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delivering benefits through evidence

Asset performance tools: phase 3 final report

SC140005/R1

Flood and Coastal Erosion Risk Management Research and Development Programme

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We can't do this alone. We work with government, local councils, businesses, civil society groups and communities to make our environment a better place for people and wildlife.

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Professor Doug Wilson
Director, Research, Analysis and Evaluation

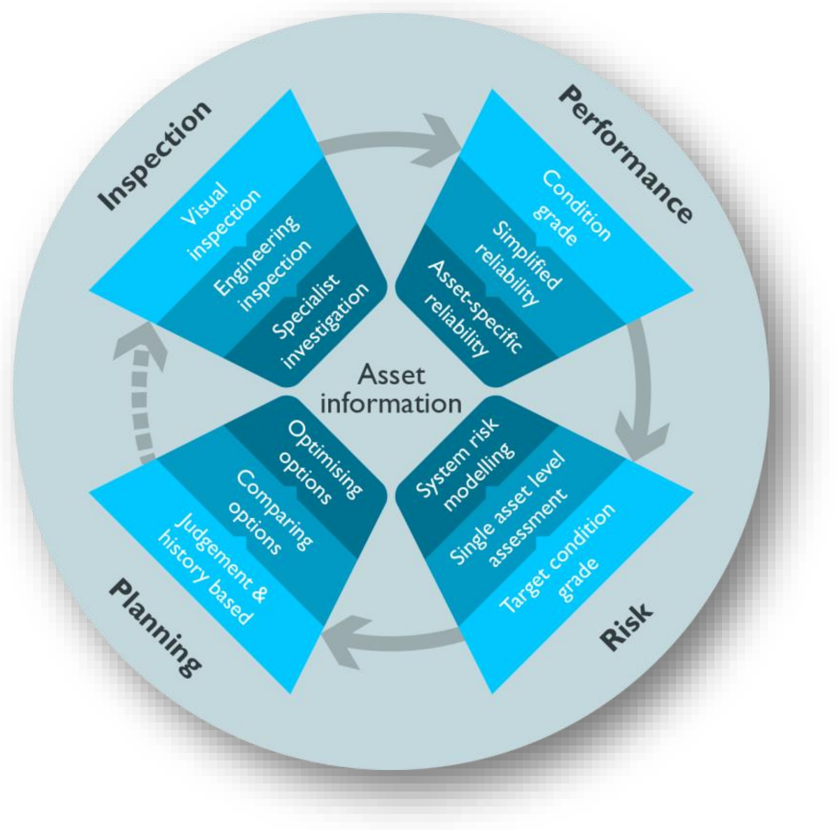
Executive summary

The aim of the Asset Performance Tools (AP Tools) project is to improve asset management decision-making by identifying where, when and how to intervene to reduce flood risk for least cost and greatest benefit. This report summarises the project's outputs and explains the benefits of each of the tools and guides developed. The report is aimed at asset managers and users of the tools and guidance.

Previous research and operational experience had identified a causal link between asset maintenance and performance. There is a need for improved understanding of how different maintenance regimes can affect the performance of flood defences over a complete range of loading events over the lifetime of the asset. Furthermore, the benefits of maintenance can be quantified and so the costs and benefits of maintenance activity should be used in decision-making. The AP Tools products also address aspects of the Environment Agency's Asset Management Strategy 2017 to 2022 and recommendations in ISO 55000, the international standard for asset management.

An overarching framework groups 4 component activities: inspection, performance, risk and planning. As shown in the diagram below, each component is divided into 3 levels of complexity, starting at a basic assessment and moving (inwards in the diagram) to more detailed levels of assessment. This framework facilitates appropriate asset condition and performance assessment, risk analysis and optimisation, supporting the move from reactive to proactive asset management. It promotes whole life analysis and a risk-based approach, applicable for both fluvial and coastal flood risk environments.

The framework supports 8 tools and guidance documents developed to improve asset management decision-making. These products are listed in the table below.



List of products by framework component

Framework component	Product
Inspection	• Asset inspection guidance (developed by project SC110008)
Performance	• Channel conveyance assessment guidance (report SC140005/R2) • Vegetation and Roughness tool • Custom fragility curve adjustment tool
Risk	• Pre-calculated risk datasets guidance (report SC140005/R4)
Planning	• Raised defence target condition whole life cost appraisal tool[1] • Beach performance assessment tool[2] • Risk-based appraisal tool prototype

Notes: [1] The methodology is described in report SC140005/R3.
[2] Guidance on setting beach riggers is given in report SC140005/R5.

For each of the 8 products listed above, this report provides a brief description of how it works, information on the need for the product, its benefits to asset managers and its readiness for use. Relevant guidance produced outside this project is noted and case studies are used to illustrate how the products can be used in real-world examples.

The report also makes recommendations for suggested steps for product implementation and where testing or trial operational use of certain products might be beneficial – potentially leading to enhancements of product functionality.

The benefits of the tools and guidance products include:

- evidence supporting the undertaking or withdrawal of channel and flood defence maintenance
- help in identifying the best asset maintenance regime
- improving mobile working for asset inspectors, providing greater consistency and efficiency
- help to specify appropriate level of inspection, investigation or analysis
- easy to use tools requiring minimal data
- enabling structured use of local asset-specific knowledge and quantified evidence for improved decision-making and to support stakeholder discussions
- a better description of the relationship between investment and performance and risk
- evidence for ISO55000 compliance
- dissemination of best practice

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Workshop attendees:

- Environment Agency Asset Management staff
- Representatives of other risk management authorities: North Norfolk District Council, Sefton Council, Bournemouth Borough Council, Teignbridge District Council, East Suffolk (Suffolk Coastal and Waveney District Councils)

Product review:

- Project Board members
- Local practitioners: Environment Agency Asset Management staff, Environment Agency Partnership and Strategic Overview staff, representatives from the Thames Estuary Asset Management 2100 (TEAM2100), representatives from other risk management authorities

Technical experts:

- Bryan Curtis (Canterbury City Council)
- Kevin Burgess, Jonathan Rogers, Alan Frampton (CH2M)
- From the project team: Owen Tarrant (Environment Agency), Jon Wicks (CH2M), Jaap Flikweert (Royal HaskoningDHV), Jonathan Simm (HR Wallingford), Paul Conroy (CH2M), Ed Morris (TEAM2100)

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1.1 Background

Previous flood events, including winter 2013 to 2014 and winter 2015 to 2016, have tested a large proportion of the Environment Agency's flood and coastal assets. As a result of this intensive flood period, there is increasing pressure on investment to maintain assets to an appropriate standard. To enable the effective prioritisation of current and future investment in the Flood and Coastal Risk Management (FCRM) asset base, asset managers must be able to assess the likely performance of individual assets in their current and improved states, as well as understand this performance within the asset system.

To reduce the number of people, properties, infrastructure and land at risk, it is vital that flood and coastal investment is directed toward those assets where the biggest risk reduction can be made for the money available. There are also cases where there is a legal commitment to maintain an asset to a set standard for an agreed period. In addition, the benefits of investing in these assets need to be articulated quantitatively and transparently.

The international standard for asset management, ISO 55000, defines assets and the value realised from them as:

> 'the basis for any organisation delivering what it aims to do … whether public or private sector, and whether the assets are physical, financial, human or "intangible", it is good asset management that maximises value-for-money and satisfaction of stakeholders' expectations' (The Woodhouse Partnership, undated).

These FCRM physical assets are included in this research project:

- linear flood defences
- conveyance channels
- beach/groyne systems

Consultation with users suggested that new asset management tools for these asset types would have the greatest benefit.

This research project helps to achieve the recommendations from the National Audit Office and Pitt Review relating to improved asset management and better asset data sharing between risk management authorities. It also supports developments under the Environment Agency's Creating Asset Management Capacity (CAMC) Programme including its Asset Information Management System (AIMS) inventory and AIMS planning. The CAMC programme is an important component for the Environment Agency to deliver its Asset Management Strategy 2017 to 2022 (Environment Agency 2017a).

This is the final part of a phased research programme on asset tools, building on the tools and research from the Flood and Coastal Erosion Risk Management R&D programme, most notably from the Performance-based Asset Management System (PAMS) project and the previous research on asset performance tools (projects SC090038 and SC110008). Phase 1 (SC090038) of the Asset Performance Tools (AP Tools) project developed the concept of a 'propeller diagram' framework to support asset management decision-making (Environment Agency, 2010). Phase 2 (SC110008) developed tools to support the asset inspection arm of the framework

(Environment Agency, 2014a). This phase (Phase 3) further developed the framework and has provided tools and guidance to help assess performance, risk and investment planning.

1.2 Report audience

This report is intended for use by all risk management authorities – including the Environment Agency, Internal Drainage Boards and local authorities – in their fluvial and coastal asset management roles. While some specific tools and applications are aimed at the Environment Agency, much of the report (and the products) is of general relevance to all risk management authorities.

1.3 Report structure

The report is structured as follows:

- Chapter 1 – Introduction
- Chapter 2 – Drivers and needs – the project's principles, drivers, user requirements and prior research
- Chapter 3 – AP Tools products – what the tools and guidance do and how they work, why they are needed, their benefits and readiness for use
- Chapter 4 – Examples – case studies that illustrate how the tools can be used in practice
- Chapter 5 – Recommendations – suggestions for implementation of the products and/or testing and operational use, plus future research plans

A detailed listing of the products is given in the appendix.

2 Drivers and needs

This chapter presents the drivers for the AP Tools project, and how user needs and requirements are aligned to these drivers. The requirements were defined through consultation with practitioners. They inform a core set of principles to guide the development of the AP Tools, described in Chapter 3.

2.1 Project drivers

2.1.1 Asset performance during recent flood events

Predicting the likely performance of flood defence assets during flooding conditions is extremely difficult. This is because floods are inherently rare events. Other analogous infrastructure assets (for example, water utilities or highways) are, in contrast, loaded on a regular basis allowing the routine collection of information on asset performance. Furthermore, there are many different types and arrangements of flood defences used in the UK, many of which are subject to different maintenance practices and regimes.

The Environment Agency has carried out a structured review of defence performance after each of the major flood events since the 2007 summer floods, up to and including the winter 2015 to 2016 floods. One important conclusion from this sequence of reviews is that asset failure leading to breaching and flooding is rare, especially so when flood defences have been well-maintained. People, property and infrastructure in the floodplain are generally well-protected and there are genuine benefits in terms of damages avoided associated with continued maintenance. Conversely, when asset failure and breaching has occurred, the reviews have pointed to reduced levels of maintenance or cessation of maintenance as an important reason for failure.

The evidence for this causal link between maintenance and performance is an important driver for the AP Tools project. It highlights the need for an improved understanding of how different maintenance regimes can affect the performance of flood defences over a complete range of loading events. It also serves to emphasise that:

- the benefits of maintenance can be quantified
- the costs and benefits associated with maintenance activity should inform decision-making

2.1.2 Environment Agency's Asset Management Strategy

The Environment Agency's Asset Management Strategy 2017 to 2022 (Environment Agency 2017a) applies to all Flood and Coastal Risk Management (FCRM) assets that contribute toward risk management on main rivers or defend against inundation from the sea. It relates to those assets that the Environment Agency directly maintains and covers its approach to those managed by local authorities, Internal Drainage Boards, individuals and businesses. The strategy describes the desired asset management outcomes for the Environment Agency under 7 headings:

- Understanding our assets
- Managing our work
- Investing in the right places

- Optimising investment
- Making best use of resources
- Organisation culture and ways of working
- Looking to the future

The products from the AP Tools project address aspects under all of these headings, but particularly understanding our assets, investing in the right places and optimising investment. For example, the improved understanding of asset level performance gained through the AP Tools project will help all asset owners to target investment better and assess the relative benefits and cost of that investment.

The strategy defines the ways of working to achieve a step change in asset management which, by 2022, will achieve the following key outcomes:

- increased resilience
- more efficient
- enhanced skills
- greater transparency
- better quality data and information

These key outcomes relate to the following delivery outcomes:

- assets operate when required
- customer legitimacy
- more properties protected
- reduced whole life cost

The AP Tools products help achieve these delivery outcomes; Chapter 5 summarises which products support each of these outcomes.

2.1.3 International standard for asset management (ISO 55000) accreditation

ISO 55000 is a standard for an asset management system and is highly beneficial in helping to encourage and embed asset management good practice, and improving long-term investment efficiency. The Environment Agency's Asset Management Strategy 2017 to 2022 sets the goal of achieving or making significant progress toward achieving ISO 55000 accreditation by 2020 to 2022 (Environment Agency 2017a). An important first step in this process was a maturity self-assessment that the Environment Agency completed during 2016. This assessment was used to identify gaps and develop action plans to address those gaps.

Many of the review's recommendations focused on issues associated with organisation culture and leadership. The review did identify the need for more work to be carried out to 'integrate capital expenditure with operational expenditure investment plans, based on understanding risk and whole life cost'. To these ends, the products developed by the AP Tools project have been specifically targeted to help improve the risk assessment capability of the risk management authorities as well as their ability to develop quantitative whole life cost estimates. The introduction of the AP Tools products into business practice will help with the integrated planning of capital and revenue expenditure.

2.1.4 Creating Asset Management Capacity programme

The Environment Agency's CAMC programme was initiated to enable the future ways of working envisaged by the Asset Management Strategy 2017–2022. The programme is establishing an improved business process, supported by new asset management IT systems and improved asset data, to manage the whole life cycle of flood risk assets more effectively and efficiently.

There is a clear link between the AP Tools project and the CAMC programme. The ongoing CAMC programme will provide new tools for managing large FCRM projects, often referred to as capital investments. Its aim is to support a 'whole life cost' approach to asset management.

The following topics are within the scope of the CAMC programme:

- portfolio, programme and project management
- capital project pipeline development
- investment planning and funding allocation
- contract management
- improved business processes
- upskilling of staff

2.1.5 Infrastructure UK's Client Working Group – peer review

HM Treasury, Defra and Infrastructure UK (now the Infrastructure and Projects Authority) commissioned an independent peer review to establish whether the Environment Agency could further improve its performance and achieve efficiencies in the delivery of its maintenance and investment programme. Commissioned in March 2014 following the winter floods of 2013 to 2014, the review compared the Environment Agency's asset management practices, policies and procedures with those of the water sector in England and Wales (IUK 2014).

The review concluded that many aspects of the Environment Agency's asset management delivery are leading edge. However, it also concluded that the management of flood defence assets is primarily driven by asset condition, which does not help the Environment Agency forecast service and expenditure requirements.

The review also identified several areas where the Environment Agency could make improvements to its asset data and processes including:

- improving asset management datasets
- developing asset analytical and modelling capability
- developing risk-based programme optimisation capability
- improving its capability to optimise on whole life costs and benefits

The AP Tools project touches on all these aspects. Central to all of them is the quantitative understanding of asset performance under load and over time.

2.1.6 Advances in research

The AP Tools project builds on several recent research initiatives with the primary aim to move that body of research closer to a state of 'business as usual'. Perhaps the most notable project among this body of work is the PAMS project (SC040018), which developed a suite of methods and tools to support performance-based asset management (Defra and Environment Agency 2009a, 2009b). The PAMS project resulted in:

- improved guidance for asset inspection and condition assessment
- improved understanding of asset deterioration
- methods of assessing asset performance under load
- methods for channel condition assessment and management
- a risk and performance based framework for decision-making
- a review of asset management practice for coastal erosion

The AP Tools project reviewed the recommendations from the PAMS research and took on board the relevant recommendations from that research. These recommendations included the need to:

- ensure the visual inspection process triggers the most appropriate action
- further develop the research work undertaken on deterioration and whole life costs developed in projects SC040018 and SC060078
- develop a tiered approach and guidance to cover the spectrum of methods for the derivation of fragility curves from the qualitative to fully quantitative
- undertake further research to help with the estimation and attribution of risk to help in planning of asset management interventions

The AP Tools project has built from an existing portfolio of research, some elements of which are closer to being ready to embed in the business than others. The readiness of the various existing research outputs was assessed and the development pathway for the project's products planned. Figure 2.1 illustrates the testing stages each product has gone through prior to implementation.

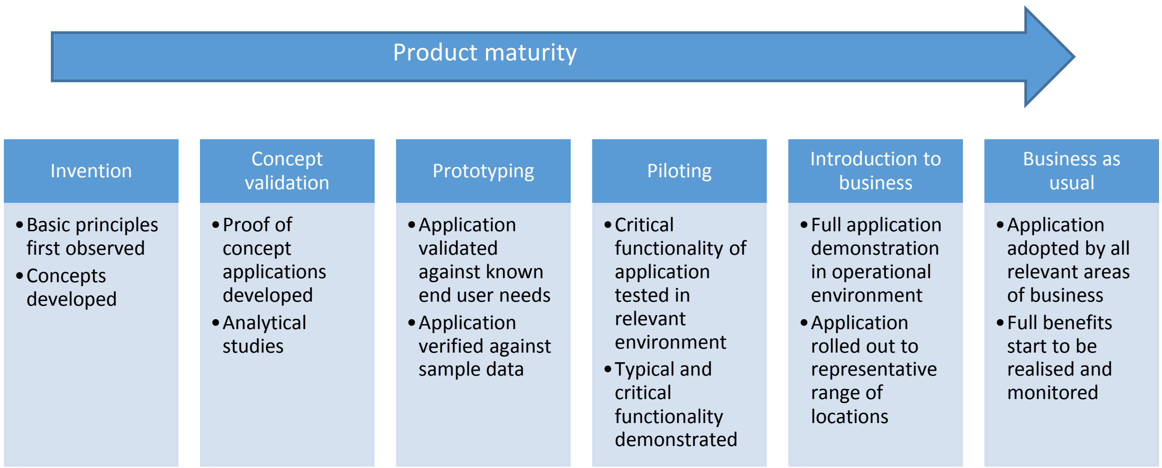


Figure 2.1 Typical pathway of development for AP Tools products

2.2 User needs and requirements

Early in the project programme, several workshops were held with asset management practitioners to:

- affirm and refine the scope of the project
- capture and prioritise any outstanding needs

The results of these workshops are reported in the Asset Performance Tools Phase 3 Project Viability Report (Environment Agency 2015a). The viability report provided a description of the products expected to be developed under the AP Tools project. The products were categorised as shown in Figure 2.2.

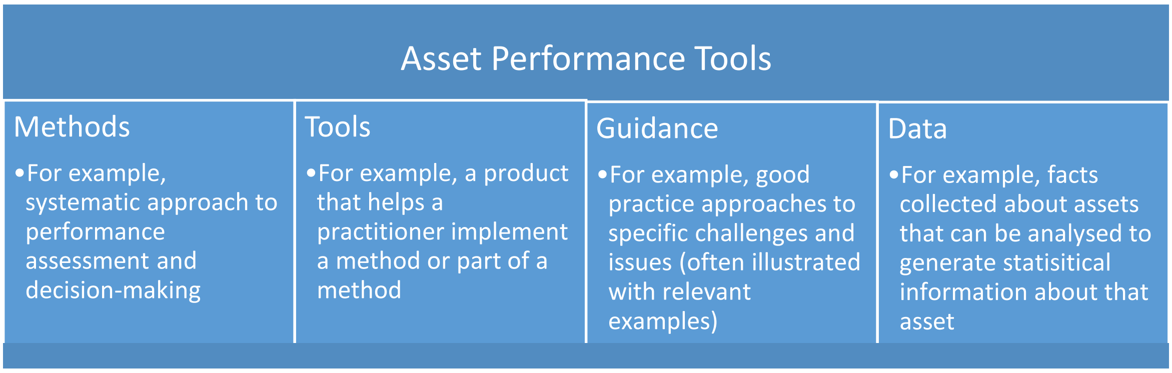


Figure 2.2 Type of products to be developed by the AP Tools project

Notes: Data (right hand panel) were not generated.

2.2.1 Generic requirements

The overall requirement for the AP Tools project was to improve asset management decision-making by helping to identify where, when and how to intervene to reduce flood risk for least cost and greatest benefit. Further requirements and needs identified through practitioner workshops are summarised in Table 2.1.

Table 2.1 Needs identified via practitioner workshops

Practicality and compatibility needs

- Tools to be applicable to all relevant risk management authorities
- Recognition that flood risk management authorities have different levels of asset management capability and manage very different asset types
- Tools and guidance need to be intuitive so that end users can:
  - understand why a particular output has been produced
  - check it for reasonableness
  - explain and defend the decision to third parties
- To fit in with the overall management systems of end user organisations
- Support implementation of ISO 55000

Proportionate and risk-based needs

- Effort to use the tools must be proportionate to the decision being made
- Resource requirements (skills and absorption capacity of the business) to use the tools are considered reasonable by end users
- To cover the most important asset types
- To support direction of investment toward those assets where the biggest risk reduction can be made for the money available
- Work within a structured and tiered framework applicable across all asset types, thus allowing analysis of 'trade-offs' to be made
- To generate results at an accuracy appropriate for the context of the decision (for example, lower accuracy will be acceptable for early stage planning and for decisions that are largely insensitive to the outputs of the tools)

Methodological needs

- Methods are based on UK and international proven concepts
- Work with the computer hardware and software environment expected to be available to end users
- Provide a degree of 'future proofing' (in terms of expected changes in data and IT hardware and potential organisational change)
- Work with nationally available data but allow local data and knowledge to be included where necessary

3 AP Tools products

3.1 Principles for product development

The drivers, user needs and prior research described in Chapter 2 informed a set of principles that guided product development. The principles are summarised in Figure 3.1 and expanded upon below.

Risk-based	• Performance is dependent on relevant failure modes, rates of deterioration and range of loading events • Consequence of failure influences decision
Proportional	• Simple tools for simple situations • Analysis effort is commensurate with decision
Hierarchical	• Logical transitions from one method/tool to another are defined when greater certainty in investment decision required
Business ready	• Maturity of products understood and assured against real-world problems
Practitioner driven	• Strongly linked to identified needs of risk management authorities • Tailored to specific groups of practitioners
Sensitive to the effects of maintenance	• Tools developed to quantify how routine maintenance can alter performance
Enable optimisation	• Methods and tools developed will enable practitioners to identify balance between capital and revenue expenditure over the whole life of the asset

Figure 3.1 Principles adopted by the AP Tools project to guide product development

3.1.1 Risk-based

Central to the risk-based management of flood and coastal erosion risk assets is the ability of the asset manager to assess and express the likely performance of the asset and the asset system. This understanding of performance needs to be based on both its likely failure modes and how performance changes as the asset deteriorates.

Performance of an asset also needs to be assessed for the complete range of potential loading events that the asset is likely to experience over its whole life, including those events which exceed the original design criteria.

Decisions to maintain an asset should be based on flood impacts avoided that can be attributed to the maintenance activity via its effect on performance (such as reducing breach probability) over the asset whole life considering costs and any legal requirements.

3.1.2 Proportional

The tools and methods created by the project are organised into tiers, ranging from simple to complex. Practitioners will be able to use their understanding of the risk associated with the asset to select the most appropriate tools or guidance for the job. This ensures effort is proportional to the risk to be managed.

3.1.3 Hierarchical

The project has developed guidance to help practitioners move to more complete analysis methods and investigation techniques (see Section 3.2.3). In this way, the case for investment is developed with increasingly quantified information.

3.1.4 Business ready

An important aim for the project is to move existing research tools and methods into the business environment via piloting and demonstration as well as prototyping new concepts. The readiness or maturity of each product is stated in this chapter, sub-section 5 of each product. All products have been assured and readied for implementation by following the stepwise pathway shown in Figure 2.1.

3.1.5 Practitioner driven

The project has responded to the needs of the practitioners in risk management authorities as well as taking account of some of the important findings from the sequence of Environment Agency asset performance reviews.

For each of the project's products, the end user audience has been identified and engaged in the process of product development and testing. Potential end users have been categorised as:

- national policy/process developer
- local asset manager
- field operative/local asset practitioner

3.1.6 Sensitive to the effects of maintenance

With this principle, the project recognises that maintenance can and does affect performance by slowing defence deterioration and increasing resilience. The project also recognises that, if the change in performance associated with maintenance activities can be quantified, then the benefits associated with that change can also be measured.

3.1.7 Enable optimisation

The project has set out to analyse and identify optimum management strategies that combine both capital expenditure and revenue expenditure for the entire life of the asset.

3.2 AP Tools framework

The project developed a set of outputs (the products) that meet the needs described in Chapter 2 and are guided by the principles set out in Section 3.1. The 8 products are listed in Table 3.1 and fully described below, with case study examples provided in Chapter 4. The outputs sit within a framework developed from the guiding principles. They range from simple pragmatic tools to more detailed guidance and tools, and proofs of concept.

The 4 asset management components within the AP Tools framework (Inspection, Performance, Risk and Planning) are inter-related (Figure 3.2).

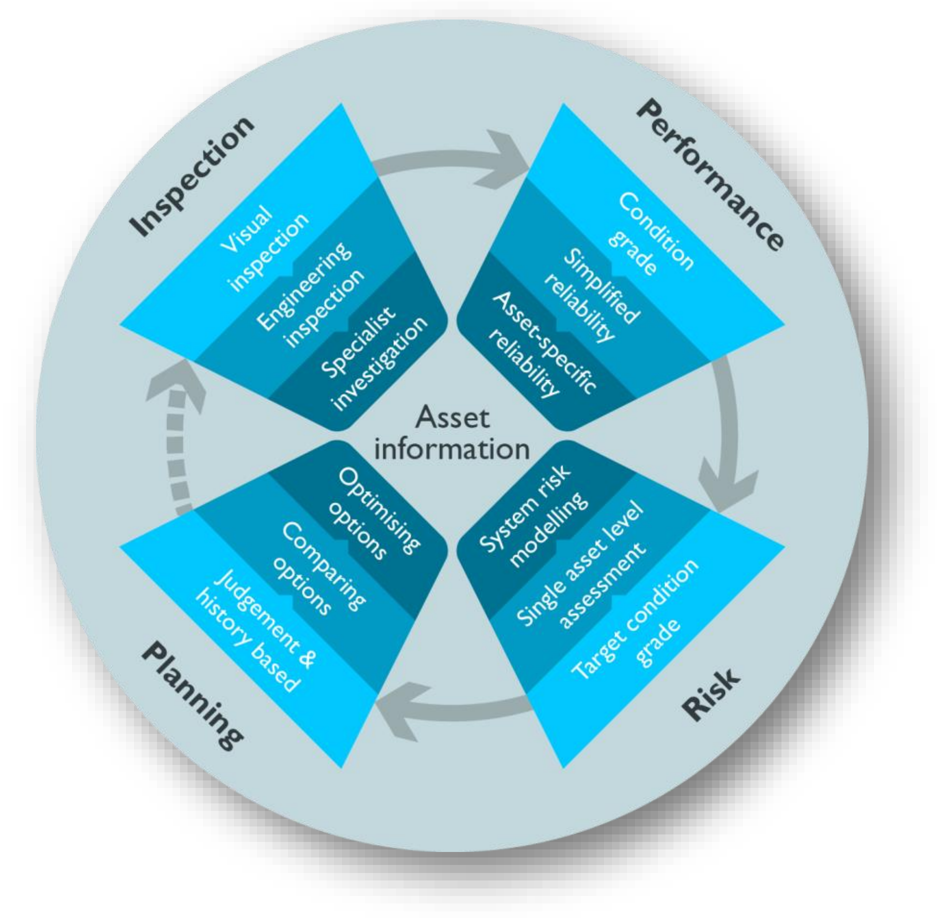


Figure 3.2 AP Tools framework, highlighting the 4 asset management components ranging from simpler approaches at the outer edge to more detailed approaches in the centre

The tools and guidance products developed all align to these 4 components (Table 3.1).

Table 3.1 AP Tools products

Section	Product	Framework component
3.3	Asset inspection guidance[1]	Inspection
3.4	Custom fragility curve adjustment tool[2]	Performance
3.5	Channel conveyance assessment guidance[2,3]	Performance
3.6	Vegetation and Roughness tool[2,3]	Performance
3.7	Pre-calculated risk datasets guidance	Risk
3.8	Raised defence target condition whole life cost appraisal tool[2]	Planning
3.9	Beach performance assessment guidance[2]	Planning
3.10	Risk-based appraisal tool prototype[2]	Planning

Notes: [1] Developed previously (Environment Agency 2014a)
[2] Case studies available in Chapter 4
[3] Both products are used in the same case studies.

Each component is divided into 3 levels of complexity, starting at a basic assessment and moving (inwards in the diagram) to more detailed levels of assessment. This organisation of the components forms a framework for asset assessment. It promotes whole life analysis and a risk-based approach, applicable for both fluvial and coastal flood risk environments.

Asset data and information underpin all levels of the framework, with the more detailed levels of assessment usually requiring more data and being costlier to undertake.

3.2.1 Using the AP Tools framework

The AP Tools framework should be used when developing a new asset management process, communicating a process and/or working through a specific process. It is designed to be flexible, used iteratively, provide an audit trail for recording decisions made and be future-proof.

- **Flexibility**. The framework can be used at any complexity level and for any of its 4 components (Inspection, Performance, Risk and Planning) individually or in combination as required. Users are encouraged to enter the framework at any tier; it is not necessary to start at the outer, most simple level, for example.
- **Iterative use**. The framework can be used once to obtain initial results and then again, either at the same or a more complex level to obtain improved, refined or more detailed results.
- **Audit trail**. Decisions made by asset managers can relate back to the framework to record the reasons for taking a specific decision and how the framework supported those decisions. In this way, it aligns with the user needs (Table 2.1).
- **Future-proof**. The framework is designed to remain valid as methods improve in the future – also aligned with user needs (Table 2.1).

3.2.2 ISO 55000 alignment

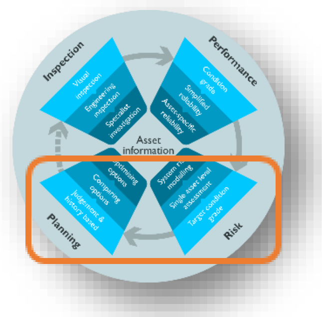
The long-term, risk-based and auditable approach that the framework promotes – and the integrated nature of the tools – is entirely aligned to ISO 55000, the international standard for asset management (BSI 2014). The tools support users in their implementation of this standard, identified as a user need (Table 2.1) and enable many of the components essential to an ISO 55001 compliant asset management system (Table 3.2).

More widely, the use of standardised practices demonstrates that an organisation has an efficient and planned approach to asset management. It aids the understanding, planning and communicating of asset management maturity, while providing flexibility to practitioners to implement the level of complexity required.

Table 3.2 Benefits provided by the framework and tools for an ISO 55001 compliant asset management system

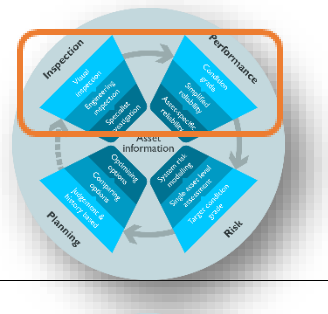
Clause 6.2.2: Planning to achieve asset management objectives

- Evidence to link corporate objectives directly to decision-making and asset management activities, supporting a structured and integrated approach to planning
- Consistent, documented process for assessing risks and opportunities, determining the significance of assets in achieving asset management objectives and allowing prioritisation of activities
- Direct calculation of the resources required to support asset management activities, so that these can be committed to



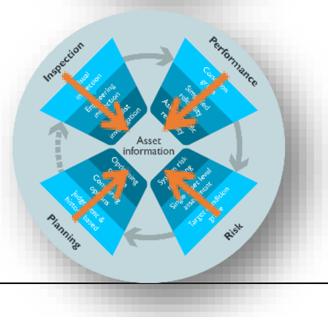
Clause 9.1: Monitoring, measurement, analysis and evaluation

- Standardised method for evaluating and reporting on asset performance and the performance of the asset management system, allowing the system's effectiveness to be evaluated



Clause 10.3: Continual improvement

- Tools that can be tailored to the current maturity of the asset management system, with the framework providing developed options for improvement where the suitability/effectiveness of current tools is found to be insufficient



3.2.3 Examples of moving between the tiers in the framework

This section presents examples of how the framework can be used in practice for 2 of the 4 components of the framework. The first example illustrates how the framework can be used for inspection (Figure 3.3). The answers to a series of questions determine the level of inspection detail required.

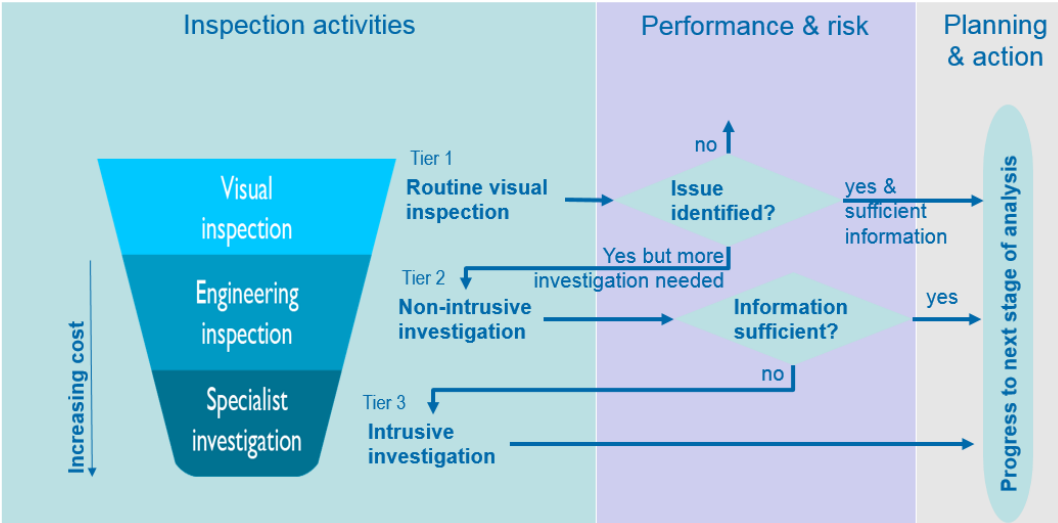


Figure 3.3 Illustration of steps to assess the level of detail required for inspection activities using the AP Tools framework

The second example, which features an earth embankment flood defence, demonstrates how the framework can be used to assess asset performance (Figure 3.4). The user is guided through a series of steps to determine the detail of performance assessment required. The 'confident in result?' question is there to assess whether the condition grade is providing a good indicator of the level of performance of the defence within the context of the risk and decision. Given the properties and other risk receptors on the floodplain, the user should ask whether this adequately represents the likely performance.

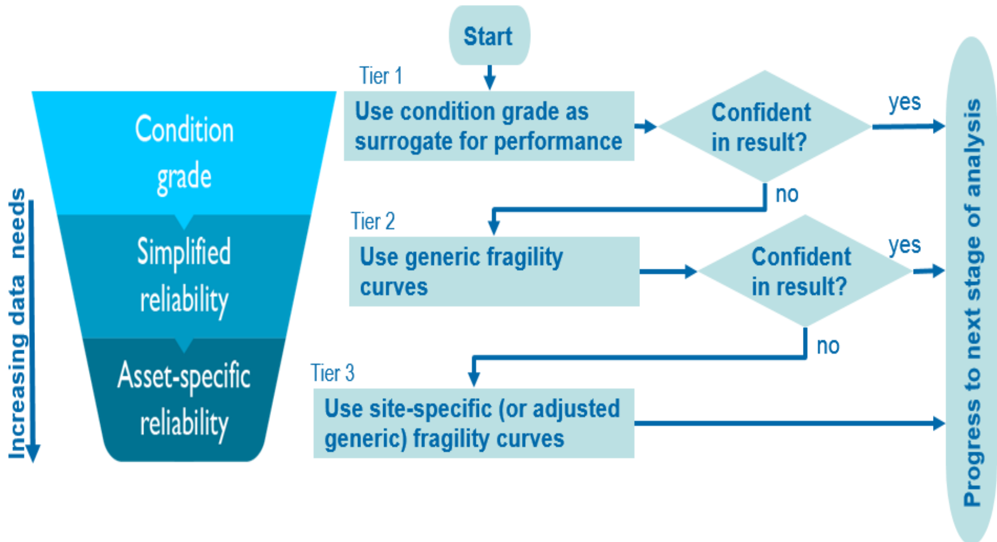
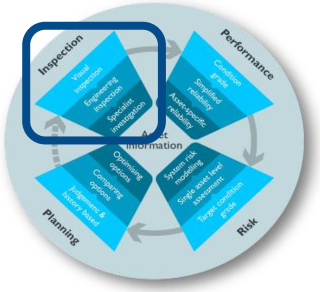


Figure 3.4 Illustration of the steps involved in the hierarchy process for an earth embankment flood defence example

3.3 Asset inspection guidance

3.3.1 Intended use and users

This guidance, which was developed in project SC110008 (Environment Agency 2014a), is intended for use when ascertaining asset condition (for example, to inform understanding of the residual life of the asset or the need for maintenance). The guidance is designed for developers of national process and will also be useful for local asset managers and field operatives/local asset practitioners as a reference document.



3.3.2 What does the guidance do?

The asset inspection guidance (Environment Agency 2014a) provides generic inspection advice applicable to all asset types, and specific advice for:

- channels and culverts
- linear defences
- coastal defences
- beach structures
- structures and point assets

It covers routine visual inspections (Tier 1) plus more advanced inspections (Tier 2 and Tier 3). It also includes health, safety and environmental considerations.

3.3.3 Why is the guidance needed?

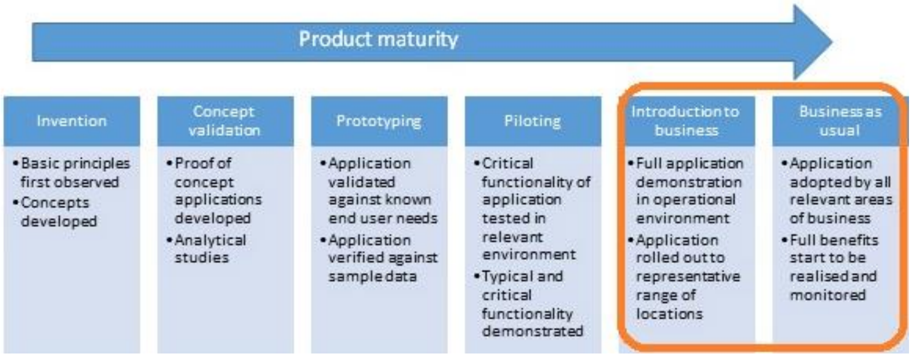
The guidance has been important in enabling efficiency, consistency and a risk-based approach to asset inspection and condition assessment.

3.3.4 What are the benefits?

The guidance disseminates best practice in asset inspection and supports a more targeted approach to timing and the level of detail of inspection. It was also used to help build the Environment Agency's CAMC Asset Inspection app to improve mobile working for asset inspectors, providing greater consistency and efficiency.

3.3.5 Is it ready to be used?

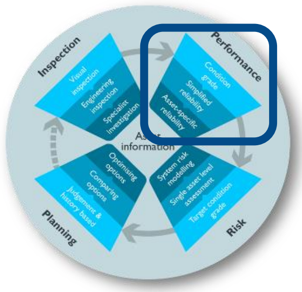
The guidance was issued in 2014 and parts are in use – its maturity therefore spans the 'introduction to the business' and 'business as usual' steps in the maturity scale shown in Figure 2.1 (reproduced below).



3.4 Custom fragility curve adjustment tool

3.4.1 Intended use and users

The Custom Fragility Curve tool can be used to help understanding the probability of failure (likeliness of breach). The primary intended user is a local asset manager or local asset practitioner who wants to assess likelihood of asset failure taking account of local data and knowledge.



3.4.2 What does the tool do?

Fragility curves describe the probability of failure depending on water level or wave overtopping, and are needed to quantify flood risk for asset failure (breach). The Custom Fragility Curve tool allows users to estimate the probability of failure of a linear asset (flood wall, shingle beach and so on) across a full range of return periods. By assessing how similar an asset is to a collection of generic attributes, the tool allows users to quickly and simply bring in local knowledge to generate an estimate of failure probability based on existing generic fragility curves.

The methodology is described in report SC140005/R3

Developed within Microsoft® Excel, the tool:

- provides an intuitive, and easy to use graphical interface
- keeps input data to the bare minimum
- uses only local knowledge and close-to-hand information such as asset type, basic geometry and visual condition grade for each component asset type
- outputs a bespoke estimate of the probability of failure of an asset under a full range of loading conditions
- allows an assessment of an asset to be undertaken in less than one hour

Typical interface screens are shown in Figure 3.5.

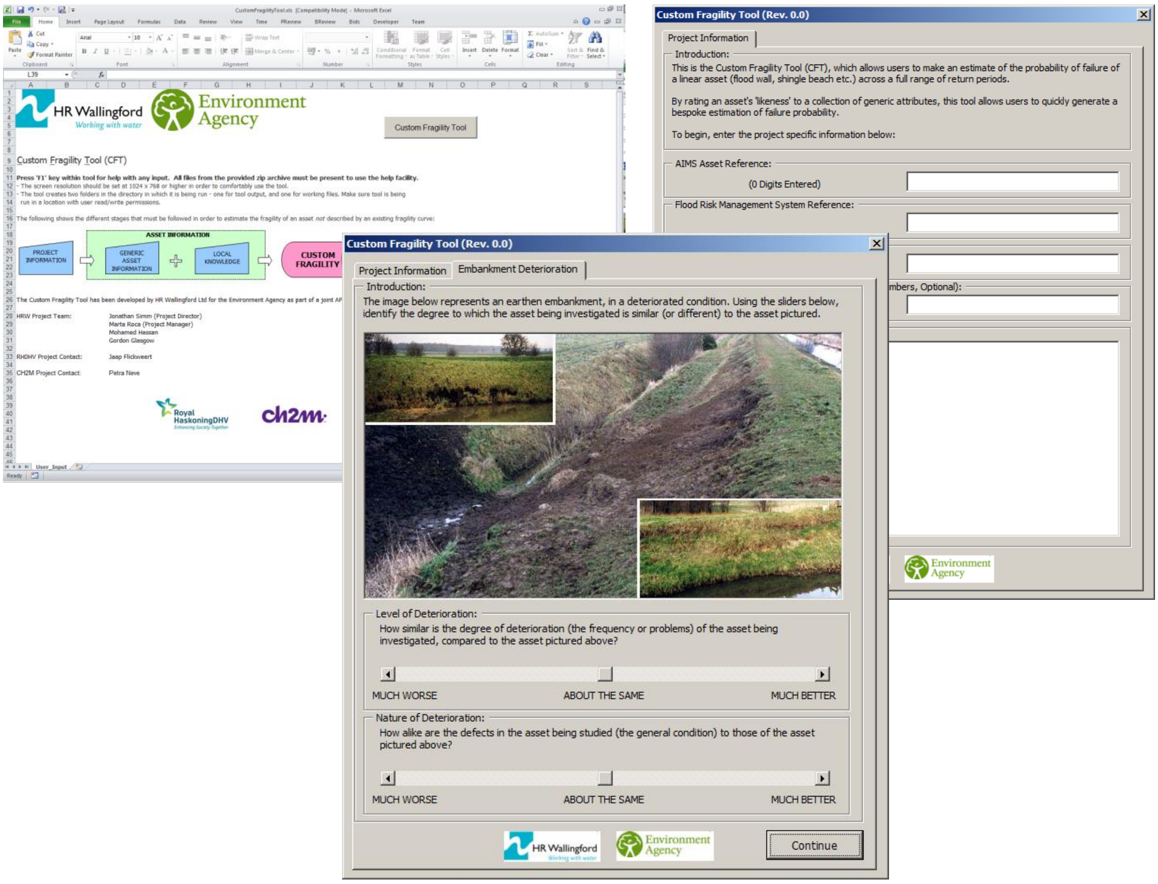


Figure 3.5 Example screens from the Custom Fragility Curve tool

The tool output is a bespoke estimate of the probability of failure of an asset, based on 2 failure modes (overtopping and piping) under a full range of loading conditions. An output example is shown in Figure 3.6.

The estimate of the probability of failure for the asset can replace the generic fragility curves in models. The data can also be exported from the tool using an ‘Export Results’ function. This creates an Excel file that contains the probability values for a range of loading conditions.

The tool assumes that raised linear defences that are imperfectly described by a single generic asset type do have a similarity to more than one generic fragility curve. This assumption means that, instead of selecting a single fragility curve to represent an asset, a weighted sum of all fragility curves should be used instead. The weighting is called the ‘Membership’ and it is assumed to lie in the range of 0.0 (no likeness) to 1.0 (strong likeness).

The key concept behind the approach that the tool uses to estimate the bespoke curves is fuzzy logic, a technique designed to help answer/understand qualitative and uncertain questions.

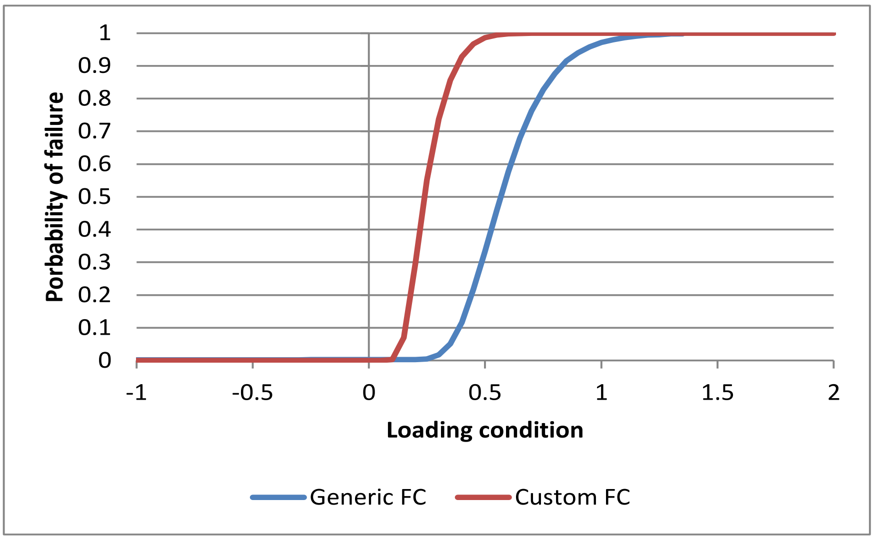


Figure 3.6 Example asset-specific fragility curve ('custom FC')

The tool has 2 main limitations. The first is that the generic fragility curves used as an input are based on

- typical asset geometries, specifically:
  - embankments with simple side slopes between 1:2 and 1:3 and of average height 2m
  - simple flood walls that are located on the floodplain and not part of a retaining wall
- typical observed failure mechanisms, specifically:
  - for fluvial embankments, just 2 mechanisms: overtopping-driven external erosion and seepage-driven internal erosion
  - for coastal embankments, just overtopping-driven erosion
  - for fluvial vertical gravity walls, just landward-sliding under the pressure of water in the river
  - for coastal vertical walls, just the overtopping-driven erosion mechanism
  - for sheet piled walls, bending

Hence the tool may not be suitable for very large defences or defences for which the failure mechanism(s) are significantly different from those assumed.

The second limitation is that the fuzzy logic approach is not relevant to determining probabilities of failure at transitions between structure types. This is because, at these locations, the physical processes operating are different in nature and/or magnitude.

3.4.3 Why is the tool needed?

Generic fragility curves underpin many decision support tools currently used by the Environment Agency. They are also used to generate flood risk data products that are publicly available such as the National Flood Risk Assessment (NaFRA), but can be locally inaccurate.

Full local reliability analysis is too expensive, complex and data hungry to undertake for specific assets. The Custom Fragility Curve tool allows users to estimate the probability of failure of linear assets using local knowledge of the asset to adjust generic fragility curves to provide a more realistic description of performance with minimal data.

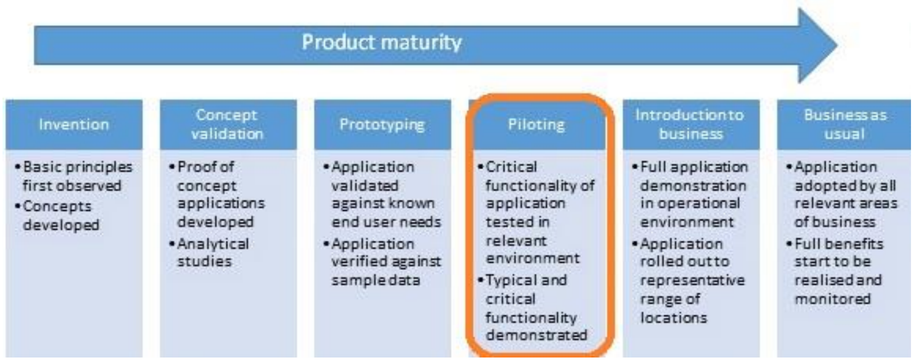
3.4.4 What are the benefits?

Local asset-specific knowledge can be used to adjust fragility curves, providing a better assessment of the current performance of an asset and thus supporting improved decision-making. It could also be used to assess various maintenance options (for example what is the change in performance by improving a grass front face with a permeable material).

The tool is easy to use and has low data requirements.

3.4.5 Is it ready to be used?

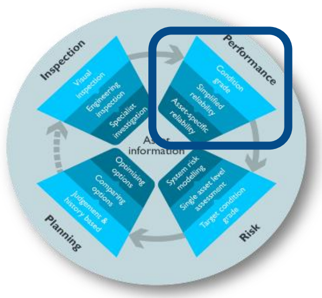
Although the tool is ready to use, it is a new approach and will need proving. The tool is ready to be embedded and can be used ‘with appropriate care’, potentially in CAMC Future where optimisation and prioritisation techniques may be introduced for some asset groups at the asset level. Integration of the tool with the risk attribution field tool (RAFT) should enable the user to simply assess the impact (properties at risk) based on the custom fragility curve, rather than the generic fragility curve.



3.5 Channel conveyance assessment guidance

3.5.1 Intended use and users

The channel conveyance assessment guidance (report SC140005/R2) is for assessing the performance of a watercourse with and without channel management. It is intended for use by local asset practitioners/managers and for those involved in developing a national process.



3.5.2 What does the guidance do?

Conveyance is a measure of the discharge carrying capacity of a watercourse. It relates the total discharge to a measure of the watercourse slope. Conveyance is influenced primarily by the cross-section geometry, which can be modified due to dredging or desilting activities and by the reduction of flow area due to blockages (for example, at bridges and culverts). Conveyance also depends on flow resistance due to vegetation, substrate and channel irregularities.

The project has developed a structured framework to support decision-making on whether to undertake channel conveyance maintenance works for the purposes of flood risk management. The main steps of the assessment are provided in Figure 3.7.

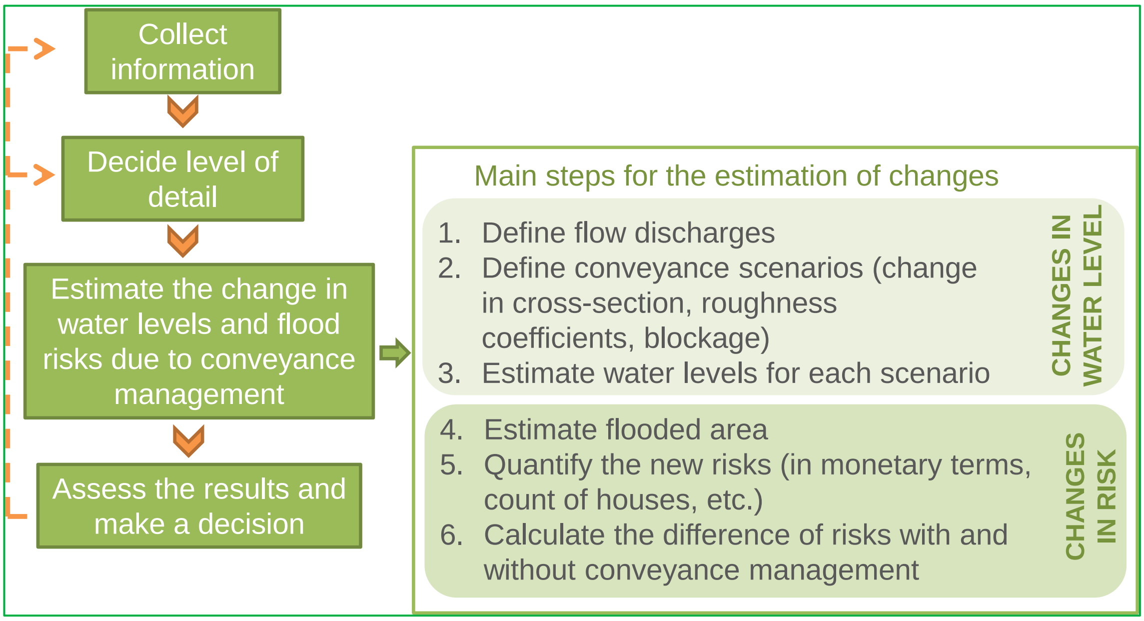


Figure 3.7 Summary of assessment steps for decision support in undertaking channel conveyance maintenance works

Consistent with the overall AP Tools framework of applying basic to more complex approaches depending on need, the channel conveyance decision support guidance uses a tiered approach:

1. Simplified level requiring only a general knowledge of the watercourse and access to existing datasets to help to understand the impact of changes in conveyance on flood risk for the site of interest – a qualitative assessment
2. Medium level that requires more analysis than the simplified level but provides a quantitative assessment
3. Detailed level applicable to a relatively small number of maintenance activities where the perceived risks or impacts to receptors are likely to be high

3.5.3 Why is the guidance needed?

Tools, methods and data related to conveyance maintenance are available to asset managers but these are not well used. The guidance, and the related Vegetation and Roughness tool (see Section 3.6) addresses the need for a consistent approach which can be followed across the Environment Agency and other risk management authorities. This builds on previous research, including the Channel Management

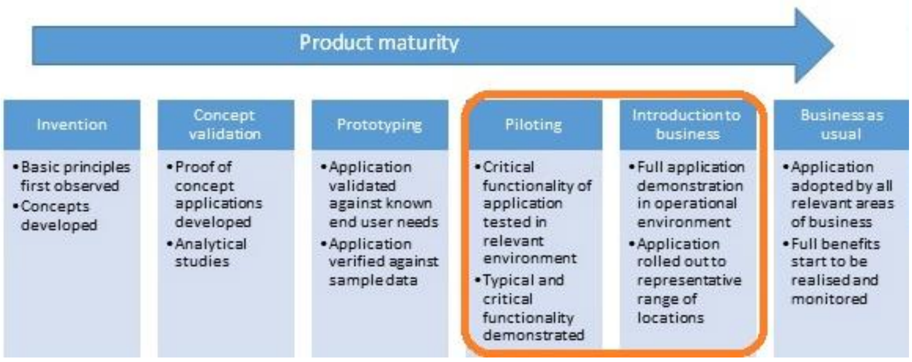
Handbook (Environment Agency 2015b) and the Conveyance Estimation System (CES).[1]

3.5.4 What are the benefits?

Application of the guidance will help to justify undertaking or withdrawing channel maintenance from a flood risk perspective and will help to communicate the decision. The guidance helps users to decide on the appropriate levels of analysis – which can then be carried out directly by the Environment Agency and other risk management authorities, or by supply chain partners. Its common use will mean good practice is shared and encouraged.

3.5.5 Is it ready to be used?

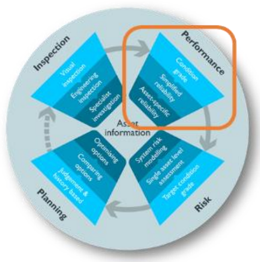
The guidance is ready to be used and referred to by asset managers to support decisions on channel maintenance. It is thus in the 'piloting' to 'introduction to business' stages of maturity.



3.6 Vegetation and Roughness tool

3.6.1 Intended use and users

The Vegetation and Roughness tool is for estimating channel water levels 'with' and 'without' channel vegetation maintenance. It is designed for use by local asset managers and practitioners.



3.6.2 What does the tool do?

Supporting the conveyance guidance, the Vegetation and Roughness tool was developed to estimate channel water levels 'with' and 'without' channel vegetation maintenance. It is a simplified tool, implemented in Excel, which makes no allowance

[1] www.river-conveyance.net

for backwater effects or intricate geometries. It is therefore within the second tier of the performance component of the framework ('Simplified reliability').

The user provides information on a typical cross-section geometry, bed material (sediment) and channel vegetation. Additionally, options for vegetation cutting are entered. The tool then uses the CES to estimate the change in water level associated with the vegetation cutting for a range of river discharges.

3.6.3 Why is the tool needed?

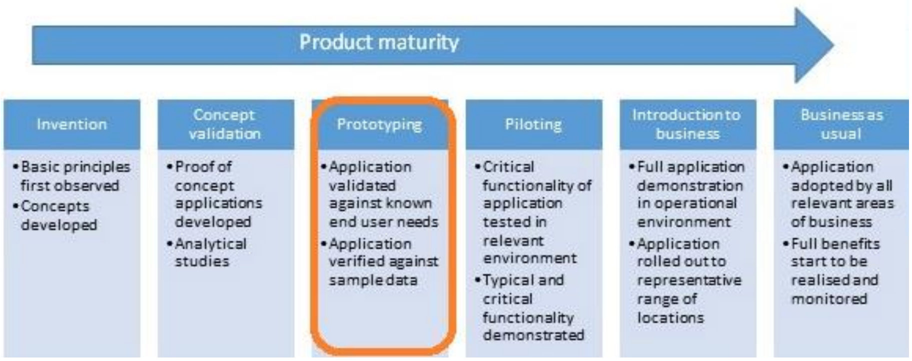
This tool is needed to provide an easy to use and consistent way of making local analyses to assess channel conveyance maintenance. It enables users to estimate changes in water levels or flow capacity for different options of vegetation cutting.

3.6.4 What are the benefits?

The tool provides improved evidence for decision-making and provides quantified evidence on possible changes in water level and conveyance/flow. It is a simple approach that can be used by Environment Agency and other risk management authority staff. It is designed to help with prioritisation decisions and to provide evidence to support stakeholder discussions.

3.6.5 Is it ready to be used?

The tool is ready to use and the concept is mature, but the tool would benefit from more real-world testing.

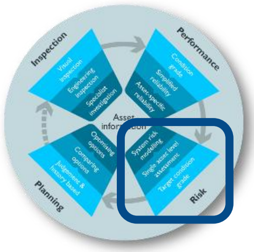


3.7 Risk datasets guidance

3.7.1 Intended use and users

The risk datasets guidance (report SC140005/R4) will help staff in risk management authorities to identify suitable pre-calculated datasets on flood risk to help local asset management decision-making. The guidance is also intended for policy and process developers to help them understand the requirements for risk information, including specifying new regional and national datasets (for example, NaFRA2).

The guidance is thus designed for use by both local asset managers/practitioners and national policy/process developers.



3.7.2 What does the guidance do?

This guidance describes the availability of pre-calculated flood risk data to support rapid and cost-effective asset management investment decisions. Detailed descriptions are provided for the following datasets:

- NaFRA
- NaFRA State of the Nation
- NaFRA2
- National Coastal Erosion Risk Mapping (NCERM)
- Long-term Investment Scenarios (LTIS)
- Conveyance Key Performance Indicators (KPI) dataset

For each of these datasets, the guidance summarises the data and assesses:

- how the data can be used for asset management purposes
- the data's advantages and limitations in use
- how to source the data

The guidance also covers the requirements for risk information for use in asset management and discusses the attributes of an ideal dataset.

3.7.3 Why is the guidance needed?

Risk modelling is often costly and costs can be disproportionate to the decisions being made. Using nationally available risk information can be a cost-effective way of testing and justifying decisions.

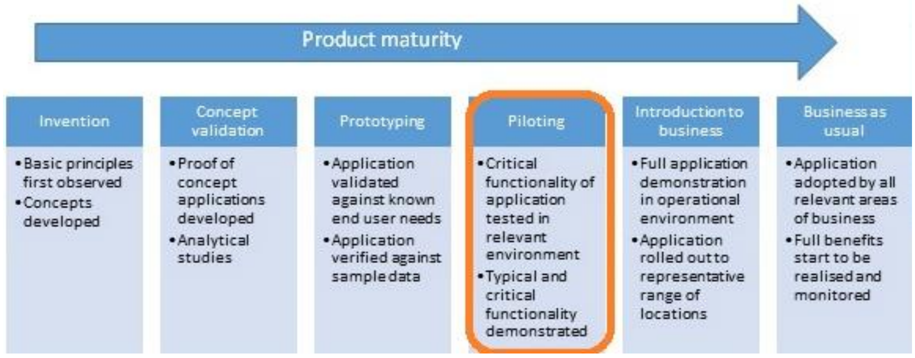
3.7.4 What are the benefits?

The guidance improves asset management decision-making by making use of existing information on risks and therefore helping to better identify where, when and how to intervene to reduce flood risk for least cost and greatest benefit. The available datasets can contain risk estimates for a small set of maintenance options, which can support the development of maintenance programmes that provide best value.

The guidance also provides an opportunity to share good practice and knowledge of data. This leads to increasing efficiencies, better decisions and improved monitoring.

3.7.5 Is it ready to be used?

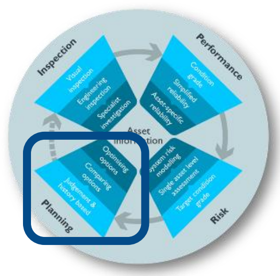
The guidance is ready for use. However, users should be aware that available data will change over time and updates to the guidance may be needed in future. Users should also bear in mind that data may not always be available or appropriate and should consult the guidance for further advice on this matter.



3.8 Raised defence target condition whole life cost appraisal tool

3.8.1 Intended use and users

The Whole Life Cost tool should be used when investigating maintenance investments to achieve a target condition grade for an asset. It is designed for use by local asset managers/practitioners.



3.8.2 What does the tool do?

The Whole Life Cost tool enables the investigation of alternative maintenance investments to identify the least whole life costs required to achieve a target condition grade. It is an enhancement of the tool developed in project SC060078 (Environment Agency 2013). The tool assumes a definition of whole life cost as the sum of all expenses associated with an asset including acquisition, operation, maintenance and disposal (ISO 55000 definition). The methodology is described in report SC140005/R3.

The tool works on calculating whole life costs for a target condition grade for an asset. It can be used for both linear and point assets, and includes deterioration curves (as described in Environment Agency 2013) that can be adjusted to include local information. The tool is implemented in Excel. The tool does not use risk information such as monetised flood damages avoided.

3.8.3 Why is the tool needed?

The Whole Life Cost tool is needed to enable improved asset decision-making using the whole life approach.

3.8.4 What are the benefits?

Use of the Whole Life Cost tool helps to identify the best maintenance regime. It provides:

- evidence for ISO 55000 compliance
- asset managers with a structured process that encourages consideration of options

It can also help all risk management authorities in assessing longer term investment needs, including the Environment Agency's Area allocation process.

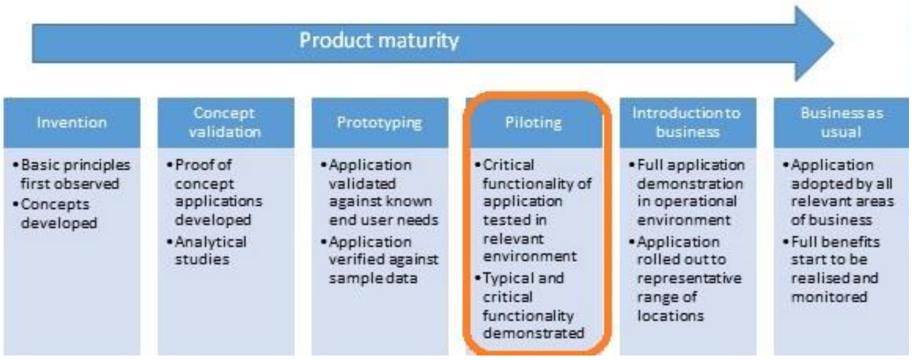
The tool can be used to answer questions such as:

- What are the savings that can be achieved by implementing the highest level of Annual Maintenance Regime to slow the deterioration process?
- Could a 10-year life extension applied at a given condition grade reduce the total whole life cost, but lead to the asset spending longer in poorer condition grades?

3.8.5 Is it ready to be used?

The tool is ready to be used as an Excel spreadsheet. It is relatively complex to use and training/support may be required. For more widespread use, it would benefit from integration with Environment Agency processes/systems – a particular benefit of such integration would be access to the latest cost datasets. The tool is being used on the Thames Estuary Asset Management 2100 (TEAM2100) programme as part of its ISO 55000 accreditation but, at the time of writing, had not been applied across a representative range of locations.

The aim of the Environment Agency's CAMC programme is to support a whole life cost approach to asset management. The Whole Life Cost tool therefore aligns well with the CAMC programme, supporting whole life costing in investment planning and funding allocation.



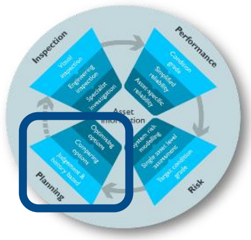
3.9 Beach performance assessment

3.9.1 Intended use and users

This guidance, presented in report SC140005/R5, is a supplement to the CIRIA Beach Management Manual (Rogers et al. 2010) for setting trigger values for beach management interventions and is intended for the many beach types throughout the UK. The guidance is therefore intentionally generic, but provides a framework for beach and asset managers to work within, specific to their local situation.

Trigger setting for beach management forms part of investment planning, informed by risk assessment. The regular assessment whether the beach meets the trigger values (based on inspection) forms part of performance assessment.

The guidance is designed for use by local beach managers.



3.9.2 What does the guidance do?

This guidance is a supplement to the Beach Management Manual for setting trigger values for intervention. Because every beach is subject to specific morphology and processes, performance assessment can be a complex task. The guidance provides a framework to make this process more accessible, with a step-by-step methodology and sketches that illustrate the background concepts and science. The guidance includes worked case studies to demonstrate application. The accompanying tool enables the user to follow the guidance.

The guidance is made up of 3 parts, namely:

- Part 1: Guidance – a written document presenting the key principles of the guidance (SC140005/R5)
- Part 2: Flow charts – providing more detail on the methodology and a stepwise approach (Figure 3.8) implemented in a guided spreadsheet tool, the beach triggers tool developed as part of project SC140005
- Part 3: Case studies – worked examples for 3 locations (Torcross in Devon, Walcott in Norfolk and Eastbourne in Sussex) covering various beach types and functions (see Section 4.4)

The ultimate aim of the beach performance assessment is to set threshold or trigger values (that is, values beyond which some action such as continued monitoring or intervention, is required to ensure that functions are not compromised). A distinction is made between CRISIS and ALARM trigger values (see Figure 3.8).

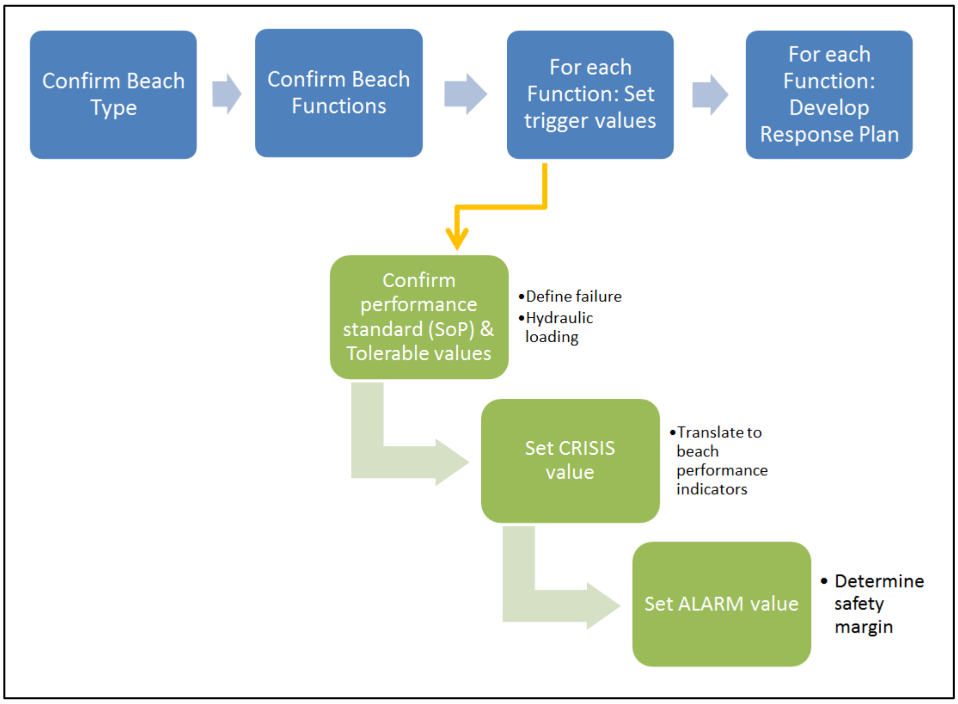


Figure 3.8 Stepwise process of determining triggers

3.9.3 Why is the guidance needed?

The guidance is an addendum to existing guidance presented in Section 8.5.2 of the Beach Management Manual (Rogers et al. 2010). Local managers have expressed the need for more practical methods to plan in advance their response to change in their beaches.

The Beach Management Manual introduces the importance of monitoring and performance assessment as part of the beach management cycle. It identifies a range of beach functions, and suggests the establishment of performance indicators and corresponding thresholds or triggers beyond which these functions can be compromised. However, the Beach Management Manual does not provide specific guidance for beach and asset managers on how to relate each beach function to relevant performance indicators or how to set appropriate trigger values.

The guidance complements the broader guidance provided within the Beach Management Manual, in particular for developing trigger values associated with management objectives and subsequent actions defined within different forms of Beach Management Plans. This relationship is shown in Figure 3.9.

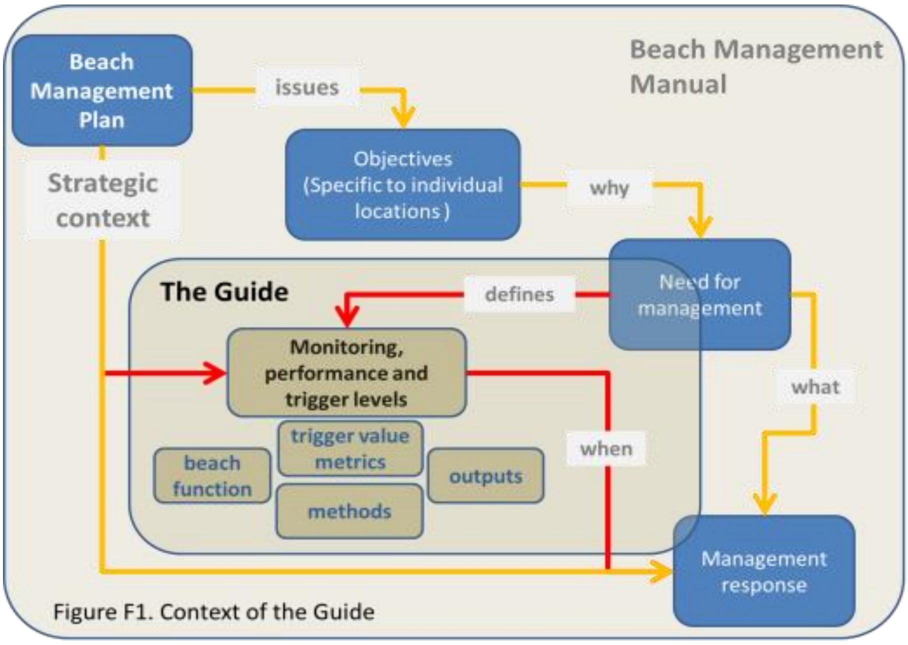


Figure 3.9 Schematic outlining the relationship between the beach performance assessment guidance and the Beach Management Manual

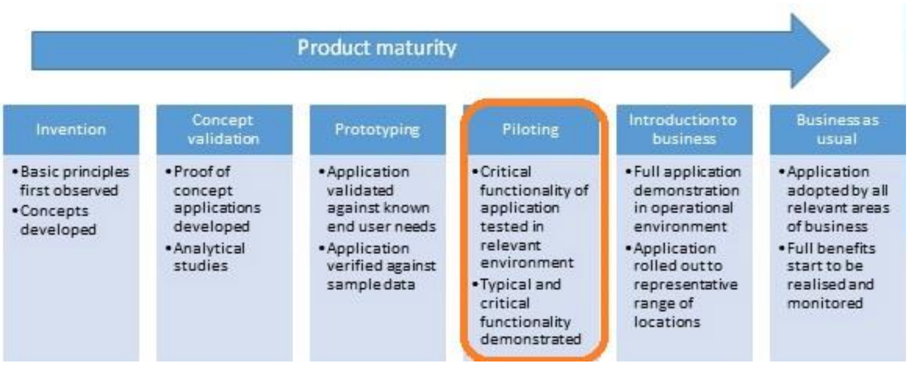
3.9.4 What are the benefits?

Once the guidance is applied and trigger values are determined, these should inform decisions in the beach and asset management process. For example, use of the guidance should:

- avoid catastrophic failure (for example, at Dawlish in Devon in February 2014)
- lead to more optimal spend of maintenance budgets with a clearer justification

3.9.5 Is it ready to be used?

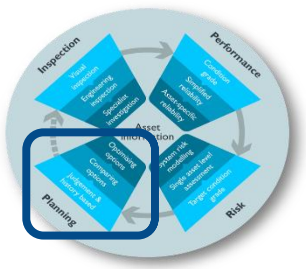
This is a new approach and requires a guided rollout with a focus on practicality and accessibility. A formal CIRIA review process will be required for the guidance to become an addendum to the CIRIA Beach Management Manual (Rogers et al. 2010).



3.10 Risk-based appraisal tool

3.10.1 Intended use and users

A prototype tool has been developed to demonstrate how risk information (monetised damages avoided by maintenance activities) could be used within a whole life cost framework planning tool. The prototype is not intended for operational users, but is instead intended to inform national policy/process developers.



3.10.2 What does the tool do?

This is an Excel-based investment planning tool that accounts for flood risk within the life cycle cost calculation. The tool uses the same deterioration curves and maintenance assumptions as the whole life cost appraisal tool (see Section 3.8), but accounts for the increased risk exposure as the asset deteriorates from one condition grade to the next. The tool operates on individual assets.

The tool requires data to be provided on the residual risk (as annual average damage) associated with asset breach for the full set of condition grades.[2] Outputs are whole life total risk, total cost and benefit to cost ratios for a set of maintenance options. The tool also plots the time evolution of risk, cost and condition grade over the appraisal period.

3.10.3 Why is the tool needed?

The Whole Life Cost tool allows the review of options in maintenance regimes, but without taking into account any risk information. The prototype tool demonstrates how risk information can be included within a whole life cost assessment of maintenance options.

3.10.4 What are the benefits?

This tool demonstrates how a better description of the relationship between investment, performance and risk could be developed. An operational version of the tool would support risk-based (as opposed to purely condition-based) asset management. This would:

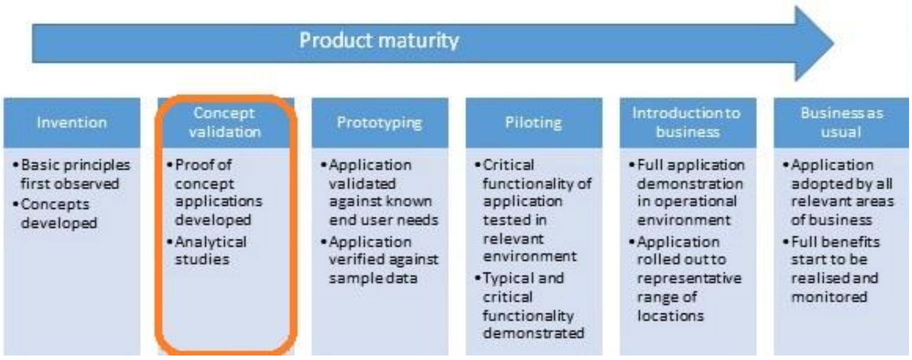
- allow users to compare options
- identify the asset level investment regime that yields the best value in terms of the balance of whole life cost and risk
- support effective operational and maintenance decisions
- have the potential to target investment on those assets or asset types within the system where the risks or benefits are greatest

[2] 1 = Very good; 2 = Good; 3 = Fair; 4 = Poor; 5 = Very poor

The tool can also be used for re-programming maintenance should funding levels change and to identify the best use of available funds.

3.10.5 Is it ready to be used?

The tool is a prototype to demonstrate the potential of the approach and is not intended for operational use. Further investigation would be needed to develop the tool and data before it is ready for operational use. It is recommended that the CAMC programme considers further development of the approach.



4 Case study examples

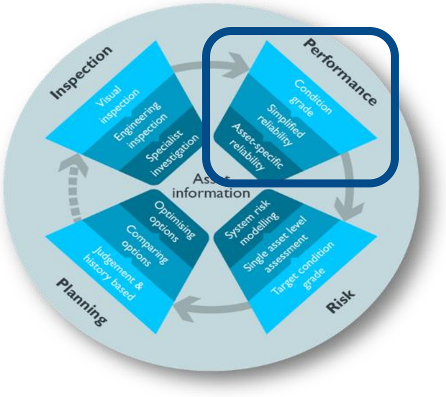
The cases studies in this chapter demonstrate how the various AP Tools can benefit asset managers, helping to bring the products to life. The case studies selected represent real assets and use real data where appropriate. The component of the AP Tools framework to which they relate is shown at the start of each case study and in the list of case studies given in Table 4.1.

Table 4.1 List of case studies

Case studies	Section
Custom Fragility Curve tool (Performance)	**4.1**
Understanding the risks of a single asset: a generic coastal defence using RAFT	4.1.1
Identifying the most risky assets in a system: 2 flood defences in Corbridge (River Tyne)	4.1.2
Reproducing expert developed fragility curves: a combined asset in Canvey Island, Essex	4.1.3
Channel conveyance assessment guidance and Vegetation and Roughness tool (Performance)	**4.2**
Estimating water levels with and without vegetation cutting	4.2.1
Effectiveness of additional dredging on the Somerset Levels and Moors	4.2.2
Dredging activities in the River Kent in Cumbria	4.2.3
Assessment of maintenance options in Great Eau	4.2.4
Raised defence target condition whole life cost appraisal tool (Planning)	**4.3**
Flood defence at Canvey Island	
Beach performance assessment guidance (Planning)	**4.4**
Torcross, Devon	4.4.1
Walcott, Norfolk	4.4.2
Eastbourne, East Sussex	4.4.3
Risk-based appraisal tool prototype (Planning)	**4.5**
Flood defence at Canvey Island	

4.1 Custom Fragility Curve tool case studies

Three case studies are presented:



- Understanding the risks of a single asset: a generic coastal defence using RAFT (Section 4.1.1)
- Identifying the most risky assets in a system: 2 flood defences in Corbridge (River Tyne) (Section 4.1.2)
- Reproducing expert developed fragility curves: a combined asset in Canvey Island, Essex (Section 4.1.3)

4.1.1 Understanding the risks of a single asset: a generic coastal defence

The aim of this case study is to show how the risks associated with a single asset can be improved with local knowledge by developing specific fragility curves with the Custom Fragility Curve tool. Assessing the single asset risk is done through use of a specialist tool (RAFT), based on an asset's condition grade. RAFT is designed to make use of local knowledge, minimising the data or modelling requirements, and with most data used embedded within the tool itself. The outputs of RAFT are:

- the annual probability of asset failure at its current and target condition
- the consequences associated with failure of an asset expressed as expected annual properties flooded
- the additional risk associated with the asset being in a condition below its target condition when compared to being in target condition, expressed in terms of 'additional households at risk'

These outputs are used by Environment Agency asset management teams in investment planning and reporting.

Understanding the link between RAFT and the Custom Fragility Curve tool

RAFT utilises basic user knowledge about the physical characteristics of the asset such as type of asset, crest and toe level to identify the most suitable fragility curve to represent the performance of an asset. The RAFT approach relies on the understanding of local asset managers of the area behind the defences to estimate the potential consequences of asset failure.

RAFT assesses the probability of asset failure and its consequences to estimate the risks. Figure 4.1 shows the general RAFT approach and the sources of information it uses. In the case of fragility curves, RAFT uses the standard fragility curves by default. However, based on local knowledge about the asset, customised fragility curves could be developed making use of the Custom Fragility Curve tool. However, the standard RAFT tool will not import the customised fragility curve directly and manual calculations will be necessary to make use of it to derive the RAFT-type outputs.

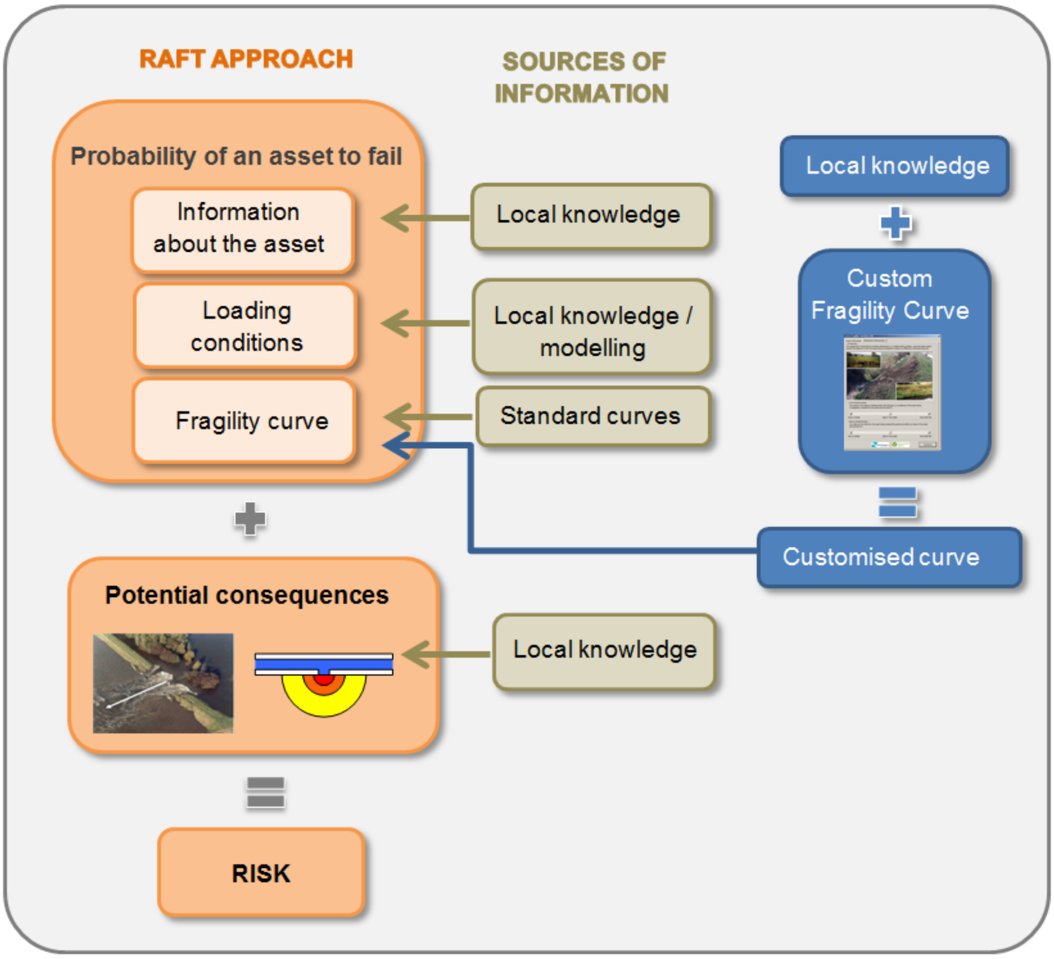


Figure 4.1 Link between RAFT approach and the Custom Fragility Curve tool

Description of the generic asset and the new fragility curve

This case study considers a generic coastal defence. The defence used as example is a wide, coastal, earth embankment with grass turf protection; its characteristics are given in Table 4.2.

Table 4.2 Defence characteristics

Parameter	Value
Total length of asset	268 m
Crest level of asset	4.60m AOD
Toe level of asset	2.12m AOD
Current condition grade	3
Percentage of asset at current condition grade	100%
Target condition grade	2
Percentage of asset at target condition grade	0%
Number of receptors behind asset	165

Notes: m AOD = metres above Ordnance Datum

The asset is in the Cromer region in Norfolk. Table 4.3 shows the relationship between water levels and return periods.

Table 4.3 Relationship between water levels and return period for asset location

Return period (years)	Water level (m AOD)
1	3.49
10	4.02
100	4.57
1,000	5.09

It is assumed that the defence has been maintained by improving the permeable front face with permeable material instead of only grass (Figure 4.2). The Custom Fragility Curve tool was used to obtain a new set of fragility curves for this asset.

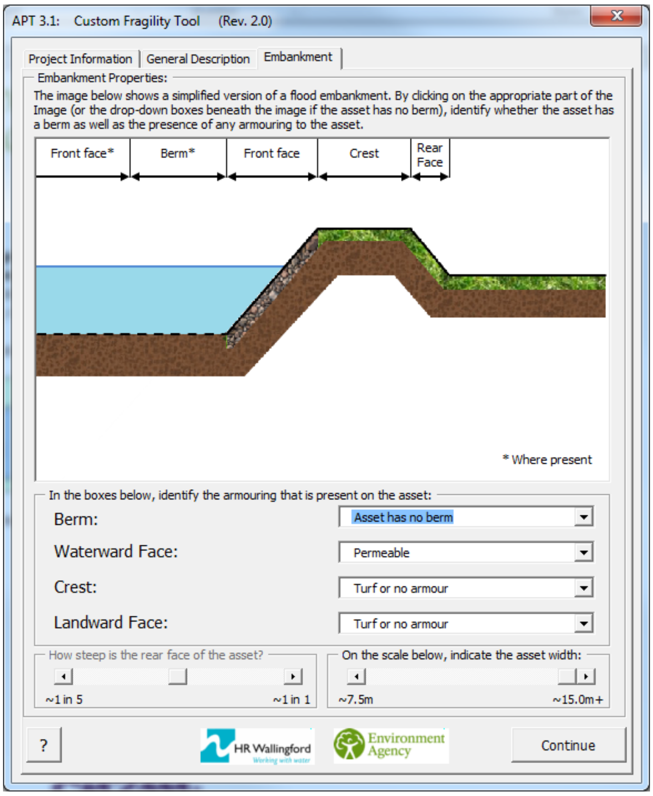


Figure 4.2 Change in the characteristics of the front face of the asset in the Custom Fragility Curve tool

Discussion of results

RAFT was applied to estimate the annual probability of failure of the coastal asset based on the generic fragility curve and loading conditions at the site. The results (Figure 4.3) show that the probability of failure of the asset at its current condition grade (3) is 3.94%, and higher than the probability of failure at the target condition (2), 0.59%. The expected annual properties flooded is obtained by multiplying these probabilities by the number of residential properties at risk (0.0394 × 168 = 6.6 properties).

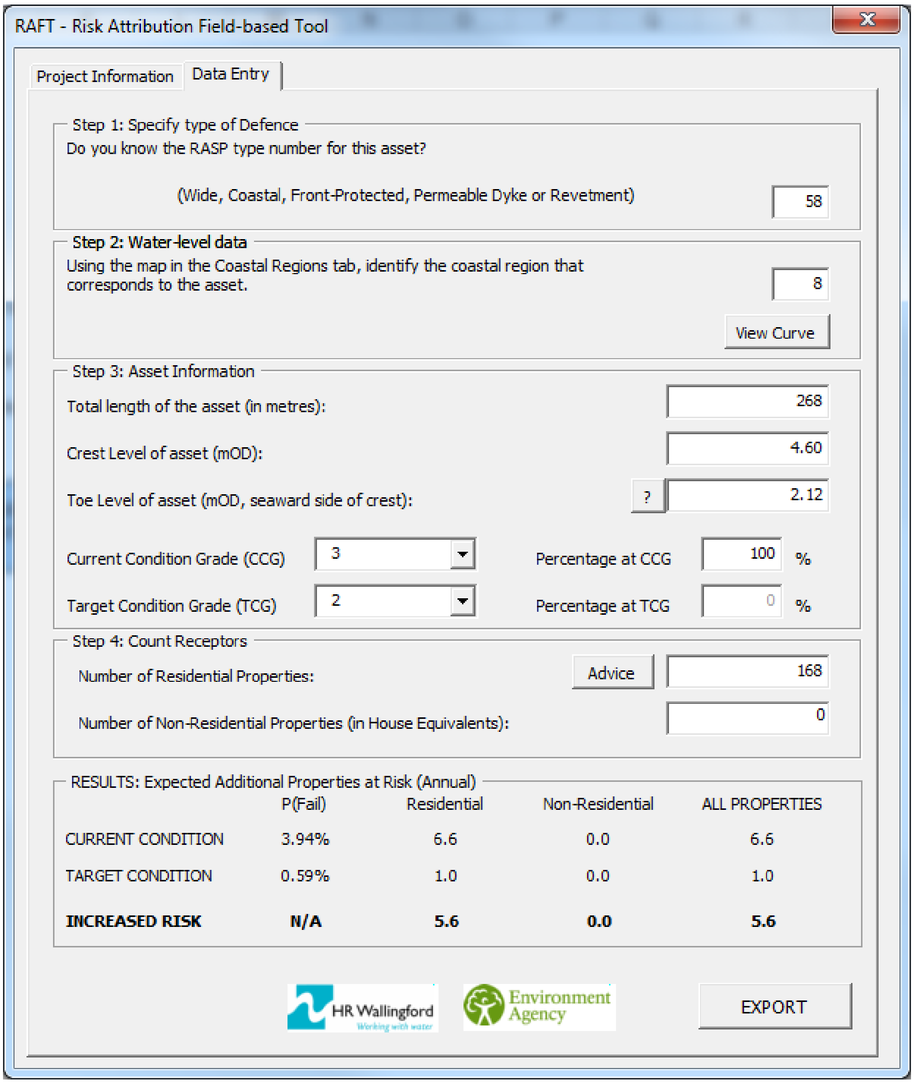


Figure 4.3 Input data and results obtained with RAFT considering generic fragility curves

RAFT does not currently have an option to import or use alternative fragility curves. An ad hoc modification of RAFT was therefore implemented to consider the custom fragility curves obtained with the Custom Fragility Curve tool following improvement of the defence. The results obtained are presented in Table 4.4.

Table 4.4 Annual probabilities of failure considering generic and bespoke fragility curves

Condition grade	Annual probability of failure	
	Generic curves	Custom curves
Current	3.94%	1.23%
Target	0.59%	0.31%

As expected, the improvement made on the front face of the defence reduces the annual probability of failure for any condition grade. The reduction in probability of failure is greater as the condition grade of the defence worsens (reduction of 69% for condition grade 3 and 47% for condition grade 2). This translates to a reduction in the expected properties at risk (Table 4.5).

Table 4.5 Annual expected properties at risk considering generic and bespoke fragility curves

Condition grade	Expected properties at risk (annual)	
	Generic curves	Custom curves
Current	6.6	2.1
Target	1.0	0.5

Conclusions

This case study shows the lower annual probability of failure using a bespoke fragility curve that takes into account the improvements made in the defence (in this example protection of the front face) rather than the probability obtained using generic curves. This result helps asset managers to quantify the impacts on risk of maintenance activities of raised assets.

The combination of the RAFT and the Custom Fragility Curve tool can provide an easy way to estimate how the improvements in maintenance activities reduce the annual probability of asset failure and thus reduce flood risk. In the same way, if the condition of a defence deteriorates, the tools can provide an understanding of the increase in annual probabilities and risks. Note that, as of September 2017, RAFT and the Custom Fragility Curve tool have not been linked and the customised curves cannot be readily used within RAFT.

4.1.2 Identifying the most risky assets in a system: 2 embankments in Corbridge (River Tyne)

The aim of this case study is to show how a custom description of the asset’s fragility helps to get a better understanding of locations with higher risks and how the distribution of risk changes.

Two assets are identified where the generic fragility curves appear to significantly underestimate the chance of failure of the asset. The Custom Fragility Curve tool is applied to these assets to generate a revised set of fragility curves.

Description of the assets

The Corbridge case study area was chosen following a review of the condition of the defences following flooding. Some of the information about the assets is extracted from the report of the review (Royal HaskoningDHV 2016).

The assets under consideration are located at grid reference NY 97927 64533 on the right bank of the River Tyne upstream of Corbridge. Figure 4.4 shows their location and their IDs in AIMS.

Asset AIMS 82477 is formed of 2 different construction types:

- an earth embankment
- a hybrid structure at the upstream end of the asset consisting of an earth bund to the river side face supported by an old masonry wall on the landward side

The embankment is 2m high. It has side slopes of 1 in 3 and a crest width of 3m. The target condition grade of this asset is 3. In this study the original condition grade considered is 2.

Asset AIMS 30476 is a raised earth embankment of sandy and loose material, 2.5m wide at the crest and steep-sided. The condition grade assigned is 3.

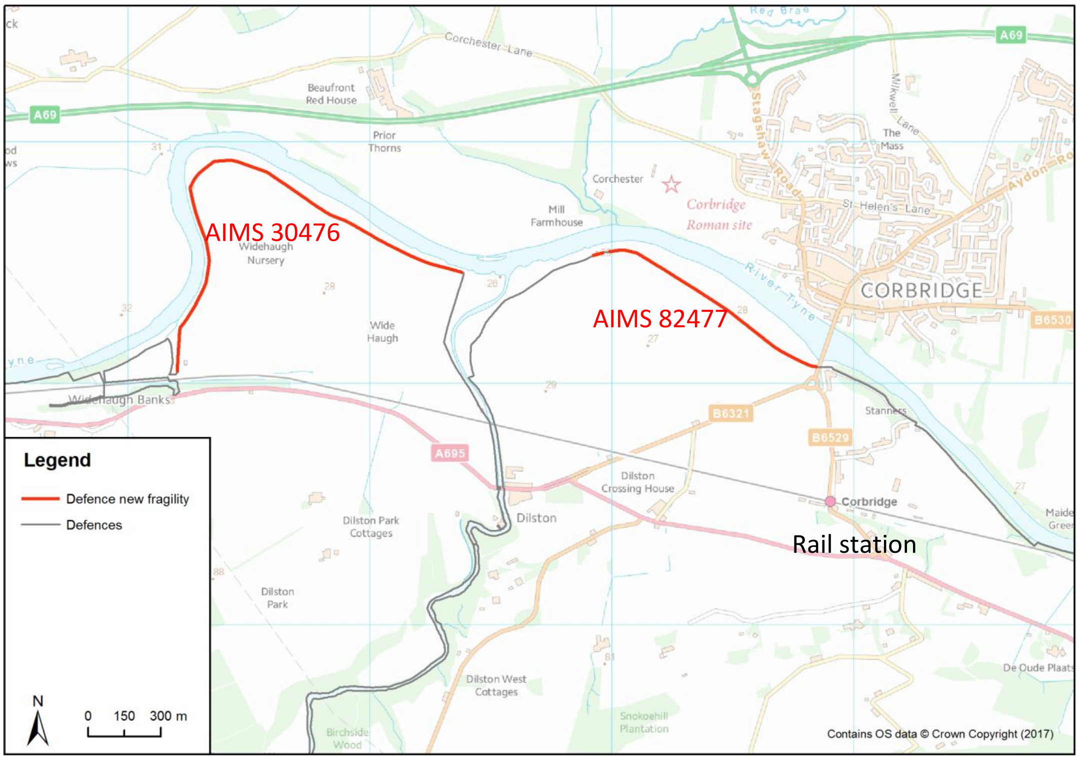


Figure 4.4 Location of AIMS defences for which the asset-specific fragility curves are applied

There have been breaches along embankment AIMS 82477, including 3 breaches in January 2005 and one in 2015. During the Storm Desmond flood event, the first reports of defences being overtopped in Corbridge were received at approximately 15:00 on Saturday 5 December 2015. Later that afternoon the embankments upstream of the bridge started to overtop and water was flowing down Station Road toward the railway station (see Figure 4.4). Properties along Station Road from the bridge to the railway station were flooded up to 2m depth.

Two breaches occurred during 5–6 December 2015 event in asset AIMS 30476, flooding the agricultural area behind it.

Why different fragility curves are needed

Royal HaskoningDHV (2016) reviewed flood defence failures during the winter 2015 to 2016 events and compared the data with the standard fragility curves.

The analysis of asset AIMS 82477 concluded that the likely failure mechanism was scour induced by overtopping at the embankment toe of the landward face where it transitions to the vertical wall. As transitions are not explicitly captured by standard fragility curves, the analysis of this type of assets needed to be reviewed bearing in mind that transitions are likely to be more fragile than the adjoining assets.

For asset AIMS 30476, Figure 4.5 shows the generic fragility curves for condition grades 3, 4 and 5, and the vertical line for the estimated water level compared with the crest height at the time of the event.

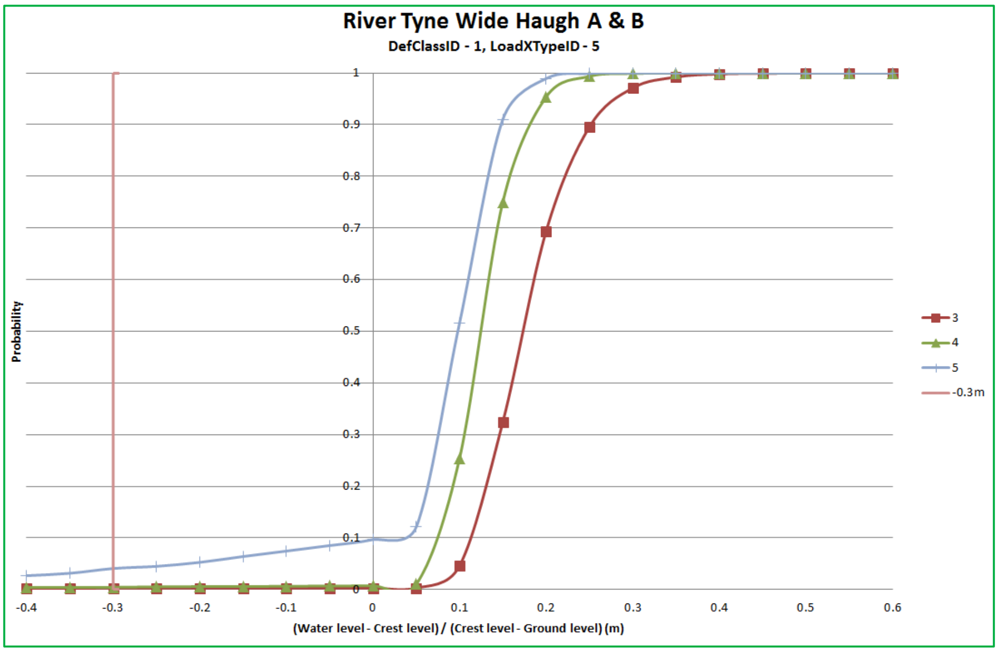


Figure 4.5 Fragility curves for condition grades 3, 4 and 5 compared with water level during the event (vertical line)

Source: Royal HaskoningDHV (2016)

A condition grade 3 was assigned to the embankment although, based on information collated after the event, the asset was probably in a poorer condition. With a condition grade of 4, the predicted probability of breach would have been 0%, while for a condition grade of 5, it is 4%. Royal HaskoningDHV (2016) concluded that these numbers were low and that, for this specific asset, the fragility curves were significantly underestimating the probability of failure as 2 breaches had occurred over a relatively short length of asset.

In this example, 2 assets are identified where a single generic fragility curve appears to significantly underestimate the chance of failure. The Custom Fragility Curve tool was applied to these assets to generate a revised set of fragility curves. Based on expert judgement and the information available, the tool was used to estimate specific fragility curves for the site. The derivation of the Custom Fragility Curve tool and the effect on risk are described separately below for each of the 2 assets. This is followed by a review of the annualised risk in the area using the custom fragility curves for both assets and some concluding remarks.

Asset AIMS 82477

Custom fragility curve

Figure 4.6 shows the different screens of the tool where changes were introduced. It was considered that:

- the asset was mainly an embankment with some characteristics of a 'vertical wall' embedded on it
- the wall was a gravity structure
- the rear slope and width were slightly different

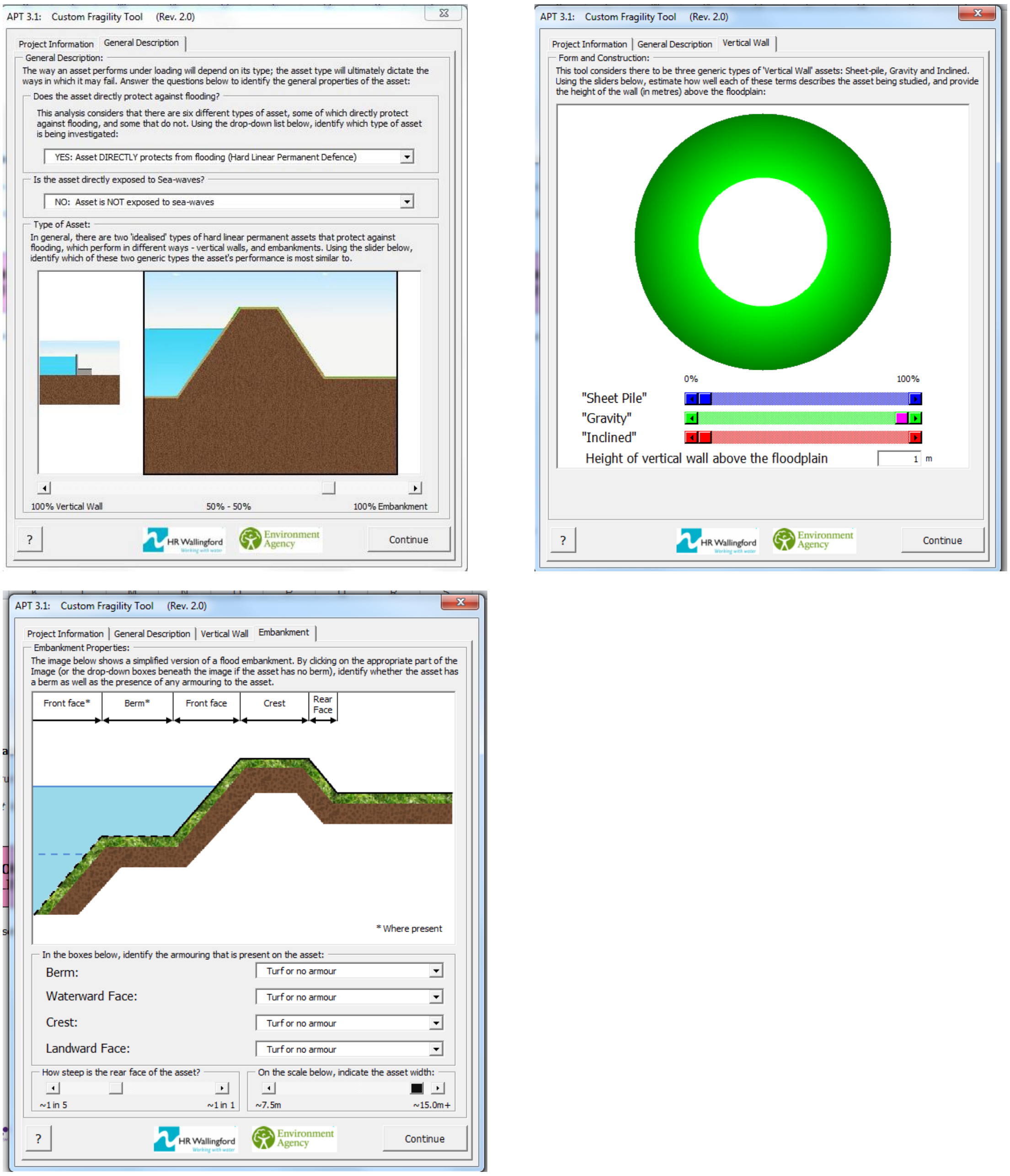


Figure 4.6 Screens of the Custom Fragility Curve tool where changes were introduced for asset AIMS 82477

The changes are reported in a summary spreadsheet produced by the tool (Figure 4.7).

Project Information		
User Name:	M Davison	-
Asset Reference:	82477	-
Defence Type:	Type 5: Wide Fluvial Turf Embankment	-
Condition Grade:	CG 3	-
Notes and Comments:	Any notes and comments can go here	-
General Descrtiption		
Type of Asset:	YES: Asset DIRECTLY protects from flooding (Hard Linear Permanent Defence)	-
Exposed to Sea Waves?	NO: Asset is NOT exposed to sea-waves	-
Degree to which asset is vertical:	Asset is more of an embankment than a vertical wall	-
Vertical Wall		
Percentage Sheet Piled:	0	%
Percentage Gravity:	100	%
Percentage Inclined:	0	%
Height of Wall above Floodplain:	1	m
Inclination of Asset:	Not Applicable	m
Embankment		
Berm:	Turf or no armour	-
Waterward Face:	Turf or no armour	-
Crest:	Turf or no armour	-
Landward Face:	Turf or no armour	-
Steepness of Asset	1 in 2.4	m
Asset Width:	14.63	m
Condition		
Earth, Concrete or Natural Defence:	Embankment	-
Condition Grade:	Condition Grade 3	-
Condition Grade Adjustment:	0	%
Proportion of Asset in Identified CG:	100	%
How much better is average CG:	Not Applicable	Condition Grades
Geology		
Soil Type:	Clay soil	-
Soil Type Adjustment:	Selected image a good representation of local conditions.	-
Man Made Change:	No man made loading evident	-
Evidence of Recent Flooding:	No evidence of asset having withstood recent flood event.	-

Figure 4.7 Summary spreadsheet of changes introduced for asset AIMS 82477

The new fragility curves for asset AIMS 82477 are presented in Figure 4.8. Their comparison with the standard fragility curve corresponding to condition grade 3 is presented in Figure 4.9. The new fragility curve has higher probabilities of failure for the same loading conditions.

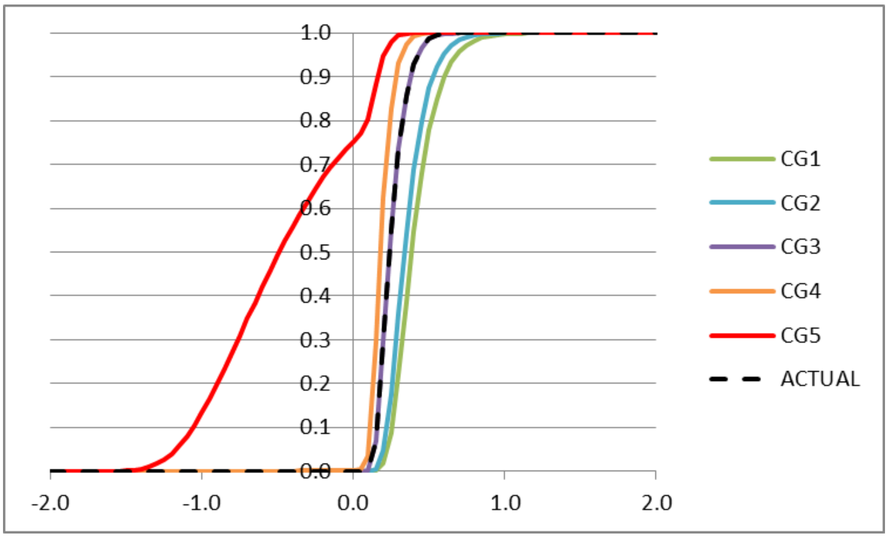


Figure 4.8 Output fragility curves (asset AIMS 82477)

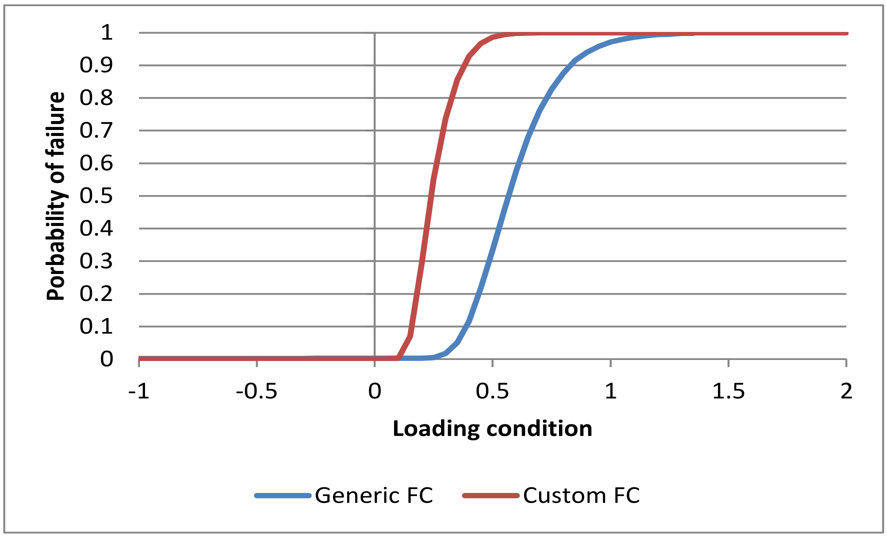


Figure 4.9 Comparison of fragility curves for condition grade 3 (asset AIMS 82477)

Comparison of estimated risks

The risks were estimated using Modelling and Decision Support Framework 2 (MDSF2). In this modelling platform, it is considered that long assets (>300m) may have an interdependency between the different parts, increasing the chances of failure when compared with shorter assets with the same characteristics. Therefore, long assets are divided in shorter ones to perform the calculations. In this particular example asset AIMS 82477 is subdivided in 4 assets: 22049, 21966, 21973 and 21978.

The probabilities of failure of each of the sub-assets that form AIMS 82477 were compared for the generic and the specific fragility curves (Figure 4.10). These probabilities are obtained for a range of return periods. A clear increase in the probability of failure can be seen in some areas of the asset. However, this increase occurs for return periods greater than 200 years, except in sub-asset 21966, where differences can be observed for more frequent events.

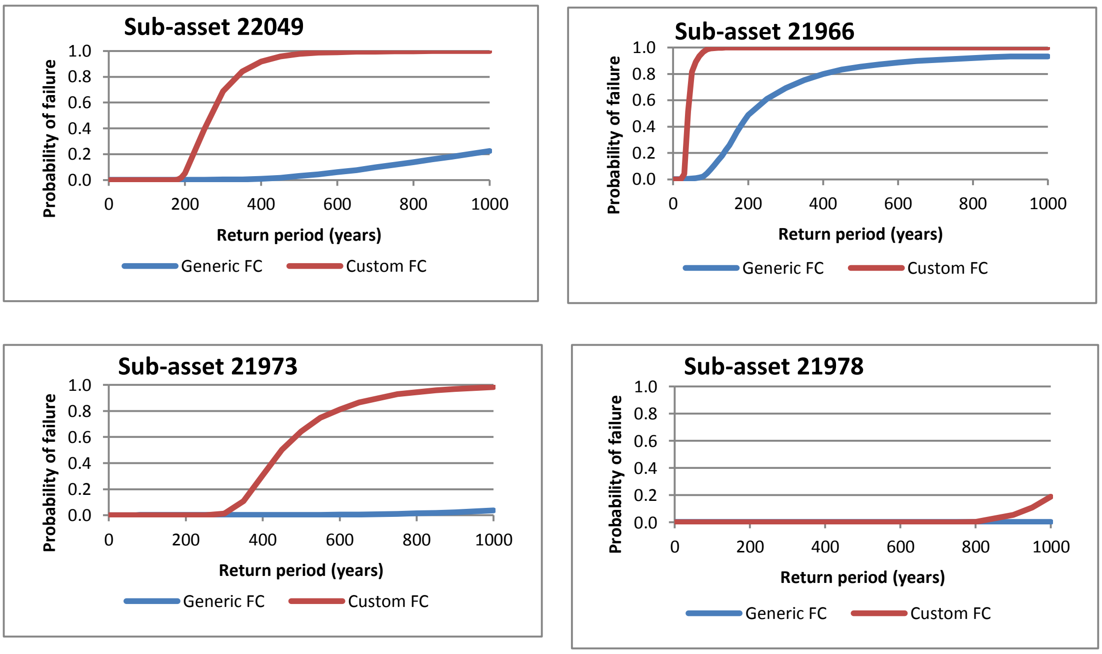


Figure 4.10 Probability of failure of sub-assets in AIMS 82477

The probabilities were integrated across the whole range of return periods to obtain an annual probability of failure. Table 4.6 shows that the annual probabilities of failure have increased substantially for sub-asset 21973. The results for sub-asset 22049 have not been calculated because the rounding errors are of the same order of magnitude as the very small values of probabilities.

Table 4.6 Annual probabilities of failure of different parts of the sub-assets of AIMS 82477

	Annual probability of failure	
Sub-asset	**Generic fragility curve**	**Custom fragility curve**
21966	0.0055	0.026
21973	0.0478	0.190
21978	0.0041	0.015

Asset AIMS 30476

Custom fragility curve

Figure 4.11 shows the 2 screens of the Custom Fragility Curve tool where changes were introduced. It was considered that the asset had a steeper slope on its rear face and that the condition grade was marginally worse than 3.

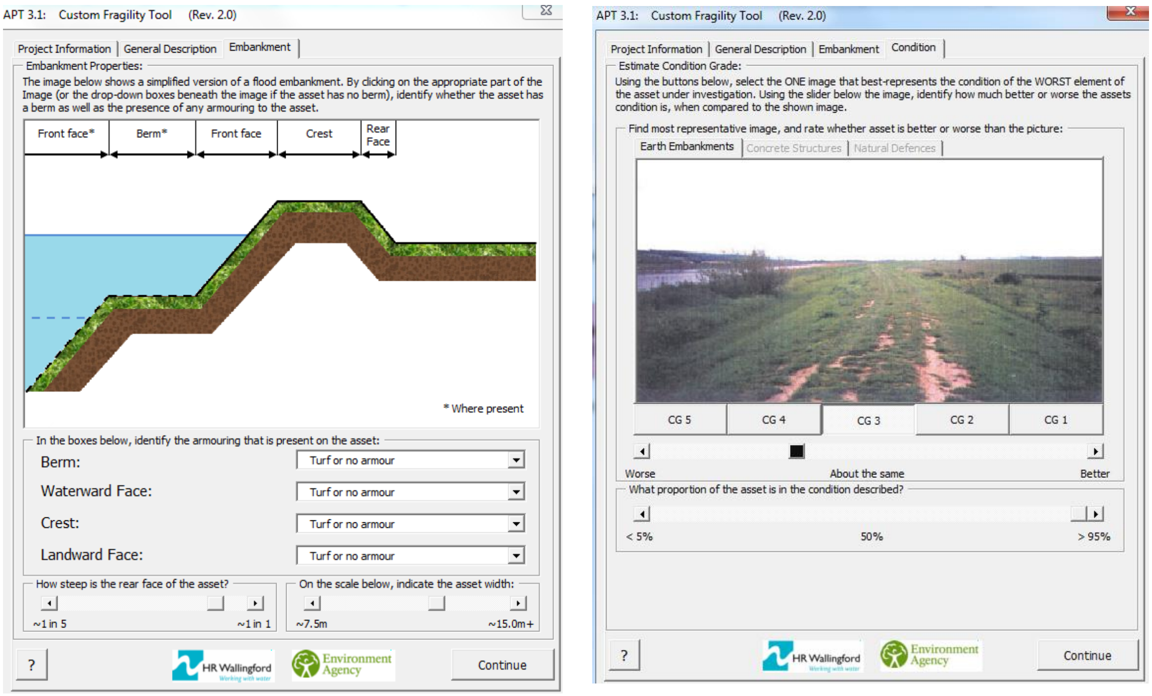


Figure 4.11 Screens of the Custom Fragility Curve tool where changes were introduced for asset AIMS 30476

The new fragility curves are presented in Figure 4.12 and their comparison with the standard fragility curve corresponding to condition grade 3 is presented in Figure 4.13. The new fragility curve presents higher probabilities of failure for the same loading conditions although the probabilities for negative loading conditions (water levels below crest level) are still negligible except for condition grade 5. When comparing these results with field observations, it can be concluded that the generic curves (used by the tool) may still have a limitation to capture the failure mechanisms occurring when loading conditions are lower than crest level.

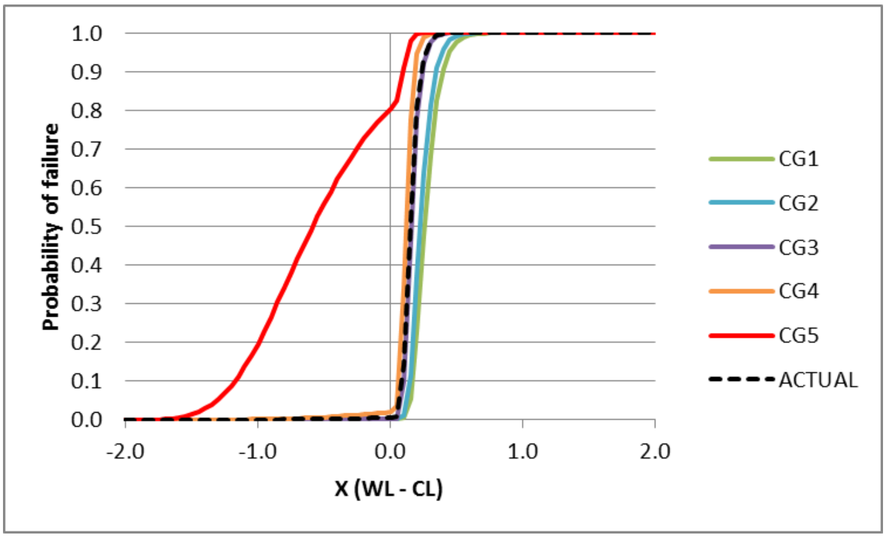


Figure 4.12 Output fragility curves for asset AIMS 30476

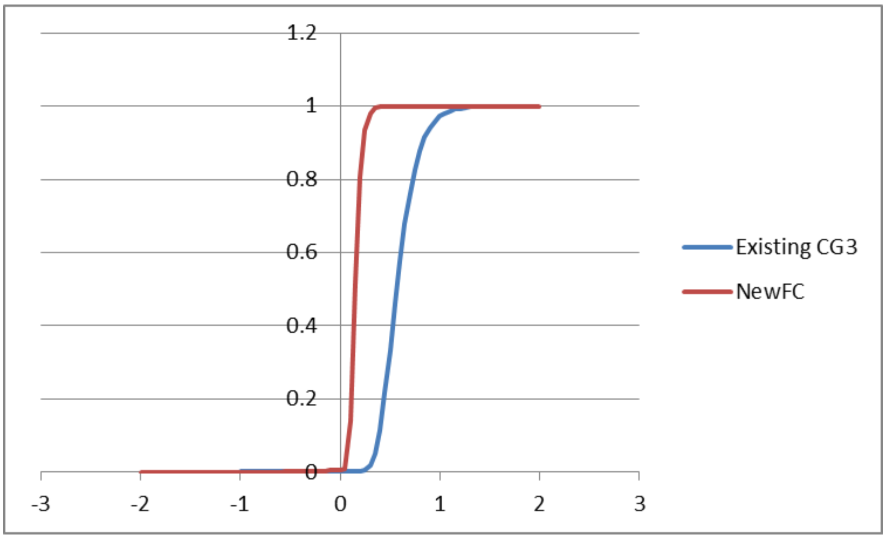


Figure 4.13 Comparison of fragility curves (asset AIMS 30476)

Comparison of estimated risks

The risks were estimated with MDSF2. For the same reason as given above for AIMS 82477, asset AIMS 30476 is divided in 5 sub-assets: 21453, 21499, 21519, 21577 and 21582. The naming is based on the convention followed in the NaFRA State of the Nation project.

The same type of analysis as for AIMS 82477 was repeated for the sub-assets of AIMS 30476. Only sub-asset 21582 was found to have significant probabilities of failure (Figure 4.14). The annual probability of failure of this sub-asset increases from 0.0143 to 0.0248.

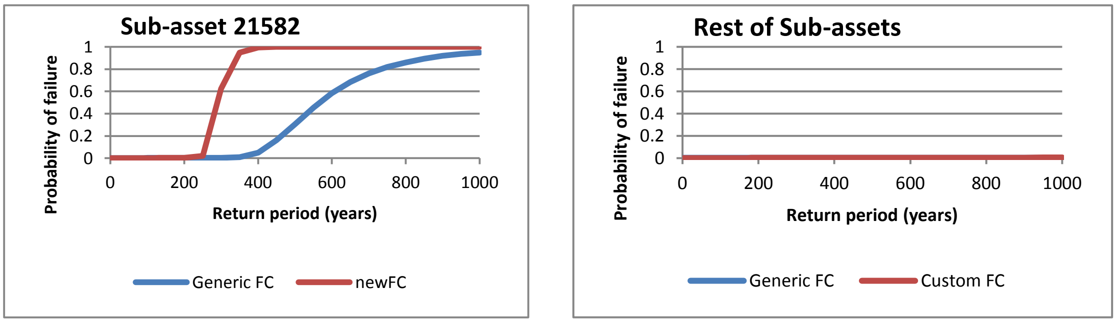


Figure 4.14 Probability of failure of sub-assets in AIMS 30476

Annualised risk – re-assessed

Figure 4.15 shows the damages expressed as estimated annual damages (EAD) in the area. This shows that the damages are relatively small and no appreciable differences (of the order of few hundred pounds) can be observed when the results obtained with the generic and custom fragility curves are compared. Overtopping is having a greater influence than breaching, and so from the viewpoint of total risk, the changes made to the fragility curves are not significant.

Figure 4.16 shows the asset contribution to risk in terms of EAD. The results are presented for the whole system. The increase in the probability of failure of asset AIMS 82477 has increased its contribution to the overall risk. This implies a redistribution of risk in the whole system, and a reduction in the contribution of risk of the adjacent defences.

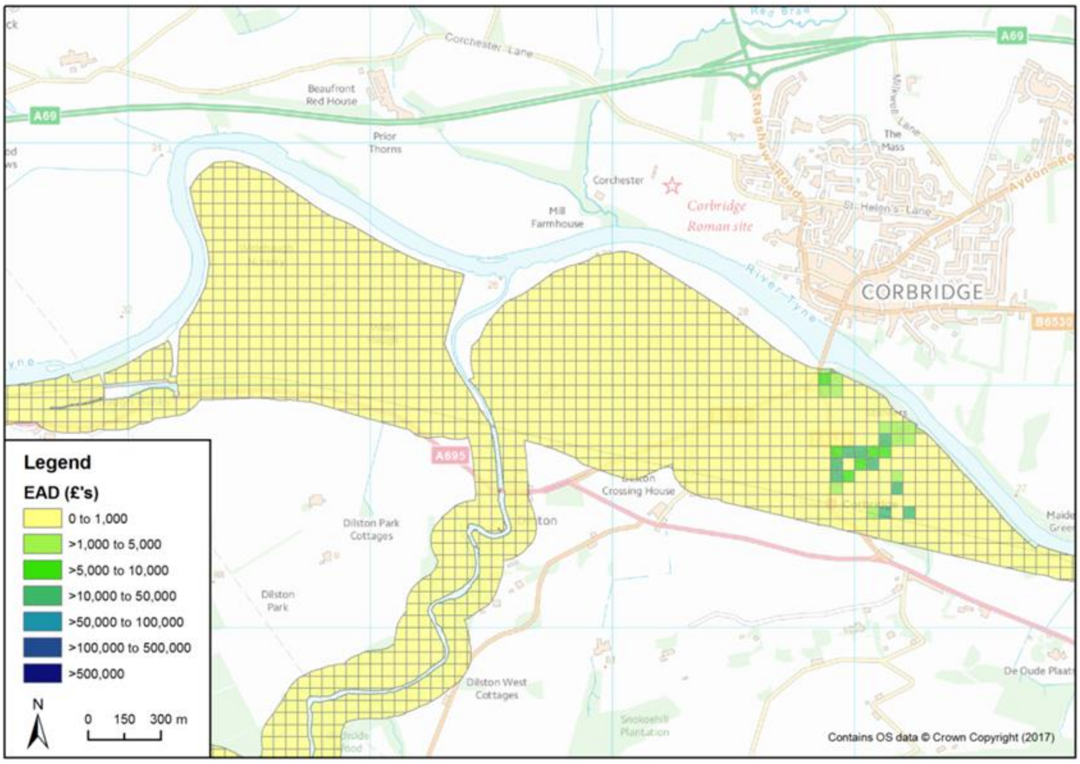


Figure 4.15 Damages expressed as EAD obtained with the generic and custom fragility curves

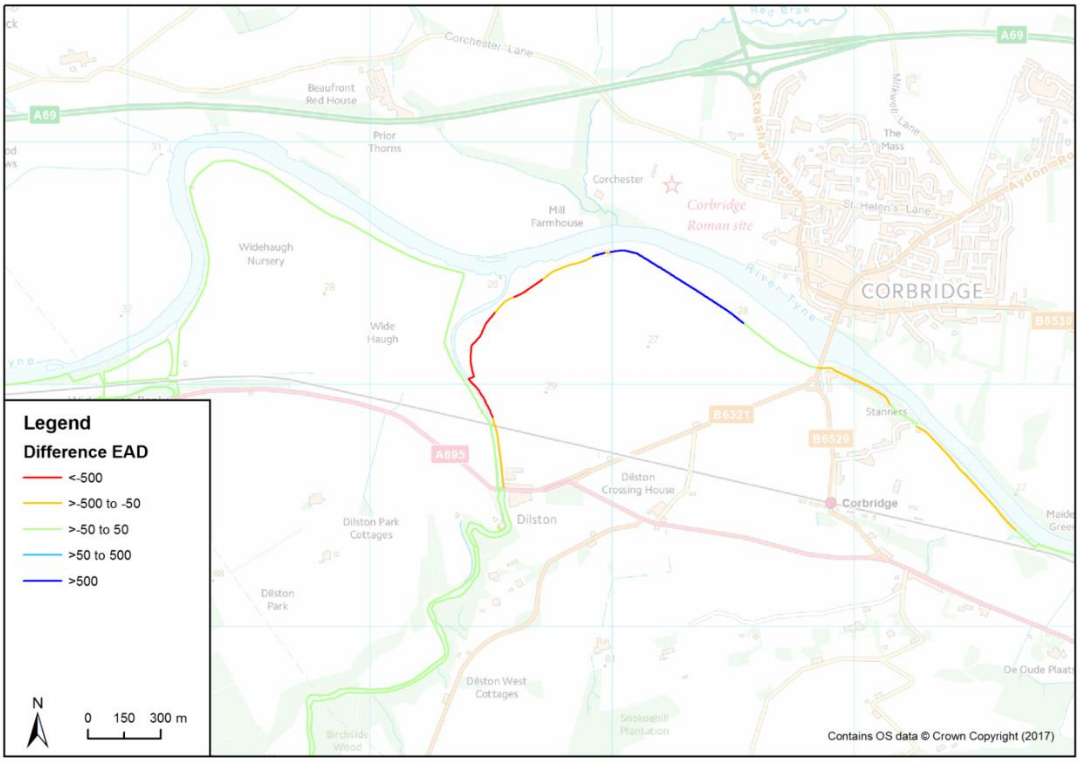


Figure 4.16 Comparison of risk contribution to assets using generic and custom fragility curves

Notes: Negative values: reduced contribution to risk
Positive values: increased contribution to risk

Conclusions

The analysis shows that the tool's approach of combining multiple fragility curves according to the asset's similarity to the underlying generic assets produces a set of custom fragility curves that predicts a significantly higher chance of failure, over a wide range of loading conditions. It also shows that, when compared with observations, there is a significant underestimate of failure probability at low water levels. This suggests that the performance of the asset at low water levels is significantly different from the performance assumed in the generic fragility curves.

In this example, the risks to properties are very low and no significant changes are observed in the general risk map when using the generic and custom fragility curves. However, changes are observed in the risk attribution among assets when considering different curves. This implies that changes in the fragility curve had an impact on how the risk is distributed in the system.

4.1.3 Reproducing expert developed curves: a combined asset in Canvey Island

The aim of this case study is to demonstrate the ability of the Custom Fragility Curve tool to reproduce bespoke fragility curves developed under the Thames Estuary 2100 (TE2100) project. It also discusses the implementation of custom fragility curves in the MDSF2 system risk estimation modelling platform.

Description of the assets

Canvey Island in the Thames Estuary in Essex has an area of approximately 7 square miles and a population of 38,000. The majority of the tidal defences around Canvey Island are classified as Risk Assessment of Flood and Coastal Defence for Strategic Planning (RASP) type 9, fluvial vertical wall (Figure 4.17).

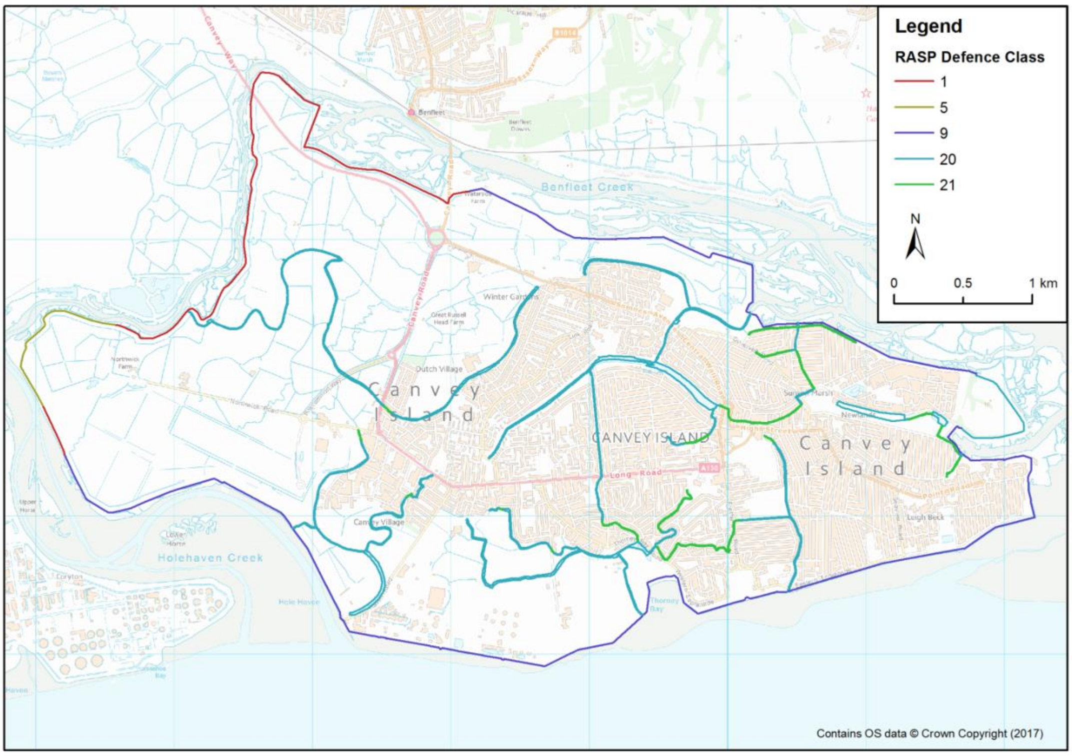


Figure 4.17 RASP types of Canvey Island defence assets

Why a different fragility curve is needed

The TE2100 project has developed a flood risk management plan for the Thames Estuary covering 100 years which made best use of existing current defence infrastructure and optimised the costs and benefits of future investment (Environment Agency 2017b).

In the TE2100 project, specific fragility curves were produced for some sites (known as ‘exemplar curves’). The Environment Agency recognised that, although generic fragility curves represent the nationally available consistent dataset on defence fragility, they are based on simplified representations of the overall defence condition, limited local data and a limited number of failure modes (Environment Agency 2008). To ensure more reliable policy and decision-making at the Thames Estuary local scale, more specific and accurate representations of fragility were considered necessary.

One of the specific fragility curves developed was on the south side of Canvey Island. The defence asset, named as EX2, is shown in Figure 4.18. The EX2 defence is a composite structure with an upstand wall and cut-off supported by embankment.

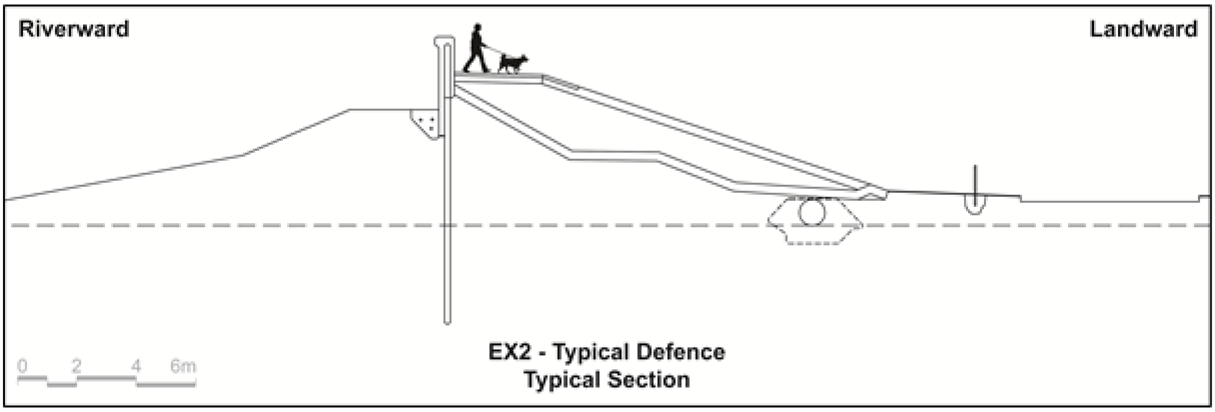


Figure 4.18 EX2 defence type cross-section of existing defence on the south side of Canvey Island

Source: Environment Agency (2008)

The new curves developed under the TE2100 project considered the failure modes for these tidal Thames assets. The failure modes considered were:

- block sliding of the landward section of embankment
- overturning
- piping failure
- negative skin friction
- erosion of the back face
- structural failure of sheet pile wall

The EX2 fragility curve developed for TE2100 is significantly weaker than the generic RASP type 9 fragility curve for the same condition grade that was used in the first National Flood Assessment (Figure 4.19).

The RASP type 9 load on the x-axis was converted to water level minus crest level, (WL-CL in Figure 4.19), assuming a crest level of 6.5m to allow direct comparison with the TE2100 curve.

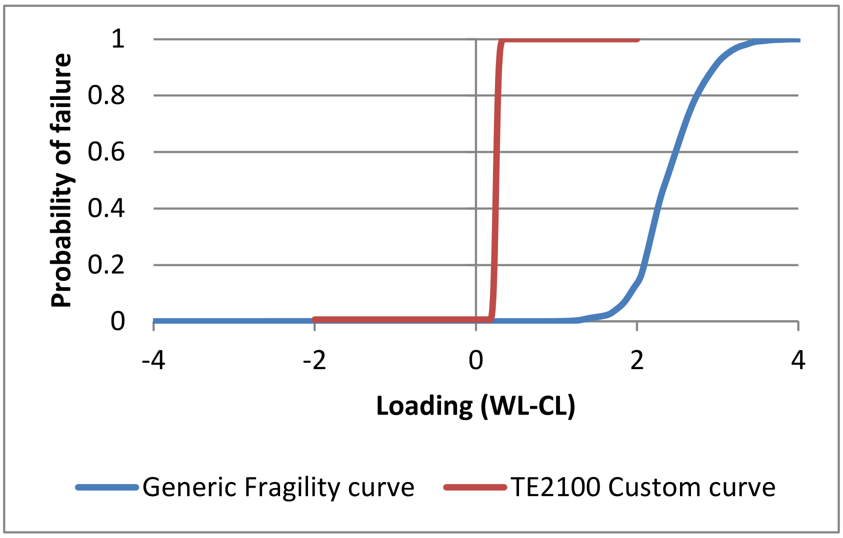


Figure 4.19 Comparison of generic and specific TE2100 custom fragility curve (condition grade 2)

Custom fragility curve

The case study checked the ability of the Custom Fragility Curve tool to better reproduce the fragility curve developed under TE2100. It was considered that the asset was 50% embankment and 50% wall, which had a height of 1m. Other variables were unchanged.

The results obtained with the tool are similar to those obtained on the TE2100 project (Figure 4.20). Treating the defence as a composite asset moves the curve to the left, with significant probabilities of failure now occurring with loadings of about 0.2m above crest (compared with 2m for the generic fragility curve in Figure 4.19).

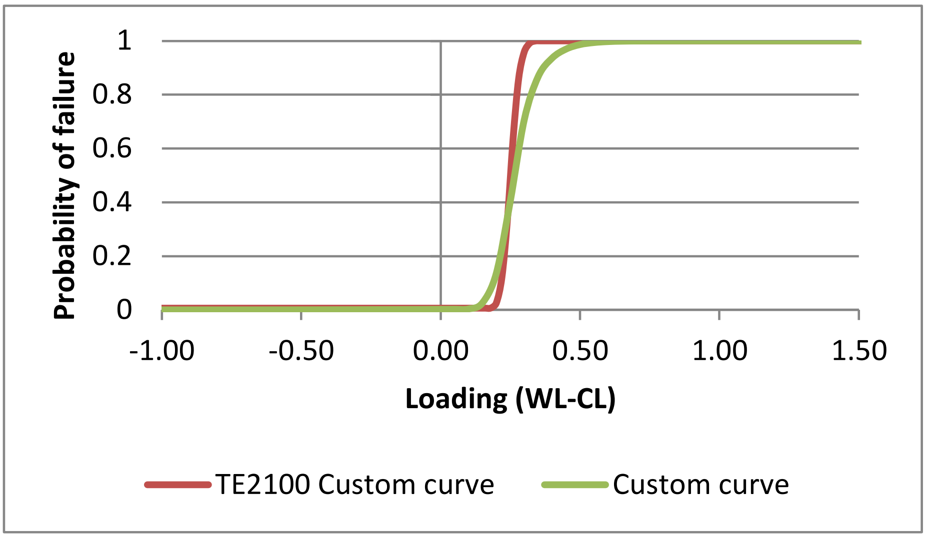


Figure 4.20 Comparison of TE2100 custom fragility curve with the one obtained by the tool

Comparison of estimated risks

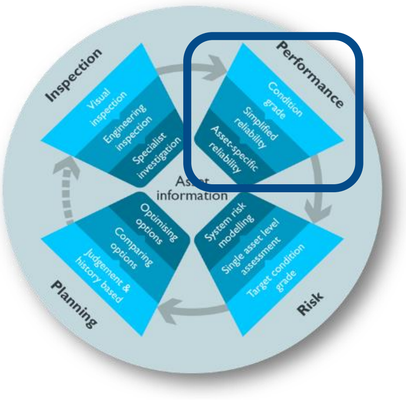
In Canvey Island, the existing defences are designed to withstand loading conditions corresponding to very large events (with return periods up to 1,000 years) with a minimum freeboard of 0.30m. Figure 4.20 shows that, for freeboards of 0.3m, the probabilities of failure in both curves (TE2100 and custom) will be essentially zero and only for very large events will probabilities of failure be significant.

The modification of the fragility curves in TE2100 did have an impact on the risk estimations because large events, with return periods up to of 10,000 years, were considered in the study. The current national MDSF2 system performs risk estimations up to events with a 1,000 year return period and therefore it is not able to estimate the risks in the range of events (with a higher return period greater than 1,000 years) that may have an impact on the defences of Canvey Island analysed in this example.

Conclusions

In the case of the identified Canvey Island defences, the Custom Fragility Curve tool could reproduce the specific fragility curves developed for that asset. Although there are some differences between the custom and the generic fragility curves, these differences will only be encountered on the most extreme of loading conditions (return periods greater than 1,000 years). Given the nature of the defences in this location, such differences are likely to have a very low impact on calculated risk using a probabilistic modelling technique.

4.2 Conveyance guidance and Vegetation and Roughness tool case studies



Four case studies are presented in this section in order of increasing complexity (Table 4.7).

Table 4.7 Summary of example case studies

Case study	Tier	Tools used
Estimating water levels with and without vegetation cutting (Section 4.2.1)	Simplified	Vegetation and Roughness tool
Effectiveness of additional dredging on the Somerset Levels and Moors (Section 4.2.2)	Simplified to screen sites, then Detailed	Hydraulic models (Flood Modeller and TUFLOW)
Dredging activities in the River Kent in Cumbria (Section 4.2.3)	Medium/Detailed	CES and hydraulic model with mobile bed
Assessment of maintenance options in Great Eau (Section 4.2.4)	Detailed	Hydraulic model (Flood Modeller) and MDSF2

4.2.1 Estimating water levels with and without cutting

This example assumes that, due to a change in priorities, there is pressure to reduce maintenance spend on channels in a catchment. The Vegetation and Roughness tool is used to investigate:

- what the impact of reducing the frequency of vegetation cutting would be
- which channels would be least sensitive to changes in the maintenance regime

This is a simple method requiring minimal data. The data entered consist of:

- typical bed width, channel depth, bank slope and channel gradient
- channel sediment material type
- vegetation type and extent
- option for vegetation cutting (cutting of vegetation on bed and/or banks)

The tool is then used to produce results from which changes in water levels at specific flows can be extracted (Table 4.8). Knowing the bank top levels and properties protected, the asset manager can then make a rough assessment of the impact of these changes on flood risk. The method used does not account for any backwater effects (for example, from bridges or weirs) and assumes steady flows.

Table 4.8 Illustrative example showing results of analysis to assess cutting impact on water levels

Return period	Flow (m^3/s)	Water level (m)	
		No cutting	With cutting
1:2	4.1	10.1	10.0
1:30	5.6	10.8	10.6
1:100	8.2	11.3	11.0

4.2.2 Effectiveness of additional dredging on the Somerset Levels and Moors

Area of study

The Somerset Levels and Moors is a large low-lying area in south-west England. Following the major flooding in 2013 to 2014, 8km of the rivers Tone and Parrett were dredged. Further dredging is being considered as part of the 20 Year Flood Action Plan (Environment Agency 2014b).

Purpose

The Environment Agency carried out an assessment of the effectiveness of further dredging at 10 potential locations in order to:

- better understand the benefits of further dredging
- be able to prioritise any further dredging

The 10 sites were selected using a simplified approach based on expert judgement and stakeholder views on where a lack of dredging was thought to be a direct cause of increased flood risk (Environment Agency 2014b). A detailed tier assessment was then undertaken for the 10 sites.

Tools used

The main tools used for the detailed assessment were linked one-dimensional (Flood Modeller) and two-dimensional (TUFLOW) hydraulic models. A rapid assessment was possible because hydraulic models already existed for most of the required sites. 'With' and 'without' dredging simulations were made for the historic event and design events. Results were extracted for the impact on both in-channel water levels and flood extents.

Results obtained

The impact of the simulated dredging at the 10 sites was assessed in terms of:

- flood risk benefits (properties not flooded and change in flood duration)
- water level management benefits
- environmental benefits

An effectiveness ranking was derived for each site based on impacts and expected costs. This information is shown in Table 4.9 for the 5 highest priority sites.

Assessment of the approach

The approach involved an initial screening of locations using a simplified approach, followed by a detailed approach that made use of existing one- and two-dimensional models.

The assessment of benefits, negative impacts and costs was made at a high level using available information and expert judgement appropriate to prioritise the sites. Further analysis would be necessary to support implementation.

Table 4.9 Example assessment impacts of further dredging

Site	Scale	cost	Flood risk benefits		Water level management benefits	Increased risk of flooding	Environmental Benefits	Effectiveness
			Properties	Duration				
Parrett: North Moor Pumping St to M5 bridge 3.2km)	small/med	med/high	up to 20 properties	reduced duration of up to 20 days for 25 -35 properties	Reduced duration of floods - may reduce agricultural damages (particularly applies to spring/summer floods in this area as experienced in 2012) Maintenance dredging will enable compliance with WLMP/Favourable Condition status to achieve required seasonal levels.	low/medium	medium	1
Tone: Ham to Hook Bridge (6.9km)	large	high	fewer than 5 properties	reduced duration of up to 2 days in some moors, properties and A361	Reduced duration of floods - may reduce agricultural damages (particularly applies to spring/summer floods as experienced in 2012) Maintenance dredging will enable compliance with WLMP/Favourable Condition status to achieve required seasonal levels.	low	low	2
Parrett: Langport to Tone confluence (7.8km)	large	high	no change	reduced duration up to 2 days at Westover Trading Estate and Thorney properties	Reduced duration of flooding in some moors - may reduce agricultural damages. Maintenance dredging will enable compliance with WLMP/Favourable Condition status to achieve required seasonal levels.	medium	medium	3
Glastonbury Millstream (4.3km)	small	low	no change	no reduction to duration of property flooding	Potential benefits for improved summer water supply/drainage to adjacent agricultural land. Funded by IDB precept.	low	low	4
Parrett: Thorney to Langport (6.2km)	small	medium	no change	reduction in duration up to 2-4 hours for properties at Westover Trading Estate	Increased capacity of channels may allow earlier pumping. Maintenance dredging will enable compliance with WLMP/Favourable Condition status to achieve required seasonal levels.	low	low	5

4.2.3 Dredging activities in the River Kent in Cumbria

Area of study

The River Kent in Cumbria is a gravel bed river. It is heavily modified through:

- mining in the upstream sections
- weirs and other control structures in the middle and lower reaches
- a flood alleviation scheme in the town of Kendal

As a result of high coarse sediment loads, shoals develop frequently in the flood alleviation scheme in Kendal (Figure 4.21) and are routinely removed.

Figure 4.21 Large gravel shoal in the River Kent

Purpose

The study was part of the River Sediments and Habitat Project. This aimed to improve the understanding of the interaction between sediments, habitats and channel management actions (Environment Agency 2011). The study assessed the impacts of sediment removal on flood risks.

Tools used

The study used a one-dimensional hydraulic model with mobile bed capability and the CES, which provides more detailed information on the lateral variation in flow depths and velocities.

Results obtained

The hydraulic model provided an understanding of the variations in water depth, flow velocity and shear stresses over an annual cycle. The maximum, 75th percentile, mean, 25th percentile and minimum values were determined for each variable (including the standard deviation of the variables) (Figure 4.22).

The hydraulic modelling, supported by field observations and monitoring, showed that the bar growth within the channel does reach a point where it becomes self-regulating and does not compromise the standard of defence of the flood alleviation scheme.

However, this was dependent on sufficiently high flows occurring to reduce the onset of vegetation colonisation.

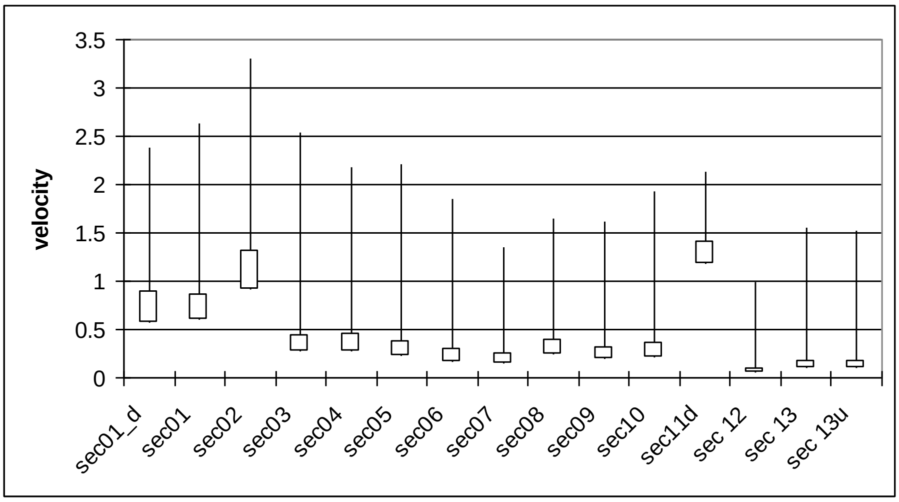


Figure 4.22 Longitudinal variation in velocity along the different cross-sections of the River Kent

Notes: From upstream section 13 to downstream section 01

Assessment of the approach

Sensitivity tests using hydraulic sediment modelling were useful to define an adaptive management routine. In this case, partial sediment removal at key points was considered to see whether this would provide an opportunity to achieve a balance between improved ecological status, while maintaining the standard of defence and ensuring the integrity of flood defences in downstream reaches.

4.2.4 Assessment of maintenance options in Great Eau

Area of study

Great Eau in Lincolnshire is a predominantly fluvial and rural catchment with almost all the land dedicated to agriculture. It therefore has many drainage channels and ditches. The study covers approximately 15km of the Great Eau River from the river mouth in Saltfleet to Withern. The case study also includes the Long Eau River from Manby to the confluence with the Great Eau River (about 8km). Flood defences in the area are mainly turf-protected embankments.

Purpose

The objective of the case study was to estimate the influence of different maintenance scenarios (Table 4.10) on the risk of flooding, primarily as a result of their impact on river conveyance. The study was part of the PAMS project (Defra and Environment Agency 2009a, Defra and Environment Agency 2009b, Environment Agency 2009) set up to develop, test and document a suite of methods and tools that could deliver step-by-step improvements in the way flood and coastal defence assets are managed.

Tools used

The study used a one-dimensional hydraulic model, Flood Modeller, to quantify the changes of water levels in the channel and MDSF2 type tools to estimate the risks and economic damages involved with the different maintenance scenarios considered.

Results obtained

The study followed the steps defined in Figure 3.7.

Ten management scenarios were defined (Table 4.10) and analysed with the hydraulic model, calculating water levels associated with different return periods. As an example, Figure 4.23 presents water levels obtained from the hydraulic model for some of the scenarios.

Table 4.10 Scenarios considered in the hydraulic model

Scenario	Vegetation management	Other management works
1	Business As Usual	–
2	Business As Usual	Lowering of 300mm in Great Eau
3	Business As Usual	Increase of 20% in capacity of pumps
4	Business As Usual	Increase of embankment crest in some reaches of Great Eau
5	Do Nothing	–
6	Do Nothing lower tidal reach	–
7	Increased Maintenance	–
8	Increased Maintenance in the upper reach, considering 2 cuts per year at 80%	–
9	Business As Usual	Lowering of 300mm in Great Eau + neap tide as boundary condition
10	Business As Usual	Raise of 300mm in Great and Long Eau
11	Business As Usual	– (same as scenario 1 but using neap timed as boundary condition)

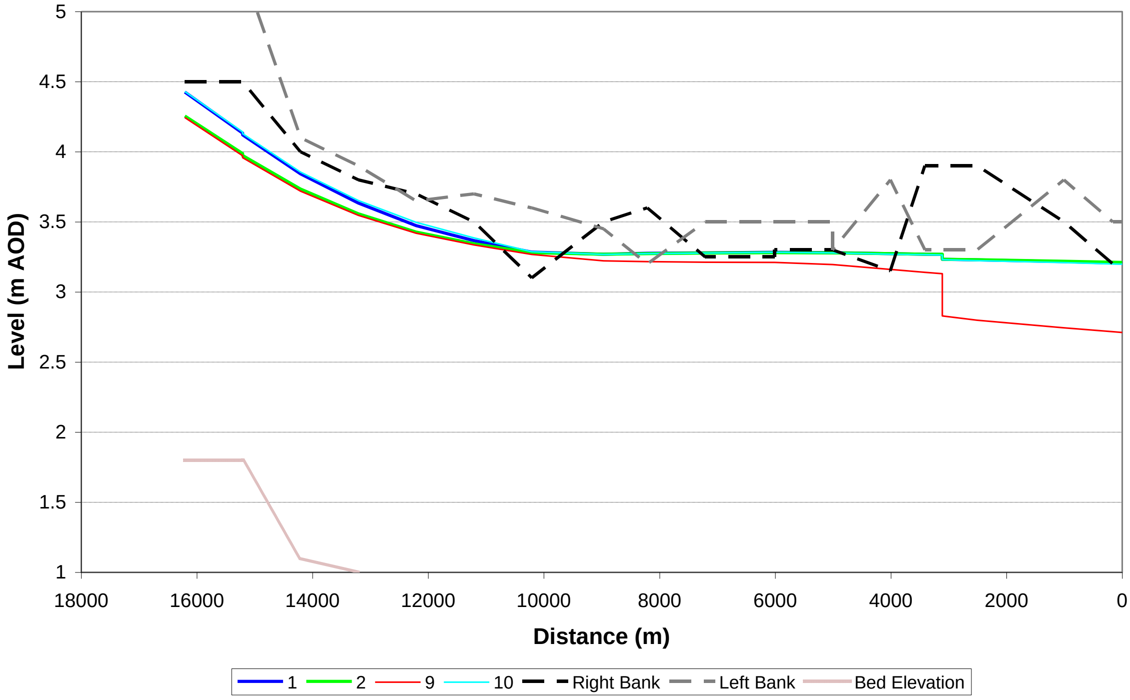


Figure 4.23 Water levels for the 100-year return period event for the Business as Usual (option 1) and different dredging options (2, 9 and 10)

Probability of inundation maps (Figure 4.24) and EAD maps were produced. The results from the latter are summarised in Figure 4.25.

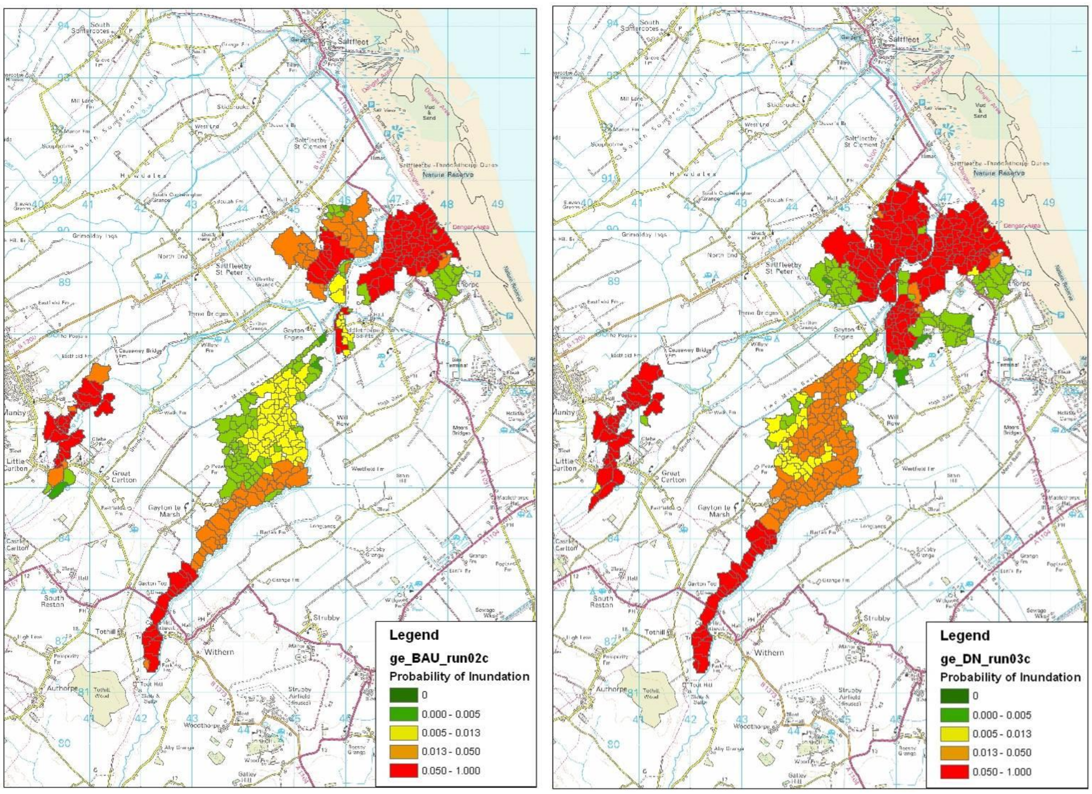


Figure 4.24 Probabilities of inundation in the Business as Usual (left) and Do Nothing (right) scenarios

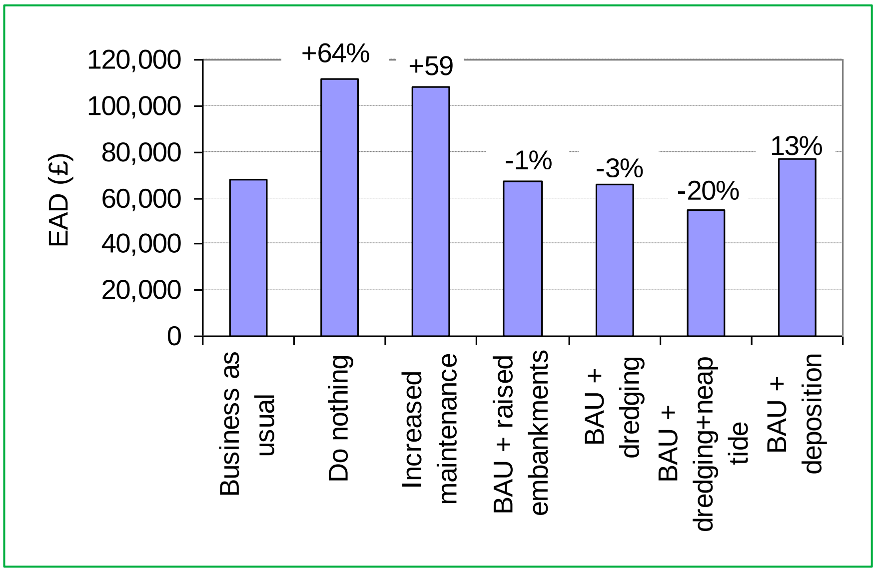


Figure 4.25 Comparison of EAD for the different management scenarios

Notes: BAU = Business as Usual

Assessment of the approach

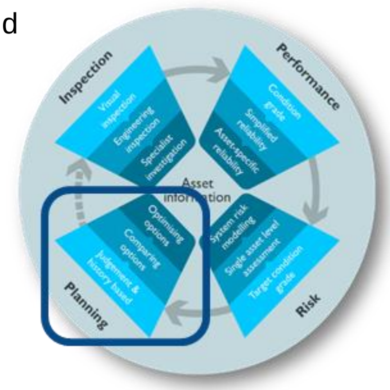
Use of the more detailed tier tools was necessary to capture the complexity of the Great Eau system. They were able to appropriately describe the 'flow-dominated' upper reaches of the watercourse, where conveyance management had a much bigger impact than in the lower reaches, which were 'storage and tidal dominated'.

The results highlighted the strong interaction between the upper and lower reaches, and the possibility of transferring flooding problems from one area to another due to variations in the maintenance strategy. This finding emphasised the need for a system-approach rather than an assessment based on tools applied at local level.

The estimation of probabilities of inundation with a MDSF2 type tool was extremely useful to assess the influence of boundary conditions (spring and neap tide levels) on channel capacity.

The use of these tools required expert knowledge and resources.

4.3 Raised defence target condition whole life cost appraisal tool case study



This case study uses the Whole Life Cost tool to understand and identify the least whole life cost maintenance options for a flood defence asset. It focuses on a flood defence at Canvey Island in Essex.

The asset has an effective crest height of 6.7m and a design standard of protection of 1 in 1,000 years. In AIMS, the 384m long asset is described as a vertical wall of brick, masonry and concrete. An aerial view of the asset shows that the landward sloped face is vegetated and grassed over. Other details of the asset from AIMS are provided below:

- Exemplar 2: Embankment with sheet pile or concrete crest wall

- rasp_026_type_5_cp_conc (42)
- AIMS ID: 165843
- Location: The Point – Thorney Bay. Canvey South – Beach

The target condition grade for the defence is 2 and at an inspection the worst condition element of the defence was described at condition grade 4.

The defence protects many properties. The probability of breaching, overtopping and the consequences of failure are important considerations, but are not examined using the Whole Life Cost tool.

4.3.1 Defining the asset in the Whole Life Cost tool

The asset was entered in the tool as a vertical wall made of concrete. The tool suggested that the dominant failure modes were likely to be scour leading to undermining and rotational slip. An engineering review confirmed these were representative of the likely failure modes. If this had not been the case, it may not have been appropriate to continue the assessment using this toolkit.

The exposure environment was selected as 'Coastal/Estuarine' and the 'clearing method' set to 'Manual'. A summary of the guidance on the exposure conditions suggested that the fastest rate of deterioration should be selected because:

- the beach level may vary
- the sediment material may be coarse (abrasive to the concrete)
- it is a saline environment

For the purposes of the assessment, the wall was set as 'narrow' and 8m high. The current condition grade was set at 2 to represent the weighted condition and the poorest allowable condition at 3.5.

Using the selections described, the tool suggested an asset value (based on substantial refurbishments/replacements) of £3 million. If used for analysis outside this case study, this value should be confirmed using an alternative costing methodology.

4.3.2 Examining maintenance options

Establishing the baseline

The baseline whole life costing assumed that:

- the defence would be refurbished or replaced when it had deteriorated to condition grade 3.5
- the asset is subject to Annual Maintenance Regime 1, the lowest standard of annual maintenance (Figure 4.26)

All analyses were made over the same 100-year time horizon using standard long-term discounting assumptions. The total whole life cost was estimated to be £4.184 million and 5 asset renewals over the analysis period were forecast.

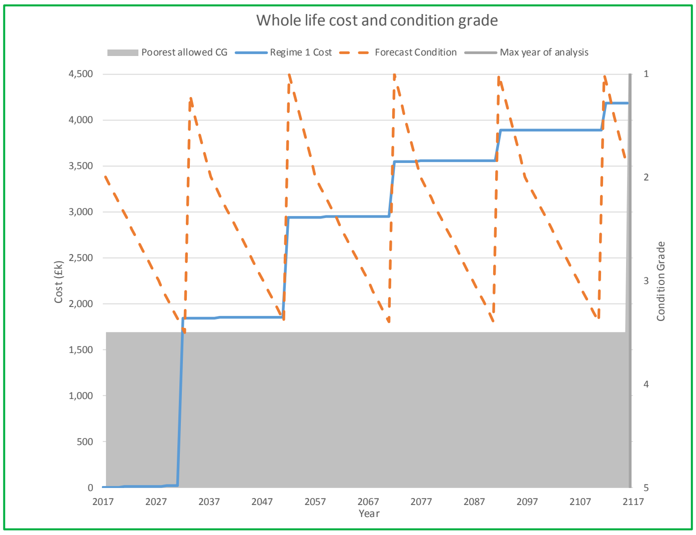


Figure 4.26 Annual Maintenance Regime 1

Considering different maintenance regimes

The whole life cost of the defence was assessed for Annual Maintenance Regimes 2 and 3. An investigation of Annual Maintenance Regime 2 (Figure 4.27) showed 4 refurbishments or replacements over the time horizon at a whole life cost of £3.591 million. Annual Maintenance Regime 3 (Figure 4.28), the highest standard of annual maintenance, showed a total whole life cost of £3.020 million and 3 refurbishments or replacements forecast.

The analysis indicated that Annual Maintenance Regime 3 would result in the lowest whole life cost (by approximately 28% compared to Annual Maintenance Regime 1), with 3 major refurbishments or replacements forecast over the 100-year analysis period.

Figure 4.27 Annual Maintenance Regime 2

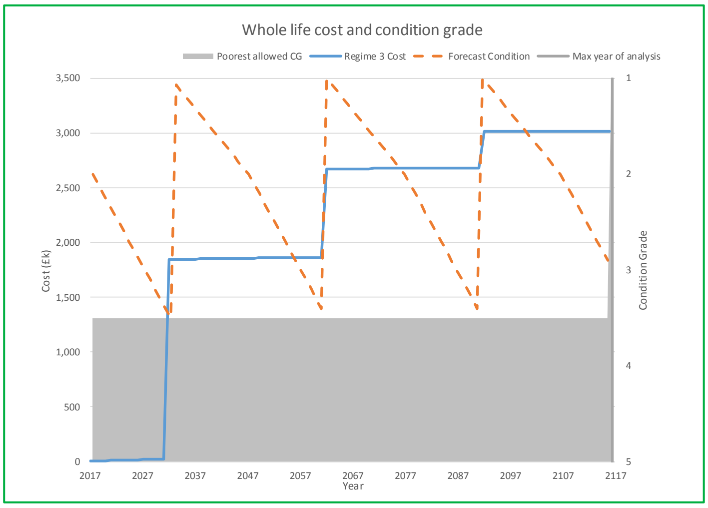


Figure 4.28 Annual Maintenance Regime 3

A comparison of the condition profiles that were achieved for the different Annual Maintenance Regimes and the discounted 100-year whole life cost is given in Table 4.11. There is a trade-off between the whole life cost and the condition of the asset over the analysis horizon. In this analysis, the lowest total whole life cost also has the most favourable condition profile based on a count of the number of years where the asset is forecast to be in more favourable condition grades (23 years in condition grade 1, 41 years in condition grade 2 and 35 years in condition grade 3). The next section considers whether intermediate minor or major maintenance/refurbishment activities could reduce the whole life cost further.

Table 4.11 Comparison of condition over whole life cost for alternative Annual Maintenance Regimes

Number of years in condition grade[1]	**Annual Maintenance Regime**		
	1 (baseline)	**2**	**3**
1 (1 and <1.5)	14	19	23
2 (≥1.5 and <2.5)	35	40	41
3 (≥2.5 and <3.5)	50	40	35
4 (≥3.5 and <4.5)	1	1	1
5 (≥4.5 and ≤5)	0	0	0
Total number of years	100	100	100
Whole life cost (100-year discounted in millions)	**£4.184**	**£3.591**	**£3.020**

Notes: [1] Condition grades range from Very good (1) to Very poor (5).

Considering refurbishments and intermediate minor and major maintenance

The analysis of alternative regimes indicates that Annual Maintenance Regime 3 (the highest standard of annual maintenance) would provide the least whole life cost and most favourable condition profile. This section considers whether intermediate maintenance or refurbishment could provide a more favourable profile of cost and condition.

The Whole Life Cost tool enables the user to investigate potential interventions to improve the condition and extend the life of an asset. Users can select points in the life of the asset, at specific condition grades and then the number of years by which the life of the asset may be extended.

Within the tool, there is a predefined relationship that makes an estimate of the cost associated with the intervention, though the user is encouraged to review and challenge the assumptions. It is possible to assess many combinations of intermediate maintenance or refurbishments, and the tool provides a semi-automated process for finding the least whole life cost options.

Table 4.12 shows the findings from the automated analysis where combinations of life extension in 5-year steps were trialled, as the asset moved into condition grade 2 and condition grade 3. The analysis returned whole life cost values between £2.901 million (10 time extensions to condition grade 2 and none to condition grade 3) and £3.605 million (15 time extensions to condition grade 2 and 10 to condition grade 3). The whole life cost of £2.901 million is about 4% lower over the whole life compared with the replacement/refurbishment at the condition grade 3.5 profile identified previously.

Table 4.12 Comparison of intermediate maintenance/refurbishment options

		Time extension in years into condition grade 3			
		0	**5**	**10**	**15**
Time extension in years into condition grade 2	**0**	£3,020,690	£3,372,830	£3,392,810	£3,137,720
	5	£2,976,720	£2,917,490	£3,068,110	£3,254,060
	10	£2,900,500	£3,021,880	£3,414,720	£3,320,120
	15	£3,155,120	£3,423,280	£3,605,460	£3,293,730
Minimum whole life cost					**£2,900,500**

The condition and cumulative whole life cost profiles are shown in Figure 4.29. The extensions to asset life can be seen as the asset moves from condition grade 2 to condition grade 1.4. Furthermore, the intermediate intervention would be required almost immediately. The intermediate interventions to extend the asset life have reduced the number of replacement/refurbishments to 2 – rather than 3 – over the analysis horizon.

The reduction in whole life cost has an associated reduction in the average condition over the analysis horizon. This is can be seen in Table 4.13, which shows that the least whole life cost intervention regime results in the asset being in a poorer condition grade (3) for longer (that is, 48 years compared with 35 years). The weighted average condition grade over the 100-year planning horizon is 2.39 compared with 2.14.

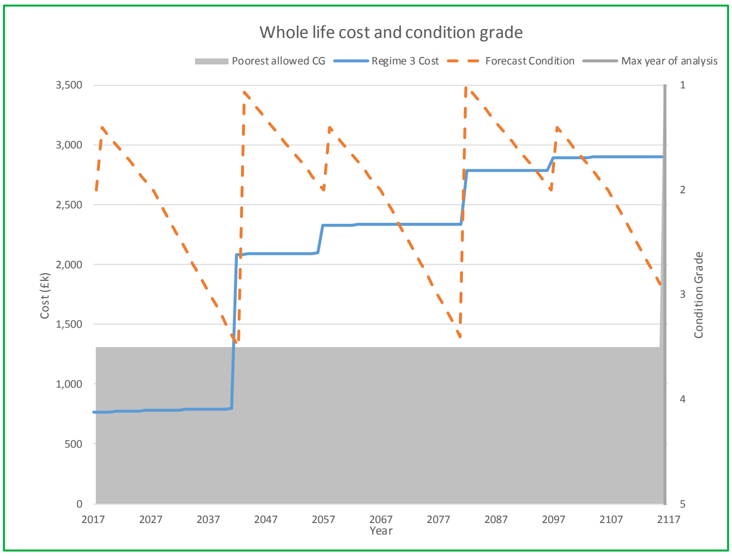


Figure 4.29 Least whole life cost with intermediate interventions

Table 4.13 Comparison of condition for least whole life cost option

Number of years in condition grade	**Intervention option**	
	Annual Maintenance Regime 3 with replacement/ refurbishment at condition grade 3.5	**Annual Maintenance Regime 3 with replacement/refurbishment at condition grade 3.5 and intermediate refurbishment/ maintenance to produce 10 year life extension at condition grade 2**
1 (1 and <1.5)	23	11
2 (≥1.5 and <2.5)	41	40
3 (≥2.5 and <3.5)	35	48
4 (≥3.5 and <4.5)	1	1
5 (≥4.5 and ≤5)	0	0
Total number of years	100	100
Whole life cost (100-year discounted in millions)	**£3.020**	**£2.901**
Average weighted condition grade	**2.14**	**2.39**

4.3.3 Examining forecast sensitivities

The analysis process first identified the Annual Maintenance Regime with the least whole life cost and then looked at a series of intermediate refurbishment/maintenance activities to extend the life of the asset to achieve a slightly lower whole life cost (by 4%). The trade-off for the reduced whole life cost was quantified in the context of slightly poorer average condition over the analysis horizon. This poorer condition may have an impact on flood risk.

The analysis used the generic model assumptions to make the forecasts. A sensitivity analysis is recommended to understand the impact of the model assumptions on the decision. Tools such as the Whole Life Cost tool are designed to support decisions rather than make them – user judgement and experience are important in the decision-making process.

It is important not to over-state the precision with which long-term forecasts can be made in the context of the inherent uncertainties that exist. The Whole Life Cost tool is best used to identify where clear and material differences between different maintenance and refurbishment options can be identified.

Compared with the baseline maintenance assumption of the lowest standard of annual maintenance, the model forecasts that adopting the highest annual maintenance standard will save approximately 28% over the analysis period. In comparison, the 4% saving identified by adding intermediate refurbishment/maintenance activities at condition grade 2 can be described as insignificant. Table 4.14 shows the impact on the whole life cost forecasts of the intermediate refurbishment/maintenance activities cost ±10% of the modelled assumption.

The intervention to provide a life extension of +10 years, moving from condition grade 2 to 1.4, was forecast by the tool to cost £0.763 million. If it actually costs ±10% of the expected cost, the cost would be £0.839 million and £0.683 million respectfully. The difference in whole life cost compared with the expected cost is shown in Table 4.14.

The analysis shows that, if the cost of the intermediate refurbishment/maintenance at condition grade 2 was +10% more (column E), the total whole life cost would be very similar to not undertaking the intermediate intervention (column C). If the cost of the intermediate maintenance was 10% less (column F), there would be a more significant whole life cost benefit, but the average weighted condition is still less favourable than the just Annual Maintenance Regime 3 option (column C).

Table 4.14 Comparison of findings

	Annual Maintenance Regime			**Least whole life cost with intervention to extend life by 10 years**		
	1 (baseline)	**2**	**3**	**(10,0)**	**(10,0) + 10%**	**(10,0) – 10%**
	A	**B**	**C**	**D**	**E**	**F**
Whole life cost	£4.184 million	£3.591 million	£3.020 million	£2.901 million	£3.010 million	£2.790 million
Difference compared with baseline	0%	-14%	-28%	-31%	-28%	-33%
Average weighted condition grade	2.38	2.23	2.14	2.90	2.90	2.90

4.3.4 Conclusions

Use of the Whole Life Cost tool enables different Annual Maintenance Regimes and intermediate refurbishment and maintenance options to be assessed. Implementing the highest level of Annual Maintenance Regime saves about 28% compared with the defined baseline.

Applying the tool to identify the least cost intermediate interventions identified that a 10-year life extension applied at condition grade 2 (equivalent to improving the condition from 2 to 1.4) could reduce the total whole life cost by a further 4%. However, the trade-off for this small reduction in whole life cost was that the asset was forecast to spend longer in poorer condition grades.

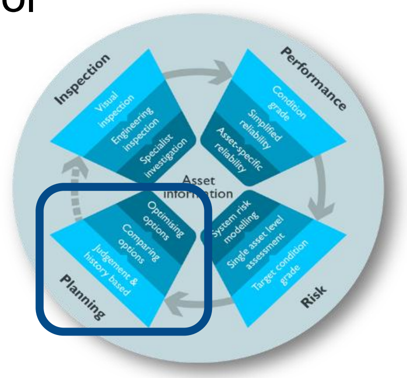
An assessment of the sensitivity of the cost of the intermediate interventions in the least cost solution showed that a 10% increase in intervention costs would negate any benefit when compared with the profile without intermediate interventions.

Given the sensitivities to the cost of the intermediate refurbishment/maintenance activities and the poorer overall condition that may results from the intervention profile, it is concluded that the first intermediate intervention may not be worthwhile as the change in whole life cost is not significant.

Subject to an assessment of flood risk associate with allowing the asset to deteriorate to condition grade 3.5, it is recommended that:

- the asset is maintained as the highest level of annual maintenance to slow the deterioration processes
- a whole life cost analysis is repeated in the future using information that subsequently becomes available with the intention of improving the analysis certainty

4.4 Beach performance assessment tool case studies



Three case studies are presented for setting trigger levels for beach management actions at the following locations:

- Torcross, Devon (Section 4.4.1)
- Walcott, Norfolk (Section 4.4.2)
- Eastbourne, East Sussex (Section 4.4.3)

Please refer to the separate report, Asset Performance Tools: Guidance for Beach Triggers (SC140005/R5), for good practice guidance on setting trigger values for different beach types and their functions.

4.4.1 Case study: Torcross, Devon

Beach type:	Type I – Beach with a structure behind
Beach functions:	Ia – Protect the toe of the structure from undermining
	Ib – Reduce wave overtopping
	Ic – Reduce the wave loading on the structure

The case study describes the setting of trigger values for the beach type and its functions with reference to the good practice guidance (report SC140005/R5).

Context

Torcross is a village in the South Hams District of Devon. It is located at the southern end of Slapton Sands, a narrow strip of back barrier marsh and shingle beach which separates the freshwater lake of Slapton Ley from Start Bay, and carries the A379 coastal road north to Dartmouth (Figure 4.30). A number of properties are located within this strip of land, between the road and the beach, protected against the action of the waves by a seawall and promenade that extend along approximately 320m (Figure 4.31). Net annual longshore transport is toward the north.

Figure 4.30 Location plan for Torcross

Figure 4.31 Aerial photograph of the beach at Torcross, fronting a number of properties and road

The seawall was constructed in 1980. From sea to land, it consists of a sheet piled wall with capping beam, a grouted rock revetment and a reinforced concrete wave return wall. Figure 4.32 shows details of the cross-section of the seawall and Figure 4.33 shows a photograph taken looking across the beach and seawall.

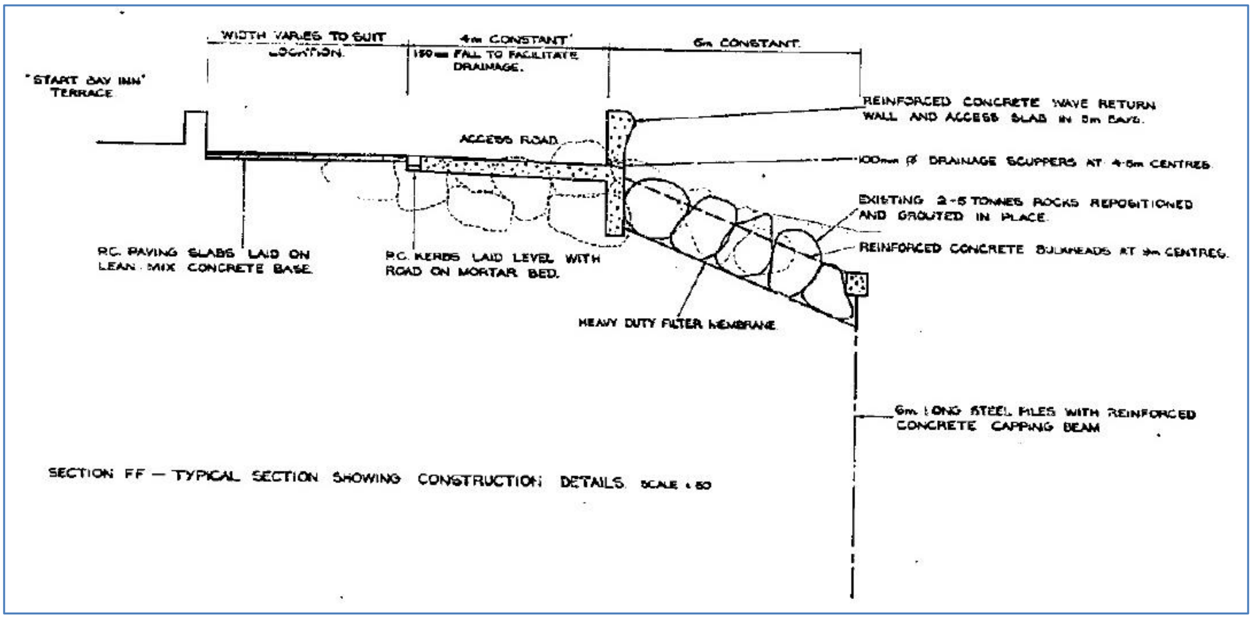


Figure 4.32 Selected details of the seawall and promenade fronting Torcross Beach

Figure 4.33 Photograph taken looking north across the beach at Torcross

Notes: The sheet piled wall at the toe to the seawall can be seen to be partially exposed. Source: Google Earth Pro

The piling is frequently exposed at Torcross during storms (see Figure 4.33), but the beach level recovers naturally to some degree during the following weeks or months. However, the storms in winter 2013 to 2014 resulted in a significant reduction of sediment in front of the structure. Regular monitoring of beach levels in subsequent months showed that sediment levels had not recovered as much or as quickly as anticipated before heading into autumn. Given the surplus of beach material available at the northern end of Slapton beach, a decision was made to replenish levels by transporting shingle; the works took place before the 2014 winter.

In early 2016, the seawall suffered some storm impact movement and a 30mm movement crack appeared behind the structure. Repair works have been proposed, with the preferred option consisting of a new steel sheet piled wall, 0.5m in front of the existing defence to a depth of ~12.0m.

Both recent incidents suggest that the area could benefit from a beach management regime based on beach performance and trigger levels. Such an approach could help to anticipate and to some extent prevent further damages to infrastructure and/or properties in Torcross.

Assumptions

The standard of protection (SoP) for the seawall is taken as a 1 in 50 per year event (2% annual exceedance probability, AEP), assumed to be against breaching. The related wave parameters assumed for this study based on data from the Start Bay's directional buoy for the period 2007 to 2015[3] are given in Table 4.15.

[3] Available from the Channel Coastal Observatory's website (www.channelcoast.org)

Table 4.15 Assumed wave parameters

Parameter	Value
Significant wave height for 1 in 50 year storm	5.4m
Extreme water level	3.2m
Mean wave period	4.5 seconds

Based on the information given in Table 4.15, a number of calculations were made for use in the case study, including the following.

- A wave length was assumed to be 1.5 times the square of the wave period, that is, approximately 30m.
- Based on available data, the average beach level over a wave length was assumed to be –0.5m Ordnance Datum Newlyn (ODN). Therefore water depth (d) under extreme water levels is assumed to be 3.2 – (–0.5) = 3.7m, for the purposes of this assessment.

Functions of the beach and associated performance indicators

The beach at Torcross falls within the first type of beaches, that is, a beach with a structure behind. There are 3 potential flood and erosion risk management related functions for this type of beach. In the case of Torcross, the beach performs all of them:

- protect the toe of the structure against overturning
- limit overtopping over the structure
- limit wave loading against the structure

Table 4.16 lists the proposed direct and indirect performance indicators for these functions.

Table 4.16 Performance indicators for beach at Torcross

Function	Direct indicator	Indirect indicators
Ia: Protect the toe of the structure	Beach level (average near structure toe)	Beach volume, slope or width; wall exposure
Ib: Limit overtopping over the structure	Beach level (average over one wave length)	Beach volume, slope or width; sediment over structure
Ic: Limit wave loading against the structure	Beach level (average over one wave length)	Beach volume, slope or width; wall exposure

Ia: Setting trigger levels to protect the toe of the structure

The sediment of the beach supports the structure. Lowering of the beach can compromise the support of the structure and lead to seaward displacement or even overturning of the wall. The beach level in front of the structure is therefore a direct indicator for the stability of the structure.

How the beach protects the toe of the structure at Torcross

As shown in Figure 4.32, the seawall fronting Torcross incorporates a sheet piled wall that provides vertical and horizontal support to the structure over about 320m. The beach in its turn supports the sheet pile wall. Lowering of beach levels reduces this support directly, but in addition there is a risk of a feedback process causing further beach erosion. With beach levels low enough to leave the sheet piled wall exposed, waves are reflected against the sheet piled wall first, enhancing the scour of sediment. The seawall continues further north with a more conventional concrete buttress wall and rock armour for about 135m; this suffered from undermining in early 2016.

A geological report was produced in August 2016 as part of the repair works along the frontage in Torcross and showed strata layers approximately 7–12m deep of storm beach deposits, described as loose to dense brown sandy, fine to coarse gravel of mudstone, sandstone slate and flint with low cobble content. This type of sediment is non-cohesive. It therefore has limited resistance to lateral displacement and is easily erodible by the action of the waves. A beach level that is too low may contribute to the instability of the structure, and its eventual failure under wave loading and its own structural load.

This case study does not incorporate structural or geotechnical calculations. However, the fact that the proposed repair works consist of adding a deeper sheet piled wall (12m against the existing 5m) in front of the structure indicates the need for further structural support.

Setting trigger values

The method presented in the good practice guidance (report SC140005/R5) suggests using the average beach level over a beach width equal to 5 times the structure toe depth (in this case 25m) as the primary indicator to determine the trigger values. This is based on the part of the sand body that provides passive resistance to seaward structural deformation.

The CRISIS trigger (that is, signalling a direct need for intervention) for function Ia is the beach level beyond which the stability of the structure is compromised and emergency remedial action becomes necessary. The calculation should be based on good practice design rules for structural stability.

This case study does not include structural or geotechnical calculations, but makes use of available information and expert judgement. The double sheet piled wall support of the existing structure suggests that this critical level may be fairly low, at approximately –1m ODN.

The guidance suggests incorporating an additional allowance to account for the scour taking place during a storm. On scour in front of a seawall, the 'Toe Structures Management Manual' (Environment Agency 2006) recommends the use of a maximum allowance of 0.8 times the significant nearshore wave height for the SoP considered; this would mean 4.3m for a 1 in 50 per year event, and a minimum of 0.9m.

The difference between the estimated and observed CRISIS values suggests that an allowance of at least 1m should be considered; good practice described above indicates that a more appropriate minimum allowance would be 0.9m.

Therefore, the CRISIS trigger value advised for Torcross in relation to the function of protecting the toe of the structure is an average beach level over ~25m width of –0.1m ODN.

In the absence of stability calculations, actual past experience of damage to the structure is a good indicator in cases where it is available. At Torcross, evidence shows that the start of failure of the seawall occurred with 2–2.5m of sheet pile exposed (that is, 0m to +0.5m ODN). This is in the same order as the theoretical value estimated above.

Values for the ALARM trigger (that is, signalling a need to prepare for potential intervention) can be calculated by adding an additional margin of safety to the CRISIS value. This can be done using historical survey data. If historical profile survey data are available, it is possible to quantify the maximum beach level drop produced by a storm. The ALARM trigger value would be the result of adding that historical maximum difference between pre and post-storm beach levels to the CRISIS value.

At Torcross, the 2014 storm resulted in a drop in beach level of ~2.5m averaged over a width of 25m – see the light blue (September 2013) and orange (March 2014) plot profiles in Figure 4.34. This is the largest difference appearing in the historical records available. Accordingly, and assuming a CRISIS trigger value of –0.1m ODN, the ALARM trigger value for protection of the toe of the structure at Torcross is +2.4m ODN. This value equals the top of the sheet pile wall. It is interesting to note that survey data show that beach levels were below this value in December 2015 (profile plotted in red in Figure 4.34) before being hit by the early 2016 storms that caused damage to the seawall and the repair works mentioned above. Figure 4.34 also shows the profile of the beach after the recycling works carried out in early 2015 (green plot).

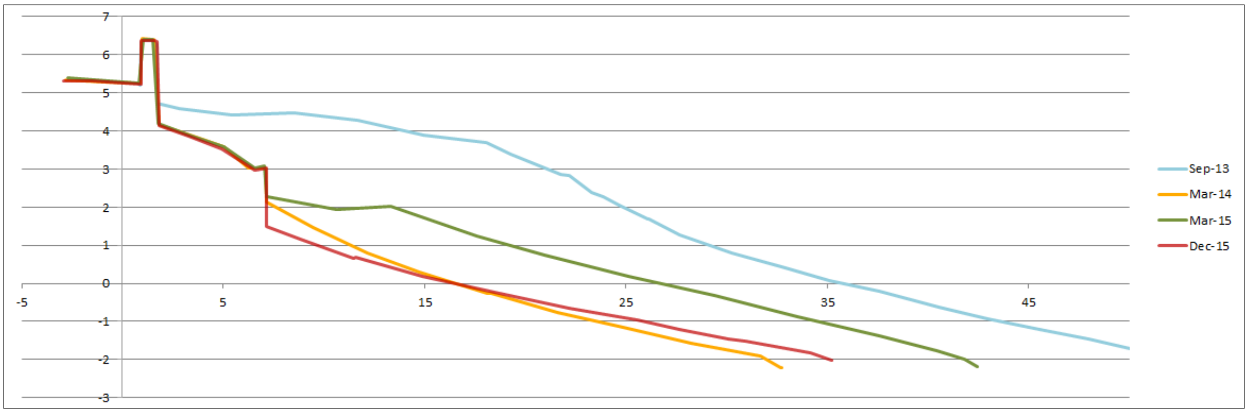


Figure 4.34 Survey data for profile 6b01319 fronting Torcross

Indirect indicators for protection of the toe of the structure

As long as the required beach level is present over the required width, the state of the beach further seaward does not influence structure stability directly. However, low beach levels further seaward can be a predictor for reducing beach levels in front of the sheet pile toe. This relates to 2 processes; a low seaward beach volume could induce transport of sediment from in front of the structure and/or lead to higher waves reaching the toe of the structure, causing toe scour. Other relevant indirect indicators can be beach volume, beach slope or beach width down to a particular tidal level. Each of these can be used, depending on available monitoring.

Survey data available for Torcross allow an assessment of the evolution of a number of these variables. Profiles plotted for different points in time are shown in Figure 4.35.

One of the most evident indicators in this case is the beach width down to mean sea level (0.34m at Torcross, represented as a red line in the plots in Figure 4.35). It is possible to see how the beach width declined considerably as a result of the sediment being washed away by the 2013 winter storms. The new narrow beach was not able to dissipate as much wave energy as before, leading to a drop in beach levels next to the wall even during summer months. This can be seen by comparing the plots for March 2014 and November 2014; although the beach narrowing is not very significant during this 8-month period, beach levels are ~0.4–0.5m lower at the toe of the structure. The results of the next survey (March 2015) show a wider beach as a result of the sand replenishment works carried out by the end of 2014. However, it only took a few months for the waves to wash away much of the added sediment and narrow the beach again. This left the beach levels at the toe more exposed resulting in a further 0.2–0.3m drop.

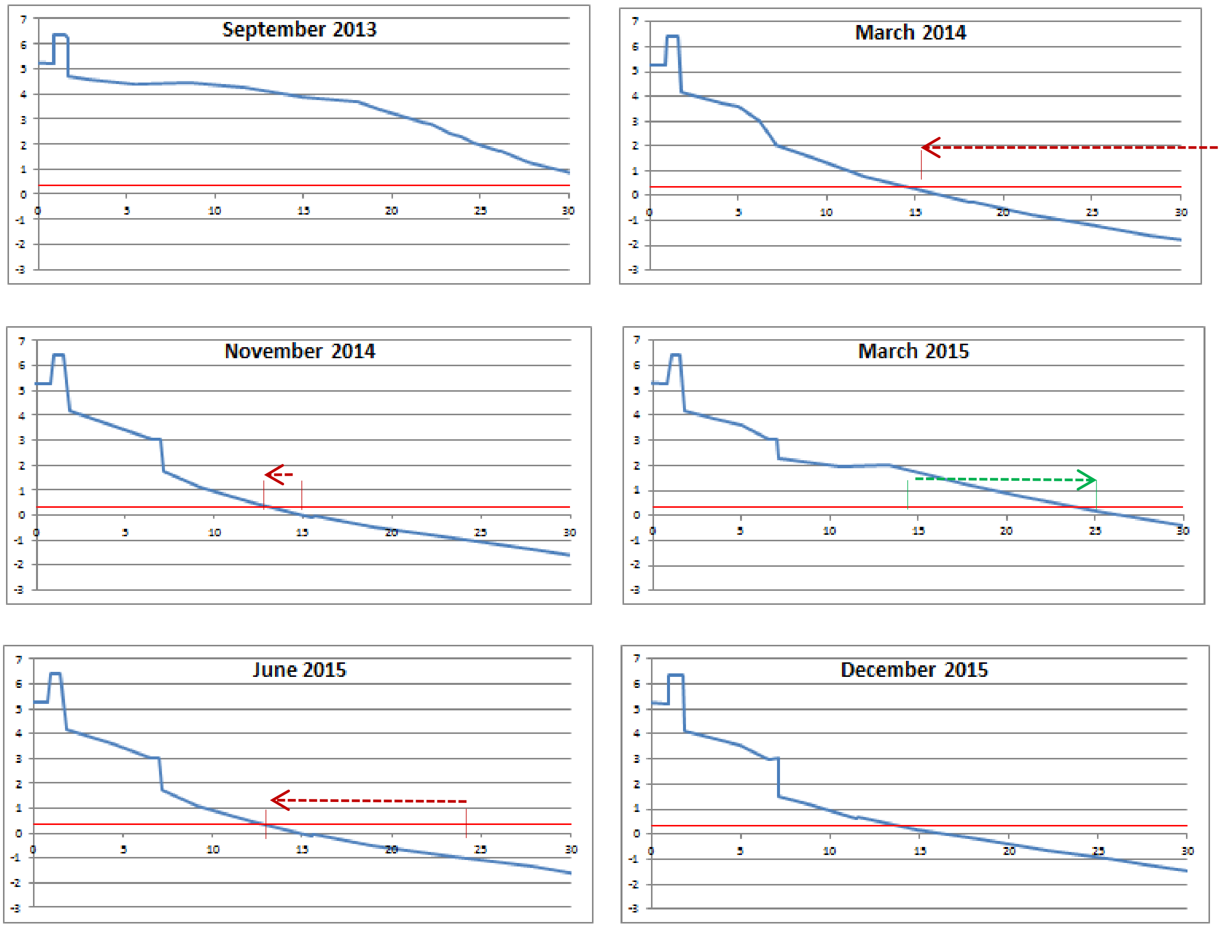


Figure 4.35 Survey data for profile 6b01319 – beach narrowing process

Notes: The red lines show the beach width down to mean sea level.
The blue lines show the beach profile at the time of the survey.

Ib: Setting trigger levels for reducing overtopping over the structure

Start Bay's directional buoy data indicate a mean period equal to 4.5 seconds. This leads to a wave length of ~30m. This is the length over which average beach levels will be considered; most available surveys at Torcross assess ≥30m from the seawall.

How the beach reduces overtopping in Torcross

The seawall provides protection against wave overtopping to the properties located along the strip of land of Slapton Sands. The energy of the waves reaching the frontage is dissipated by friction with the seabed and the beach, the concrete and rock revetment and the wave return wall.

An assessment of nearshore conditions carried out in 2014 compared how the difference between pre-storm (May 2013) and post-storm (March 2014) beach levels affected overtopping over the Torcross promenade.

Although the actual defence structure and defence crest is the dominant element in reducing overtopping, the modelling results show that overtopping rates due to long period waves for recurrent annual storms (for example, a 1 in 1 per year event) are significantly higher with a low beach level. The study also highlighted that beach levels have an influence on the way in which wave overtopping occurs. With a lower beach, berm wave action causes higher wave plumes above the crest of the wall, as a consequence of more energy reaching the structure. This could result in significantly greater overtopping if wave overtopping is backed by strong onshore winds.

One of the assessment's conclusions was that increasing beach levels would reduce overtopping.

Setting trigger values

The average beach level over a beach width equal to one wavelength is used as the primary indicator to determine the CRISIS trigger value. The trigger value is obtained through an iterative process, based on ensuring that overtopping discharges over the structure do not exceed tolerable values in storm events with the chosen probability of exceedance.

In this case, a serviceability criterion – for example, 10 litres per metre per second (l/m/s) in a 1 in 1 per year storm – could be used in combination with an ultimate limit state criterion (for example, 100l/m/s in a 1 in 100 per year storm). The goal of the iteration is to match the overtopping rate obtained under local wave and beach geometry conditions to the specified criteria. The iteration process can be carried out using the web-based EurOtop calculation tools; this resource was not available at the time of developing the case study but the process is described below.

For the applicable SoP, and assuming depth limited waves reaching the structure, the wave height (Hs) = 0.6 × d (in this case Hs = 0.6 × 3.7 = 2.22m) and the wave period (T) = 4.5 seconds. The overtopping rate (q) is calculated as follows:

- If $q < q_{tolerable}$, lower beach level by 0.5m (d′ = 3.7 + 0.5) and repeat calculation.
- If $q > q_{tolerable}$, raise beach level by 0.5m (d′ = 3.7 – 0.5) and repeat calculation.

The beach level that gives the closest to $q = q_{tolerable}$ is the minimum required average level over a width equal to one wave length. This is the CRISIS value.

ALARM trigger values are calculated by adding an adequate margin of safety to the CRISIS value. As described above, this can be done either based on historical data analysis – that is, adding a value equal to the largest historical beach level drop (~2.5m in Torcross to the CRISIS level – or by recalculating the value through iteration based on a higher SoP; in this case, a 1 in 500 per year event (0.2% AEP). Both approaches could be applied for Torcross, but this has not been elaborated at this stage.

Indirect indicators for wave overtopping

A good practical predictor for future reduction of average beach level is the development of beach volume in neighbouring frontages. However, it is difficult to quantify this relationship and connect it to ALARM and CRISIS levels as, in practice, this has to be based on local knowledge and judgement. This is therefore not examined in this case study.

Ic: Setting trigger levels for reducing the wave loading against the structure

How the beach level reduces wave loading against the structure at Torcross

The role of the beach in dissipating energy before waves strike the structure is outlined above. However, it is important to note that it is the beach level profile over a certain beach width that matters for wave loading and not just the level next to the structure. In order for the incoming waves to lose any significant energy, they need to be subject to friction from the seabed and beach over a width of at least one nearshore wave length.

Wave impacts on vertical walls are the most significant loads this type of structure can be subjected to. With a lower beach level, larger waves are able to affect the structure and produce significant pressures; in most of the formulae used to quantify the pressure exerted by a breaking wave against a vertical seawall (sheet pile section), the load is primarily dependant on wave height and water depth.[4] Significant wave height data for Torcross are presented in Table 4.15. The load applied to the seawall crest is internally transmitted to the whole concrete structure, resulting in compression–tension that may cause damage to the structure.

Setting a trigger value for wave loading on the structure

Average beach level over a beach width equal to one wavelength is used as the primary indicator to determine the CRISIS trigger value. As for function Ib above, the trigger value is obtained through an iterative process based on ensuring that wave loading on the structure does not cause damage to the structure in storm events with the chosen probability of exceedance.

If as-built information is available, the critical wave conditions will be equal to the design wave conditions if the condition of the structure has not changed significantly (for example, through deterioration) and the criticality of the seawall has not changed (for example, through housing development behind the structure).

In this case study, however, as-built data are not directly available. In which case, carrying out a structural assessment of the defence to estimate the applicable critical wave conditions is recommended. This is beyond the scope of this case study.

The damage occurred to the seawall as a result of storms in early 2016 included cracks and movement of the structure seawards that are likely to have compromised its structural integrity. Therefore a structural assessment of the defence in its current state would be recommended to inform the calculation of trigger values. For illustration purposes, this case study follows the process based on assumed values. The process is as follows.

1. Based on design/newly assessed data, estimate the maximum tolerable load that the structure could resist without being damaged (F_{max}).
2. Using the maximum tolerable load value and good practice formulae, obtain the critical significant wave height (H_{sc}). In this case, H_{sc} is assumed to be 4.0m.
3. Assume the critical depth (d_c) equals $H_{sc}/0.6$. In this case, $d_c = 4/0.6 = 6.6$m.
4. Calculate the beach level corresponding to the critical depth (h_c) = water level SoP – d_c. In this case, the extreme water level for a 1 in 50 per year event (2% AEP) is +3.2m ODN (Table 4.15). Therefore, $h_c = (3.2 – 6.6) = –3.4$m ODN.

The obtained beach level (-3.4m ODN) is the CRISIS trigger value for limiting or reducing wave loading to the structure. This value is lower than the actual depth of the

[4] BS 6349 Code of practice for marine structures

sheet piles (–3m ODN) and the structure is likely to fail due to structural stability before reaching that level. This suggests that, in this case, wave loading to the structure is not the dominant mode of failure – but of course this is based on an assumed value for H_{sc}.

ALARM trigger values can be calculated by adding an adequate margin of safety to the CRISIS value, either based on historical data analysis (2.5m) or by recalculating the value based on a higher SoP. Based on the assumption that wave loading is not the dominant mode of failure, the recalculation is not done in this case.

Indirect indicators for wave loading on the structure

As explained for function Ib, a good practical predictor for future reduction of average beach level is the development of beach volume in neighbouring frontages. However, this is difficult to quantify for the same reasons as given for function Ib and is beyond the scope of this testing exercise.

Conclusions

Torcross Beach plays an important role in 3 flood risk management related functions:

- protecting the toe of the seawall against undermining
- reducing overtopping over the seawall
- reducing wave loading against the seawall

Beach levels at Torcross vary significantly due to storm events and the sheet piled wall supporting the front of the structure is often exposed. Low beach levels have a direct influence on how the beach performs the 3 functions identified above. The storms in early 2014 and early 2016 caused significant beach loss and ultimately caused damage to the seawall structure. This suggests that the area could benefit from beach management practices based on beach performance and trigger levels.

The case study applied the methodology for setting trigger values developed for the AP Tools project. This methodology suggests that average beach levels over various widths are appropriate indicators for the various flood risk functions of Torcross Beach. Trigger values were determined as far as possible with available site-specific information. For CRISIS values, this is based in principle on good practice design rules; the case study shows that, in some cases, actual experience with asset performance during low beach situations provides useful additional evidence. ALARM values include a safety margin compared with the CRISIS value, which in the case of Torcross can be based on the maximum beach level drop from monitoring data.

Indirect indicators such as beach volume, beach width and slope are also suggested as they may help to predict beach variations down to a trigger value.

Table 4.17 lists the CRISIS and ALARM trigger values determined in this worked example.

Table 4.17 Determined CRISIS and ALARM trigger values for Torcross case study

Beach function	CRISIS trigger	ALARM trigger
Ia Protect the toe of the structure	–0.1m ODN	+2.4m ODN
Ib Limit wave overtopping[1]		
Ic Reduce wave loading on the wall	–3.4m ODN	–

Notes: [1] A full analysis was not possible because the EurOtop tool was not available, impeding calculation of trigger levels in relation to the beach function of reducing overtopping. For beach function Ib, an assumed value for critical wave height results in a CRISIS level of –3.4m ODN, a value lower than the actual depth of the sheet piles (–3m ODN). If confirmed through structural assessment of the seawall, this result suggests that wave loading to the structure is not the dominant mode of failure in this case.

4.4.2 Case study: Walcott, Norfolk

Beach type: Type I – Beach with structure behind

Beach function: Ia – Protect the toe of the structure from undermining

Ib – Reduce wave overtopping

Ic – Reduce the wave loading on the structure

The case study describes the setting of trigger values for the beach type and its functions with reference to the good practice guidance (report SC140005/R5).

Context

Walcott is a village in north-east Norfolk (Figure 4.36). A number of properties are located within the immediate hinterland, along with the B1159 coast road (Figure 4.37). The properties and road are protected from flood risk and coastal erosion by a seawall and promenade. The beach is further managed by groynes, typically at 100–150m centres and extending 80m seaward. The seawall ends at the south-east of the village, where the cliff is protected by timber breastwork and small groynes.

The seawall at Walcott was constructed in 1954 and consists of a sheet piled wall 6m long at a varying elevation. For the purposes of this assessment, the sheet pile wall is considered to be from 2.8m ODN down to –3.2m ODN. The sheet pile wall is topped with a capping beam. From seaward to landward, the seawall comprises a sheet pile wall with capping beam, sub-horizontal reinforced concrete deck, sloped reinforced concrete wall and concrete wave return wall. A detail of the cross-section of the seawall is shown in Figure 4.38 and a photo in Figure 4.39.

Figure 4.36 Location plan for Walcott

Source: Google Earth Pro

Figure 4.37 Aerial photograph of Walcott village taken in 2014

Source: Google Earth Pro

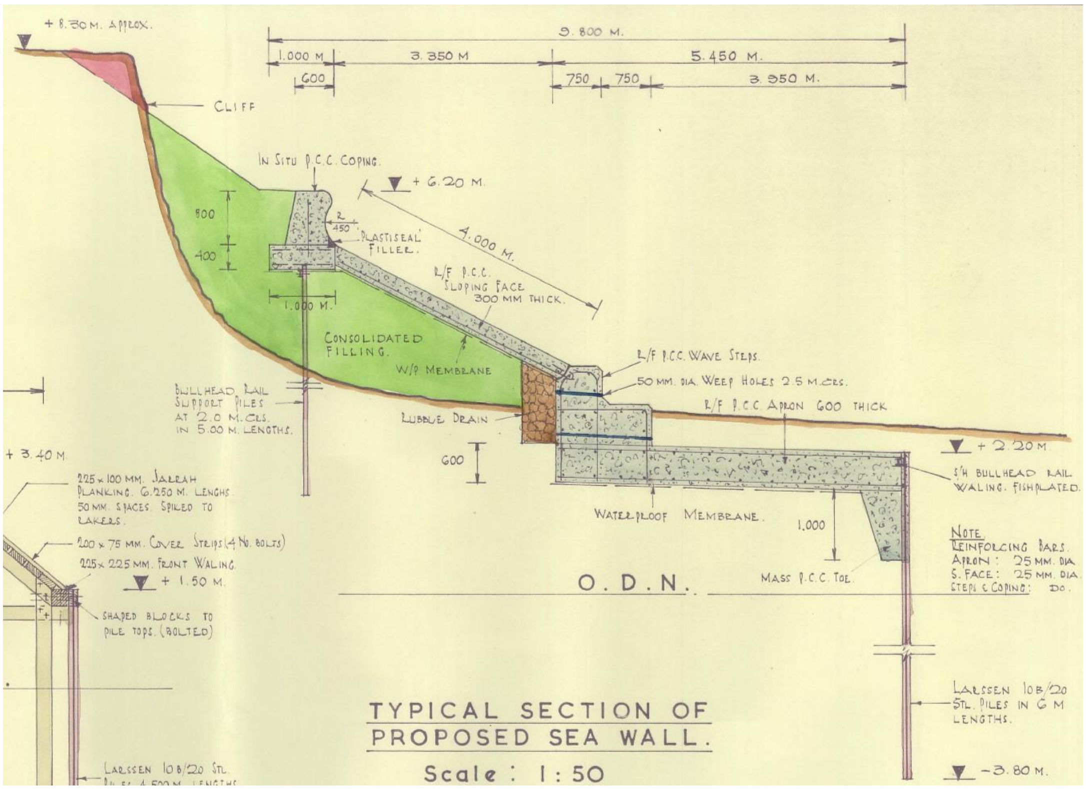


Figure 4.38 Detail of seawall and promenade at the back of the beach at Walcott

Figure 4.39 The Walcott frontage looking south

Source: Courtesy of Royal HaskoningDHV

The coast of north-east Norfolk between Cromer and Happisburgh is an almost continuous line of glacial tills cliffs.

The tidal range in the area is around 3.5m on a spring tide, with the tidal range varying significantly along the coastline. The area is subject to significant surge activity, raising water levels above those of the predicted tide. On average, the highest water level in a year exceeds predicted levels by 1m. The extreme 1 in 100 per year water level is around 2m higher than normal mean high water springs.

While storm waves typically approach the shoreline from the north through to the east, the dominant sector is from north–north-east through to the north-east. The net wave energy is slightly out of alignment with the orientation of the shoreline. Typical wave heights are shown in Table 4.18. Net sediment transport is to the south-east.

A feature of this coast is the process, under certain wave conditions, of sediment being drawn from the upper beach down to form a nearshore bar running along much of the shoreline. Sediment can then feed back onto the shoreline under different wave conditions.

Table 4.18 Estimated wave parameters for various return period storms

Return period	Wave height Hs (m)	Wave period Ts (seconds)
1	3.3	8.7
10	3.6	8.9
50	3.8	9.0
100	4.0	9.1

During storm surges, large waves predominantly from the north and north-west can combine with strong nearshore tidal currents to transport large volumes of sediment offshore and alongshore.

Over time several key areas of the coast have been protected by seawalls, including the Walcott frontage. In other areas, protection has been in the form of timber breastworks and groynes, retaining the upper beach and providing a degree of protection to the back cliffs, such as to the south of Walcott. In particular, following the storm of 1953, major protection works were put in place over much of the frontage.

Foreshore lowering is also an issue throughout this region, along with temporary steepening following a storm event. When the beach is stripped away during storms, the platform beneath becomes exposed and eroded causing foreshore lowering.

The Kelling to Lowestoft Ness Shoreline Management Plan No. 6, published and adopted in 2012, sets out the high level coastal management policies for the north Norfolk coastline over the next 100 years. It recommends management policy for 3 'epochs':

- short term (0–20 years)
- medium term (21–50 years)
- long term (51–100 years)

The policy for Walcott is Hold the Line, Managed Realignment and Managed Realignment for the 3 epochs respectively. An assessment of defence conditions in 2012 suggested that some of the defences might fail in the short term.

Assumptions

The SoP for the seawall is assumed to a 1 in 50 per year event (2% AEP).

Table 4.19 lists the related wave parameters assumed for this case study. Based on these assumptions, the following calculations were made.

- A wave length is calculated to be 54m (see Box 3.3 in report SC140005/R5 for relevant calculation).
- Based on available data, the average beach level over a wave length (54m) is observed to be –0.5m ODN. Therefore, depth under extreme still water levels equals 3.2 – (–0.5) = 3.7m.
- Based on the above and the guidance, the depth limited wave height at the structure equals d x 0.6 = 3.7 * 0.6 = 2.2m.

Table 4.19 Assumed wave parameters for a 1 in 50 per year storm event (2% AEP)

Parameter	Value
Significant wave height	3.88m
Depth limited wave height at structure	2.2m
Extreme still water level	3.2m ODN
Mean wave period	9 seconds

).

Functions of the beach and associated performance indicators

The beach at Walcott falls within the first type of beaches – a beach with a structure behind. The beach at Walcott performs all of the 3 potential flood and erosion risk management related functions for its type, that is:

- protect the toe of the structure against overturning
- limit overtopping over the structure
- limit wave loading against the structure

Table 4.20 lists the proposed direct and indirect performance indicators for these functions.

Table 4.20 Performance indicators for beach at Walcott

Beach function	Direct indicator	Indirect indicators
Ia: Protect the toe of the structure	Beach level (average over 5× toe depth	Beach volume, slope or width; wall exposure
Ib: Limit overtopping over the structure	Beach level (average over one wave length)	Beach volume, slope or width; sediment over structure
Ic: Limit wave loading against the structure	Beach level (average over one wave length)	Beach volume, slope or width; wall exposure

Ia: Setting trigger levels for protecting the toe of the structure

The sediment of the beach supports the structure. Lowering of the beach can undermine the support of the structure and lead to seaward displacement or even overturning of the wall. The beach level in front of the structure is therefore a direct indicator for the stability of the structure.

How the beach protects the toe of the structure at Walcott

As shown in Figure 4.40, the seawall backing the beach at Walcott incorporates a sheet piled wall that provides vertical and horizontal support to the structure. The beach in its turn supports the sheet pile wall. Lowering of beach levels reduces this support directly, but there is also a risk of a feedback process causing further beach erosion through reflection scour. With beach levels low enough to leave the sheet piled wall exposed, waves are reflected against the sheet piled wall first, enhancing the scour of sediment. A too low beach level may contribute to instability of the structure and its eventual failure under wave loading and its own structural load.

Figure 4.40 Seawall at Walcott showing partially exposed steel sheet pile wall (white arrow)

Source: http://www.geograph.org.uk/photo/719884

Setting of trigger values for protecting the toe of the structure

The method suggests using the average beach level over a beach width equal to 5 times the structure toe depth as the primary indicator for how beach performs its function of supporting the structure. The sheet pile wall is 6m long, with a toe depth of –3.0m ODN. Applying a typical rule of thumb for sheet pile walls of two-thirds of the length embedded for stability, the depth of the toe is taken as 4m. However, a recent structural assessment of the seawall at Walcott has demonstrated a factor of safety of 1.2 for a section of wall which is currently exposed by 3.3m. For the purposes of this case study, this is considered the critical level for the structure. The depth of toe from the critical level is therefore considered to be 2.7m. This is based on the part of the sediment body that provides passive resistance to seaward structural deformation.

The CRISIS trigger value for this function is the beach level beyond which the stability of the structure is compromised and remedial action becomes necessary. This case study does not include structural or geotechnical calculations, but makes use of available information and expert judgement. The sheet piled wall support of the existing structure suggests that this critical level may be fairly low, at around –0.5m ODN.

The good practice guidance (report SC140005/R5) suggests incorporating an additional allowance to account for the potential for scour taking place during a storm. it recommends the use of a maximum allowance of 0.8 times the significant wave nearshore for the SoP considered. This would be 1.8m (2.2m × 0.8) for a 1 in 50 per year event; this exceeds the minimum of 0.9m.

The depth of the toe below the critical beach level is 2.7m. Average beach level is therefore considered over a horizontal distance from the toe of 14m.

Table 4.21 provides a summary of the calculations outlined above**.**

Table 4.21 Summary of important required variables for Walcott case study

Required variable	Calculation	Determined value
Critical level for toe[1]	–0.3m ODN	–0.3m ODN
Wave height	Hs = 0.6 × d, where d = 3.7m	2.22m
Potential scour depth during storm	Maximum of 0.8 × Hs (2.2) and 0.9m	1.8m
Distance over which beach is considered	Depth of toe (2.7m) x 5	14m

Notes: [1] An assumption made for use in this case study, not based on a detailed structural or engineering assessment.

As a result, the CRISIS trigger value advised for the beach at Walcott in relation to the function of protecting the toe of the structure is an average beach level over ~14m width of 1.2m ODN.

ALARM trigger values can be calculated by adding an additional margin of safety to the CRISIS value. This can be done using historical data. It is possible to quantify the potential maximum reduction in beach level produced by a storm. The ALARM trigger value would be the result of adding that historical maximum difference between pre-storm and post-storm beach levels to the CRISIS value.

Beach profile surveys at Walcott were therefore reviewed. For available data (1997 to 2016), the average beach level over a horizontal distance of 45m was calculated. The largest reduction in average beach level between consecutive surveys is 1.1m, which was recorded between the 2001 and 2002 surveys (Figure 4.41).

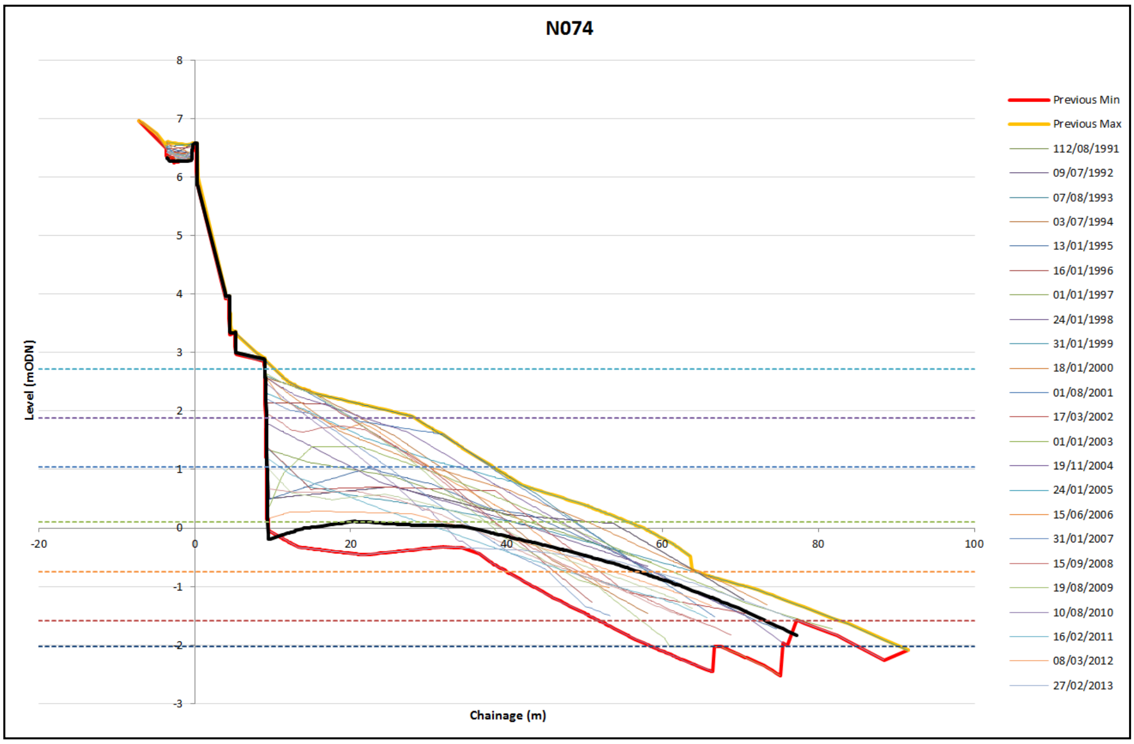


Figure 4.41 Summary of survey data collected between 1997 and 2016 for profile 74 (located north of Walcott)

Assuming a CRISIS trigger value of 1.2m ODN (as determined above), the ALARM trigger value for protection of the toe of the structure in Walcott would be an average beach level over a horizontal distance of 45m of +2.3m ODN. Taking into account the typical beach profile based on survey data, such a trigger level equates to a beach level at the toe of around 3m ODN, which is around the top of the sheet pile wall.

Indirect indicators for protection of the toe of the structure

As long as the required beach level is present over the required width, the state of the beach further seaward does not influence structure stability directly. However, low beach levels further seaward can be a predictor for reducing beach levels in front of the toe. This relates to 2 processes. A low seaward beach volume could induce transport of sediment from in front of the structure and/or lead to higher waves reaching the toe of the structure, causing toe scour. Other relevant indirect indicators can be beach volume (or cross-sectional area), beach slope or beach width down to a particular level (tidal level, underlying sediments and so on). Each of these can be used, depending on available monitoring and knowledge of the local environment.

Survey data available for Walcott allow a number of these variables to be assessed over time. Profiles plotted for different points in time are shown in Figure 4.41.

One of the most evident easily identifiable indirect indicators in this case is the beach width down to mean sea level, 0.11m at Walcott. It is possible to see how the beach width decreases as the general average beach level decreases. This can be seen by comparing the plots presented above. However, care should be taken particularly when comparing low beach levels. For example, when comparing the 2014, 2015 and 2016 beach profiles at Walcott, the profiles from the 3 different years intersect the mean sea level (0.11m ODN) at a similar location (distance from the structure), but each has a very different average beach level. A more appropriate indirect indicator in this case may be beach volume (or cross-sectional area).

Ib: Setting trigger levels for reducing overtopping over the structure

Data indicate a mean period equal to 9 seconds, which indicates an approximate nearshore wave length of 30m. This is the length over which average beach levels will be considered.

How the beach reduces overtopping at Walcott

The seawall provides protection against wave overtopping to the properties and the road. The energy of the waves reaching the frontage is dissipated by friction with the seabed and the beach, the concrete slope and wave return wall. Wave overtopping occurring at Walcott during 2013 storm events is shown in Figure 4.42.

Figure 4.42 Wave overtopping at Walcott in 2013

Source: www.itv.com/news/anglia/2015-11-23/east-anglia-coast-on-alert-for-risk-of-high-tides-and-potential-flooding/

Setting of trigger values

The average beach level over a beach width equal to one wavelength is used as the primary indicator to determine the CRISIS trigger value. The trigger value is obtained through an iterative process, based on ensuring that overtopping discharges over the structure do not exceed tolerable values in storm events with the chosen probability of exceedance.

Tolerable discharges could relate to access for people or vehicles in relatively normal conditions (for example, the average once a year storm), or to structural integrity of the defence, or direct flooding, in extreme conditions (for example, design conditions), or a combination. Both are used for this case study.

The serviceability criterion is taken as 10l/m/s in a 1 in 1 per year storm, based on tolerable values for vehicles according to the EurOtop Manual.[5] The ultimate limit state criterion is taken as 100l/m/s in a 1 in 50 per year storm in order to illustrate the situation when properties behind the seawall are flooded. The goal of the iteration is to match the overtopping rate obtained under local wave and beach geometry conditions to the specified tolerable values. The iteration process can be carried out using the web-based EurOtop calculation tools. For the case of Walcott, the composite slope tool was used.

[5] www.overtopping-manual.com/manual.html

For the applicable SoP (in this case 1 in 50 years), and assuming depth limited waves reaching the structure, the wave height (Hs) is 2.22m (Table 4.21) and the wave period (T) is 4.5 seconds. The overtopping rate (q) is calculated as follows.

- If $q < q_{tolerable}$, lower beach level by 0.5m (d′ = 3.7 + 0.5) and repeat calculation.
- If $q > q_{tolerable}$, raise beach level by 0.5m (d′ = 3.7 – 0.5) and repeat calculation.

Note that as stated in the good practice guidance (report SC140005/R5), an interval of 0.5m would typically be the appropriate level of precision, but it may be more useful or applicable to use an interval of say 0.1m. This should be determined by the user.

The beach level that results the closest to $q = q_{tolerable}$ is the minimum required average level over a width equal to one wave length; this is the CRISIS trigger value.

Using the method above within the EurOtop tool (Figure 4.43), a 1.2m wave height at the structure was considered to exceed the overtopping threshold of 100l/s/m. Based on this wave height, a critical depth (d_c) of 2m was calculated which is equivalent to a beach level of 1m ODN. This is the CRITICAL trigger value.

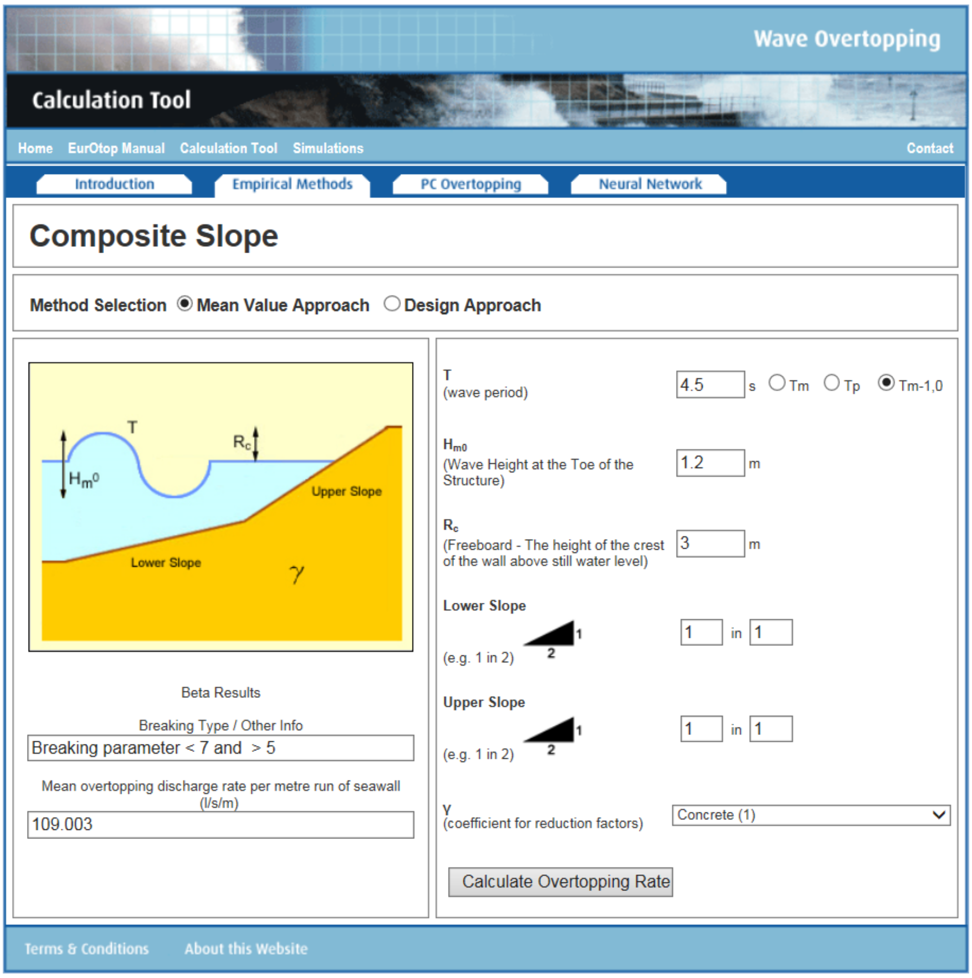


Figure 4.43 Screenshot of the EurOtop online tool with values used in the assessment (© HR Wallingford)

ALARM trigger values are calculated by adding an adequate margin of safety to the CRISIS value. This can be done based on historical data analysis, that is, adding to the

CRISIS level a value equal to the largest historical beach average beach level drop over 25m (~2m at Walcott recorded between 1997 and 1998 surveys).

Indirect indicators for wave overtopping

A good practical predictor for future reduction of average beach level is the development of beach volume in neighbouring frontages. However, it is difficult to quantify this relationship and connect it to ALARM and CRISIS levels, and in practice this has to be based on local knowledge and judgement. This is not elaborated in this case study.

Ic: Setting trigger levels for reducing the wave loading against the structure

How the beach level reduces wave loading against the structure at Walcott

The role of the beach in dissipating energy before waves hit the structure has already been addressed in this case study. It is important to note that it is the beach level profile over a certain beach width that matters for wave loading, and not just the level next to the structure. In order for the incoming waves to lose any significant energy, they need to be influenced by friction from the seabed over a width of at least one wave length (approximately 1.5 times the square of the wave period in metres).

Wave impacts on vertical walls are among the most severe and dangerous loads this type of structure can suffer. With a lower beach level, bigger waves get to reach the structure with very high pressures; in most of the formulae used to quantify wave pressure exerted against a vertical seawall, the load is directly dependent on wave height. Significant wave height data for Walcott are presented in Table 4.21. The load applied to the seawall crest is internally transmitted to the whole structure, resulting in compression–tension that may cause damage to the structure in the form of more or less critical cracks. An example of wave loading on the structure at Walcott during a storm event is shown in Figure 4.44.

Figure 4.44 Waves impacting the seawall structure at Walcott in 2013

Source: www.itv.com/news/anglia/2015-11-23/east-anglia-coast-on-alert-for-risk-of-high-tides-and-potential-flooding/

Setting a trigger value for wave loading on the structure

Average beach level over a beach width equal to one wavelength is used as the primary indicator to determine the CRISIS trigger value. The trigger value is obtained through an iterative process, based on ensuring that wave loading on the structure does not cause damage to the structure in storm events with the chosen probability of exceedance.

If as-built information is available, the critical wave conditions will be equal to the design wave conditions if the condition of the structure has not changed significantly (for example, through deterioration) and the criticality of the seawall has not changed (for example, through housing development behind the structure).

As-built data are not directly available for this case study, carrying out a structural assessment of the defence to estimate the applicable critical wave conditions is recommended. This is beyond the scope of this case study.

For illustration purposes, this case study follows the process based on assumed values. The process is as follows.

1. Based on design/newly assessed data, estimate the maximum tolerable load that the structure could resist without being damaged (F_{max}).
2. Using the maximum tolerable load value and good practice formulae, obtain the critical significant wave height (H_{sc}). In this case, H_{sc} is assumed to be 1.55m.
3. Assume the critical depth (d_c) equals $H_{sc}/0.6$. In this case, d_c 1.55/0.6 = 2.58m.
4. Calculate the beach level corresponding to the critical depth (h_c) = water level SoP – d_c. In this case, the extreme water level for a 1 in 50 per year event (2% AEP) is +3.2m ODN (Table 4.19). Therefore h_c = (3.2 – 2.58) = 0.62m ODN.

The obtained beach level (0.72m ODN) is the CRISIS trigger value for limiting or reducing wave loading to the structure.

ALARM trigger values can be calculated by adding an adequate margin of safety to the CRISIS value, based on historical data analysis. The largest reduction of the average beach level over 25m (one wave length) was 1.1m (see Figure 4.41). This value is added to the CRISIS value to determine the ALARM trigger value.

Indirect indicators for wave loading on the structure

As explained for the function Ib, a good practical predictor for future reduction of average beach level is the development of beach volume in neighbouring frontages. However, it is difficult to quantify this relationship and connect it to ALARM and CRISIS levels. In practice this has to be based on local knowledge and judgement which is beyond the scope of this testing exercise.

Conclusions

The beach at Walcott has the following 3 flood risk management related functions:

- protecting the toe of the seawall against undermining
- reducing overtopping over the seawall
- reducing wave loading against the seawall

Beach levels at Walcott vary significantly due to storm events and the sheet piled wall supporting the front of the structure is often exposed. Low beach levels have a direct influence on how the beach performs the 3 functions listed above.

The application of the methodology for setting trigger values suggests that average beach levels over various widths are appropriate indicators for the various flood risk functions of Walcott beach. Trigger values were determined as far as possible with available information. For CRISIS values, this is based in principle on good practice design rules; the case study shows that, in some cases, actual experience with asset performance during low beach situations provides useful additional evidence. ALARM values include a safety margin compared with the CRISIS value, which in the case of Walcott can be based on the maximum beach level drop from monitoring data.

In addition, indirect indicators such as beach volume (or cross-section area), beach width and slope are also suggested as they may help to predict future beach variations down to a trigger value.

Table 4.22 lists the CRISIS and ALARM trigger values determined in this worked example. See Figure 4.41 to compare the trigger values in the table with previously observed beach profiles.

Table 4.22 Determined CRISIS and ALARM trigger values for Walcott

Beach function	CRISIS trigger	ALARM trigger
Ia Protect the toe of the structure	1.2m ODN (over a beach width of 14m)	2.3m ODN
Ib Limit wave overtopping	+1m ODN (over a beach width of 50m)	+3m ODN
Ic Reduce wave loading on the wall	0.62m ODN (over a beach width of 50m)	+1.28m ODN

4.4.3 Case study: Eastbourne, East Sussex

Beach type: Type I – Beach with a structure behind

Shingle beach

Beach function: Ia – Protect the toe of the structure from undermining

Ib – Reduce wave overtopping

Ic – Reduce the wave loading on the structure

The case study presents an alternative trigger level methodology for shingle beaches. It describes the setting of trigger values for the beach type and its functions with reference to the good practice guidance produced for this project (report SC140005/R5).

Notes and assumptions

The methodology used in this case study was developed by Canterbury City Council and the Environment Agency for a suite of Regional Beach Management Plans for south-east England, and is hereafter referred to as the RBMP method. The plans were produced to:

- provide a consistent approach to management across a single sediment cell to assess relative SoPs
- ascertain whether beach management works can be combined across legislative boundaries, within the same sediment cell

For detailed design of management works, it is suggested that a more in-depth approach is taken using engineering design equations, computational models and expert judgement.

The RBMP method was developed and validated predominantly for shingle/gravel beaches. If it was to be applied to other areas (that is, sand beaches), then the scour methodology would need revising and further validation would be required. Where assumptions have been made, which may not be applicable to non-gravel beaches, this is stated in the good practice guidance (report SC140005/R5).

The method relies heavily on data from the Regional Coastal Monitoring Programmes of England (RCMP). These data are freely available for the majority of the English coastline.[6]

Context

Examples are provided for RCMP survey unit 4cSU24 which covers Eastbourne, a large town in East Sussex (Figure 4.45). The west of the unit is backed by cliffs; moving eastwards, there is a large flood basin that contains ~7,000 residential properties. Sovereign Harbour is situated at the unit's western extent.

The town of Eastbourne is fronted by a shingle beach and various types of concrete seawall (Figure 4.46). The shingle beach is maintained by 95 timber groynes, typically at 60m centres and extending 90m seaward. The unit loses beach material through longshore processes at an average rate of 11,000m^3 per year. This is mitigated by annual capital shingle recharge, which is funded in 5–6 year beach management cycles.

[6] www.coastalmonitoring.org

Figure 4.45 Location plan for Eastbourne

Source: Google Earth Pro

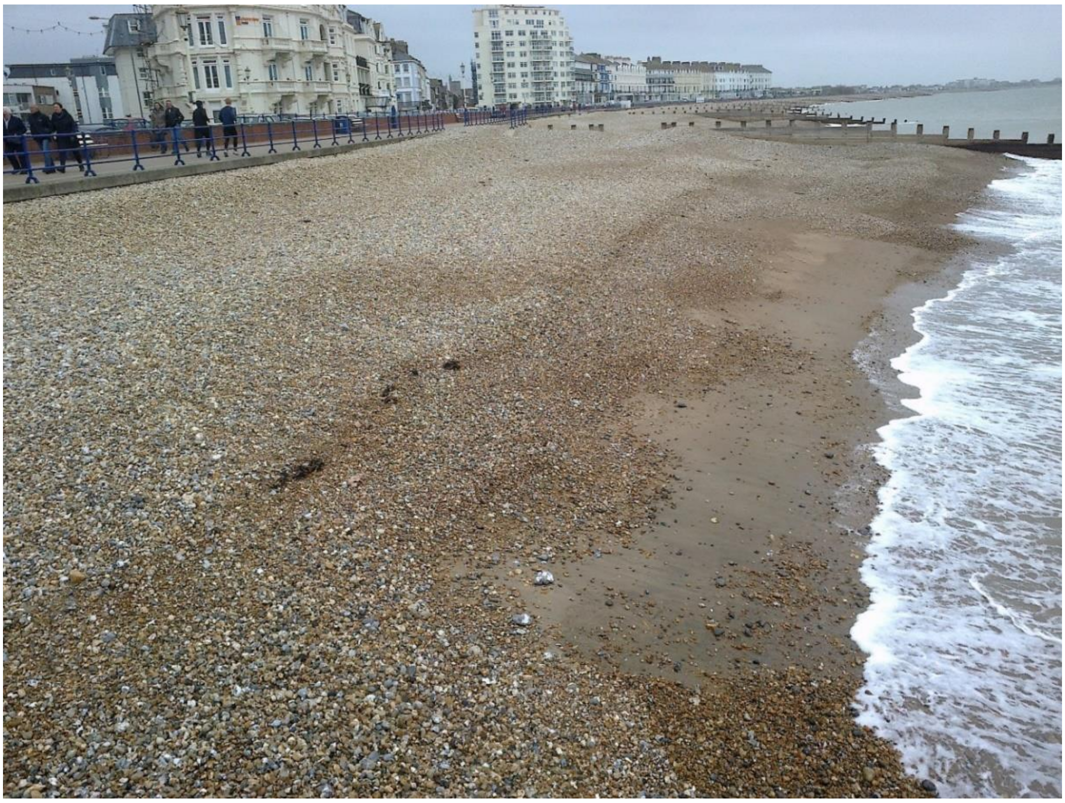


Figure 4.46 Eastbourne frontage looking east after 2013 to 2014 storms

Source: Environment Agency (2014a)

Stepwise RBMP methodology

Step 1: Data collection

The following data are required:

- topographic beach levels (height of beach at wall/back beach, crest height beach toe height) – from RCMP
- foreshore level – from RCMP
- crest and toe height of hard defence (ideally as-built schematics) – from Environment Agency/local authority

A substitute for as-built drawings is the structure survey cross-sections from the RCMP, where available. Previous reports and studies commissioned by the Environment Agency, local authority and RCMP will also be useful. Additional surveys/investigations may need to be commissioned where data are missing.

Step 2: Define defence sections

This step is comparable with ‘Confirm Beach Type’ in the good practice guidance produced for this project; see Figure 2.1 in Asset Performance Tools: Guidance for Beach Triggers (report SC140005/R5).

Define representative defence sections based on similar physical conditions (Figure 4.47 and Figure 4.48). The method requires the user to run overtopping calculations for each wall type or height change in the promenade or rear seawall.

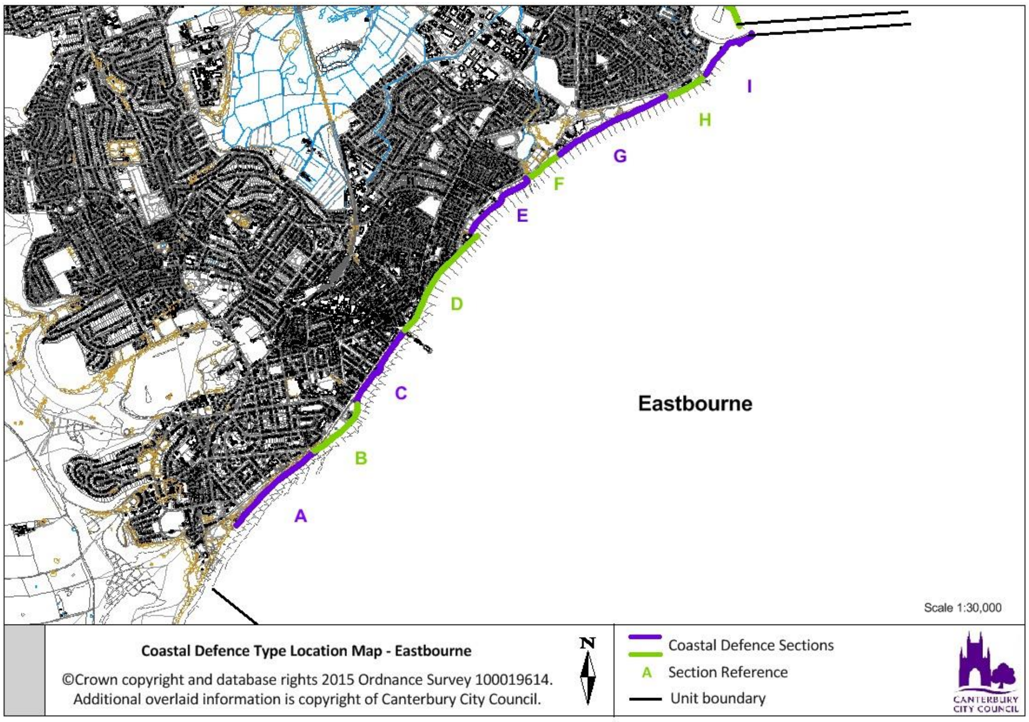


Figure 4.47 Defence sections for the Eastbourne example

Defence Section		Beach				Defence			
Unit	Section	Start Profile	End Profile	Foreshore Level (mOD)	Foreshore Level OT (mOD)	Front Defence Type	Front Defence Elevation (mOD)	Rear Defence Type	Rear Defence Elevation (mOD)
4cSU24 - Eastbourne	A	4c01848	4c01831	-1.5		Seawall	8.1		
	B	4c01829	4c01818	-1.5		Seawall	7.8	Rear wall	12.5
	C	4c01817	4c01803	-1.5		Seawall	6.2	Rear wall	9.5
	D	4c01802	4c01783	-1.5		Seawall	6.2	Rear wall	7.15
	E	4c01781	4c01771	-1.5		Unfounded Prom	6.2		
	F	4c01770	4c01765	-1.5		Unfounded Prom	6.2		
	G	4c01763	4c01745	-1.5		Unfounded Prom	7-8 (7)		
	H	4c01744	4c01737	-1.5		Unfounded Prom	6.7		
	I	4c01735	4c01732	-1.5		Rock revetment	6.5		

Figure 4.48 Characteristics of the Eastbourne defence sections

Step 3: Define potential hazards/failure mechanisms

This step is comparable with ‘Confirm Beach Functions’ in the good practice guidance produced for this project; see Figure 2.1 in Asset Performance Tools: Guidance for Beach Triggers (report SC140005/R5).

Define the potential hazards/failure mechanisms (Figure 4.49).

For the RBMP methodology, these were overtopping and structure failure (undermining and wave attack). Calculations are run for each failure mechanism. Although erosion is not treated as a failure mechanism, an allowance is made for erosion in the trigger levels (see Step 5) and an allowance for flooding is made in the allowable overtopping rates.

For overtopping calculations, see Step 4a.

For wave attack calculations, see Step 4b.

For undermining calculations, see Step 4c.

Defence Section		Failure Mechanism Calculations	
Unit	Section	Potential Hazards	Calculations to run
4cSU24 - Eastbourne	A	Structure Failure, Overtopping	Overtopping, Undermining
	B	Structure Failure, Overtopping	Overtopping, Undermining
	C	Overtopping, Structure Failure	Overtopping, Undermining
	D	Overtopping, Structure Failure	Overtopping, Undermining
	E	Overtopping, Structure Failure, Flooding	Overtopping, Undermining
	F	Overtopping, Structure Failure, Flooding	Overtopping, Undermining
	G	Overtopping, Structure Failure, Flooding	Overtopping, Undermining
	H	Overtopping, Structure Failure, Flooding	Overtopping, Undermining
	I	Overtopping, Structure Failure, Flooding	Overtopping, Undermining

Figure 4.49 Potential hazards and failure mechanisms to be modelled for the Eastbourne example

Step 4a: Assess overtopping failure

This step is comparable with function Ib (Reduce overtopping) in the good practice guidance produced for this project; see Section 3.1 of Asset Performance Tools: Guidance for Beach Triggers (report SC140005/R5).

For each beach section, find or calculate joint return probability (JRP) conditions and pick the most appropriate overtopping model (Figure 4.50); the RBMP method used the EurOtop online tool (Figure 4.51) as this offered a fairly quick and consistent way to estimate overtopping for large areas of coast. JRP conditions (wave and water level combinations for a range of return periods) were used from the JRP study for the south-east by the Channel Coastal Observatory (Mason 2013). If recent JRP conditions do not exist, they will have to be calculated before running overtopping calculations.

Foreshore levels were used to depth limit the wave heights.

Defence Section		Overtopping Calculations		
Unit	Section	Front Defence	Rear Defence	JRP Conditions
4cSU24 - Eastbourne	A	Composite Slope with Wall		MO444
	B	Composite Slope with Wall	Composite Slope with Wall	
	C	Composite Slope with Wall	Composite Slope with Wall	
	D	Composite Slope with Wall	Composite Slope with Wall	
	E	Composite Slope		
	F	Composite Slope		
	G	Composite Slope		
	H	Composite Slope		
	I	Rock Revetment		

Figure 4.50 Overtopping calculations for the EurOtop tool, using JRP site MO444 from the JRP study (Mason 2013) for the Eastbourne example

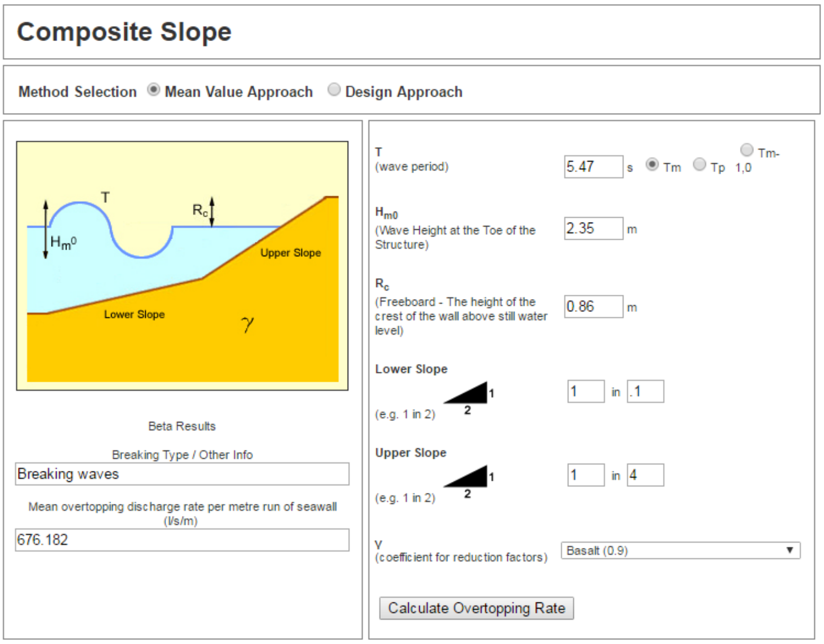


Figure 4.51 Example calculation using the EurOtop online tool (© HR Wallingford)

Notes: A reduction coefficient value of 0.9 is used, which was found to be valid for gravel beaches. Sensitivity testing and validation will need to be run for other beach types.

For the RBMP method, the EurOtop tool was run for a series of slopes which were translated to cross-sectional area (CSA). This is readily comparable with RCMP data (Figure 4.52).

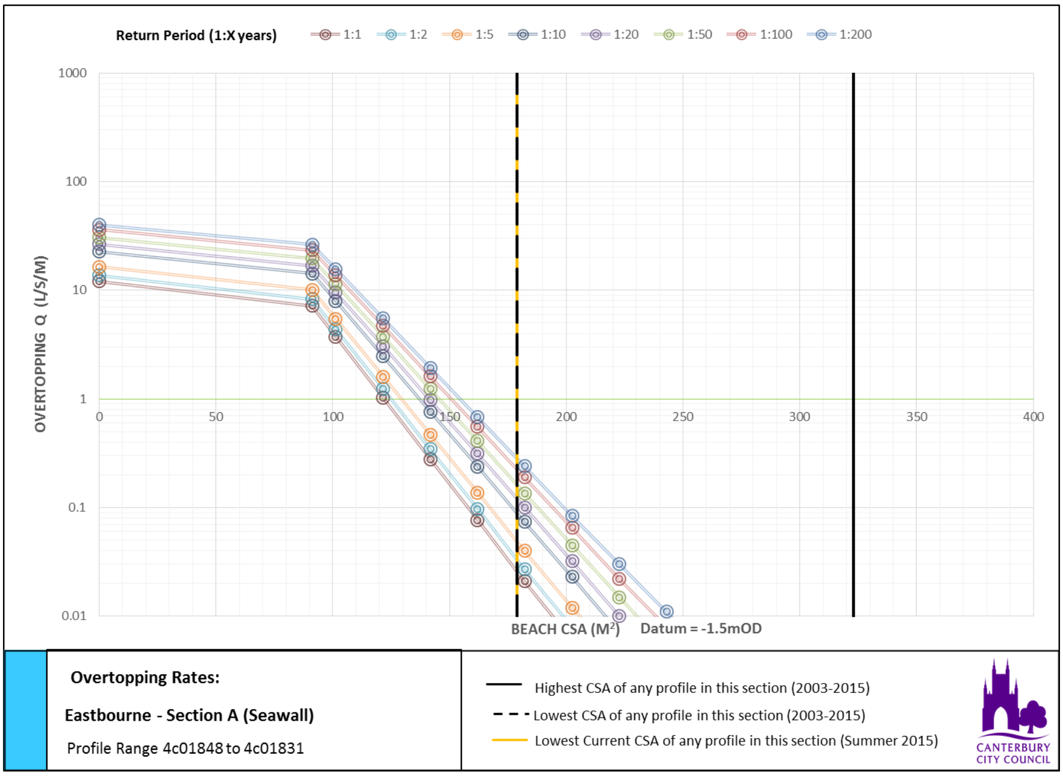


Figure 4.52 Overtopping results for Eastbourne defence section A

Notes: Calculations were run for a range of return periods and CSAs and are plotted against current and historic CSAs from the RCMP data.

It is essential to validate overtopping results (where possible). This can be done using a combination of photographs, data from observed events, anecdotal evidence such as shingle on the promenade and additional modelling such as using X-beach-G for gravel beaches (Masselink et al. 2014), Shingle-B (HR Wallingford 2016) or the improved wave run-up formula (HR Wallingford 2014).

For each defence section, an allowable overtopping rate is defined to determine the critical CSA of beach required to limit overtopping for a defined SoP (Figure 4.53). These values are based on the type of defence and the receptors present behind the defence. Guidance is available for recommended values in the EurOtop Manual, but for this project, the values were taken from the 'Coastal Engineering Manual' (USACE 2002).

Defence Section		Standard of Defence	
Unit	Section	Behind Defence	Allowable OT (l/m/s)
4cSU24 - Eastbourne	A	Cliffs	2
	B	Wishtower	2
	C	houses	1
	D	houses	1
	E	houses	1
	F	setback houses	10
	G	setback houses	10
	H	houses	1
	I	harbour	10

Figure 4.53 Allowable overtopping values

Step 4b: Assess wave attack failure

This step is comparable with Function Ic (Reduce the wave loading on the structure) in the good practice guidance produced for this project; see Section 3.1 of Asset Performance Tools: Guidance for Beach Triggers (report SC140005/R5).

For failure of defence through wave attack, an allowable overtopping discharge of 50l/m/s was applied to the front sea defence and the overtopping graphs were used to evaluate a minimum beach level. This is the value of overtopping that is likely to cause damage to most sea defence structures (USACE 2002).

Step 4c: Assess undermining failure

This step is comparable with function Ia (Protect the toe of the structure from undermining) in the good practice guidance produced for this project; see Section 3.1 of Asset Performance Tools: Guidance for Beach Triggers (report SC140005/R5).

For failure of defence through undermining, a beach level was calculated that prevents the defence foundations from being exposed, allowing for a 1 in 10 slope (due to drawdown during a storm event) and a 0.5m depth of scour (Figure 4.54). The 1 in 10 slope and 0.5m scour depth are applicable to gravel beaches for a design storm of 1 in 200 years (Powell and Lowe 1994). These values will be different for other return periods and beach types.

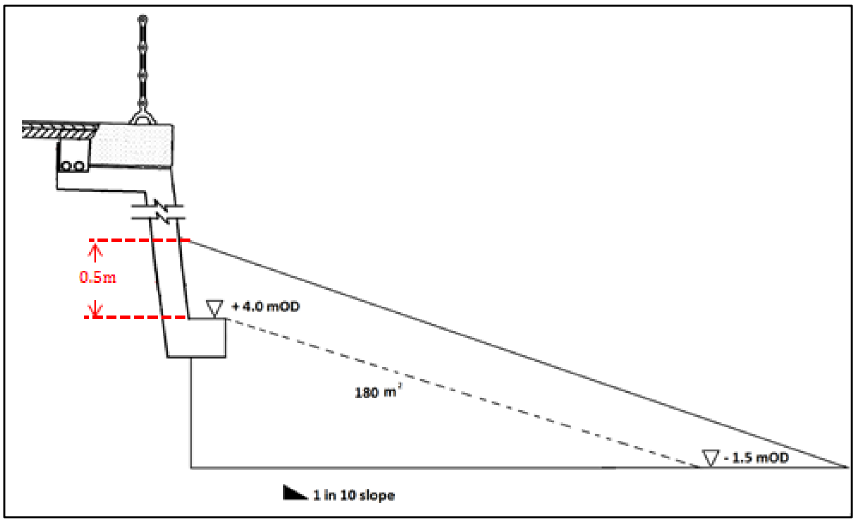


Figure 4.54 Critical beach level to prevent undermining of the defence foundations, including a 50cm allowance for scour

Step 5: Setting trigger levels

The RBMP methodology uses 3 trigger levels: Critical, Maintenance and Design.

- CRITICAL LEVEL. This is the minimum beach level required to prevent overtopping exceeding tolerable limits and/or a significant risk of structural damage or undermining to a given storm event. A subcritical level can also be defined, which is the equivalent level for a smaller SoP.
- MAINTENANCE LEVEL. This beach level is higher than the critical level and is defined by the largest observed annual drop in beach level (since monitoring began in 2003), or where greater, the largest loss during a storm event.
- DESIGN LEVEL. This beach level is higher than the maintenance level and takes into consideration the impact of the defence failing (through undermining or significant overtopping); it also builds in an appropriate factor of safety. When carrying out works, the beach size should be increased to this level where possible. For beaches where regular work is scheduled or plant is available onsite, this additional factor of safety may not be required; this is a decision for the operating authority.

The terminology was chosen to better reflect the way each level is used rather than using ‘alarm’ and ‘crisis’, which are less intuitive. In general, the RBMP Critical level is synonymous with the Beach Management Manual's Crisis level (Rogers et al. 2010), and the RBMP Maintenance level is similar to the Beach Management Manual’s Alarm level, in that it defines when work should be done or planned. The RBMP Design level gives an additional safety factor, allowing a longer period of time between a beach being managed to Design level and additional work needing to be carried out.

For defence sections where there are multiple applicable failure mechanisms, the critical level is the largest of the calculated critical CSAs; that is, if the required CSA to protect against overtopping failure is 50m^2 and the required CSA to protect against undermining is 60m^2, then the critical CSA will be 60m^2.

Figure 4.55 puts RCMP data, or other beach profile data, put into the context of the RCMP method's trigger levels. Outputs are discussed in Section 4 of Asset Performance Tools: Guidance for Beach Triggers (SC140005/R5).

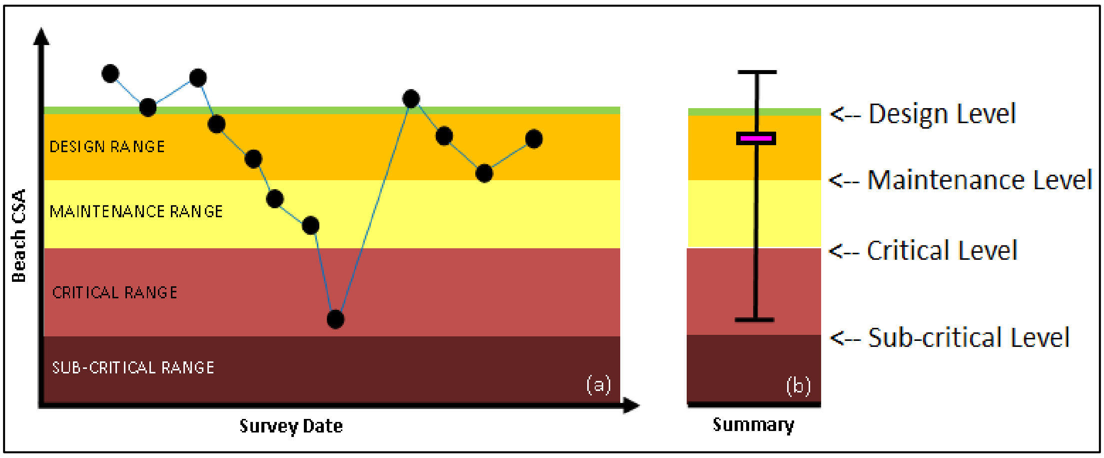


Figure 4.55 (a) Presentation of beach CSA in the context of trigger levels. (b) Historic variation of beach CSA summarised as pink bar showing current beach level and black bars showing the historic high and low

The output is a graphical view (with corresponding spreadsheets) that provides an overview of the state of each beach profile in relation to the defined trigger levels across the entire study frontage (Figure 4.56). The x-axis lists each beach profile, the y-axis shows beach size in terms of the CSA (in m^2), and the box and whisker profile shows the lowest and highest the beach has ever been (since 2003) and its current state (pink line).

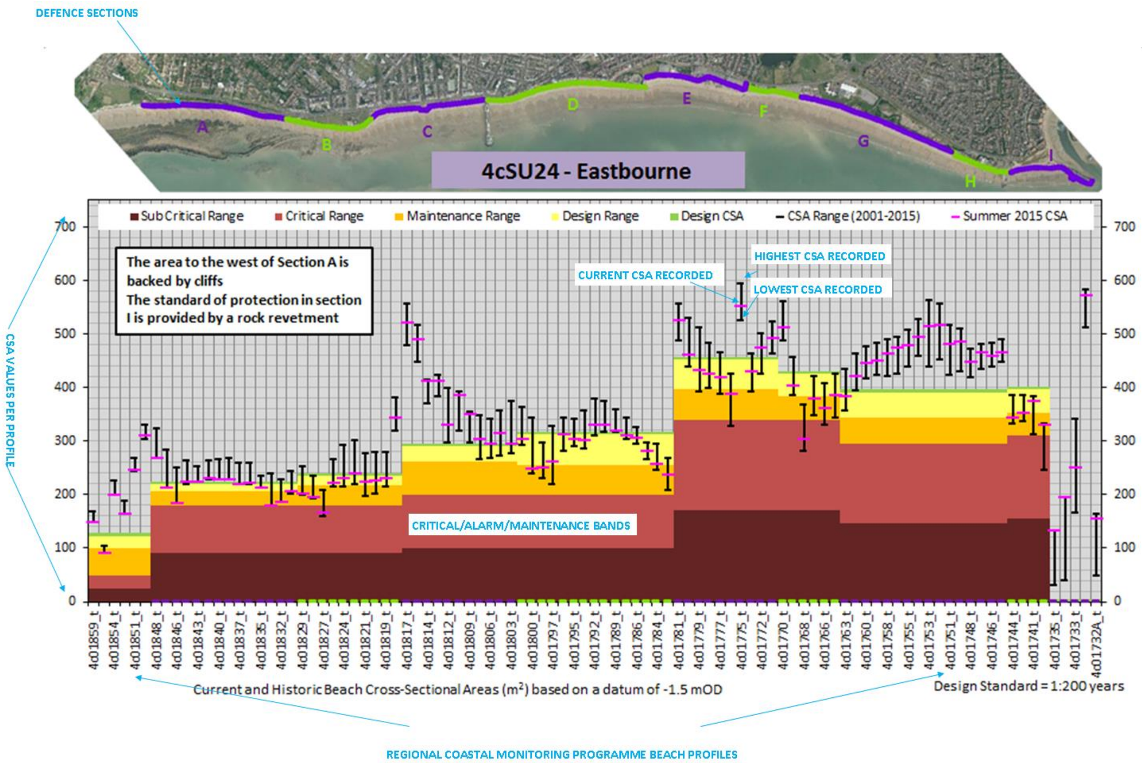
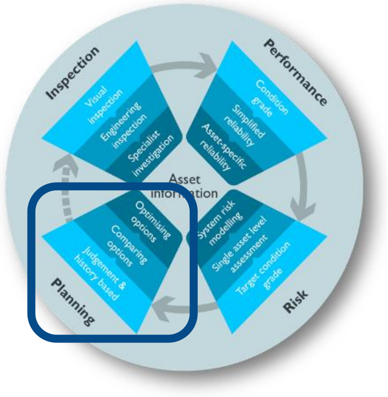


Figure 4.56 Observed CSA changes within the context of beach trigger levels for the Eastbourne example

4.5 Risk-based appraisal tool prototype case study

4.5.1 Area of study



This case study is based on the same example embankment as for the Whole Life Cost tool presented in Section 4.3, that is, a flood defence on Canvey Island, Essex with a design SoP of 1 in 1,000 years and a length of 384m. Given the high SoP and large freeboard, it was necessary to adjust some of the characteristics of the defence and flood risk to provide an informative case study that did not conflict with the more detailed analyses in progress under the TEAM2100 programme of work. This adjustment also reflects that a 1 in 100 or 1 in 200 year SoP is more typical in a tidal area and for its associated assets.

4.5.2 Purpose

The case study investigates the question of whether inclusion of quantified flood risk would change the recommended maintenance regime derived from the whole life cost target condition grade analysis.

Tools used

Flood risk data are needed for different condition grades. The pre-calculated risk guidance was used to identify if such data are available (Report SC140005/R4).

The Whole Life Cost tool was used to derive costs for assessed maintenance regimes.

The risk-based appraisal tool prototype was used to generate whole life residual damages/benefits and compare with whole life costs.

Data and results

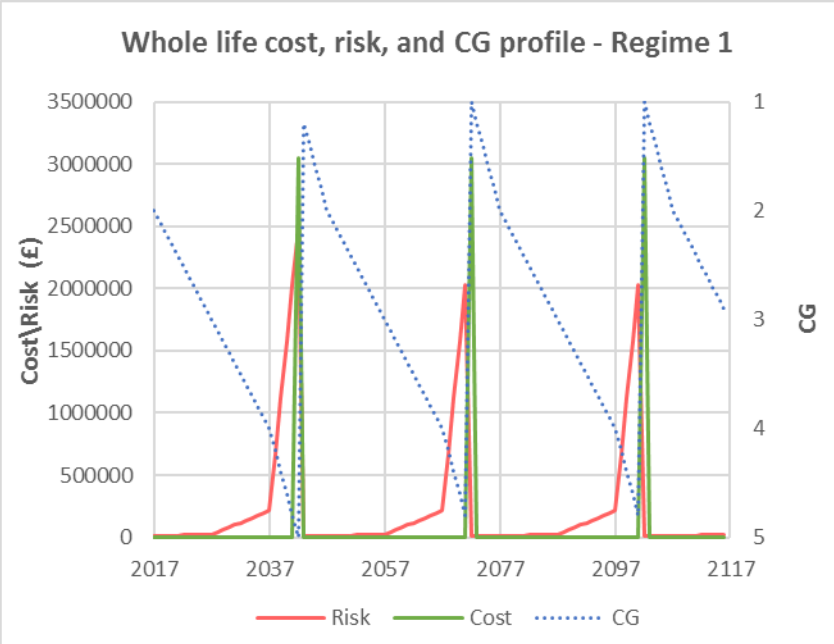
Table 4.23 shows the example residual damages attributed to the defence for the range of condition grades (input data). Table 4.24 shows the effect of different maintenance regimes on quantified whole life risk, cost and benefit–cost ratios. The variation in time of the costs, risks and condition grade are shown in Figure 4.57.

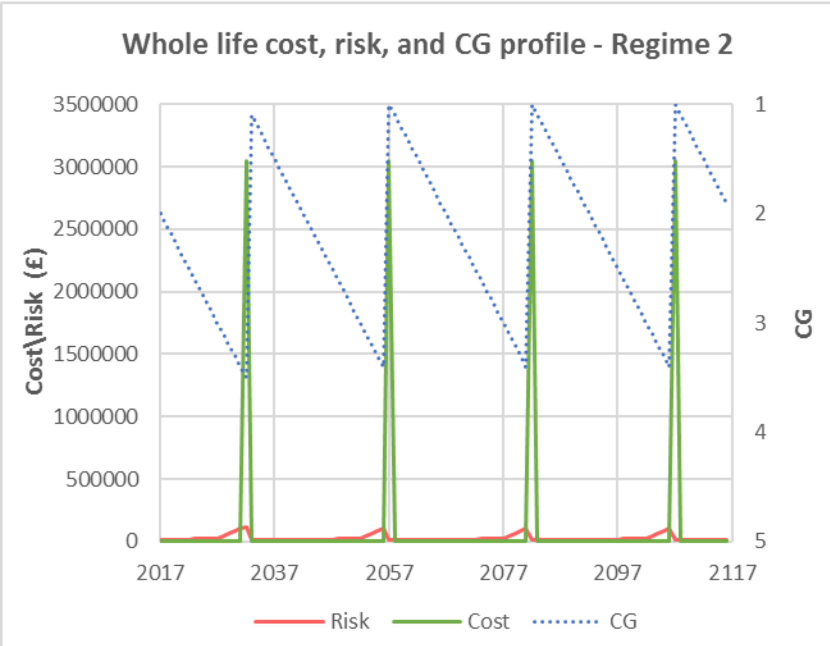
Table 4.23 EAD values for different condition grades

Condition grade	EAD
1	£10,137
2	£10,582
3	£24,427
4	£213,380
5	£2,480,868

Table 4.24 Varying benefit–cost ratios for different Annual Maintenance Regimes

Regime	Total risk	Total cost	Benefit–cost ratio
1	£6,836,782	£2,264,652	Not applicable
2	£819,638	£3,552,263	1.69
3	£759,650	£3,008,595	2.02





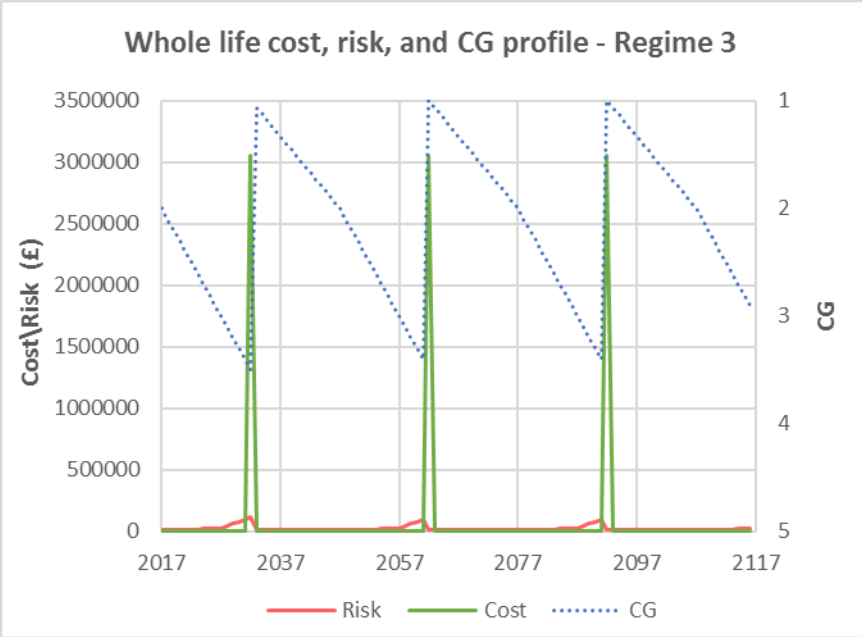


Figure 4.57 Cost, risk and condition grade time profile for Annual Maintenance Regimes 1, 2 and 3

Assessment of the approach

For this case study example, the inclusion of risk information does not change the optimum maintenance regime determined using the Whole Life Cost tool, that is, Annual Maintenance Regime 3.

In other cases, the explicit use of risk data could identify better value maintenance regimes. The use of such an approach can also be used to show that the Environment Agency is moving toward whole life 'with risk' approaches. In particular, it is useful for demonstrating compliance with ISO 55001 (for example, Clause 6.2.2b – see Table 3.2). It could also be a useful approach for support monitoring of the Environment Agency's KPI965 (one of its key FCRM KPIs).[7]

The addition of risk brings new information and insight to the decision-making process. It helps to measure the impact of the asset investment in a more direct manner (compared with the impact being reported as a change in condition grade). It can help to rank the options and assess whether value is being provided (through a benefit–cost ratio). It can also help to prioritise investments between different assets by providing a common basis for comparison.

The whole life cost and risk analysis is linked with condition grade; therefore the definition and the assessment of the condition grade should adequately reflect or link all the important factors involved in asset maintenance, deterioration and failure mechanism. For example, if the fragility curve used with the condition grade does not capture the failure mode of a particular defence, then risk cannot be appropriately assessed.

Significantly more data (risk data attributed to the defence for all condition grades) are required for the risk-based approach. The risk estimation process itself usually requires a significant amount of data and computation, and can involve high uncertainty. National calculations of risk are likely to be more cost-effective than ad hoc calculations for each defence.

[7] KPI965 quantifies the number of households that are at increased flood risk from assets that are not at their target flood defence condition ('failing' assets) (IUK 2014, p. 118).

5 Recommendations

The AP Tools project has developed a set of user-focused tools and guidance that can be applied by flood risk management authorities to improve asset maintenance. An overarching framework has also been provided that covers inspection, performance, risk and investment planning.

The tools and guidance are at different levels of maturity. Table 5.1 shows the status of each of the products at the time of writing this report, their maturity level (consistent with Figure 2.1, reproduced below for reference) and a recommendation for the next steps for the product.

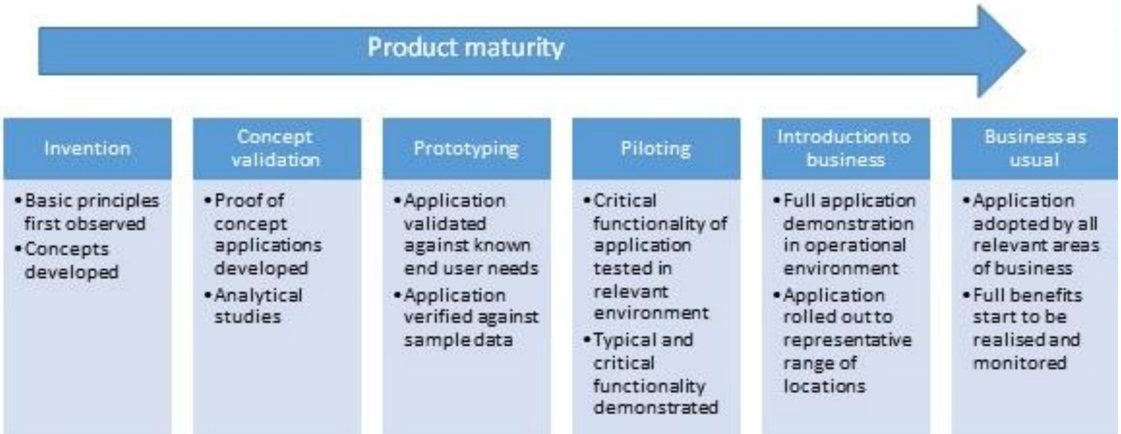


Table 5.1 Status of AP Tools project outputs, product maturity and possible next steps for products

Output	Product maturity (as of autumn 2017)	Possible next step for product
Inspection guidance	**Introduction to business** • Key aspects already embedded	• Continued use
Custom Fragility Curve tool	**Piloting** • Ready to be embedded • For limited role-out and use with appropriate care	• Train catchment engineers (who can be local custodian and do onward local training) – roll out alongside 'risk at asset level' programme • Embed with RAFT tool and develop processes to use the tool in this context • Central storage of the adjusted fragility curve for use elsewhere (for example, NaFRA2) • Potential use in CAMC programme • Disseminate via standard R&D route
Conveyance	**Piloting**	• Consider inclusion in existing

Output	Product maturity (as of autumn 2017)	Possible next step for product
guidance	• Ready to be embedded • For limited role-out and use with appropriate care	Operational Instruction • Promote to Internal Drainage Boards • Dissemination: standard R&D route plus take to Operations Managers' assets portfolio • Roll out with new conveyance KPI965 Conveyance (2018 to 2019)
Vegetation and Roughness tool	**Prototyping** • Mature concept but needs more real-world testing	
Pre-calculated risk datasets guidance	**Piloting** • Ready to be embedded • For limited role-out and use with appropriate care	• Dissemination: standard R&D route plus target the NaFRA2 and CAMC programme teams • Guidance shared with Asset Management Data team for links to NAFRA2 • Share with CAMC programme team
Whole Life Cost tool	**Piloting** • Ready for use in specific circumstances (for example, TEAM2100), and elsewhere with appropriate care • Needs further development to align cost rates and address other limitations	• Logic could be incorporated within CAMC programme and/or the Environment Agency's Project Cost Tool • Dissemination: standard R&D route plus target the CAMC teams • To achieve consistency, possibly disseminate to other risk management authorities through appropriate Environment Agency channels
Risk-based whole life cost prototype tool	**Concept validation** • Demonstrator of concept • Needs further development before production use	• Dissemination: standard R&D route plus discussion with CAMC programme about piloting and further development
Beach performance assessment guidance and tool	**Piloting** • Has been tested and engaged with beach managers	• Dissemination: CIRIA publication as addendum to Beach Management Manual; standard R&D route; target chairs of coastal groups
Investment decision support for beach	**Invention** • Scoping level document produced	• For consideration by Defra and Environment Agency Joint Programme and other funders whether to take forward

Output	Product maturity (as of autumn 2017)	Possible next step for product
management		recommendations
Suite of project reports	Not applicable	• Disseminate: standard R&D route; parts could be extracted for specific uses such as training
Slide presentation (short and long versions)	Not applicable	• Disseminate: standard R&D route; parts could be extracted for specific uses such as training

The AP Tools project was conceived to assist the Environment Agency and other risk management authorities in achieving their strategic plans for asset management. Table 5.2 shows how each of the products contributes to achieving the delivery outcomes defined in the Environment Agency's Asset Management Strategy 2017 to 2022 (Environment Agency 2017a).

Future research requirements in this field will be informed by the experience of asset managers in using the tools and guidance developed in this project. Feedback on the application of the AP Tools products in real-world situations is therefore welcomed.

Table 5.2 Summary of how tools and guidance contribute to Environment Agency's Asset Management Strategy 2017 to 2022

Output	How it can contribute to the strategy			
	Assets operate when required	Customer legitimacy	More properties protected	Reduced whole life cost
Inspection guidance	✓			
Custom Fragility Curve tool	✓	✓		
Conveyance guidance				✓
Vegetation and Roughness tool		✓		
Pre-calculated risk datasets guidance				✓
Whole Life Cost tool	✓			✓
Risk-based whole life cost prototype tool	✓			✓
Beach performance assessment guidance and beach trigger tool	✓			✓
Investment decision support for beach management (scoping)			✓	✓

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List of abbreviations

AEP	annual exceedance probability
AIMS	Asset Information Management System [Environment Agency]
AP Tools	Asset Performance Tools
CAMC	Creating Asset Management Capacity [Environment Agency]
CES	Conveyance Estimation System
CSA	cross-sectional area
EAD	estimated annual damages
FCRM	Flood and Coastal Risk Management [Environment Agency]
JRP	joint return probability
KPI	key performance indicator
m AOD	metres above Ordnance Datum
MDSF2	Modelling and Decision Support Framework 2
NaFRA	National Flood Risk Assessment
ODN	metres Ordnance Datum Newlyn
PAMS	Performance-based Asset Management System
RAFT	Risk Attribution Field Tool
RBMP	Regional Beach Management Plans
RCMP	Regional Coastal Monitoring Programme
SoP	standard of protection
TE2100	Thames Estuary 2100 [Environment Agency project]
TEAM2100	Thames Estuary Asset Management 2100 [Environment Agency program]

Appendix: List of products

Table A.1 lists the tools, guidance documents and reports produced by the project.

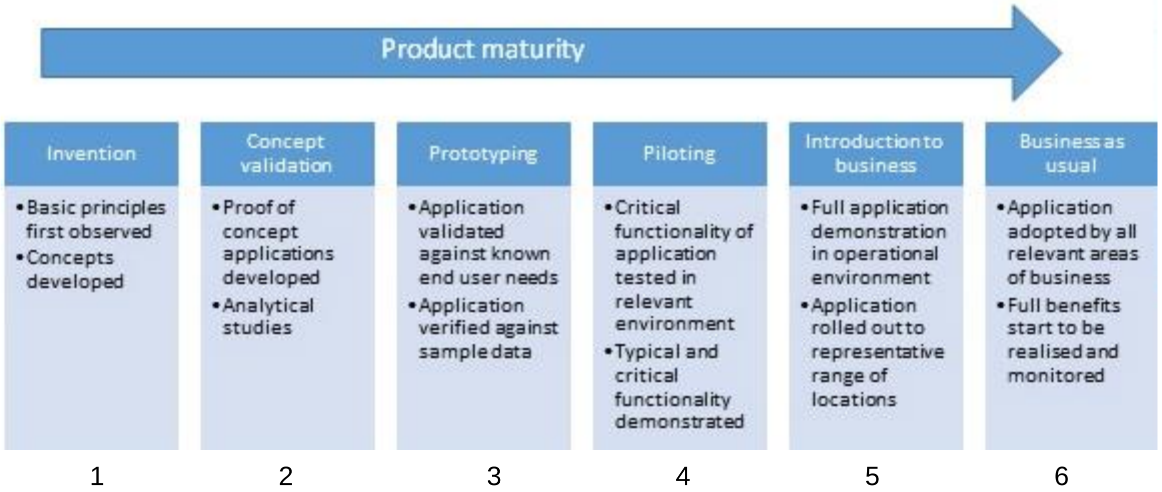
Table A.1 AP Tools – documents, guidance and tools

Product name	Type[1]	Description	Version	Final	Maturity[2]	External publication	Reviewers / user testing	Accepted?
Inspection guidance	D	Inspection guidance (SC110008) (developed in earlier phase of AP Tools project)	Final	Yes	5	Environment Agency (2014a)	Yes	Yes
Viability report	D	Initial AP Tools project phase 3 report Subsequent discussions resulted in adjusted scope for the remainder of the project.	6	Yes	n/a	No	Project Board	Yes – Project Board
Final project report	D	AP Tools final report, including case studies related to the various tools and guidance documents	Final	Yes	n/a	This document SC140005/R1	Project Board	Yes
Evidence Summary	D	Standard Evidence summary	Final	Yes	n/a	SC140005/S	Project Executive	Yes
Improving defence performance curves using local knowledge – methodology	D	Report builds on past research and a consultation workshop with a number of practitioners within the Environment Agency	Final	Yes	4	Report SC140005/R3	Workshop	Yes – Project Board
Custom fragility curve adjustment tool	TE	An Excel-based tool which enables the derivation of an asset-specific fragility curve through interpolation between the existing generic fragility curves. This is achieved through a structured workflow using a series of set questions. The tool is similar in user-interface as the existing RAFT tool. Guidance is provided within the tool. The methodology is described in Report SC140005/R3.	3p1 revision 2.3	Yes	4	Make available	Workshop Limited number of local practitioners within Asset Management teams (Environment Agency)	Yes – Project Steering Group
Raised defence target condition whole life	TE	An Excel-based tool enabling whole life costing appraisal for an asset, including variation of maintenance regimes and flexible	January 2018 revision 1	Yes	4	Make available + quick guide	Workshop TEAM2100 Project Board	Yes – Project Steering Group

Product name	Type[1]	Description	Version	Final	Maturity[2]	External publication	Reviewers / user testing	Accepted?
costing appraisal tool		setting of intervention points (between condition grades). Includes functionality to derive an asset-specific deterioration curve. Builds on a prototype tool created in past research. Adjustments made to enable wider FCRM use of the tool. Quick start guide (PPT) and guidance provided within the tool.					members	
Guidance for beach triggers	D	Guidance for setting beach triggers, including flowchart. Case studies included in AP Tools final report (this document).	Final	Yes	4	Report SC140005/R5	Workshop Technical experts	Yes
Beach trigger tool	TE	Excel-based tool guiding the user to set beach trigger levels in line with the guidance on the beach performance method	3p2 revision 1.0	Yes	4	Make available	Project level	Yes
Coastal defence whole life costing tool feasibility	D	A scoping study for a methodology and a simple user focused tool for coastal erosion asset managers to justify investment in maintenance by connecting performance of their assets to risk	Final	Yes	1	No	Project level Technical experts	
Channel conveyance assessment guidance	D	Guidance with a strong link to (but not a repeat of) the Channel Management Handbook (that is, it explains the processes and tools that can be used for the scenarios set out in the Handbook), aquatic plant management guidance and debris blockage guidance	Final	Yes	4	Report SC140005/R2	Project Executive Limited number of local practitioners within Asset Performance teams (Environment Agency)	Yes - Project Board
Vegetation and Roughness tool	TE	Compare changes in water levels in ‘with’ and ‘without’ channel management scenarios. Can	3p4a revision 1.3	Yes	3	Make available	Project level Limited	Yes – Project Steering

Product name	Type[1]	Description	Version	Final	Maturity[2]	External publication	Reviewers / user testing	Accepted?
		be used to support conveyance risk assessments, but it does not provide (change in) risk metrics. Guidance provided within the tool. Separate PDF guides the user through the steps needed in the CES.					number of practitioners (Environment Agency)	Group
Risk-based appraisal tool prototype	D	Included within final report (see case study)	n/a	Yes	2	No	Project level	n/a
Pre-calculated risk datasets guidance	D	Guidance to identify suitable pre-calculated datasets on flood risk to help local asset management decision-making	Final	Yes	4	Report SC140005/R4	Project level	Yes – Project Steering Group
Slide presentation	PPT	Slide deck with full detail of AP Tools and all Products.	11	Yes	n/a	Yes	Project Executive	Yes (9 November 2017)
Slide presentation – short version	PPT	Slide deck to provide a 20 minute presentation on AP Tools and one of the Products	11_20m	No	n/a	Yes	Project Executive	Yes (9 November 2017)

Notes: [1] D = document/report; TE = Excel-based tool; PPT = presentation
[2] Maturity status: see diagram
[4] One of suite of reports published at the same as this final report
n/a = not applicable



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