this vein.

Scoping study methodology

The barrier beaches report has collated and summarised the state of the art understanding of barrier beaches both in terms of relevant processes and management practices. Barrier beaches have been defined, their geomorphological classification reviewed, and our understanding of structural and morphological characteristics has been outlined. Barrier morphology has been divided into two, not entirely independent, time-scale categories namely; that relating to cross-shore processes (short-term) and that relating to longshore processes (longer-term). Methods used to study barrier beaches have been discussed, outlining desk-based, field-based and model-based approaches.

Typical application of state-of-the-art models used to determine the morphodynamic evolution of barrier beaches in the short-term has been described. Understanding the short-term storm response together with the barrier's behaviour following short-term storm impact (e.g. its ability to self-heal, i.e. resilience) is important with regard to efficient and effective flood defence management. However, a lack of methods available which can provide the type of information required has been highlighted.

A series of case histories has been selected to highlight not only the variety found around England and Wales in terms of geomorphology, geometry, and morphological processes, but also in terms of the flood protection roles played, and the consequent management practices adopted. Of particular note was the varying degree of site-specific knowledge that exists. Also of note was the lack of continuity from site to site with regard to management practice. A lack of guidance available to managers of barrier beaches was highlighted.

Current management methods which include mitigation measures and monitoring practice has been reviewed, with site-specific examples of management practice being provided. Those techniques adopted have been reviewed, and such methods as re-profiling, recharge, and re-cycling expanded upon. A review of monitoring procedure culminated with suggested analysis.

A mapping of barrier beaches around England and Wales was undertaken. To facilitate such a task, and to assist in the dissemination of findings from the scoping study, a dedicated website (www.barrierbeaches.org.uk) was set up and exploited during the course of the research program.

As a result of the review of current knowledge presented in this report, and the consultation exercise undertaken, the limited range of tools and guidance currently available to aid management of barrier beaches has been highlighted. This study has provided justification and scope for further research into the performance of barrier beaches as flood defences.

The Performance-based Asset Management Systems (PAMS) research programme, funded by Defra and the Environment Agency, has furthered performance-based flood-risk assessment through, for example, the concepts of fragility, resilience and deterioration. PAMS is specifically designed for the identification and prioritising of works needed to manage existing flood defences. Part of the reason for the lack of management guidelines for barrier beaches is our relatively poor understanding of the processes driving their short-term morphology and long-term evolution. The recommendations for further research, and the further research itself, will be embedded in the Environment Agency's Sustainable Asset Management theme. As such, the proposed research, whilst still firmly and unavoidably centred upon improved process understanding, is placed into the context of performance-based flood-defence management. Ultimately, the research is expected to provide the framework for the evolution of a "Best Practice" guide.

Review of process understanding

In order to discuss what does, or does not constitute a barrier beach, both for this specific study and as defined in other studies of such features around the world, it is useful to first introduce some explanation of the terms used by geomorphologists. By clarifying these specialist terms, and relating them to the ideas and terminology used in coastal engineering, it is hoped that the relevance of many previous reports and scientific papers dealing with such beaches can be made more relevant and useful in the context of their management by coastal engineers.

The essential feature of a “barrier beach” as defined in this study is that it has a distinct crest separating the seaward beach face and a well-developed back-slope. In many cases, such beaches have (or once had) an area of water on their landward side, whether an estuary, lagoon or brackish-water. Beaches with these characteristics may be further sub-divided into “barrier islands”, “spits” and “barrier beaches”, depending on whether they have none, one or both of their ends attached to a land mass. Such distinctions, however, can become blurred, for example given a narrow beach that periodically breaches allowing water to pass into the area to landward. Further discussion of these distinctions is presented later in this section, although these may not be particularly important from the viewpoint of managing such features, as opposed to the geomorphological approach to describing and classifying them.

A barrier beach may be attached at both ends or remain offshore, whilst a spit is attached to the coastline at its proximal end and detached at the distal end. Cope (2004) notes that morphology alone cannot always be relied upon to indicate the origin of these forms. There are many instances where there is no clear distinction between barriers and spits as each may exhibit features common to the other and may alter rapidly from one to the other. This has resulted in conflicting and contradictory terminology (Price, 1951; Riddell *et al.*, 1998). Because of this, it is important to establish whether or not a beach experiences a long-term net longshore drift of sediment, both from a geomorphological viewpoint and, more crucially, from a beach management perspective.

Where there is no possibility of any long-term addition from or loss of sediment to adjacent sections of coastline, for example in deeply indented pocket bay beaches, the beaches tend to adopt a plan-shape that ensures a zero net longshore sediment transport, at least when averaged over a long time period. Geomorphologists refer to such beaches as “swash aligned” and concentrate on the movements of sediment perpendicular to the beach contours, i.e. onshore-offshore transport as being the mechanism that brings about long-term changes in such beaches.

In contrast to “swash alignment”, many beaches experience a persistent, i.e. long-term, net longshore drift of sediments and their plan shape, and hence alignment, is determined by and maintains the variations in that drift rate along the coastline. Such beaches are termed “drift aligned” by geomorphologists. To maintain their alignment, such beaches need a continuing supply of fresh sediment at their updrift ends, e.g. from an eroding cliff or (overseas) a major river.

The long-term evolution of such beaches will normally be dominated by changes in longshore drift rates, caused for example by variation in the sediment supply or in wave conditions. Onshore-offshore sediment transport processes still occur but are of secondary importance to the evolution of such beaches. If there is a continuing supply of fresh sediment to a beach, it will be more readily able to adjust to sea level rise or an increase in the heights of incident waves, e.g. by increasing its crest height, than will a beach with a fixed volume of sediment.

While the development of a barrier beach in a geomorphological context is linked to sea level rise it is usually short-term events that bring about change. During exceptionally severe wave/tidal conditions a barrier may be breached or overwashed. This results in beach material being transferred from the seaward to the landward side, producing a net landward displacement of the feature (without necessarily losing volume).

Understanding morphodynamic change is important for the quantification of barrier condition, and assessing their performance as flood defences. Such assessments enable design and consequent improvements to the standards of defence afforded by barriers to be made. The following sub-sections briefly describe influences on barrier morphology. For more in-depth discussion see Stripling *et al.* (2008).

Berm formation

Berm formation is the most frequently-occurring process, which reshapes the supra-tidal section of the beach; it occurs close to the limit of wave run-up, when the swash fails to reach the crest. Beach deposits arising from this process are ephemeral and berms may only exist for a single tidal cycle, depending upon the prevailing wave conditions (Nicholls, 1985).

Through-flow

Limited investigations have been undertaken on this process, despite its significance in both evolution and flood-defence terms. This probably reflects the difficulty of obtaining field measurements and the possibility of

reproducing the beach permeability correctly within physical models. Studies of relevance to this process, but with the focus on internal flow within the beach include investigations at Slapton (Austin and Masselink, 2006) and the Grosse-Wellen-Kanal (Lopez de San Román-Blanco *et al.*, 2006).

Site specific investigations have been conducted by Hydraulics Research (1984) to examine the internal flow within Chesil Beach, with a view to design of a beach drainage structure. Observations made of instrumented boreholes are recorded by the Environment Agency at Chesil Beach but these investigations produce inconclusive results, suggesting that whilst the flow data is of some considerable management value, there is a requirement to modify the measurement programme further to include forcing variables such as wave conditions and also to add further measurement control.

Crest level

The crest level of a shingle barrier beach is one of the most critical parameters in defining its stability (Nicholls, 1985) and is dependent upon wave run-up and sediment availability. Landwards recession occurs when wave conditions exceed the unconfined crest: this can occur on barriers that lay many metres above mean sea level.

Crest elevation reduced by foreshore widening (cut back)

Bradbury (1998, 2000) notes that crest elevation can be reduced through cut back of the profile and foreshore-widening between the wave breaking point and run-up crest, to form a more dissipative foreshore. This process is more commonly occurring on beaches that have been managed, and where the crest elevation is artificially high relative to the usual environmental conditions.

Crest reformation

Bradbury and Powell (1992) and Bradbury (1998) note that overwashing can also result in the post storm crest elevation being raised, relative to the pre-storm profile. The process and response is controlled essentially by the surface emergent cross section of material available, sediment supply, back barrier geometry and the shape of the pre-storm beach profile (Bradbury, 1998, 2000).

The initial response is usually a reduction in crest elevation arising from the overwashing waves, but the crest may rebuild further to landwards of its original position if there is sufficient material within the cross section to allow a dynamic equilibrium profile to occur with reformation of the post-storm crest, at a higher level than the pre-storm crest elevation. This process occurs where there is sufficient sediment supply, marginal pre-storm conditions compared with the overwashing threshold, if the beach rolls back onto rising land, or where a barrier outflanks a topographic low (Bradbury, 2000).

Foreshore level

The influence of the foreshore level, relative to the toe of the beach, is significant in influencing the development and change in beach profiles - particularly below static water level. The water depth at the toe of most beaches is shallow, although beaches with deep water at the toe of the beaches were modelled by Powell (1990). There are a few exceptions, notably Chesil Beach, which has relatively deep water at the toe of the beach, under certain tidal conditions.

Overstepping

Barrier overstepping is the condition by which a barrier remnant is left on the shoreface, whilst the upper part of the sediment body moves rapidly onshore, often with short-term rapidly rising sea level (Forbes *et al.*, 1991), in the form of surge-generated overwashing (Orford and Carter, 1995). The condition is a component of progressive barrier landward migration, which may be irregular or episodic (Forbes *et al.*, 1991; Bray, 1997). Orford and Carter (1995) investigated inter-annual, sub-decadal and decadal (mesoscale) processes affecting barrier overstepping at Story Head, Nova Scotia. There is a strong dependence upon the nature of the foreshore solid geology. Muddy estuarine deposits capping sands or clays frequently occur in such environments.

Overtopping

Overtopping occurs in response to appropriate combinations of wave and water level conditions, and beach geometry. Orford and Carter (1982) and Orford *et al.* (1991a), suggest that where the volume of unconstrained run-up is small, sediment deposition tends to be confined to thin veneer overtop deposits; this results in vertical crestal accretion, when wave energy is inadequate to pass over the crest. Such deposits occur as virtually horizontal open-work shingle.

Overtopping is characteristic of coarse-clastic, as opposed to fine-clastic barriers, due to larger clast size promoting higher permeability and thus creating a steep reflective seaward profile. Little research has been carried out on overtopping and overwashing events for coarse grained barriers (Bradbury and Powell, 1992; Orford and Carter, 1982). However, Bradbury's (1998) conclusions from studying the profile response of Hurst Spit, Hampshire, to extreme hydrodynamic forcing conditions provide new insights into these processes.

Overwashing

Overwashing takes place when swash continues over the unconfined crest onto the back crest of the beach. Differentiation between the processes on sand and shingle barriers relates to the higher permeability of shingle beaches (Nicholls, 1985). Overtopping and overwashing are the processes that drive landward rollover for swash-aligned barrier beaches and spits. Orford *et al.*, (1991b) note that through time and with sea level rise, the crest gradually builds to the height of extreme swash run-up. The rate of rollover is dependent on the rate of sea level rise, degree of storminess in relation to the basement condition, nature of the material and the geometric and volumetric properties of the barrier (Bradbury and Powell, 1992; Bradbury, 1998; Carter *et al.*, 1987; Orford *et al.*, 1991a), with sediment availability dominating over sea level rise.

Breaching

Cope (2004) notes that an exposed coastal breach can be defined as an entrance through a barrier or spit protecting low-lying land, bay, lagoon or estuary which is characterised by tidal flow. Such a process is infrequently occurring. Recent examples of sustained breach formation within the past 50 years are evidenced at Porlock (Plate 6), which has remained as an open breach since 1996 and at Sowley in the western Solent, which has remained open for about 50 years.

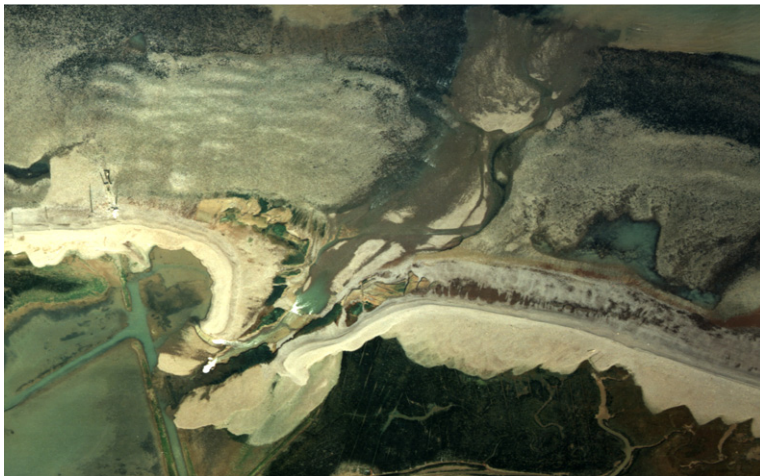


Plate 6 Example of Porlock barrier, Somerset, that breached 26th October 1996 (Environment Agency)

For swash-aligned barriers, backed by lowland, wetland or lagoon, stability is achieved by maintaining an adequate sediment volume in relation to the rate of sea level rise. This needs to be sufficient to sustain a steadily increasing crest elevation and maintain sediment sorting. This would have been the situation throughout the early Holocene, due to an abundance of paraglacially derived sediment. However, the latter part of the Holocene transgression is marked by a depletion of sediment due to reworking of the finite source within coastal systems (Jennings and Orford, 1999). These sediment shortages cause landward migration and possibly breakdown, where sea level continues to rise and the barrier morphology attempts to adjust (Jennings and Orford, 1999). As sediment supply declines and/or rate of sea level rise increases, barrier crest height cannot be maintained with respect to tidal levels and becomes vulnerable to processes such as overwashing that further lowers the crest.

Once a barrier crest has been lowered, through overwashing or crest cut back, the probability of waves reaching the crest increases along the overwashed section thereby promoting further crest reduction (Bradbury, 1998). Bradbury (1998) notes that development of a washover fan or breach is affected by the cross-sectional geometry of the beach, which in turn is influenced by the backbarrier topography as it migrates onshore. Where sediment is displaced into a low lying backbarrier area the overall barrier cross-sectional area will be reduced and is therefore prone to further crest reduction and breaching. The most important factor governing a breach location is antecedent barrier height as the water from seaward and/or landward will take the path of least resistance.

Methods of study

There are various successful state-of-the-art approaches used when studying barrier beaches. Methods range from analysis of aerial imagery to detailed numerical modelling (mostly developed around the dynamics of sandy sediments). Links between observations and models are important in order to achieve greater process understanding; some methods requiring the exploitation of decades of measurements. The range and application of such methods demonstrate the relative infancy of investigations into coarse-clastic barrier beaches such as those that predominate around the coasts of England and Wales.

Methods preferentially adopted include:

- Desk-based studies

- Field-based investigations
- Site specific physical models
- Empirical models based on field observations
- Empirical models based on physical modelling
- Process-based numerical models

Application of state-of-the-art to coarse-clastic barriers

Whilst various methods for studying barrier beaches are available, relatively few are routinely applied. This is indicative of the general absence of definitive methods which are appropriate to the barrier beaches around the UK coastline. Most notably, the research effort to date has concentrated on sandy beaches (e.g. Jimenez and Sanchez-Arcilla (2004)), and where coarser material has been considered (e.g. Clarke *et al.*, 2004), the complex behaviour has proven difficult to describe and deterministic models are themselves correspondingly complex.

As a consequence, simpler parametric approaches (which generally cost less to apply, and appear to offer greater value for money) are often adopted. In England and Wales, this generally means that the practitioner is restricted to a conceptual-type model when investigating long-term morphology and how it might be influenced by sea level rise, for example, whereas when investigating short-term behaviour, the industry is restricted to the application of models such as those described by Powell (1990) (SHINGLE) and Bradbury (2000) (Dimensionless Barrier Inertia Model). These methods are workable, but how applicable they really are is uncertain.

Field performance at a range of key sites

Barrier beaches around the UK tend to perform an important role as flood defences. The dynamic nature of these beaches and the sometimes sudden failure in their role as defences makes management difficult and necessary. Often, the consequences of defence failure are dramatic and shocking imagery is readily exploited by the press. Where assets are at risk, management difficulties are compounded by the uncertainties in determining risk. These uncertainties, with regard barrier beaches, stem from incompleteness in our understanding of the governing processes, and the resultant limitations of our predictive tools.

This situation, coupled with a lack of definitive guidelines, means that managers are often left with inherited practices, or are left to find a way through issues by trial and error. In addition EC directive on coastal and flood defence works and the majority of barrier beaches being assigned statutory protective status (such as SSSI, SPA, SAC etc.) means that environmental impact assessments must be carried out. It sometimes evolves that different stakeholders have different remits or requirements and as such the coastal manager can find that making headway through the management process is a struggle.

The performance of a range of selected barrier beach field sites is presented in Stripling *et al.* (2008). Each barrier is located on a map, and a brief overview of the site starts each description. The barrier beaches are varied in character, experience differing forcing conditions, have formed through different processes and, perhaps most importantly, offer different levels of flood protection – clearly dependent upon anthropogenic use of the environment surrounding the barriers. The information presented for each site ranges from the geomorphological context, through physical processes to conservation, defence role and beach management.

As part of Defra commission FD1924 (Stripling *et al.* 2008), a dedicated website www.barrierbeaches.org.uk was established. The website offers a focal point for publicising the research, and amongst other elements, contains an interactive mapping feature that allows visitors to locate and access summary database information relating to barrier beaches around England and Wales. The Links page enables visitors to readily discover detailed information (such as statutory designations, intervention, dimensions etc.) relating to many of our barrier beaches, and is a valuable starting point for many studies.

Review of current management methods

In many parts of England and Wales, barrier beaches form either the only defence against flooding of the hinterland, or a vital component of such defences. In these circumstances, and where the coastal defence management strategy for the frontage has been defined in the relevant Shoreline Management Plan as either 'Hold the Line' or 'Advance the Line', consideration will need to be given to assessing, and if necessary, reducing the risks of flooding by managing the barrier beach so that it provides a satisfactory standard of defence.

There are many factors that need to be taken into account when considering intervention on barrier beaches to reduce flooding risks, for example:

- Level of expenditure warranted;
- Coastline length over which intervention is needed;
- The structural condition of any existing defence structure(s);

- Environmental sensitivities, particularly environmental conservation, amenity and aesthetic concerns;
- Strengths of longshore currents and drift rates; and
- Required lifetime of any measures undertaken.

It is clear from this that the choice of an appropriate management method will depend considerably on local conditions. Consequently, different methods might be appropriate for two barrier beaches along which the waves, tides and coastal morphology are similar.

In considering how best to manage a barrier beach, it is logical to start with an assessment of the existing situation (through monitoring, for example), first defining the **condition** of the beach, and any existing structure(s) such as groynes or a seawall on its crest, as joint components of the coastal defence.

This should be followed by an assessment of the expected **performance** of this defence during storm events (i.e. a combination of high tidal levels and large waves), before deciding whether or not to intervene.

At present, there is no established “Good Practice” guidance manual specifically providing guidance on managing barrier beaches. Where such management has been undertaken around the UK coastline, it has often been developed on an *ad hoc* basis. A number of mitigation techniques have been reviewed by Stripling *et al.* (2008), including; emergency response to overtopping and flooding, beach re-grading, recharge and recycling, beach control structures. However, the review did not reveal much information on the choice of the management measures applied or on their design, costs and effectiveness.

Little published guidance exists relating specifically to monitoring of barrier beaches. Some site-specific studies of barriers have been undertaken, and these have included a wide range of monitoring techniques. Stripling *et al.* (2008) highlight some of the features of site-specific monitoring programmes and outline the approach adopted for design of monitoring of barrier beaches for the south east and south west regional coastal monitoring programmes as a generic approach to programme design. Bradbury (2002) suggests a risk-based approach to design of coastal monitoring programmes in general and highlights barrier beaches as high-risk coastal features that require a high spatial resolution of coverage in order to provide adequate information for effective management.

Conclusions and research needs

Observations made at the case study sites, the analyses of existing techniques, and the review of process understanding as presented by Stripling *et al.* (2008), have highlighted some major deficiencies in the predictive tools available for barrier beaches. Tools for management are generally weak, primarily as a result of uncertainty with regard to process understanding. In particular there is limited capability associated with flood-forecasting arising from either overwashing or breaching. Environment Agency asset management teams have expressed concerns that high-risk sites are vulnerable, but that there are no flood-forecasting tools available to predict whether breaching of the crest will occur, and whether flooding is likely.

A gulf in understanding between those processes occurring on sandy coastlines and those occurring on coarse- and mixed-sediment coastlines has been highlighted. Since the majority of barrier beaches around England and Wales consist of these coarser sediments, recommendations are focused solely around these barrier-types.

Evidence from the case histories and issues raised through review and consultation indicate that the basic understanding of pathway component processes is not in line with “end-user” requirements. There is a clear requirement to improve our knowledge of the responses of barrier beaches particularly in storm events, and of the consequences, and a need to review and improve predictive models of their performance. “Best Practice” management guidelines are also needed.

During the course of this study, the project team have discussed the best way forward and it is suggested, that a future research programme be established which concentrates on examining the processes of barrier beaches through experiment and monitoring, with subsequent development of reliable and robust predictive models. The development of Best Practice guidelines would evolve in stages, starting with the review of monitoring and mitigation practices presented in Stripling *et al.* (2008).

A specific request by the Environment Agency has been made that any proposed further research suggested here be centred upon current Environment Agency requirements. Whilst the scoping study itself has been centred on process understanding in accordance with the tender specification issued by Defra, the proposed research, although still firmly and unavoidably centred upon improved process understanding, is placed in to the context of flood-defence performance-based management. It would be necessary to phase the programme such that experiment and monitoring research could usefully inform the development of predictive models. Typical techniques which are used to investigate barrier beaches include monitoring, physical models and numerical models (where this category includes empirical and parametric models). The recommended research programme

expects to make further use of such techniques, and no need for investigating the development or use of alternatives is envisaged at this stage. The following sections identify topics suitable for investigation in the short- to medium- term, and are ordered in terms of perceived priority.

Phase 1: Improving pathway component process understanding

The first phase of research should review state-of-the-art methods for studying barrier beaches, using the review presented by Stripling *et al.* (2008) as a starting point. These methods will include, but not necessarily be limited to; physical modelling, numerical modelling and the gathering, collection and analysis of field data. It is likely that there will still be a need, as there is now, to produce appropriate data relevant to barrier beaches, and that that data can be obtained through physical modelling and monitoring. Appropriate research topics include:

Physical model experiments

Physical model investigations of barrier beach processes are required to develop reliable flood forecasting tools that are able to estimate flooding arising from overwashing, through-flow, and also the processes influencing the evolution of the barrier crest such that the onset of breaching can be better understood. These investigations should ideally be undertaken at large scale in order to examine the response of shingle and mixed sediment barrier beaches, which are the most frequently occurring. Experiments conducted in scale models could reasonably be expected to enhance our understanding of reliability through improved fragility curves.

Other advantages of increasing the available dataset of concurrent morphodynamic response and associated hydrodynamic forcing conditions include the value that these add to the development and range of applicability of parametric and deterministic predictive tools.

Gathering and analysis of field data

There is some considerable merit in establishing a national database, perhaps allied to the National Flood and Coastal Defence Database (NFCDD), containing details of barrier beaches including beach profiles, aerial surveys and LIDAR. Simultaneous measurements of forcing conditions (waves and tides), through-flow, permeability and over-topping would also be required. Subsequent analysis of data could be based upon on procedures adopted by the Channel Coastal Observatory for beach management in southern England and in context with the framework provided in Stripling *et al.* (2008).

There is generally a shortfall of data relating to specific storm events. Hydrodynamic data describing barrier performance under extreme conditions, such as measurement of volumes of water overtopping or flowing through barriers should be obtained. Information regarding waves and tides corresponding to overtopping and through-flow events should be gathered simultaneously. A broad study including many sites is needed in order to provide detail at sites where the geometry and grain size are wide ranging and where conditions are variable.

The nature of barrier beach evolution is such that storm events are episodic and planning of a short-term field-based programme would not guarantee results within a defined timescale. The rarity of such data, however, means that obtaining records during just a single event could be regarded as a success. The existing field monitoring programmes (funded by DEFRA) could be refined to provide appropriate levels of data. On-going data collection as part of the southeast and south west regional coastal monitoring programmes could provide appropriate site-specific data to assist in this particular research objective. The long-term deployment of waverider buoys and tide gauges can provide hydrodynamic input to this programme.

There is a considerable quantity of raw data becoming available that could enable a description of the performance of barriers to be developed at both decadal scales and, to a lesser extent, storm event scale. Much of this data has not been analysed previously in context with barrier performance or management. A considerable proportion of this data is already held by the Channel Coastal Observatory (for southern England).

Data obtained by through-storm measurement of nearshore waves and gravel beach morphology, using shallow angle LIDAR for example, would prove pioneering and provide valuable insight into the behaviour of barrier beach faces. A research programme such as this would benefit from support by the Environment Agency and contribute to further understanding some of the processes active on barrier beaches.

Such investigations could usefully be combined with laboratory tests under controlled conditions to focus on testing and development of more robust and wide ranging predictive techniques.

Phase 2: Improving pathway component prediction tools

Refinement/ development of existing/ new tools for predicting performance

The main method of assessing condition and performance of barrier beaches will be through the collection of further field data and refining existing or developing new predictive methods. The first phase of recommended research (described above) relates to the collection of further data as required to aid the refinement of existing

numerical models, or the development of new numerical models, which is the recommended topic for the second phase of recommended research.

Existing numerical models include SHINGLE (Powell, 1990), the dimensionless barrier inertia model (Bradbury, 1998) and ANEMONE (Dodd et al., 2000) and any others which may come to light as a result of the Phase 1 of research.

Numerical modelling

Predictive tools are currently very limited in scope and application. Tools which are actively applied consist of Powell's (1990) SHINGLE model, and Bradbury's (2000) dimensionless barrier inertia model. Other tools which are not in routine application include the OTTP-1D process-based numerical model, developed by HR Wallingford as part of the ANEMONE suite (Dodd et al., 2000) with funding under MAFF (now Defra) commission FD0204.

The data collection and analysis research (Phase 1 of the proposed research above) is intended to lead to improved understanding of the pathway component processes. It is expected that the datasets and the improved understanding gleaned through analysis of the data will contribute to improved predictive tools. As these tools develop, so too will process understanding.

Bradbury's dimensionless barrier inertia model provides a first approximation for the prediction of overwashing threshold conditions; this can be refined further, by the selective testing of conditions close to the overwashing threshold, under more closely-controlled conditions, with minimal spatial variability (of the barrier profile). Near prototype-scale random wave-flume studies would: (a) aid the development of confidence in the modelling methodology; (b) minimise the scale effects; and (c) provide confirmation of the functional relationships over the lower part of the barrier profile (these cannot be measured, practicably, in the field). The influence of shingle grading on barrier-crest evolution should also be examined. Future development should be supported by the large-scale physical model tests and field investigations suggested as part of the Phase 1 research.

Other empirical frameworks developed for sand beaches could be examined further, but these are generally even less sophisticated.

The SHINGLE model, the use and development of which has been reported extensively during this review, while not strictly applicable to barrier beaches, could nevertheless be augmented by the proposed monitoring. The SHINGLE model is simple to apply, and is currently being applied to solve barrier beach problems. Developing this rapid spreadsheet model, therefore, would be a justifiable task with the potential to offer a low-cost solution to some of the problems faced during flood-risk assessment.

Development would include giving the model the ability to be run repeatedly for a variety of different loadings, with increased capacity to represent the overwashing process derived from physical modelling tests and monitoring – essentially deriving a probabilistic risk-based method of assessing the performance of barrier beaches. Output from the model could be expected to consist of an improved expression of the fragility of the barrier, which could then be used to better inform the RASP-type flood inundation analysis.

The focus of the short-term future numerical model development is therefore based on using Bradbury's barrier inertia framework or Powell's SHINGLE model as a starting point. However, there is no reason at this time to disregard the possibility of the development of a process-based numerical model over the medium-term. The basis for such a model could be the MAFF-funded (now Defra) OTTP-1D model developed by HR Wallingford, for example.

The OTTP-1D model was built to simulate surf-zone hydrodynamics over porous beaches, and provided predictions of overtopping rates assuming an immobile beach, and accounts for permeable structures. To further develop this model (or even the 2D version, OTTP-2D) towards full morphodynamic capability would enable detailed process-based deterministic assessment of barrier beach design in relation to standards of flood defence. Whilst this implies considerable time and resource investment, it is nevertheless considered a worthwhile task, and would result in a generic industry standard tool for assessment of likelihood of breaching of barrier beaches.

The feasibility of the 2D option predicting the development and spatial variation of the plan-shape of a shingle barrier beach due to the combined influence of longshore transport and overtopping should be investigated. The sensitivity of the barrier profile response to spatial variation of the barrier geometry should be examined in the systematic assessment of 3-dimensional response; this would require an extensive test programme to provide statistically-valid data.

The longer-term aim should be focussed on the development of a methodology to represent barrier beaches within a broad-scale systems model (such as that being developed under the FLOODsite and FRMRC research programmes) such that longshore connectivity and cross-shore processes are considered in tandem. Useful

tools and concepts developed under the RASP methodology, such as fragility and resilience, could serve to enable such a model development whilst maintaining practical computational effort and user operability. Methods for prediction to be developed in research proposed under Super Work Packages 2 and 6 of FRMRC2 (to commence in 2008) into breach may be relevant, and should be reviewed as necessary.

Providing effective and efficient management guidelines for the pathway component

Although it would be convenient to label the provision of management guidelines as a “Phase 3” research programme, i.e. to wait for a significant advancement in understanding before issuing guidance, the reality is that there is an urgent need for advice and methods in the short-term. It is suggested that first research need is a “Best Practice” document which focuses on the use of existing methods and understanding, including monitoring practice. Tools for the development of site-specific schemes of management are adequate for shingle beaches (physical models) but there is no generic guidance available that assists with the design of suitable beach geometry to enable the beach evolution to be controlled adequately.

The fundamental difficulty is to assess the volume of water passing over/ through a barrier beach under a given scenario (i.e. defined wave/ tide conditions and perhaps an assumed future beach profile). Over a longer-term it may be necessary to judge when a barrier beach will retreat over an important hinterland asset such as a coastal road. The former will need the “predictive tools” mentioned above which will involve the acquisition of information on past events that caused problems, together with the database resulting from the proposed monitoring. The second issue can be addressed through analysis of beach profiles, maps, and any data on the episodic nature of crest retreat with some degree of success.

In many cases, the first thing coastal managers will want to do is assess the need to manage a barrier beach. This will typically need a flood-risk assessment (more rarely an erosion risk assessment), which will provide an indication of the requirement to “manage”, or otherwise.

Given a good reason to manage the beach, i.e. showing that it needs maintaining or improving to reduce flood-risk (or more precisely at this stage to improve defence standards), then one can turn to deciding what to do. It is unlikely that much can be done about the source, although improved wave/ tidal prediction can be made with site-specific data collection. Similarly, the receptor could be improved so that it could accommodate greater flood/ erosion risks (e.g. move the asset out of harms way), but the source and receptor behaviour is beyond the remit of this scoping study.

To improve our management of the pathway component it is proposed, as a first step, to improve our knowledge of the pathway. This step is aimed at providing more detailed data collection (Phase 1) and modelling (Phase 2), e.g. short-term intensive measurements of beach response to validate predictions of morphological changes under “normal”, rather than extreme, forcing conditions enabling “weak points” along the barrier to be identified.

The next option is then to consider intervention methods, as discussed in Section 6. These include:

- Recycling beach material from over-stocked to under-stocked areas
- Beach re-profiling – but ideally recovering material from the landward side rather than scraping the front face upwards
- Adding temporary or permanent crest level enhancement (gabions etc.)
- Adding a seawall or rock revetment partly buried in the crest or to the rear
- Adding beach sediment – either small-scale trickle charging using construction or excavation waste or large-scale operations.

These methods would be examined alongside the enhanced predictive tools discussed above, with due consideration of the whole-life costs and environmental impacts. These might include compensating for coastal squeeze if the barrier is prevented from retreating.

Present methods make substantial simplifications of the actual morphological events that might occur as a barrier beach responds to extreme events, and of the processes of overtopping or flow through partial breaches. A review and assessment is therefore needed of the existing methods that have been and are used to calculate the risks of flooding landwards of barrier beaches. The future improvement to such methods will be greatly assisted by validation using information from the monitoring of the changes in barrier beaches during storm events and of the consequences such as the extent and depths of flooding.

There are numerous sites around the coastline of England and Wales where the problems of flooding behind barrier beaches are managed on an “emergency” basis. It is recommended that information on these schemes is also sought, in the first instance to assess the effectiveness and costs of coastal flood warning systems and emergency responses e.g. closing roads, installing demountable secondary defences and evacuation. The “post-event” actions needed at such locations, for example the pumping out of flooded areas and clearing up debris and sediments washed over the beach crest would also be worth reviewing at the same time.

The first benefit of collecting this information would be to collate, assess and disseminate good practice. However, it is also recommended that guidance is drawn up for the monitoring of future similar events, so that better information on the performance of barrier beaches can be accumulated, e.g. times of recorded through-flow, overtopping or breaching to assist in validating warning systems and extents and amounts of flooding to assess the severity of the risks associated with such events.

A revised "Best Practice" guide would evolve in much the same way that has been proposed for the Beach Management Manual II. If time-scales were to permit, a short-term review of current management practice could form part of the Defra/EA revision the Beach Management Manual II. Revisiting the online consultation method initiated as part of the present scoping study would provide assistance.

Cost estimates for recommended research

To assist with the estimated costing of the recommended research, the programme can be divided into broadly 3 categories:

- Physical modelling plus a review of existing methods for predicting performance
 - This may cost in the region of £100,000 to £150,000 dependent upon exact scope.
- Review of monitoring data/ procedures
 - This is likely to cost in the region of £75,000 - £100,000
 - Implementation of appropriate monitoring cannot be costed until such as review is made.
- Development of numerical models combining above
 - This may cost in the region of £150,000 to £250,000 depending on the exact scope.
- Producing Best Practice guidelines
 - Such guidelines are an evolving process, but to scope their development, it is thought that £30,000 to £40,000 would be required in the first instance.

Justification for these costs can be made through consideration of the possibility that there may be of the order of 50km of barrier beach where flood risks might be reduced by improved management practice. If an assumption is made that coastal defence schemes might work out to cost £2000 to £5000 per metre every 5 years, then there is a £2M to £5M saving in costs if the guidance saves 5%, and ten times that in benefits.

So the research might save £20m in 5 years, and if the recommended research costs in the order of £0.5M – then a Benefit/Cost ratio of 40 can be estimated.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

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