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Asset performance tools: guidance for beach triggers

Flood and Coastal Erosion Risk Management Research and Development Programme

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Professor Doug Wilson
Director, Research, Analysis and Evaluation

Executive summary

Beaches are recognised to provide an important aspect of coastal management and flood and coastal erosion risk management. This guide on triggers for beach management builds on the essential guidance and practice set out in the CIRIA Beach Management Manual. It focuses on how the monitoring and observation of beach behaviour and performance can be used and developed to assist in the management of the shoreline and its natural and fixed defences.

The Beach Management Manual highlights 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 triggers, beyond which these functions can be compromised.

This guide recognises that each beach brings its own specific value to overall management of the coast and shoreline system. It has 2 overall aims:

- to set out an approach for establishing these triggers in beach behaviour that will inform management decisions, allowing local managers to plan their response to change in their beaches

- to help generate the understanding of beach functions and performance essential for applying a generic approach to a specific beach
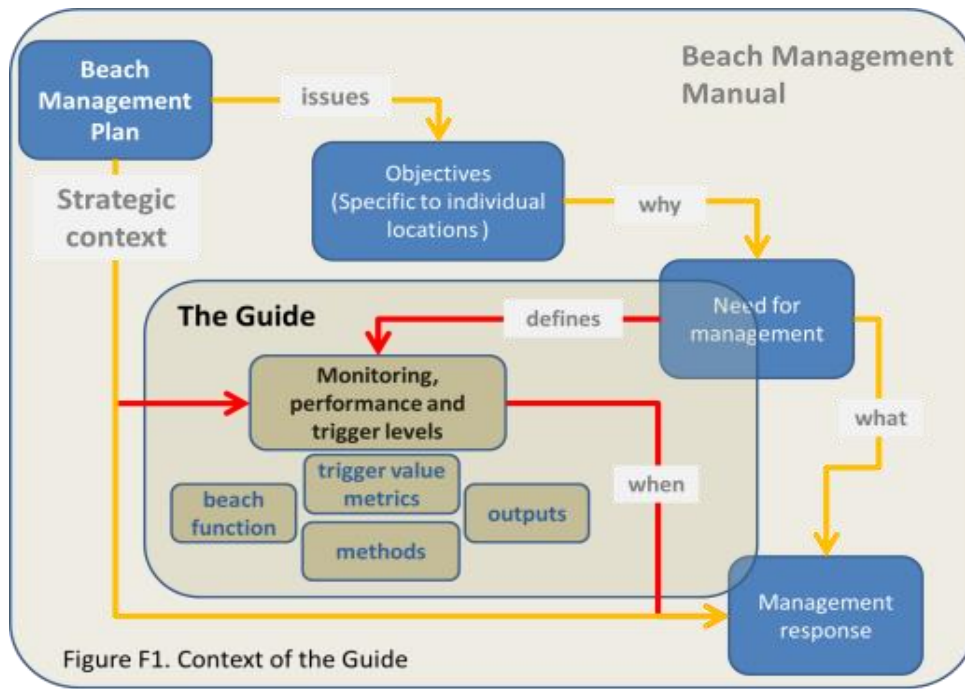
It is essential to understand the nature of the beach, its composition in terms of sediment type and structure, its natural response and, in many cases, the beach's ability to recover within the context of longer term trends and periods of extreme variation. This understanding allows managers to properly assess how beach change may:

- increase the vulnerability of other defence elements such as hard structures, a natural beach ridge or dune system

- increase the risk of longer term erosion of soft cliffs

No beach is the same as another, although at different levels many beaches do have similar or comparable characteristics. It is a prerequisite, therefore, when using the guide to think carefully about what is being managed. The guide seeks to provide an approach to assessing triggers that is generic, but that can be adapted and applied to a wide range of situations.

This guide aims to complement the broader guidance provided within the Beach Management Manual, in particular adding more specific guidance in developing trigger values associated with management objectives and subsequent actions defined within different forms of Beach Management Plans. This relationship is shown in Figure F1.

The document forms Part 1 of the guidance on beach triggers developed as part of project SC140005. Part 2 consists of flow charts that provide more detail on the methodology and a stepwise approach which is implemented in the spreadsheet-based beach triggers tool. Part 3 provides worked examples for 3 locations covering various beach types and functions; these can be found in Section 4.4 of the project Final Report (SC140005/R1).

Beach Management Manual

Beach Management Plan

issues

Objectives (Specific to individual locations)

why

Need for management

Strategic context

The Guide

defines

Monitoring, performance and trigger levels

trigger value metrics

beach function

outputs

methods

when

what

Management response

Figure F1. Context of the Guide

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1.1   Background

Beaches are recognised to provide an important aspect of coastal management and flood and coastal erosion risk management. The Beach Management Manual (Rogers et al. 2010) introduces the importance of monitoring and performance assessment as part of the beach management cycle. The manual identifies a range of functions of the beach (Chapter 2) and suggests the establishment of performance indicators (Chapter 6) and corresponding thresholds or triggers (Chapter 8), beyond which these functions can be compromised. However, it 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.

Every beach is subject to specific morphology and processes (Chapter 3 of the manual) and so performance assessment may be a complex task. This guidance on setting trigger values for intervention is a supplement to the Beach Management Manual. It 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 ultimate goal is to manage change. That is, change in the beach that affects how it functions as part of the defence system and how this may affect the vulnerability of assets or uses within the coastal area and environment. It is important to consider how monitoring can be used so that managers are able to use the information gained more effectively in:

- responding to immediate areas of concern
- planning and thinking about what actions may be required under different changes in beach behaviour

1.2   Structure of the guidance

The guidance has 3 parts:

- **Part 1: This guide** – this document presents the key principles
- **Part 2: Flow charts** – these provide more detail on the methodology and a stepwise approach implemented in a guided spreadsheet tool, the beach triggers tool developed as part of project SC140005
- **Part 3: Case studies** – these worked examples for 3 locations (Torcross in Devon, Walcott in Norfolk and Eastbourne in East Sussex) cover various beach types and functions and presented in Section 4.5 of the project Final Report (SC140005/R1)

The guidance aims to work in an asset management context. It was developed as part of the Asset Performance Tools project (SC140005), which devised the propeller diagram shown in Figure 1.1 to visualise the tactical elements of flood and coastal asset management. The propeller shows how the key activities of inspection, performance assessment, risk assessment and investment planning are interrelated and all centred on asset information.

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

The propeller also illustrates the concept of tiered approaches: use basic approaches where possible (usually for the majority of cases, illustrated by wider bars), but use more complex, detailed approaches where needed, for more critical cases where this is worth the investment of time and resource (illustrated by narrower bars) (Figure 1.1). These principles are also at the heart of this guidance.
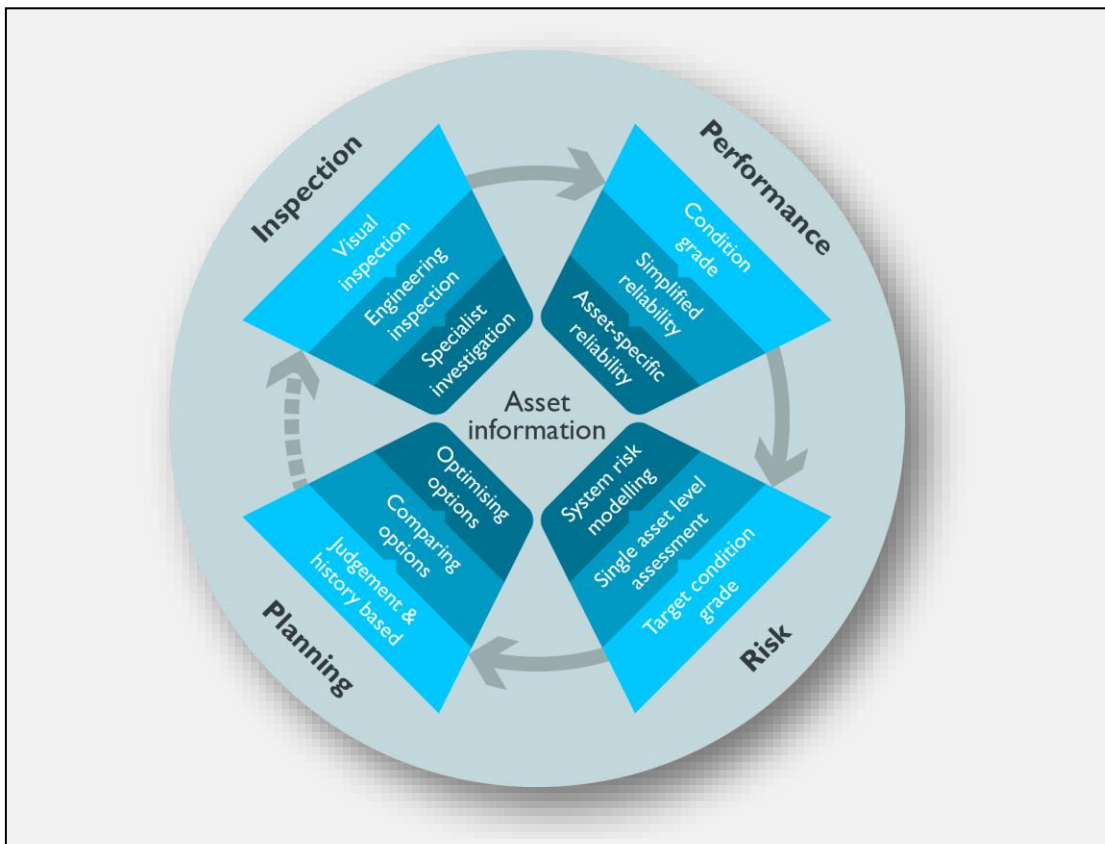
Figure 1.1   Asset performance propeller

1.3   Beach types, functions and triggers

The guidance is intended for the many beach types throughout the UK. It is therefore intentionally generic, but provides a framework for beach and asset managers to work within specific to their local situation.

To illustrate how the generic guidance can be translated and enhanced for specific situations, a method developed by Canterbury City Council and the Environment Agency for development of Beach Management Plans for south-east England is presented through a series of text boxes. The application of this approach is illustrated in one of the worked examples presented in the final project report (SC140005/R1, Section 4.4.3).

The guidance does not include triggers for supporting structures such as groynes and other physical features, though clearly these can significantly influence the characteristics of the beach. An active management of groynes may enable the beach to change towards a preferred geometry. However, groynes, similar to other management initiatives such as beach renourishment and offshore breakwaters, are a way in which beach levels, volumes or other measurable parameters may be managed to remain within trigger values, as part of a range of management methods. This choice of intervention type is beyond the scope of this guidance.

According to the Beach Management Manual (Rogers et al. 2010, Section 2.3.2), beaches can have 4 functional objectives:

- flood and coastal erosion risk management

- provision of natural environment

- provision of recreational space

- provision of commercial activities

Although it can be useful to develop performance indicators and trigger values for all these functions, the methodology in this guidance is concerned only with flood and coastal erosion risk management. Nevertheless, a similar approach could be used for the other beach functions based on local knowledge and judgement.

1.4   How to use this guidance

The guidance is set up for a pre-planned approach, in which the beach manager sets triggers to be prepared for future beach changes. This is strongly preferable to having to make a critical assessment directly after beach deformation, with little time and resources available. Some of the basic methods prescribed may be useful in that situation, but the guidance does not discuss this in detail and strongly recommends a pre-planned approach instead.

Although triggers can be used to inform management, original design parameters should not be neglected. In many cases, however, information may be limited, outdated because of changes in the asset condition, or not originally designed correctly. In this case, appropriate assumptions may be needed (in a basic assessment) or further investigation and recalculations may need to be made (in a more detailed assessment) to determine meaningful triggers. The guidance provides direction for where assumptions are required.

1.5   How to use the resulting triggers

Once the guidance is applied and trigger values are determined, these should inform decisions during the beach and asset management process. The guidance does not address how to intervene – it is management guidance not design guidance, although some of the calculation methods are also used for design. Box 1.1 presents examples of how the trigger values can be presented in practice and used for decision support. These outputs are presented in further detail in Section 4. It is suggested that beach managers have management plans in place so that they are ready to act when triggers are reached.

Calculations and modelling of beach behaviour can have significant uncertainty (Environment Agency 2014) and beach managers need to take this into account in setting triggers and using them to manage the beach. It is essential to:

- carry out regular monitoring and reviews of trigger values

- adjust the trigger values to changes in both driving forces and asset condition, or when additional information becomes available

Box 1.1: Examples of potential outputs and interpretive tools
This box and Section 4 illustrate how triggers can be presented and used in combination with monitoring data to support decisions, using the approach developed by Canterbury City Council.
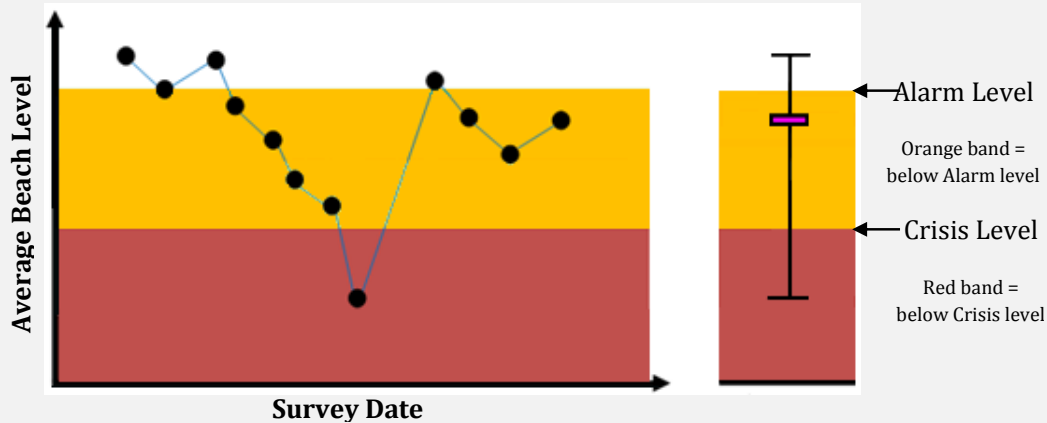
Figure 1.2   Example presentation of a beach parameter (average beach level) in the context of ALARM and CRISIS triggers

Figure 1.2 provides an overview of the state of the particular beach profile in relation to the defined triggers. The x-axis represents survey dates, the y-axis shows the average beach level, and the box and whisker plot per profile shows the lowest and highest the beach has ever been and its current state (pink bar).

Figure 1.3 shows the same features but presented across a whole frontage with the temporal element reduced to the maximum, minimum and latest values.
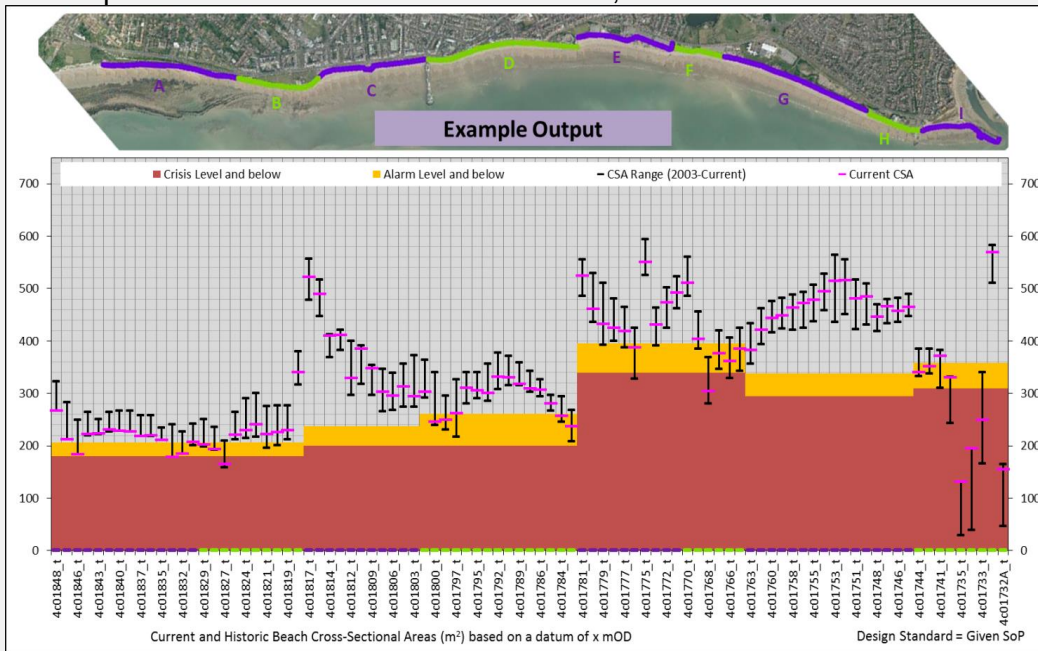
Figure 1.3   Example output showing maximum, minimum and latest values of the average beach level with time over a whole frontage

Notes: CSA = cross-sectional area

2 Methodology and terminology

This section introduces the concepts and terms used in the developed methodology.

2.1 Beach types and functions

Type of the beach refers to whether the beach has a hard defence or a cliff at the back, or is a standalone (barrier) beach.

The **functions of the beach** are defined in the Beach Management Manual (Rogers et al. 2010). The specific flood and erosion risk management function of the beach is different for each type of beach, as shown in Table 2.1.

Table 2.1   Beach types and functions in relation to flood risk management related functions

Type of beach	Flood risk management related functions	Other functions (all types of beach)
I. Beach with a structure behind (see Section 3.1)	• Protect the toe of the structure from undermining (Function Ia) • Limit overtopping over the structure (Function Ib) • Limit wave attack to the structure (Function Ic)	• Provide natural habitat/environment • Provide recreational space • Provide commercial activities
II. Beach with a cliff behind (see Section 3.2)	• Protect the toe of the cliff	
III. Standalone (barrier) beach (see Section 3.3)	• Upper beach: act as flood defence (Function IIIa) • Lower beach: limit wave loading on the upper beach (Function IIIb)	

2.2 Performance indicators

Performance indicators are measurable parameters that can be used to assess in a relatively simple, quantitative way the performance of the beach in relation to its functions (Marchand 2010). This can be a local beach level, volume or combination of measurable parameters but can also include temporal aspects such as the rate of change. This guidance presents one recommended primary performance indicator for each function of the beach, but also provides alternative performance indicators.

Performance indicators are defined as measurable parameters to determine triggers. This guidance typically suggests average beach level over a particular (function-specific) cross-shore width as the performance indicator, because this is the variable that physically determines its performance. In some cases, if other beach parameters such as beach volume (or cross-sectional area) have a direct and constant relationship with this beach level, then they can also be used as an indicator. The use of such an

approach for shingle beaches is illustrated in the Eastbourne case study (see Section 4.4.3 of report SC140005/R1).

The alongshore spacing of locations for which the beach level is measured and triggers determined is in part limited to the availability of data. As described further in Section 4, data and therefore triggers may be limited to standard profile monitoring points. This is considered a basic assessment; more detailed analysis is possible if justified by criticality. In other cases, where locations can be determined by the manager, then locations may be determined based on the presence of assets (see Section 4.4.3 of report SC140005/R1). Where beach levels are more variable alongshore, say within a groyne field, then average values may be required between groynes, for example.

2.3   Trigger values

The ultimate aim of the beach performance assessment is to set threshold or trigger values for these performance indicators (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. In simple terms, trigger values represent a value of a particular beach parameter (say average beach level) beyond which some form of intervention is required. Actions could include enhanced monitoring and preparation for intervention (in the case of ALARM triggers), or more involved and active intervention such as rock protection or beach renourishment (in the case of CRISIS triggers).

The guidance uses the terms CRISIS and ALARM for consistency with the terminology of the Beach Management Manual (Rogers et al. 2010). Alternative terms can be used, which may be more specific or meaningful to beach and asset managers. The use of such alternative terms is illustrated in the Eastbourne case study in Section 4.4.3 of report SC140005/R1.

A **CRISIS trigger value** sets the limit beyond which the beach function is compromised and remedial action becomes necessary. CRISIS values are related to good practice design rules or guidance. Following a tiered approach (see Figure 1.1), in some cases it is appropriate to use simpler, more conservative methods, while in other cases a more advanced method is needed and justified.

ALARM trigger values are predetermined values where the measured performance indicator falls to within a (locally determined) range of the CRISIS level, but has not yet resulted in failure of the function. ALARM trigger values are intended as a warning to prepare for intervention, so they need to be set with a safety margin that ensures there is sufficient time for taking action. This depends on the time needed to prepare for the intervention and how quickly the beach could change further.

This guidance recommends an approach for determining the margin of safety between the CRISIS and ALARM value based on historical beach variability (for example, how much the indicator can deteriorate in a typical winter season or the worst storm covered by the historic data). In the Walcott case study, for example, the average beach level at Walcott was observed to reduce by a maximum of 1.1m between surveys (see Section 4.4.2 of report SC140005/R1). When estimating this variability, storm sequencing and not just single storms should also be considered. In addition, it is important to reflect if the historic record is an adequate reflection of the ALARM–CRISIS situation (for example, the beach level may reach geological constraints).

Based on these concepts and terms, users of this guidance are encouraged to determine triggers in a stepwise process as presented in Figure 2.1. Details of setting

triggers values are provided in Section 3 of this document and in the SC140005 beach triggers tool (Part 2 of this guidance).
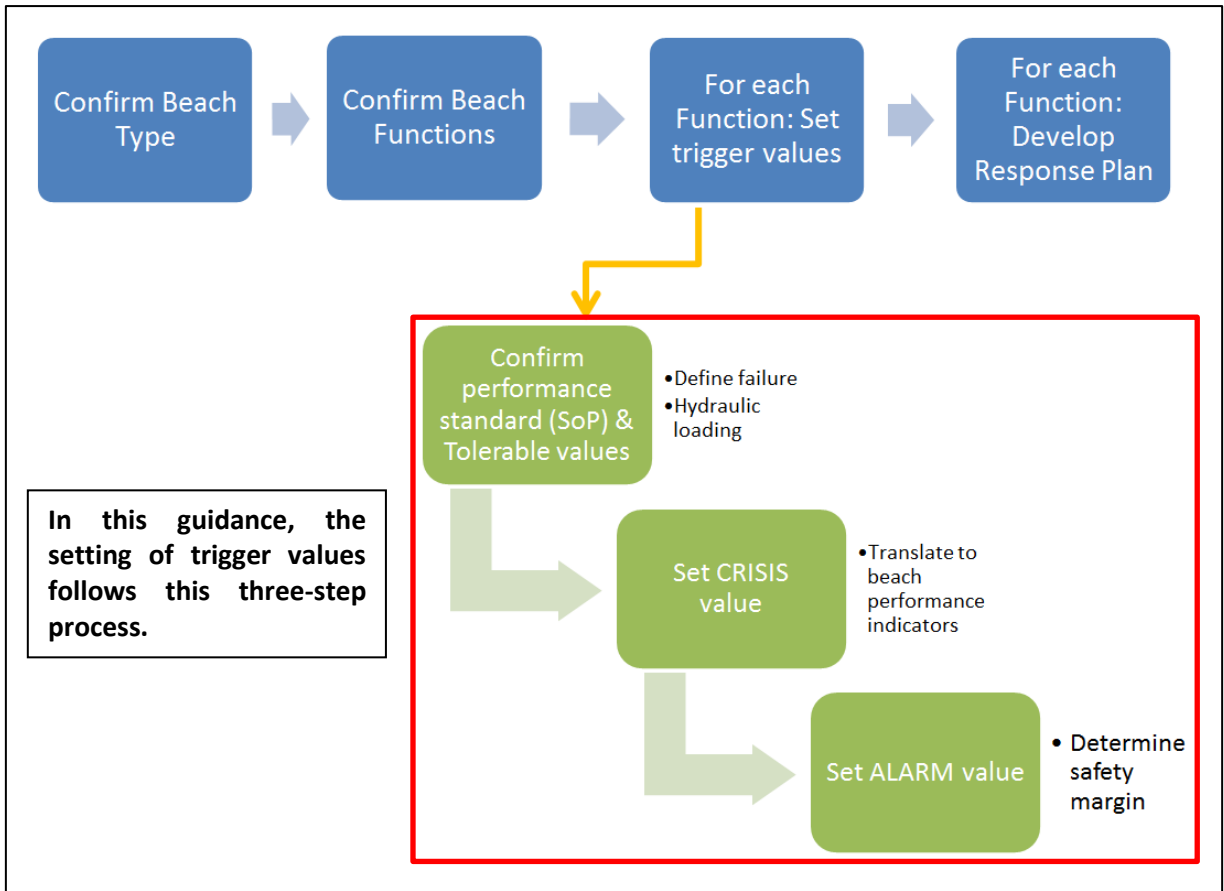

Figure 2.1   Stepwise process of determining triggers

3 Setting triggers

This section describes the process of trigger setting for a pre-planned approach, using the type of beach as the entry point.

Table 2.1 presents the 3 types of beaches and their functions. For each beach type, the functions and associated indicators are explained and illustrated. In addition, for each beach type, the user is referred to a flowchart in the SC140005 beach triggers tool, which explains how to set trigger values with reference to good practice guidance.

3.1 Type I: Beach with a structure behind

Many beaches in the UK are backed by a seawall to reduce flood risk and/or the risk of cliff erosion. In those situations, beach and structure work as a whole, with the structure dependant on the beach. However, the different nature of both elements – the structure is rigid and invariable, while the beach is flexible and variable over time – generates a complex interaction under the influence of the driving forces.

A beach in front of a structure performs 3 risk management functions.

- It protects the toe of the structure from undermining.
- It reduces overtopping.
- It reduces the wave loading on the structure.

The structure is supported and protected against wave action by beach sediment. However, waves reaching the structure can be reflected, removing sediment and causing scour. A reduced beach volume in turn leads to an increase in the wave height and wave energy reaching the structure.

In general, more sediment means better beach performance in terms of these 3 functions. The sections below set out which measurable parameters are suitable indicators for each function. In some circumstances (for example, a rock revetment), however, a greater amount of beach material can cause increased overtopping or increased damage to the seawall, depending on the type and configuration of both beach and structure (Dornbusch 2010).

3.1.1 Function Ia: Protect the toe of the structure from undermining

How beaches can protect the toe of a structure

The sediment of the beach can aid the stability of the structure. Lowering of the beach can be caused by long-term and large-scale processes, or by local scour caused by the action of waves. Lowering of the beach can undermine the structure reducing both the passive resistance and bearing capacity afforded by sediment. Removal of sediment fronting the structure down to a critical level can therefore lead to full or partial failure of a structure, such as seaward sliding or overturning, or a washout of backfill material from behind the structure, ultimately leading to damage and collapse (Figure 3.1). In addition, reflection of waves against the structure can further enhance scour (Figure 3.2).

Figure 3.1   Failure of a concrete seawall, due to undermining and washout of backfill in Aberdeenshire, Scotland

Source: Environment Agency (2006), photo courtesy of Aberdeenshire Council
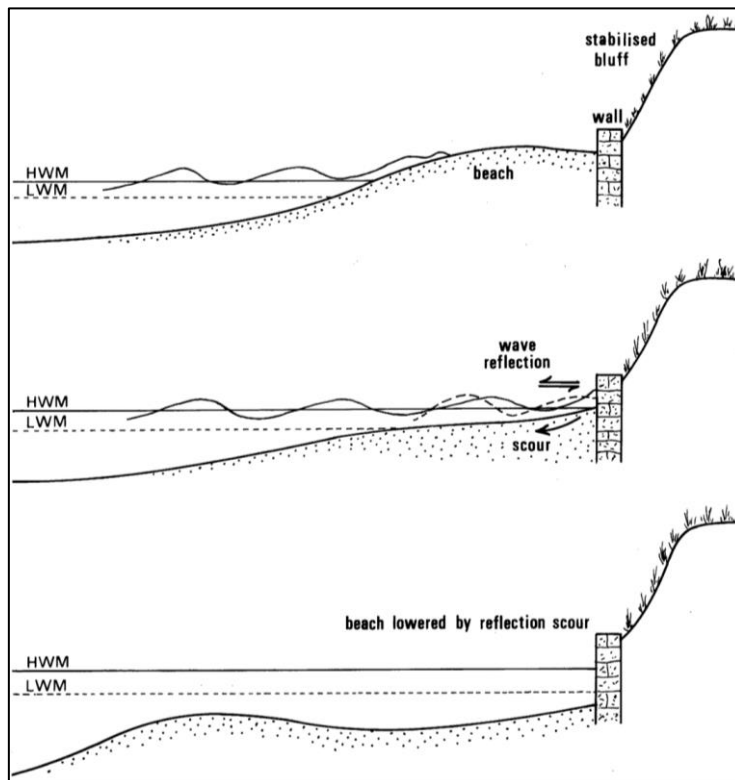
Figure 3.2   Schematic diagram presenting the concept of beach lowering as a result of wave reflection from a structure

Notes: HWM = high water mark; LWM = lower water mark
                Source: Bird and Lewis (2014)

Performance indicator: Average beach level over geotechnically supportive width

Beach level in front of the structure (seaward to a given distance) can be used as a performance indicator for the stability of the structure. If the beach level next to the structure is too low, it can cause damage or collapse. A minimum wedge of sediment has to be present to support the structure, even if scour holes develop during storm (Figure 3.3).
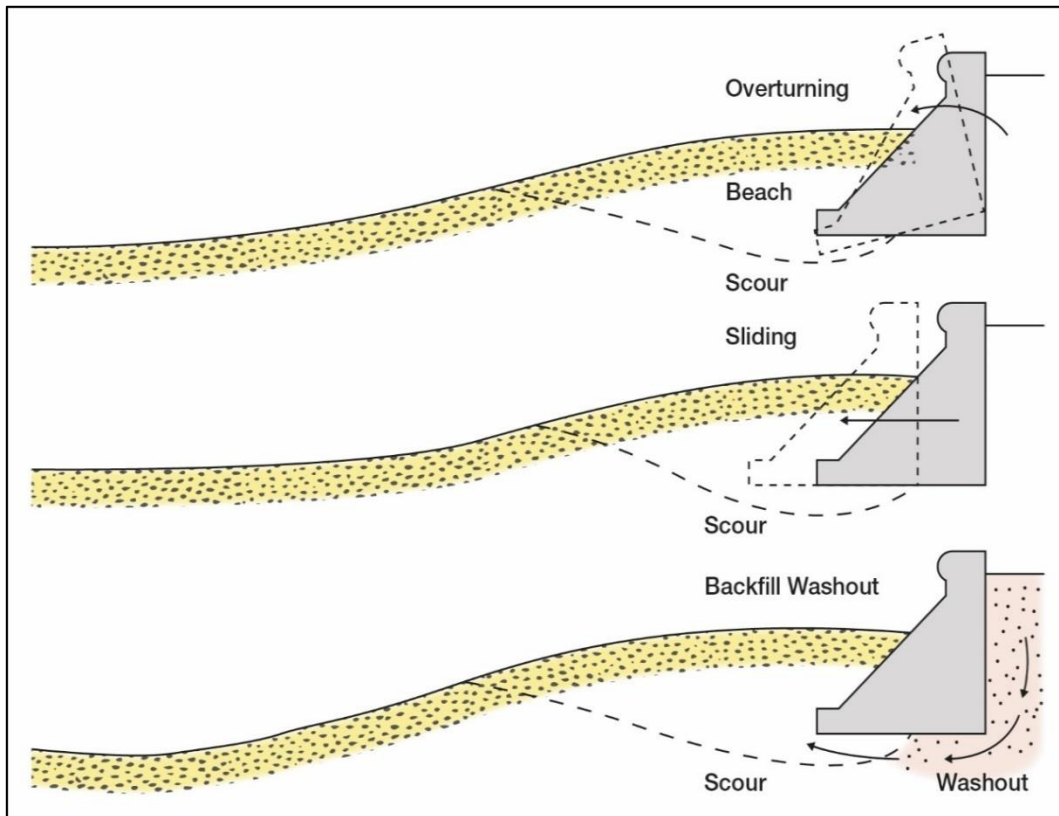
Figure 3.3   Schematic diagram demonstrating the relationship between beach level and failure mechanisms (overturning, sliding, backfill washout) of structure (gravity wall in this case)

It is the beach level over a certain beach width that matters, not just the level directly against the structure. The beach material directly supports the structure over a certain width, related to the sediment's angle of friction and the depth of the structure's toe below the beach surface. The resulting wedge of beach that supports the toe varies for the type of structure and the sediment.

Triggers for structural stability need to include an allowance for scour holes that may develop during a storm. Scour is typically not captured in monitored beach levels because of its dynamic and often short-lived nature, but it can be large enough and remain long enough to cause undermining or instability.

Setting trigger values for protection of the toe of a structure

Trigger setting follows the three-step process set out in Figure 2.1.

Step 1: Performance standard and tolerable values

The performance standard is the acceptable chance of failure of the structure, which is typically taken as the structure's standard of protection (SoP). It determines the hydraulic loading used in setting triggers. The tolerable values for structural stability (Factor of Safety, acceptable movement) are im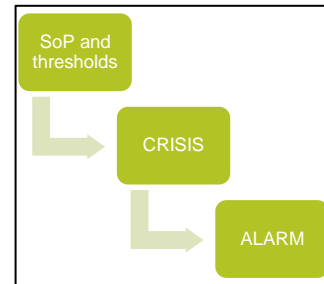plicit in the geotechnical design methods and only need to be considered when applying the 'more detailed tier' methods.

Step 2: Setting CRISIS trigger values

There are 2 parts to this calculation:

- critical beach depth

- allowance for scour during storms

The critical beach level at the structure can be determined through a review of the original basis of design and design parameters, or where not available, through engineering calculations or expert engineering judgement.

For cases where the depth of the structure toe is unknown, or where 'as-built' or design information is not available, a 'basic assessment tier' conservative assessment can be made based on observable lowest levels of the structure. A safe approach is to assume no foundations are present below the lowest known levels. For a structure(s) where the toe consists of sheet piling, a basic assessment tier estimate of toe level can be to assume that the lower two-thirds of the total length of pile is below beach levels in design conditions. If these assumptions are critical and if the extra effort is justified, the beach manager should invest in data collection to ascertain the structure toe level. Such information could be gathered through mechanical or hand dug trial pits, a geophysical survey or other intrusive methods such as boreholes or use of dynamic cone penetrometers.

The relevant beach width over which the average level needs to be taken depends on the 'wedge' of sediment that supports the structure. For a (conservative) basic assessment tier approach based on geotechnical principles, it is recommended to take into account a beach width (horizontal distance) of approximately 5 times the beach depth above the toe that was assumed in the structure's design (see Figure 3.4).
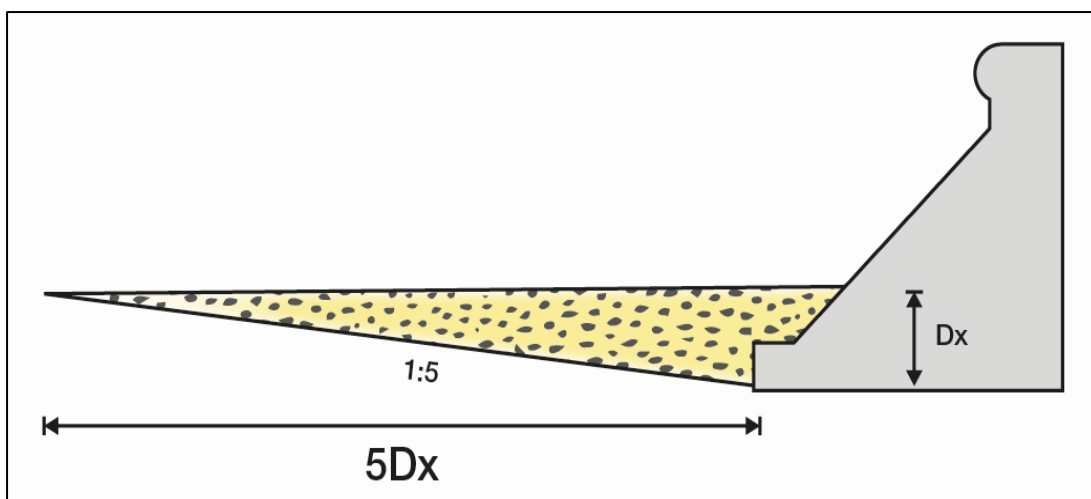
Figure 3.4 **Role of the beach in providing passive support to a structure (example shown is for a gravity seawall)**

If this mechanism is critical and better data are or can be made available, then a 'more detailed tier' approach could be appropriate, determining a less conservative value through good practice design rules for structural stability. If the beach cross-sectional area (CSA) is an adequate proxy for the beach surface level, this can be used as a performance indicator (see the Eastbourne case study in Section 4.4.3 of report SC140005/R1).

From the determined critical level for structural stability, an allowance for potential scour is then added. Development of scour can be highly variable, being dependent on beach sediment type, geology, structure type and sea state. In addition, the development of a scour trench is often short-lived (Pearce et al. 2006).

Where no specific analysis has been made, this guidance suggests incorporating an allowance to account for potential scour during a storm. Following available good practice (Environment Agency 2012, Section 3.6.4), the basic tier approach is to apply an allowance of 0.8 times the nearshore significant wave height for the design storm considered (nearshore as defined in the Toe Structures Manual, not at the structure). If data concerning the nearshore significant wave height are not available (with only offshore wave height available), an alternative is to calculate the largest wave able to reach the nearshore using the method set out in Box 3.4.

This basic tier approach is likely to be conservative, particularly for shingle beaches. If it appears critical for the triggers, then a more detailed tier approach may be justified. An obvious next step could be to consider geology: the scour depth may be restricted by the actual depth of mobile sediment above bedrock or cohesive materials. If needed and if the additional effort is justified, further methods for determining scour on both sand and shingle beaches can be found in Appendix A and Appendix B of the Toe Structures Management Manual (Environment Agency 2012).

Figure 3.5 illustrates the elements of the calculation. The CRISIS trigger level is 0.8Hs above the top of minimum required beach level, where Hs is the significant wave height (for the design storm). Dx is the depth of toe from the critical beach level.
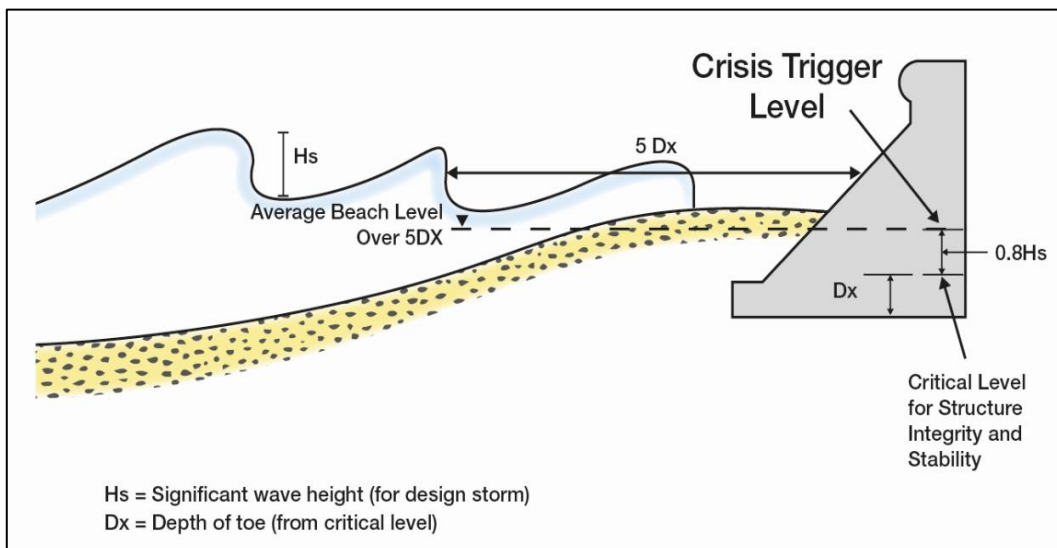
Figure 3.5   Relationship of beach level and setting of CRISIS triggers for protection of the toe

Step 3: Setting ALARM trigger values

ALARM trigger values can be calculated by adding an adequate margin of safety to the CRISIS value (see Figure 3.6). This can be achieved based on historical data analysis (Box 3.1).
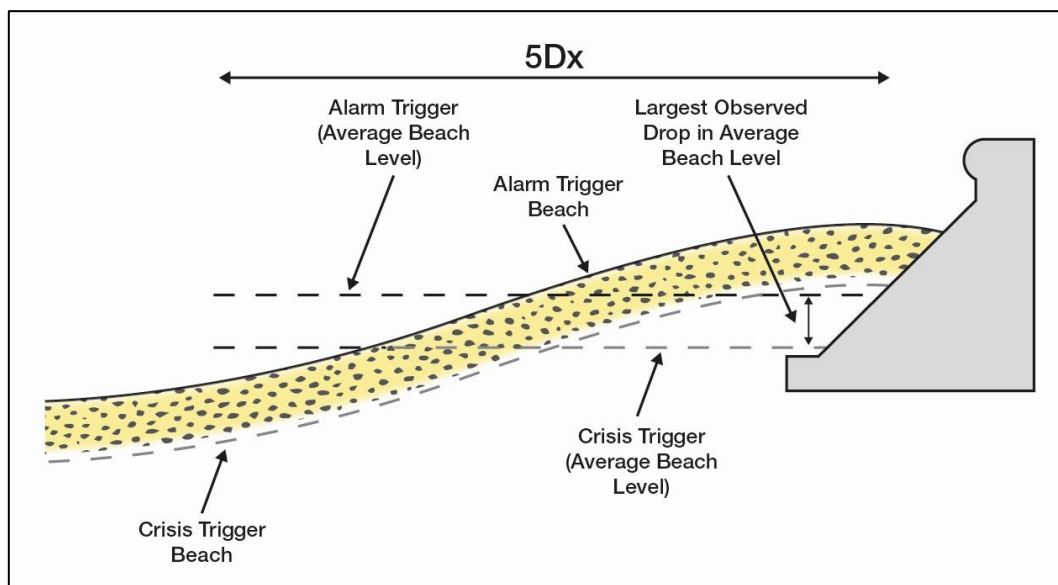
Figure 3.6   Relationship between CRISIS trigger (beach level) and ALARM trigger value for protection of the toe

Box 3.1: ALARM trigger values determined from CRISIS trigger values

ALARM trigger values can be calculated by adding an adequate margin of safety to the CRISIS value. This can be achieved based on historical data analysis. For example, the maximum observed reduction in beach profile during a storm, taking account of sequential storms and considering geological constraints, could be used as the appropriate margin between CRISIS and ALARM triggers.

An alternative method for obtaining ALARM trigger values from CRISIS trigger values is presented in Box 3.2. It is presented here for information and potential use, but is not considered further in this guidance.

Box 3.2: Alternative method of obtaining ALARM trigger values – higher SoP

As an alternative, the ALARM trigger value can be determined by repeating the CRISIS trigger calculation using the more severe design storm conditions associated with a higher SoP. Carrying out the design calculations with higher wave values and water levels would lead to a requirement of a higher beach level trigger value to safeguard structural stability. For example, if the CRISIS trigger value was set for 1% annual exceedance probability (AEP) conditions, then a greater SoP (arbitrarily 10 times greater, that is, 0.1% AEP) could be used to perform the calculations. This approach has the benefit of relating the safety margin between CRISIS and ALARM to the probability that the beach does not perform its function. In principle, this method is applicable to each beach type and function.

The SC140005 beach triggers tool provides more detailed stepwise guidance on setting adequate CRISIS and ALARM trigger values for toe structure protection.

3.1.2　Function Ib: Reduce overtopping

How beaches reduce overtopping

When waves are able to break at or close to the structure, the resulting deflection or exceedance of the crest can cause overtopping (Figure 3.7). The presence of a beach can cause waves to break, which reduces wave energy reaching the structure and consequently reduces overtopping, or even prevents the wave run-up from reaching the seawall or its crest. In some cases, however, a steep beach at the toe of the structure can increase overtopping through a ramping effect.

Figure 3.7　Wave overtopping onto a moving train, UK

Source: EurOtop (2016, Section 3).

Performance indicator: average beach level over width that affects wave height

The beach level over a certain beach width can be used as a performance indicator for wave overtopping. Wave overtopping rates are higher with a low beach level. In addition, with a lower beach berm, wave action can cause higher wave plumes above the crest of the wall, as a consequence of more energy reaching the structure. If the average beach level is too low, wave overtopping can exceed tolerable values (Figure 3.8).

Note that it is the beach level profile over a certain beach width that matters for overtopping, not just the level directly against the structure. In order for the incoming waves to lose their energy, the water needs to be sufficiently shallow over a beach width of at least one wavelength (nearshore). A conservative estimate for wavelength is 1.5 times the square of the wave period in metres. However, the formula given in Box 3.3 is likely to give a more realistic value.
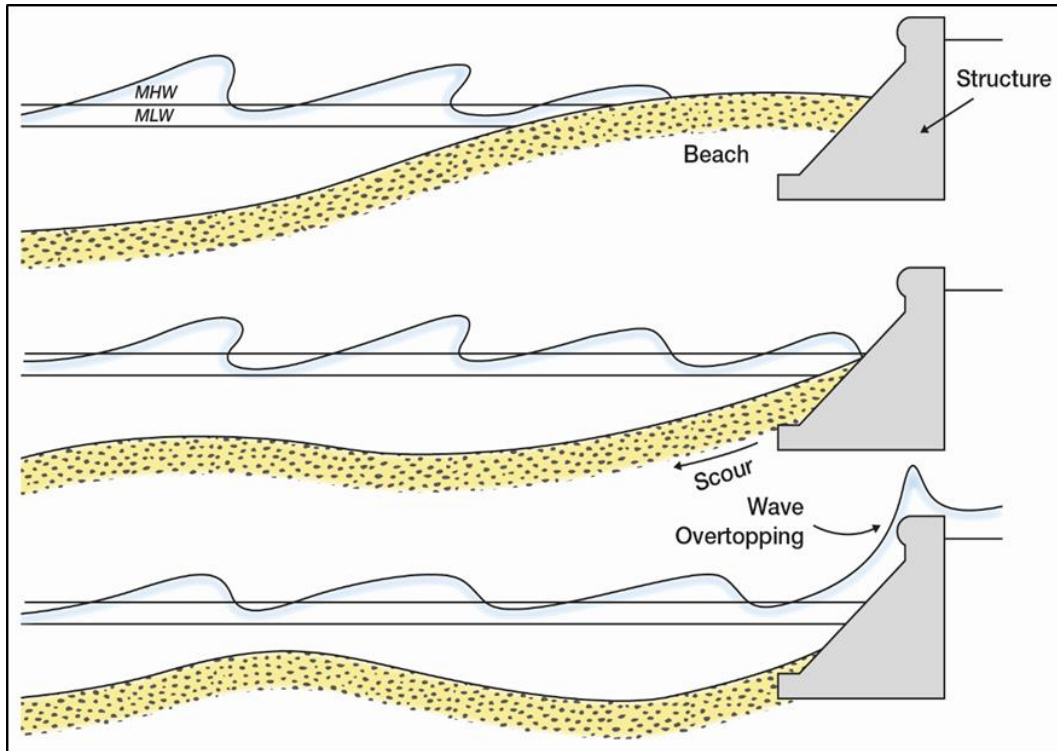
Figure 3.8 Sequential schematic diagram showing the relationship between the beach level and overtopping

Notes: The middle image represents a lowering of the beach through localised scour or general beach lowering, leading to increased wave overtopping.
MHW = mean high water; MLW = mean low water

Box 3.3: Method for calculating nearshore wavelength

The wavelength in shallow water can be calculated using the equation below, which is based on linear (airy) wave theory (USACE 1984).

$$L = T\sqrt{gd}$$

where:

L = wavelength

T = wave period at chosen probability of exceedance

d = water depth at chosen probability of exceedance

g = acceleration due to gravity

Shallow water is defined as when $\frac{d}{L} < \frac{1}{25}$

In theory, it is the full profile of the beach over a width of a wavelength, including level variations, that determines overtopping, not just the average. It is possible to use the overall profile as an indicator, but that requires relatively complex calculations with wave models; such a more detailed tier approach may be appropriate where overtopping is critical for beach management. In practice, it will usually be sufficient to take a simpler basic tier approach by using the average beach level over a width of one wavelength in design conditions as the performance indicator for the wave overtopping reduction function of the beach. If beach CSA is an adequate proxy for the beach

surface level, this can be used as a performance indicator (see the Eastbourne case study in Section 4.4.3 of report SC140005/R1).
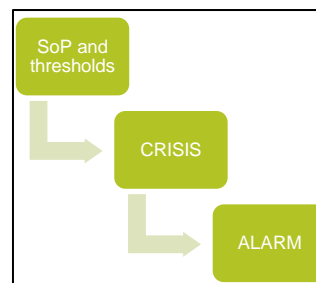
Setting trigger values for wave overtopping

Trigger setting follows the three-step process set out in Figure 2.1.

Step 1: Performance standard and tolerable values

The trigger value needs to ensure 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 (relatively low values) in relatively normal conditions (for example, the average once a year storm), but also to the structural integrity of the crest or landward slope or flooding (relatively high values) in extreme conditions (for example, design conditions of 1 in 200 per year).

It is possible to set multiple criteria for different tolerance values with associated triggers, each with their own management response (see Box 3.4 and the Torcross and Walcott case studies in Section 4.4.1 and Section 4.4.2 of report SC140005/R1 respectively). The corresponding tolerable values can be obtained from relevant guidance (EurOtop 2016 Section 3, USACE 2002).

Step 2: Setting CRISIS trigger values

The basic method is to obtain the trigger value through an iterative process that calculates overtopping rates for a range of beach levels until this matches the predetermined tolerable overtopping rate.

The basic assessment approach is to apply the EurOtop calculation tool. More detailed level approaches such as PC Overtop, AMAZON or neural networks are available if this aspect is critical and extra effort is justified.

Using the EurOtop tool, a wave height (Hs) is found to exceed a predetermined overtopping threshold. Based on this wave height, a critical depth (dc) is calculated, which is equivalent to a particular beach level. This is the CRITICAL trigger value.

As a basic assessment, it can be assumed that waves at the toe of the structure are depth-limited (see Box 3.4).

Box 3.4: Breaking wave height for depth-limited waves

The ratio of breaking height (H_b) to depth (H_b/d) is known as the breaker index and has been the subject of much research over the past 150 years. Current design guidelines (Goda 2000, USACE 2002) are based on the critical studies of Goda (1970) and Weggel (1972).

For the purpose of this guidance, the depth-limited wave height can be calculated as Hs = 0.6 × d. In practice, however, this ratio can change from a general minimum of 0.6d to a maximum of 1.56d, depending on the wave and beach steepness. Further analysis could be considered as a more detailed tier approach.

For further guidance on how to calculate adequate CRISIS trigger values for overtopping, refer to the flowcharts in the SC140005 beach triggers tool and the

worked examples in Section 4.4 of report SC140005/R1. Box 3.5 presents an alternative approach that takes more initial effort but produces much richer information for beach management.

Box 3.5: Alternative approach for determining CRISIS trigger values through multi-calculation analysis

The main text presents a basic method of calculating one trigger value through a stepwise iterative process. An alternative approach is to undertake a matrix of calculations based on multiple scenarios and parameters, from which a trigger value can then be chosen. This more detailed tier approach takes slightly more data and time and may require more expertise, but can be worthwhile if useful for management.

An example output of such calculations – developed by Canterbury City Council – is presented in Figure 3.9. It allows beach managers to compare the risk/hazard (in this example overtopping) against multiple values of a performance indicator (in this case CSA) and return periods. The approach is presented in more detail in the Eastbourne case study in Section 4.4.3 of report SC140005/R1.
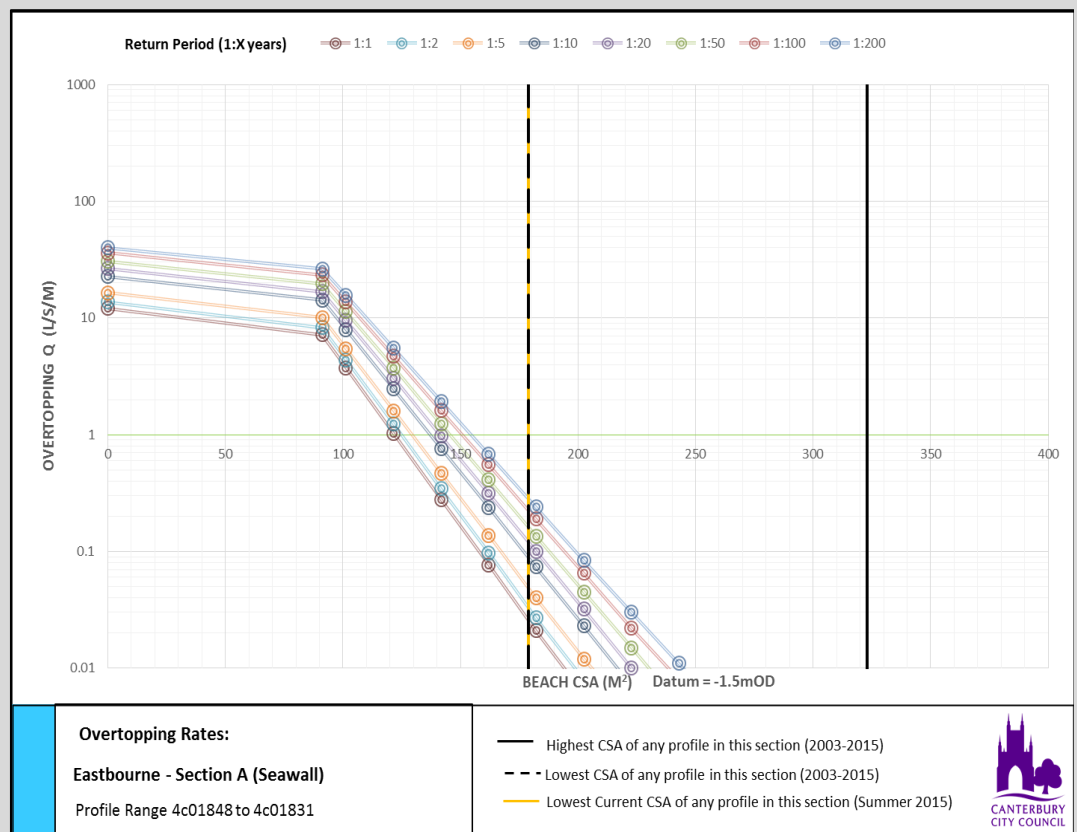
Figure 3.9   Example output from multi-calculation analysis

Step 3: Setting ALARM trigger values

ALARM trigger values can be calculated by adding an adequate margin of safety to the CRISIS value, preferably based on historical data analysis (Box 3.1). An alternative method based on a higher SoP is presented in Box 3.2.

The SC140005 beach triggers tool provides more detailed stepwise guidance on setting CRISIS and ALARM trigger values for wave overtopping.

3.1.3   Function Ic: Reduce the wave loading on the structure

How beach level can influence wave loading on the structure

For some coastal structures, severe damage and ultimately collapse through direct loading by waves is a dominant failure mode (Figure 3.10). The presence of the beach can reduce wave energy reaching the structure, and consequently reduces the loading. With a less extensive beach, waves can more easily reach and impact the wall (Figure 3.11). Although similar to function Ib (Reduce wave overtopping), the critical relationship between water level, wave height and wave period is different for function Ic. This influences the calculation of trigger values. For wave loading on a structure, critical parameters include wave height and water depth (USACE 2002, Cuomo et al. 2010, BSI 2013).

Figure 3.10   Example of wave loading on a structure (seawall)
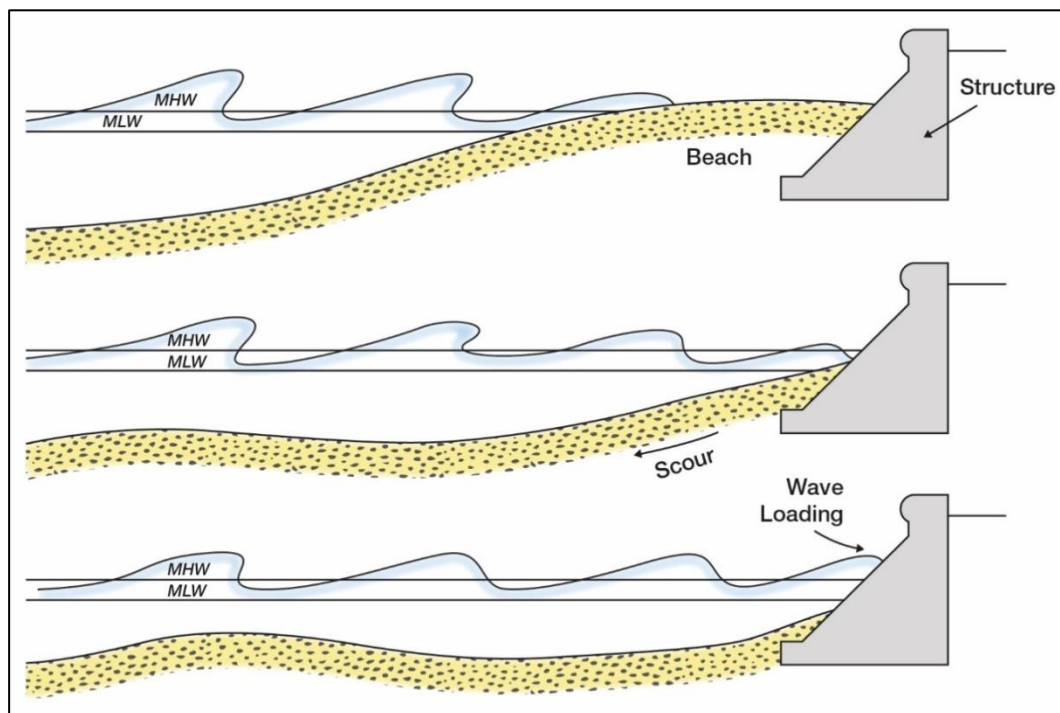
Figure 3.11   Sequential schematic diagram showing wave loading on a structure in relation to beach level

Notes: The middle image represents a lowering of the beach through localised scour or general beach lowering, leading to increased wave loading at the structure.

Performance indicator: average beach level over width that affects wave height

Beach level over a certain beach width is a performance indicator for wave loading reaching the structure. If the average beach level is too low, wave loading can exceed tolerable values.

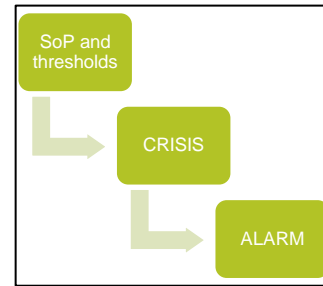Note that it is the beach level profile over a certain beach width that matters for wave loading, not just the level directly against the structure. In order for the incoming waves to lose their energy, the water needs to be sufficiently shallow over a beach width of at least one wavelength (see Box 3.3).

In theory, it is the overall profile of the beach over a width of a wavelength, including level variations, that determines wave loading and not just the average. It is possible to use the overall profile as an indicator, but that requires relatively complex calculations with wave models; this more detailed tier approach may be appropriate where wave loading is critical for beach management. In practice, it will usually be sufficient to take a simpler basic tier approach by using the average beach level over a width of one wavelength in design conditions as the performance indicator for the wave loading reduction function of the beach. If beach CSA is an adequate proxy for the beach surface level, this can be used as a performance indicator (see the Eastbourne case study in Section 4.4.3 of SC140005/R1).

Setting a trigger value for wave loading on the structure

Trigger setting follows the three-step process set out in Figure 2.1.

Step 1: Performance standard and tolerable values

The performance standard is the acceptable chance of failure of the structure, which is typically taken as the structure's SoP. This determines the hydraulic loading used in setting triggers. The tolerable values for structural integrity (Factor of Safety, acceptable damage) are implicit in the structural design methods and only need to be considered when applying more detailed tier methods.
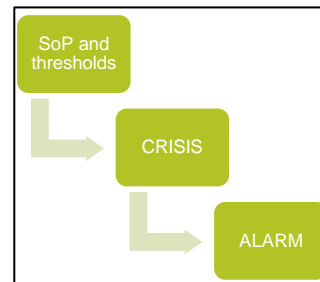
Step 2: Setting CRISIS trigger values

The trigger value is obtained through an iterative process, based on ensuring that wave loading parameters (that is, wave height and water depth) reaching the structure in storm events with the chosen probability of exceedance do not exceed values that would cause unacceptable damage to the structure.

Design wave conditions can be assumed as the critical wave conditions if the condition of the structure has not changed significantly (confirmed by as-built information) and the criticality of the seawall has not changed (for example, through a housing development behind the structure). Otherwise, the critical wave conditions for the structure must be estimated using relevant guidance (USACE 2002, BSI 2013). For ease of reference, the determination of wave impact forces ($F_{h,imp}$) on structures recommended by BS6349-1: 2000 is expressed as:

$$F_{h,imp} = 15 . \rho . g . d^2 . \left(\frac{Hs}{d}\right)^{3.134} \qquad (3.1)$$

where:

Hs = significant wave height at the toe of the wall

d = still water depth

g = acceleration due to gravity

ρ = density of the water in kg/m3

Once the tolerable wave impact force is determined, the average beach level over one wavelength is determined based on depth-limited waves reaching the structure (see Box 3.4).

Step 3: Setting ALARM trigger values

ALARM trigger values can be calculated by adding an adequate margin of safety to the CRISIS value, based on historical data analysis as per Box 3.1. An alternative method of determining ALARM triggers based on a higher SoP is presented in Box 3.2.

The SC140005 beach triggers tool provides more detailed stepwise guidance for setting adequate CRISIS and ALARM trigger values for wave loading on the structure.

3.2   Type II: Beach with a cliff behind

There is no simple general method available for setting triggers for this beach type. The same general principles as for a beach in front of a structure are valid, though this will typically require a more detailed analysis than for beaches in front of a seawall.

3.2.1   **How beach level can influence cliff erosion**

There is a strong interaction between cliff erosion and beach behaviour. Cliff erosion supplies sediment to the beach, but also gives the beach space to develop. The height and width of the beach will in turn influence the exposure of the cliff to wave action that contributes to cliff erosion.

Management objectives can relate to the risk of erosion to cliff top property and infrastructure, but in some cases continued exposure of the cliff is desirable for geological interest, ecological health, sediment supply and landscape. All these factors need to be considered when defining trigger values.

3.2.2   **Performance indicator: overall beach profile**

It is relatively rare that beaches are managed actively to reduce cliff erosion. Where they are, in most cases some cliff erosion will be acceptable and the function of the beach is not to stop but to slow down erosion.

A major challenge when setting triggers is that it is difficult to quantify tolerable wave loading. Cliffs and their setting are strongly variable, and the rapid interaction between beach and waves in the course of a storm introduces further complexity. As a result there are no good practice calculation rules and even location-specific quantitative assessments are rare.

Generally speaking, tolerable wave loading will relate to the cumulative wave energy reaching the cliff during a storm, but variability will also matter. The vertical location of wave attack could be important and there may be a process of gradual weakening in the course of the storm. A further complication is that wave loading itself is influenced by development of the beach during the storm. Beach level at the toe also has a direct influence by sheltering the part of the cliff that is covered.

In summary, the performance indicator is the overall beach profile that affects how the waves reach the cliffs, including the development of the beach during that storm. There is no obvious way to simplify this to a single parameter.

3.2.3   Setting trigger values for cliff erosion

In principle, trigger setting follows the three-step process set out in Figure 2.1.

Step 1: Performance standard and tolerable values

If there is no room to accommodate any cliff erosion, the performance standard is the acceptable chance of cliff erosion occurring. This determines the hydraulic loading used in setting triggers. Where the function of the beach is to slow down erosion, it is possible to identify multiple return periods with associated acceptable erosion losses.

Step 2: Setting CRISIS trigger values

There is no single, easily applicable method for calculating the beach profile required to limit cliff erosion. Fundamentally, the trigger value relates to the degree to which the beach limits the ability for waves to have an impact on the face of the cliff. The acceptability of wave impact will depend strongly on the localised geology of the cliffs and the history of erosion. There is no generally applicable basic tier method, but 2 more advanced but still practical approaches based on erosion during historic events are available (see Box 3.6).

Step 3: Setting ALARM trigger values

ALARM trigger values can be calculated by adding an adequate margin of safety to the CRISIS value, based on historical data analysis as per Box 3.1. An alternative method of determining ALARM triggers based on a higher SoP is presented in Box 3.2.

The SC140005 beach triggers tool provides more detailed stepwise guidance for setting adequate CRISIS and ALARM trigger values for wave loading on the structure.

Box 3.6: Approaches to setting triggers for cliff erosion in practice

A practical, more detailed tier approach was explored in 2016 as part of the Bacton to Walcott coastal management project in Norfolk. This made use of local knowledge of the cliffs' response to recent storms. The method consisted of:

1. Characterising the hydraulic loading that reached the cliff face during recent storms that were known to have caused either significant erosion or no erosion

2. Using the results to define a threshold loading level for cliff erosion

3. Designing the required beach profile to limit cliff face loading during a design storm below the threshold

The loading was characterised by the number of wave 'hits' at different levels on the cliff face during the course of a storm based on detailed overtopping analysis of a wave time series (see Figure 3.12).
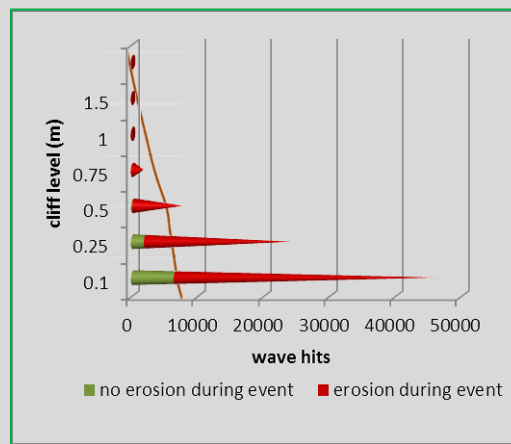
Figure 3.12   Results of detailed overtopping analysis of wave time series during a storm

A second, more detailed tier approach may be to use a previous period of monitoring data (say 2 decades) to define a relationship between observed rates of cliff recession and beach levels. For example, where there has been observed erosion between surveys then it may be concluded that beach levels were too low to prevent the storm from impacting the cliff. The amount of erosion could then be related to beach levels and if that rate of erosion was or was not acceptable. Care should be taken when using this approach as erosion and beach level should be considered in the context of the storms experienced.

3.3   Type III: Standalone (barrier) beach

3.3.1   **How beaches function as flood defences**

Shingle and mixed sand/shingle beaches are widespread in many parts of the UK. These beaches can be highly efficient forms of coastal defence which also provide ecological, amenity and aesthetic value. Sand beaches, often in combination with sand dunes, can also function as a coastal defence in a barrier-style configuration.

In many cases in the UK, barrier beaches that are managed for flood and coastal erosion management are formed of shingle and mixed (sand/shingle) sediment. For

this reason, guidance for setting triggers for shingle beaches is provided, including in the SC140005 beach triggers tool. Directions for setting triggers for sand barriers are given in Box 3.8 in Section 3.3.2.

Typically, the function of a barrier beach is to act as a flood defence barrier. This function is primarily performed by the upper beach (above still water level) and is here termed function IIIa. In addition, the lower beach (below still water) can have an important function in reducing wave loading on the upper beach. If the beach manager considers that the lower beach plays an important role in reducing loading on the barrier beach, then separate triggers could be set for the lower beach, using the guidance provided below for function IIIb (see Section 3.3.3).

In general, more sediment means better beach performance against these 2 functions. This is shown schematically in Figure 3.13 and related to relative standards of protection in Figure 3.14. The sections below set out which measurable parameters are suitable indicators for each function.
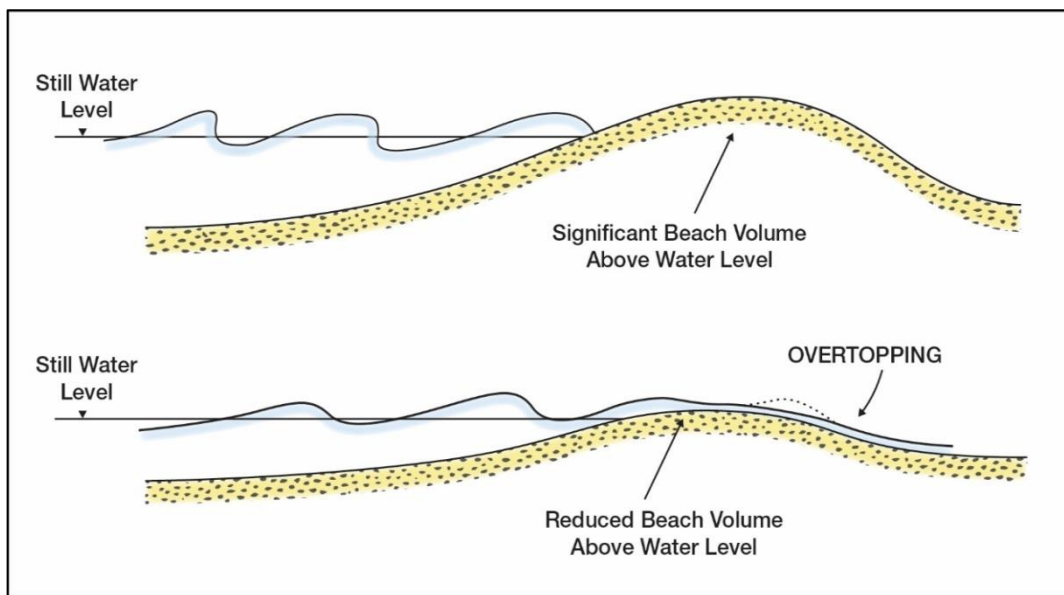
Figure 3.13   Schematic showing role of a standalone barrier beach acting as a flood defence barrier
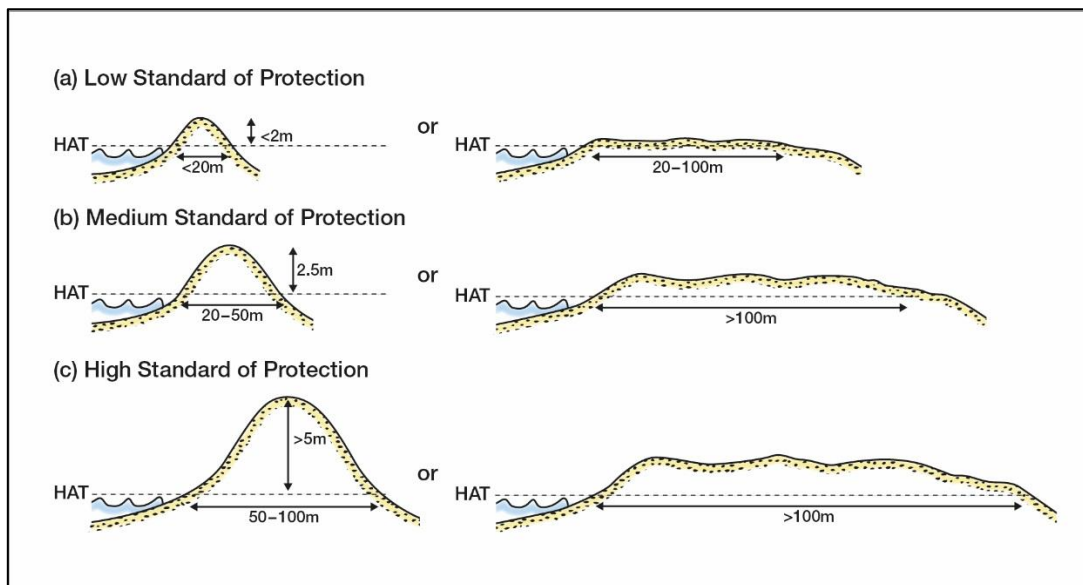
Figure 3.14   Relative SoP offered by different beach and sand dune geometries

Notes: HAT = highest astronomical tide
                Source: Pye et al. (2017)

3.3.2   Function IIIa: Beach acting as a flood defence

With no other element to impede water from going beyond, the beach itself functions as a coastal defence against sea flooding. Loss of sediment volume in the upper beach will increase the chance of breach (see Figure 3.15).

Standalone beaches are naturally variable. This means that their performance as a flood defence relies strongly on the presence of sufficient sediment volume. This volume has to ensure that, even after deformation during a storm, there is still a sufficient body of sediment to prevent breach and unacceptable overtopping or seepage of seawater. This is reflected in Obhrai and Bradbury's formula (Obhrai et al. 2008), which identifies threshold conditions for the overwashing of (shingle) barrier beaches based on physical model tests. The formula has been widely used in the past in the assessment and design of shingle barrier beaches in the UK and is expressed as shown in Box 3.7.

Although Obhrai and Bradbury's formula has been used in many locations in the UK, the data used to derive the threshold–overwash relationship are specific to the site conditions where they were measured with limited variables. Therefore the approach should only be applied to shingle beaches with a subtidal toe and within the range of 0.01 <Hs/Lm <0.06. The approach may not be valid for other sections of the coast of the UK, including sand dominated barriers (see Box 3.8 for information about setting triggers for sand barriers). For other locations, the approach should be applied as a basic tier approach only. For more information on this topic, see Stripling et al. (2008).

Relevant parameters from Obhrai and Bradbury's formula are shown schematically in Figure 3.15.

Box 3.7: Obhrai and Bradbury's formula

$$\frac{R_c \times B_a}{H_s^3} < -153.1 \times \left(\frac{H_s}{L_m}\right) + 10.9$$

where:

R_c = barrier freeboard in relation to still water level (m)
B_a = cross-sectional area of the beach above still water level (m²)
H_s = significant wave height (m)*
L_m = average wave length (m)*

* For analytical purposes, wave conditions were measured or predicted at a consistent location relative to the beach. The most suitable position is at the toe of the active beach (closure point), where conditions are relatively unaffected by the dynamic response of the beach profile. This is in suitably deep water for the waves to be unbroken, yet not too far offshore for shallow water transformations to further modify the waves on their approach to the beach. For the practical purposes of this guidance, nearshore wave height and average wave length are considered appropriate.
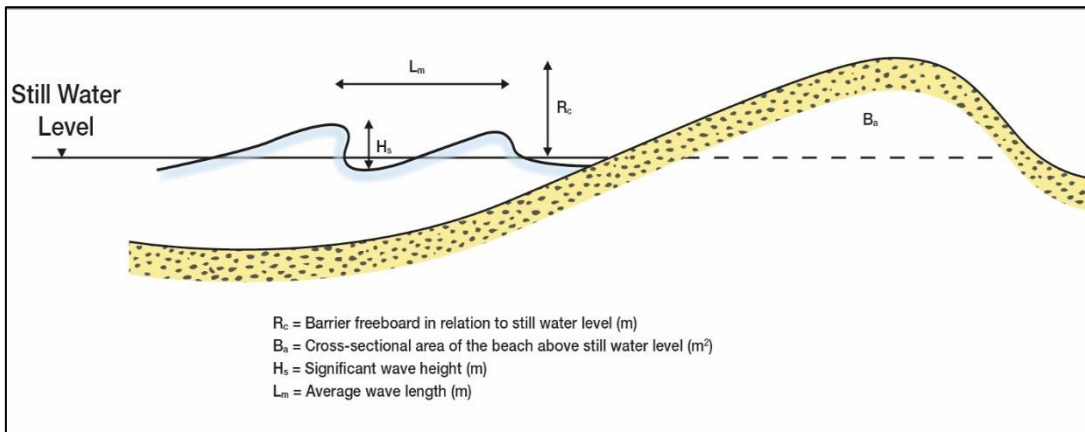

R_c = Barrier freeboard in relation to still water level (m)
B_a = Cross-sectional area of the beach above still water level (m²)
H_s = Significant wave height (m)
L_m = Average wave length (m)

Figure 3.15   Schematic profile (cross-section) of a barrier beach showing the parameters from the Obhrai and Bradbury's equation

Box 3.8: Direction for setting triggers for sand barriers

A series of empirical frameworks have been established for sandy barriers.

Morgan and Stone (1985) found that:

- dune height was the most important factor with regard to vulnerability to wave power

- the shoreface width and the island width decreased in their relative importance

As a development of the Storm Wave Susceptibility Quotient, Jiménez and Sánchez-Arcilla (2004) produced an Erosion Susceptibility Index for assessing the vulnerability of the Trabucador Bar in north-east Spain. The Erosion Susceptibility Index has a quadratic dependence on barrier height (B_h) as it is considered to be the main parameter controlling overwashing. Barrier width (X_{bw}) and distance to the barrier (X_b) are also important but are less significant.

Performance indicator: product of beach crest height and volume above still water level

Obhrai and Bradbury's formula (see Box 3.7) shows that the product of beach crest height and volume above still water level is a good performance indicator of a standalone beach's performance. If this product, calculated for a design storm situation (related to a corresponding probability of exceedance), exceeds the loading parameter, then the beach can be assumed to withstand that particular design storm.

Setting a trigger value for upper beach flood defence function

Trigger setting follows the three-step process set out in Figure 2.1.

Step 1: Performance standard and tolerable values

Similar in nature to the overtopping tolerances presented for function Ib, the tolerable values for a barrier beach are linked to the implications for people and property in the lee of the beach should overtopping or a breach occur. The tolerable values may be zero (where no overtopping is acceptable or the implications of a breach are significant), but are more likely to be a value which is tolerable but limits flooding, property damage or risk to life.
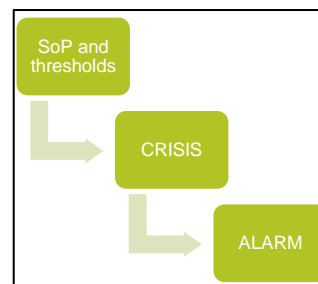
Step 2: Setting CRISIS trigger values

The combination of crest height ('barrier freeboard') and beach volume (CSA above still water level) 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 the upper beach meets Obhrai and Bradbury's formula criterion in storm events with the chosen probability of exceedance (determining significant wave height and wave length).

Step 3: Setting ALARM trigger values

ALARM trigger values can be calculated by adding an adequate margin of safety to the CRISIS value, preferably based on historical data analysis (see Box 3.1).

The SC140005 beach triggers tool provides more detailed stepwise guidance for setting adequate CRISIS and ALARM trigger values for the flood defence performance of the upper beach.

3.3.3 Function IIIb: Lower beach reducing wave loading reaching upper beach flood defence

The presence of the lower beach can cause waves to break. This reduces the wave energy reaching the upper beach and consequently reduces the chance of breach. If judged critical, this can form the basis for a separate trigger for the lower beach.

Performance indicator: average beach level over width that affects wave height

Beach level over a certain beach width is a performance indicator for wave loading reaching the upper beach. If the average lower beach level is too low, wave loading can exceed tolerable values for the upper beach.

Note that it is the lower beach level profile over a certain beach width (measured from the toe of the upper beach) that matters for wave loading and not just the level next to

the upper beach. In order for the incoming waves to lose their energy, the water needs to be sufficiently shallow over a beach width of at least one wavelength (see Box 3.3).

In theory, it is the overall profile of the lower beach over a width of a wavelength, including level variations, that determines wave loading and not just the average. It is possible to use the overall profile as an indicator, but that requires relatively complex calculations with wave models; this more detailed tier approach may be appropriate where wave loading is critical for beach management. In practice, it will usually be adequate to take a simpler basic tier approach by using the average beach level over a width of one wavelength in design conditions as the performance indicator for the wave loading reduction function of the lower beach (see Figure 3.16). If beach CSA is an adequate proxy for the beach surface level, then this can be used as a performance indicator (see the Eastbourne case study in Section 4.4.3 of SC140005/R1).
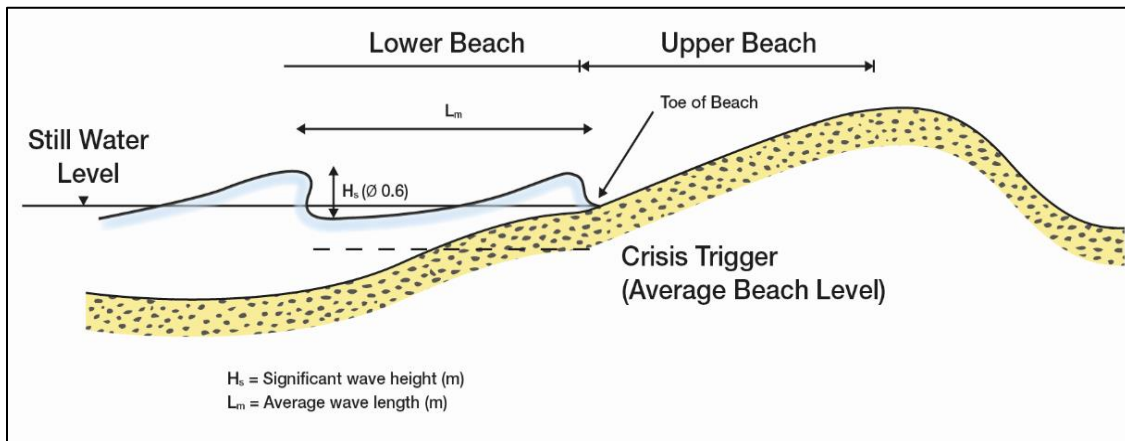

Figure 3.16   Schematic profile (cross-section) of situation showing the parameters for wave loading reduction using a lower beach profile

Setting a trigger value for wave loading reaching the upper beach

Trigger setting follows the three-step process set out in Figure 2.1.

Step 1: Performance standard and tolerable values

The trigger value is obtained through an iterative process, based on ensuring that wave loading on the upper beach does not exceed tolerable values based on Obhrai and Bradbury's formula. This approach ideally therefore follows an initial analysis of the Type IIIa. Otherwise, it is necessary to determine the tolerable wave loading.
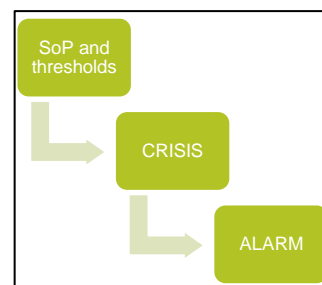
Step 2: Setting CRISIS trigger values

The process is as follows:

1. Using Obhrai and Bradbury's formula, determine the critical significant wave height (H_{sc}).
2. Assume the critical depth (d_c) = H_{sc}/0.6 (see Box 3.4).
3. Calculate the beach level corresponding to the critical depth (h_c) = water level SoP – d_c.

The corresponding beach level is measured as an average over one wavelength.

Step 3: Setting ALARM trigger values

ALARM trigger values can be calculated by adding an adequate margin of safety to the CRISIS value, based on historical data analysis (see Box 3.1).

The SC140005 beach triggers tool provides more detailed stepwise guidance for setting adequate CRISIS and ALARM trigger values for wave loading reaching the upper beach.

4 Inputs and outputs

The methods for the determination of trigger values presented in this guidance require various data and information as inputs. These inputs are summarised in this section to provide beach and asset managers with clarity on what is required. Potentially useful outputs and interpretive tools for supporting beach management decisions are also described. Figure 4.1 summarises the inputs required and possible outputs.
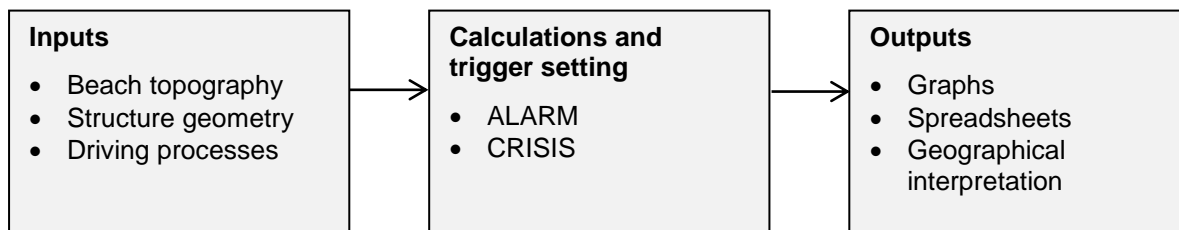
Inputs
- Beach topography
- Structure geometry
- Driving processes

→

Calculations and trigger setting
- ALARM
- CRISIS

→

Outputs
- Graphs
- Spreadsheets
- Geographical interpretation

Figure 4.1   Summary of inputs and outputs

4.1 Inputs

Use of Regional Coastal Monitoring Programme (RCMP) data is recommended when making calculations to determine triggers. The RCMP is an Environment Agency funded programme which collects topographic beach data along the English coastline. All data are freely available for beach managers and consultants to download from the RCMP website (www.coastalmonitoring.org).

The beach geometry inputs required for setting trigger values are:

- topographic beach levels – height of beach at wall/back beach, crest height of beach

- structure – toe height, crest height

The example in Figure 4.2 of a typical data output of a beach profile collected as part of the RCMP shows the height of the beach at the seawall, the foreshore levels and current beach slope. A Master Profile (red line) can be added to the graph to determine the CSA of the beach. The RCMP data contain crest elevations and widths, beach slopes, foreshore levels and CSA, all of which feed into the trigger value calculations.

Carrying out a site visit is also recommended before defining the beach functions and running the calculations in order to verify the input information and fill in any gaps in the data. Global positioning system (GPS) or levelling equipment and GPS photographs may also be useful.

In addition to the beach geometry information, further inputs are required to undertake the typical calculations within this guidance concerning the structure and the sea state conditions. These include:

- SoP of the beach and/or structure

- structure details – including the crest and toe height and critical levels for structural stability (ideally as-built schematics[1] and design parameters) (from the Environment Agency/local authority)

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[1] Structure survey cross sections (from RCMP, where available) are a substitute for as-built schematics.

- previous reports and studies commissioned by the Environment Agency, local authority and RCMP

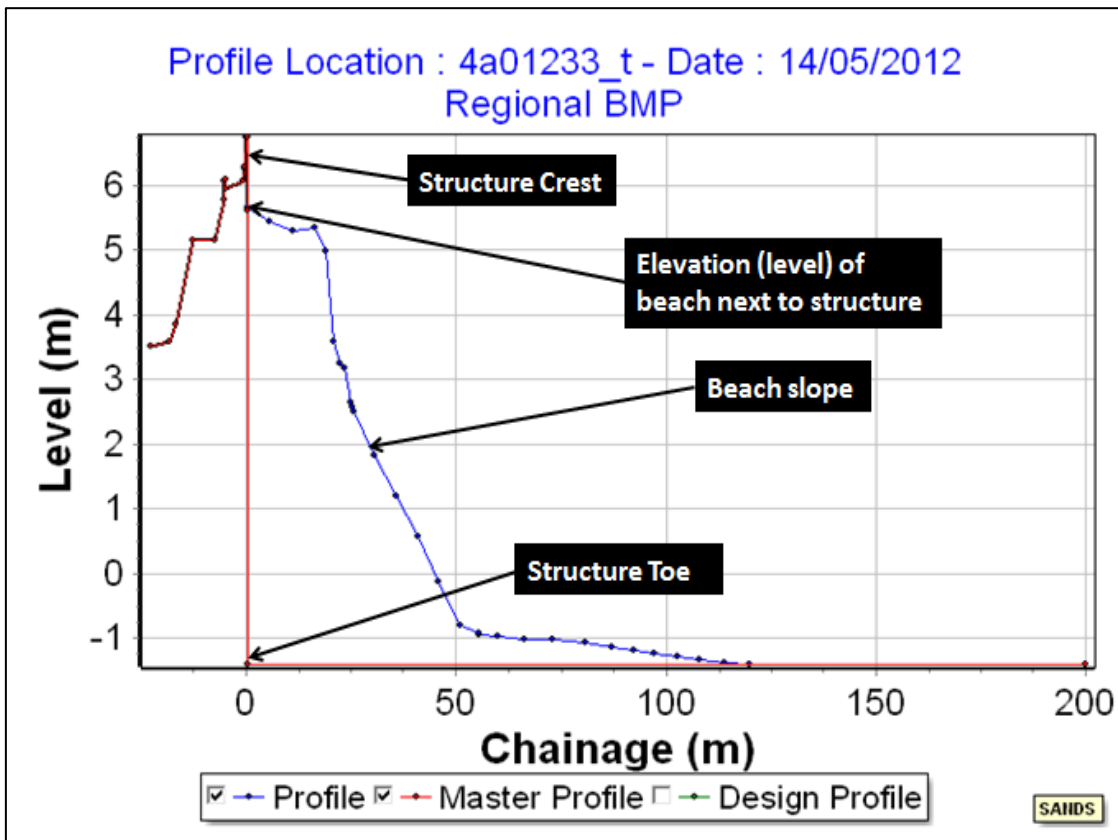- wave heights, length and period (RCMP)

- extreme water levels

**Figure 4.2   Typical data output of beach profile collected as part of the RCMP**

4.2   Outputs

Good quality data interpretation tools and graphical output are essential to:

- provide effective support for beach managers

- ensure effective stakeholder engagement

It is important to condense the large quantities of information into a format that can be readily digested and understood.

Figure 4.3 summarises current and historic beach levels for a single beach profile in the context of ALARM and CRISIS triggers. By summarising information in this way, an entire coastal frontage can be summarised within a single graph (Figure 4.4). This output allows problem areas to be easily identified and priorities for intervention to be determined.
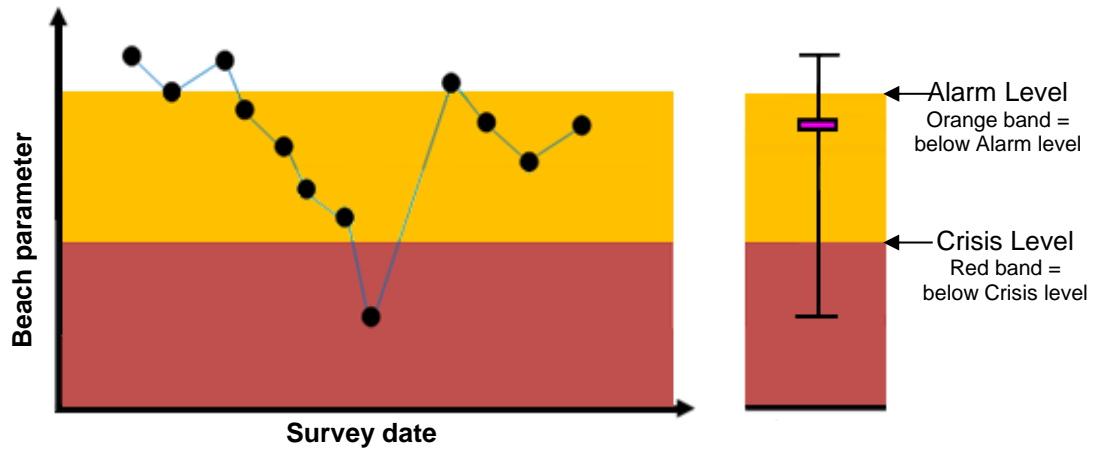
Figure 4.3   Example presentation of a beach parameter (for example, beach level or CSA) in the context of ALARM and CRISIS triggers

Notes: In this example, the beach parameter used for setting beach triggers is summarised as a pink bar showing current state. Black bars show the historic high and low (right).
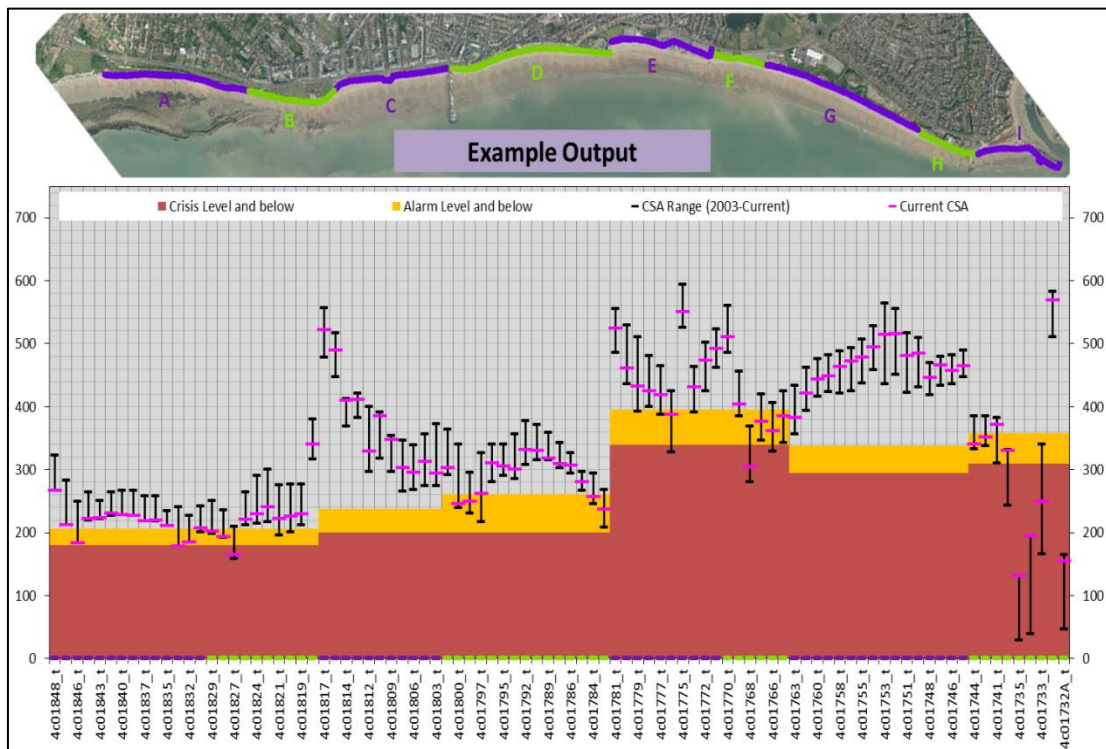
Figure 4.4   Recommended output which maps trigger level against current and historic beach CSAs

Notes: Output uses data from the RCMP.

Asset Performance Tools: Guidance for beach triggers

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BSI, 2000. *BS 6349:2000. Maritime structures. Code of practice for general criteria.* London: British Standards Institution. Note: the relevant part is in the process of being replaced (forthcoming possibly as BS 6349-1-4).

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List of abbreviations

AEP   annual exceedance probability

CSA   cross-sectional area

MHW   mean high water

MLW   mean low water

RCMP   Regional Coastal Monitoring Programme

SoP   standard of protection

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