OPTIMISING PERFORMANCE TARGETS FOR FLOOD DEFENCE ASSETS

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ABSTRACT

The Environment Agency manage over 10,000 km of raised flood defence assets (embankments, walls and structures) in England and Wales. These assets are managed to targets that are expressed as a condition grade: a number between 1 (Very Good) and 5 (Very Poor) that is determined by visual inspection according to the Condition Assessment Manual (CAM). The flood events of Summer 2007 have shown that the defences perform well: 1,000km of defences were tested, about 500km was overtopped, but only four breaches occurred. The events have also shown that breaches can have various causes and that condition grade is only one indicator of performance. Backed up by scientific analysis of defence fragility, this has led to the conclusion that in most cases, lower minimum condition grades are acceptable. This will enable more effective use of limited available funds, for example for data collection, analysis or improvement works.

KEY WORDS

Asset management, Condition, Flood defence, Flood risk, Performance, Target setting, Visual inspection

INTRODUCTION

In many countries in Europe, flood risk management is based on fixed standards of protection, sometimes (as in the case of the Netherlands and Germany), reinforced by national laws and regulations. Within the United Kingdom, investment in flood defences has to satisfy economic (benefit-cost) and other prioritization criteria and is seen within the overall context of asset management, defined (PAS55) as:

> *'Systematic and coordinated activities and practices through which an organization optimally manages its physical assets and their associated performance, risks and expenditures over their lifecycles for the purpose of achieving its organizational strategic plan.'*I

Flood risk managers in the UK therefore need to target spending in areas of greatest flood risk, whilst seeking to maximise the overall return on investment and achievement of other targets. As a result, there has been considerable debate recently within the UK on the relative value of different types of investment (improvement, maintenance etc.) to deliver that optimum whole life return on investment.

Managing flood defences involves setting crest levels and geometry to limit overtopping, together with ensuring that the structural condition of the defence is resistant to breaching and damage, even when overtopped. As part of a rational approach within England and Wales for managing the structural condition of defence assets, a method for visual condition grading of assets has been in place since the 1990s (Flood Defence Management Manual, National Rivers Authority 1995). The definition of the condition grades, as recently revised (Environment Agency, 2006), is given in Table 1. The Environment Agency (2006) also provide visual and textual guidance to their inspectors on how these condition grades should be interpreted for a wide range of defence asset types. The condition grade is used as the main performance indicator for assets and their management.

Table 1: Condition grade scale

Grade	Rating	Description
1	Very Good	Cosmetic defects that will have no effect on performance
2	Good	Minor defects that will not reduce the overall performance of the asset
3	Fair	Defects that could reduce performance of the asset
4	Poor	Defects that would significantly reduce the performance of the asset. Further investigation needed.
5	Very Poor	Severe defects resulting in complete performance failure

The introduction of the condition grade as a performance indicator was a move toward more rational, 'performance based' asset management. As this performance based approach starts being implemented, science and lessons learned from recent events show that some fine-tuning is required, in order to make the targets more realistic and more balanced with other performance indicators. In addition, there is a definition issue. Until recently the term "target" has been somewhat ambiguous. Sometimes, it has been interpreted as an *aspirational* target; implicitly setting high targets has been seen as a way to encourage ongoing investment in the asset concerned. However, others have seen the target in terms of a *minimum* requirement (National Audit Office, 2007) and here the Environment Agency has been criticized for not reaching its declared objectives. Improved clarity of guidance on this issue was therefore required.

This paper therefore describes how this improved guidance has been developed drawing on various sources of information. Part of the basis has been drawing on an improved theoretical understanding of how defences perform together with an analysis of a nationally available dataset. Another part has been based on the relatively good performance of flood defences during the major floods in the United Kingdom in June and July 2007 and the lessons learned from the very few defences that did fail. The conclusions of this work and the impact on the resulting guidance are set out.

Throughout the paper, comparisons are made with flood defence asset management in the Netherlands. This provides a contrast between a situation where decisions are, in practice, not primarily driven by optimization of performance within given (limited) funds, but by finding the optimum way to meet given (fixed) performance targets, represented by a legal safety standard, and applying nationally available methods and tools to achieve this. The safety standard is defined in the Flood Defence Act as the probability of exceedence of the water level and other relevant factors that the flood defence must be able to withstand.

ASSET PERFORMANCE AND ROLE OF CONDITION GRADING

As already mentioned, UK flood risk managers need to target spending in areas of greatest flood risk, whilst seeking to maximise the overall return on investment and achievement of other targets. This targeting first requires an improved understanding of the overall risk of flooding (Sayers *et al*, 2002), which can be determined by viewing the flood risk system as a whole, with its sources, pathways and receptors (Figure 1).

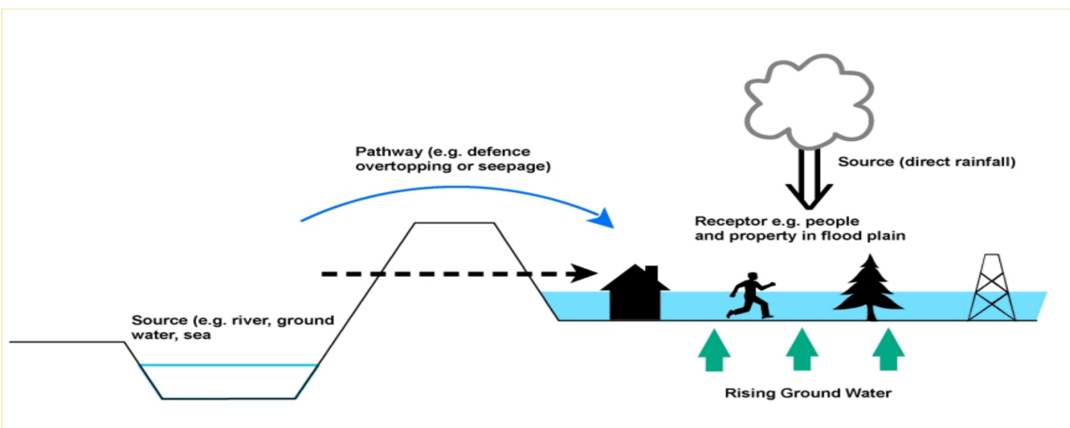

Figure 1: Source-pathway-receptor-consequence concept

The resultant risk derives from a combination of the probabilities associated with the source loadings (river levels, waves, etc) and with the conditional probabilities of overtopping or failure (breach) of the defences given those loadings, together with the economic and other consequences in the flood plain arising from the resulting inundation.

In simple terms (Gouldby & Samuels, 2005, p5):

Risk = probability x consequence

Thus the main function of defences is to reduce risk in the flood plain. The extent to which they can do this depends on the conditional probabilities of failure of the defence given a range of loadings.

'Failure', however, is a term which requires careful definition. Within Europe, a definition of failure which has found a wide degree of acceptance is "inability to achieve a defined performance threshold (response given loading)" (Gouldby & Samuels, 2005, p20).

Commonly flood defences are thought of as failing if they either overtop or breach. In fact a defence only fails by overtopping, if it overtops at an event that is less severe than its defined performance threshold. Few defences fail in this way, unless either they have deformed (e.g. settled) or climate change means that the severity of an event of a particular frequency has increased.

True failures of defences can therefore be restricted to situations in which the defence breaches, whereas the probabilities of overtopping occurring are simply a function of the hydrodynamics of the situation (Figure 2).

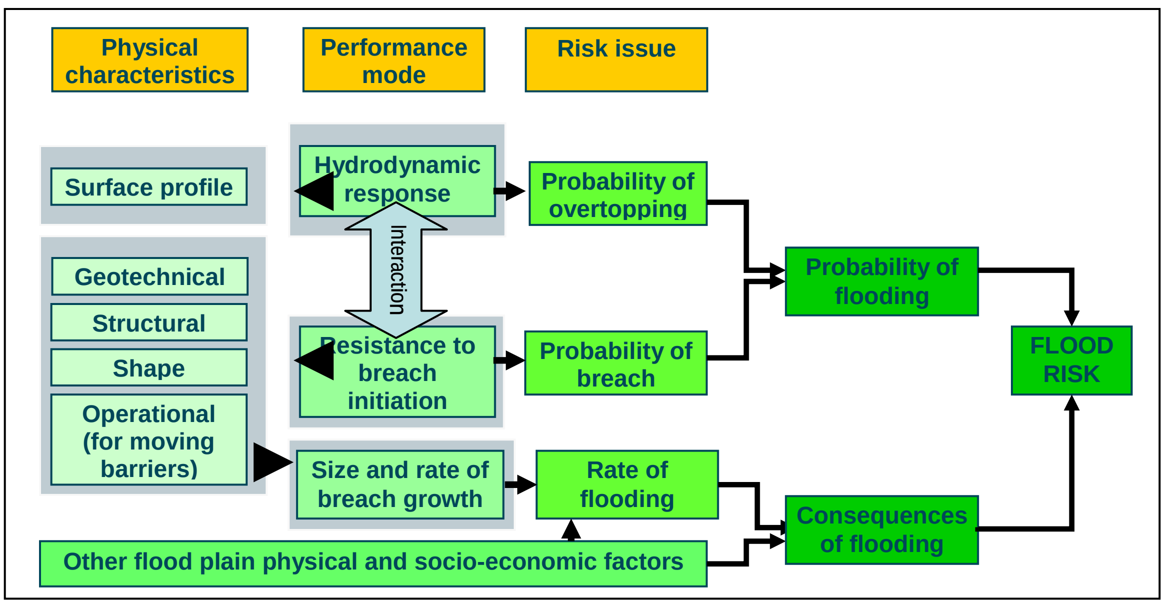

Figure 2. Performance of defences

The probabilities of breach can be represented by a fragility curve (see Figure 3). A fragility curve is a simplified probabilistic representation of structural defence performance, expressing the conditional probability of failure given flood loading. More detailed and complex methods are required to assess breach development.

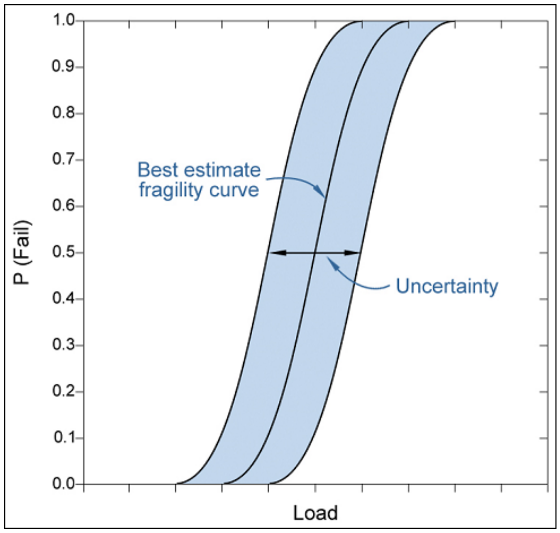

Figure 3: Fragility curve

Fragility curves provide a robust way forward for the purpose of thinking both about flood systems and the management of assets and systems of assets.

Fragility curves enable the performance of defences to be taken into account in a system-wide probabilistic flood risk analysis. Once assessed, the resulting risk can be attributed to individual assets (Gouldby *et al*, in press) and hence the likely change in risk that would result from an engineering intervention (whether maintenance or improvement). In turn, these issues can only be addressed through an improved understanding of the behaviour of a single asset and the asset system as a whole.

Generalised fragility curves have been generated for use in UK national flood risk assessment studies as part of the RASP (Risk Assessment for Strategic Planning) methodology (Hall *et al*, 2003). These curves, which represent the only nationally available consistent dataset on defence fragility, differentiate some 60 defence types and utilise the local loading conditions and some of the geometry of a specific defence. For each defence type separate fragility curves have been derived for each of the five condition grades used nationally by the Environment Agency (see Figure 4). Thus condition grade acts as a kind of ‘label’ for each fragility curve, even though the way it is assessed (visual inspection) means that it cannot take account of all the structural failure processes which may be relevant to failure.

The link between fragility curves and condition grade can be extended when thinking about deterioration. Estimates are being developed of the time it typically takes for an asset to deteriorate from one condition grade to the next (see example in Figure 5) and thus for the defence performance to move from being represented by one fragility curve to the next. The rate at which this deterioration takes place is in turn affected by the maintenance regime which is adopted, as illustrated in Figure 6.

It does need to be stressed that these fragility and deterioration curves are based on limited local data and evaluation of a very limited number of failure modes. When wishing to make reliable local asset management decisions, more accurate site/structure-specific representations of fragility become critical and here a clear understanding of which failure modes will be applicable is vital (Allsop et al, 2007). The longer term aim is to develop site-specific fragility curves that more accurately represent the performance of the assets at those sites.

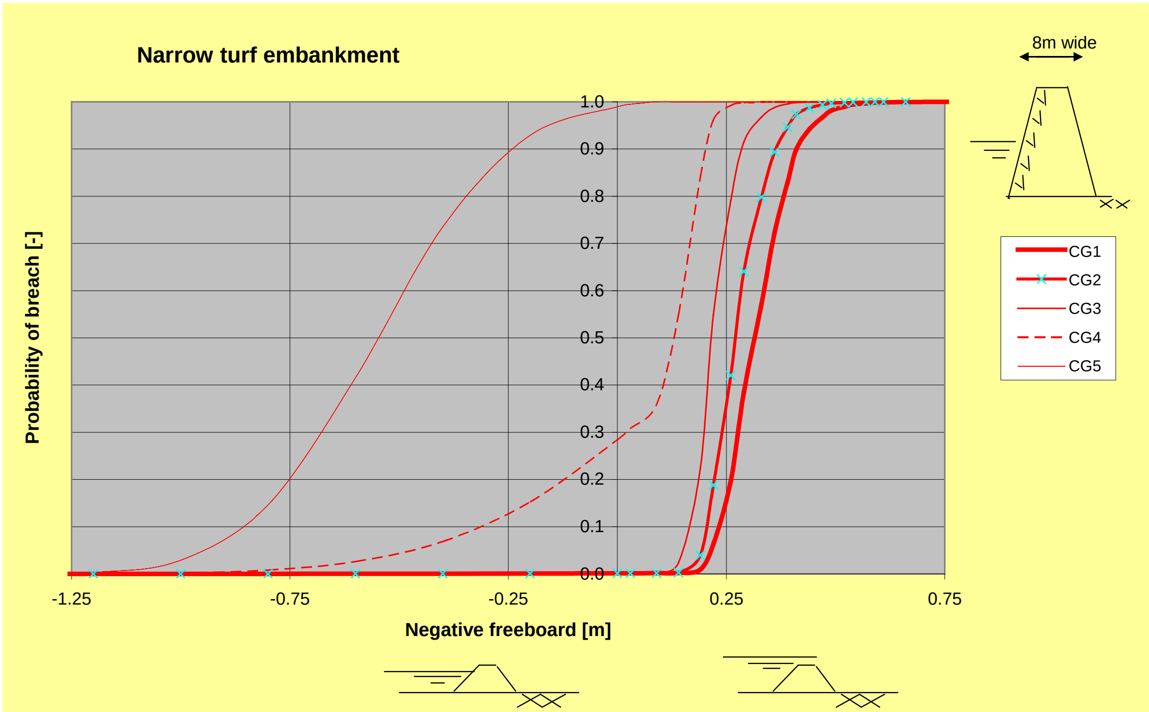

Figure 4: Fragility curves for five different condition grades

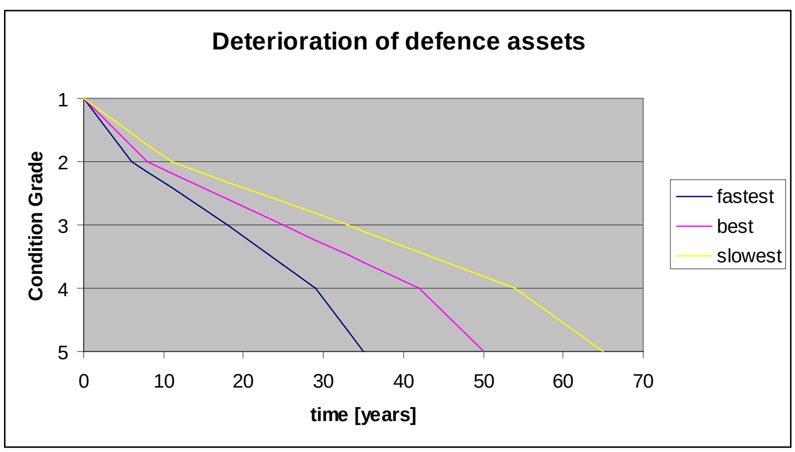

Figure 5. Deterioration curve (no maintenance)

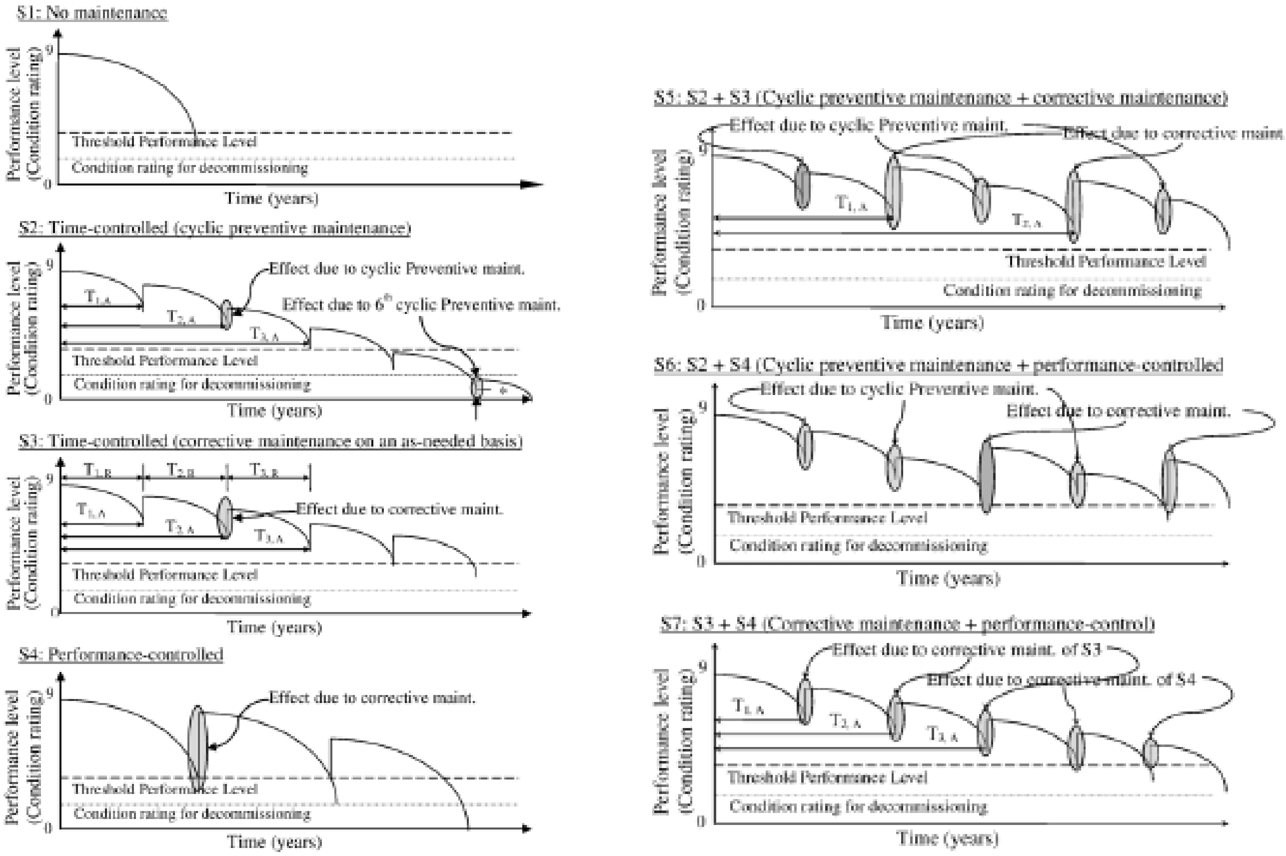

Figure 6. Influence of maintenance strategies on deterioration curve (Hong et al., 2007)

In the Netherlands, a structured and complete set of design guidance explains what it means if an asset is 'able to withstand' a certain loading: the safety philosophy (TAW, 1998) sets out the acceptable probability of failure at design loading (10% in total for all failure modes, 1% per failure mode); related design manuals provide the rules and safety factors to achieve this. Asset managers have always carried out visual inspections, but until recently this had lost some of its links to the primary purpose due to the high standard and general good quality of the defences. Recent events, such as the drought related breach of the regional defence in Wilnis, have shown that visual inspection does have a role to play and needs to be fully integrated in asset management. As a result, the Water boards and Rijkswaterstaat have started a programme to improve inspection methods and their role in asset management.

Note that since the early 1990s, there has been an ongoing development of a more advanced (risk based and probabilistic) approach. Even though the new method is clearly better from a scientific point of view, it is felt to be as yet insufficiently robust to replace the tried and tested existing approach.

EXISTING SITUATION IN ENGLAND REGARDING TARGET SETTING

The Environment Agency use the condition grade as an important indicator of defence performance. As discussed, all defence assets are inspected regularly using the prescribed methodology of the Condition Assessment Manual which results in a condition grade ranging from 1 (Very Good) to 5 (Very Poor). The inspection frequency ranges between 6 monthly and 5 yearly, based on a risk matrix that takes into account both the probability and the consequences of breach.

At the level of individual assets, the Environment Agency's Asset System Management teams define performance specifications for the maintenance of each flood defence in terms of the condition grade. This means that each asset has a target condition grade which determines how the Environment Agency's Operations Delivery teams have to maintain the asset. The Operations Delivery teams make their own decisions on the maintenance activities (inspection, vegetation management, dredging) required to achieve the target condition grade, depending on existing condition, local situation and local knowledge.

The target condition grade for each asset is presently strongly based on the receptors that the defence protects. The potential consequences of flooding determine whether the asset system is categorised as High, Medium or Low consequence and this classification has a strong influence on the target condition grade. Following a recent revision of the guidance at the end of 2007, EA staff are now also required to take asset characteristics (such as defence width and slope angle) into account; this is based on the realisation that the visually determined condition grade is more meaningful for the performance of some assets than for others. The next section of the paper expands on this issue.

High Consequence systems used to have a typical target condition grade 2 (Good), while Medium Consequence systems had a target condition grade 3 (Fair). The most recent guidance suggests a level target condition grade 3 (Fair) for most assets, with target condition grade 2 for justified exceptions.

In addition to this asset level function, the target condition grade is also used as an indicator for the performance of the organisation. One of the Environment Agency's Key Performance Indicators relates to the percentage of flood defence assets that meet their target condition grade.

As indicated earlier: whereas originally the target condition grade was perceived as an aspirational target, it is now starting to be used as a minimum standard.

In the Netherlands, the primary target for asset management is to meet the legal safety standard described above. This is assessed every 5 years based on full analysis of all relevant failure modes for each section of defence. For each failure mode, the assessment leads to a result of 'compliant' or 'non-compliant', but only if the analysis actually demonstrates that the asset does or does not stand up under the loading. If this cannot be demonstrated due to lack of data, or lack of budget to develop methods or carry out site specific specialist analysis, the outcome is 'no result'. Traditionally, flood defence managers would tend to make conservative assumptions in case of uncertainty and assume a score of 'non-compliant'. However, in the Dutch context this would then directly trigger (costly and potentially unnecessary) improvement works to guarantee compliance with the safety standard. The 'no result' outcome is an important trigger for research; however, it can also be a difficult concept to handle for politicians, who sometimes seem to prefer expensive clarity over cost-effective uncertainty. Day to day asset management does play a role in the safety assessment: a score of 'compliant' can only be given if confirmed by 'good asset behaviour', and particular failure modes (e.g. revetments) require more extensive field inspection.

EVIDENCE

Analysis of condition grade targets

As part of the PAMS (Performance-based Asset Management System) science project (Simm *et al*, 2006), some analysis of condition grade targets was carried out. A dataset of riverine linear defence assets from the national Flood and Coastal Defence Database was prepared for which information was known about both the defence crest level and the standard of protection (e.g. the 1:100 year return period water level). For each defence the freeboard (difference between the crest level and the design water level) was calculated. A reasonable conditional probability of failure for the defences under their design load was assumed to be between 1% and 5% (see discussion above on Dutch flood defence safety philosophy). For these two probabilities and for the calculated freeboard, the generic fragility curve dataset for the particular asset type being considered was interrogated to find that which just matched the probability of failure (or had a lower probability if there was no exact match). As each fragility curve is associated with a particular condition grade, it was possible to infer the required condition grade to meet the design water level loading.

The results (see Tables 2 and 3) indicated that in most cases, even where the freeboard at the design water level was negligible, a condition grade of 3 was adequate and setting a target condition grade of 2 is not necessary. It should be noted, however, that in many cases (see e.g. Figure 4) the difference in fragility between condition grade 2 and 3 is small in comparison with the difference between condition grades 3 and 4.

Table 2: Theoretical target condition grades assuming 1% probability of failure is acceptable

	Target condition grade for a given freeboard in meters (i.e. Crest level – water level)				
Narrow Defences	**1**	**0.6**	**0.3**	**0.0**	**-0.1**
Brick & Masonry Vertical Wall with Crest Protection	4	3	3	3	3
Sheet Piled Wall with Crest Protection	4	3	3	3	2
Turf Embankment	4	3	3	3	1
Embankment with flexible Front Protection	4	3	3	3	1
Embankment with flexible Front Protection & Crest Protection	4	3	3	3	1
Embankment with flexible Front Protection, Crest Protection & Rear Protection	4	3	3	3	2
Wide Defences					
Brick & Masonry or Concrete Vertical Wall with Crest Protection	4	4	3	3	3
Sheet Piled Wall with Crest Protection	4	4	3	3	2
Turf Embankment	4	4	3	3	1
Embankment with flexible Front Protection	4	4	3	3	2
Embankment with flexible Front Protection & Crest Protection	4	4	3	3	3

Table 3: Theoretical target condition grades assuming 5% probability of failure is acceptable.

	Target condition grade for a given freeboard in meters (i.e. Crest level – water level)				
Narrow Defences	**1**	**0.6**	**0.3**	**0.0**	**-0.1**
Brick & Masonry Vertical Wall with Crest Protection	4	4	3	3	3
Sheet Piled Wall with Crest Protection	4	4	3	3	3
Turf Embankment	4	4	3	3	1
Embankment with flexible Front Protection	4	4	3	3	1
Embankment with flexible Front Protection & Crest Protection	4	4	3	3	2
Embankment with flexible Front Protection, Crest Protection & Rear Protection	4	4	3	3	3
Wide Defences					
Brick & Masonry or Concrete Vertical Wall with Crest Protection	4	4	4	3	3
Sheet Piled Wall with Crest Protection	4	4	4	3	3
Turf Embankment	4	4	4	3	2
Embankment with flexible Front Protection	4	4	4	3	3
Embankment with flexible Front Protection & Crest Protection	4	4	4	3	3

Of course considerable caution has to be applied to this result, since the analysis relies upon generic fragility curves developed and used for high level flood risk modelling and application, which therefore are not locally specific. It also relies on the concept of an acceptable probability of failure at design loading. However, as a global analysis the trend of the results is indicative of the kind of defence fragility required to meet design conditions and the visual condition grade likely to be associated with that required fragility.

In interpreting these results for specific structures, care is needed to reflect the assumptions underpinning the analysis and the defence failure mode characterization implicit in the fragility curves. For example, the structural parameters (i.e. width, slope, depth of anchors etc) assumed in deriving the generic curves were determined by statistical analysis of sample structures (Defra/EA, 2005a). Examples of the mean values of structure width and slope (for embankments) used in the fragility representation are shown in Table 4. If in reality the parameters of a particular structure vary from these assumptions, the derived target condition grade may not be appropriate. This is particularly true of composite structures which are not well represented by the generic structure types. It should also be appreciated that many parameters associated with failure mechanisms implicit in fragility curves are not visually observable, unlike condition grade which is only visually observed.

Table 4. Typical values of the parameters and statistical data used in the HLM+ fragility curves for coastal defences.

Embankment type	**Distribution function**	**Mean value**	**Standard deviation (σ) or Variation**

				Coefficient (V)
Width, L_K	Narrow	lognormal	7.5 (m)	$\sigma = 0.2$
	Wide		20 (m)	
Tan α_i	Shallow	normal	0.5	V = 0.05
	Steep		0.25	

NOTES:

1. $L_{k,inside}$ (m) = width of the inside clay cover layer, that can be considered as the total width of the embankment.
2. Tan α_i (degrees) = angle of the inside slope.

Summer floods and lessons learned

The flood events in June and July 2007 were a serious test for flood defences in England. Information from the Environment Agency shows that about 1000 km of defences were tested and about 500 km were overtopped.

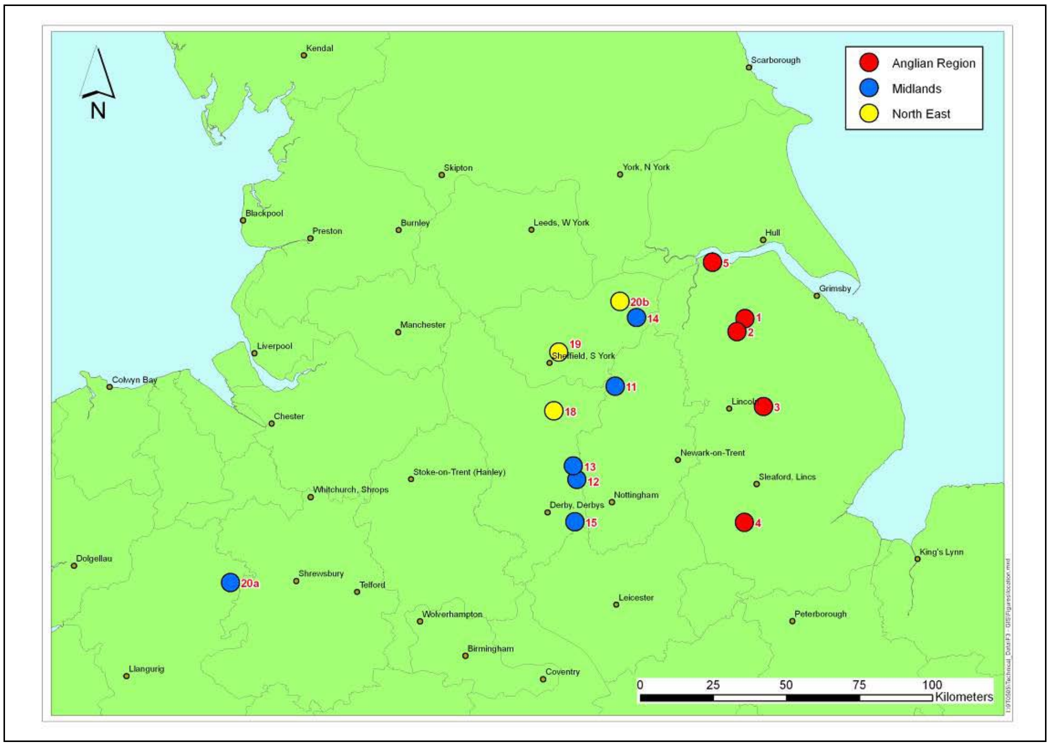

Figure 7: Location of assets for Summer floods performance analysis

Such a widespread extreme event is of course a unique opportunity to improve our understanding of the flood risk management system's performance. There have been various reviews of the events, at different scales and from different points of view. The Environment Agency commissioned a specific review of the technical performance of the defences (Royal Haskoning, 2008). This review analyses the performance of the defences that breached, overtopped or were severely tested by high water levels. Information was collated on site, from existing datasets and from anecdotal evidence, aiming to determine loading, strength and failure modes. This was then compared to existing models of defence performance (generic fragility curves in the first instance, more specific models for selected sites).

A first important finding was that only four defences actually breached during the events, over a total length of about 50m. This means that out of the total defence length that was overtopped, about 0.01% breached (or about 0.2% in terms of the number of assets). There are only limited references for the probability of breach that should be expected at 'design loading' or above. As explained in the sections above, Dutch flood defences are designed to a 'safety philosophy' which states that the probability of breach up to design loading has to be less than 10% (TAW, 1998), and this concept was recently applied to the Environment Agency's defences. Set against that background, the number of breaches during the Summer floods is very low.

Secondly, it was found that at least three of the four breaches happened while the water level was significantly below the crest (and this is uncertain for the fourth and final breach). This means that these three breaches were caused by geotechnical failure modes. The analysis shows that the breaches were not caused by an overall poor quality of design or condition, but by local irregularities. These irregularities may be visible (such as the presence of foxholes or vegetation) and hence captured in the condition grade. But they can also be invisible and related to the embankment material or to the subsoil. The analysis did not find a strong correlation between condition grade and breach.

Thirdly, of the 500 km of defences that were overtopped, all (possibly but one) were able to withstand significant overtopping, despite not having been designed for this. This finding reflects some of the latest research on resistance of grass against overtopping (predominantly by waves) in the Comcoast project; results of field tests suggest that good quality non-reinforced grass can withstand significantly higher discharges than thus far expected, and for significant durations (Royal Haskoning 2007).

For all analysed sites, the situation at the moment of breach was compared with the existing generic fragility curves (see Figure 8). The analysis generally shows that for the breached defences, the generic fragility curve shows a very small probability of breach, while for the defences that overtopped but did not breach, the generic fragility curve predicts significant probabilities of breach. Of course first of all this emphasises the limitations of applying a generic model to specific situations, as explained in the section above. However, there may also be reasons to adapt the generic fragility curves: the probability of breach due to overtopping seems higher than observed, while the probability at low loading levels (due to irregularities) seems lower than observed. This would lead to slightly 'flatter' fragility curves. These conclusions do not invalidate the results of the theoretical analysis described in the section above, but they do emphasise the need for further development of these concepts.

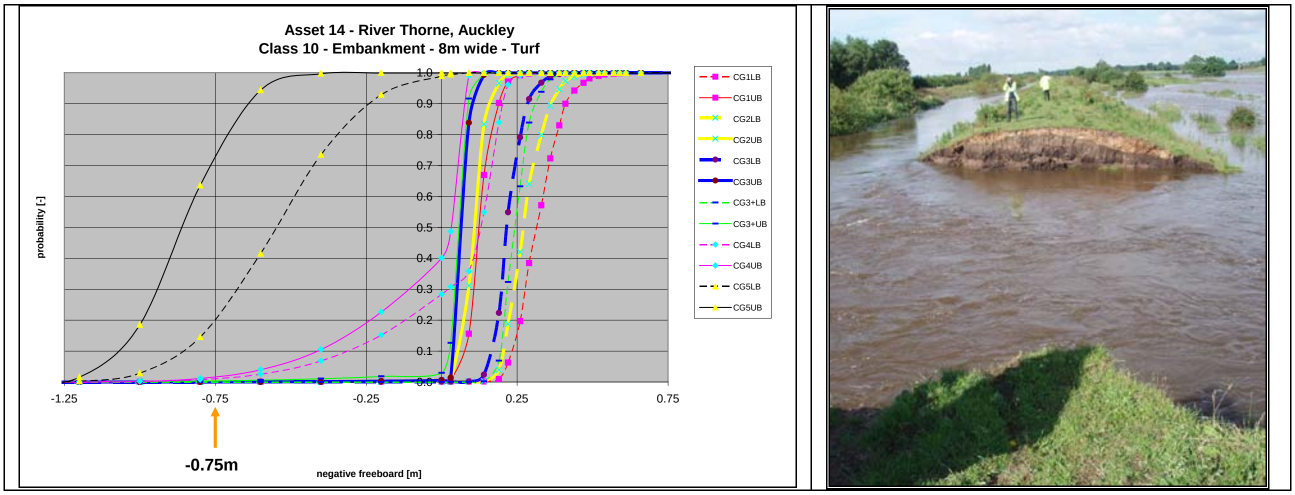

Figure 8: Breach at Auckley

The main conclusion related to asset management is, that the most important gains in terms of reducing flood risk, within the scope of defence stability, could be made by getting a better handle on irregularities in defence structure, with a focus on the geotechnical characteristics of the embankments and the subsoil. This suggests that the Environment Agency's target setting process should be extended to include other defence elements that have an impact on performance and hence on risk. This would allow for more effective spending of limited flood risk management budgets.

CHANGES TO TARGET SETTING

It does not require state-of-the-art science to realise that visual condition is only one element that determines defence performance and hence risk. And it is then easy to draw the conclusion that asset management has to find the right balance between all elements that influence performance: not only the condition, but also structural and geotechnical aspects and crest height. Possibly as important is the knowledge and information about the assets: lack of information can be translated directly to flood risk. The Environment Agency's current approach to flood defence asset management, and its focus on the condition grade, has to be seen within an ongoing development toward rational, science based and performance based asset management. Some of the currently ongoing changes are discussed in this section. The next section provides some suggestions for further developments.

Condition matters but 'fair' condition is often good enough

The analysis of generic fragility curves described above, using target conditional failure probabilities suggests that in many cases 'good condition' (condition grade 2) is not required for reasonable performance, although 'poor condition' (condition grade 4) was generally inadequate. Whilst the extra cost to maintain to 'good condition' (condition grade 2) when compared with maintaining to 'fair condition' (condition grade 3) can be significant, the analysis suggests that the difference in effective performance is small and can in many cases be permitted. These conclusions are consistent with the definitions of the condition grades given in Table 1 above.

As we move to a more balanced approach to the role of condition grade in asset management, we need to avoid moving to the other extreme: condition grade, and more generally visual inspection, remains an essential part of asset management. There is a need to keep the condition above a certain threshold, to avoid that it does start dominating the probability of breach. In addition, there are several other good arguments to keep the external condition at an acceptable level: whole life economics, health and safety of inspectors and public, and also public confidence in flood defences.

The definitions in Table 1 indicate that condition grade 4 would significantly reduce performance. The generic fragility curves reflect this definition well, as illustrated in Figure 6. The theoretical analysis of condition grade targets (Tables 2 and 3) confirms this, by indicating that most condition grade 4 assets would reach an unacceptable probability of breach before water levels had reached a point 0.3m below the crest. This theoretical approach is backed up by experience in historic events (such as 1953 both in England and the Netherlands) and also in New Orleans in 2005, where poor condition certainly played a part in the failure of the defence systems.

The Environment Agency's target setting guidance reflects these findings by requiring a condition grade 3 as a target for all assets that actually have a flood defence function.

Special cases where a better condition does improve performance
Condition grade 3 is sufficient for most assets, but for some assets a better condition grade can be justifiable. This is only the case for particular assets that:

- do not perform sufficiently at condition grade 3 (because of their structural characteristics or external influences);
- would be significantly improved at condition grade 3 (because condition grade affects features that influence performance);
- would not be improved more effectively by other measures.

This is illustrated by Figure 9, taken from the Environment Agency's work in progress on the development of operational guidance.

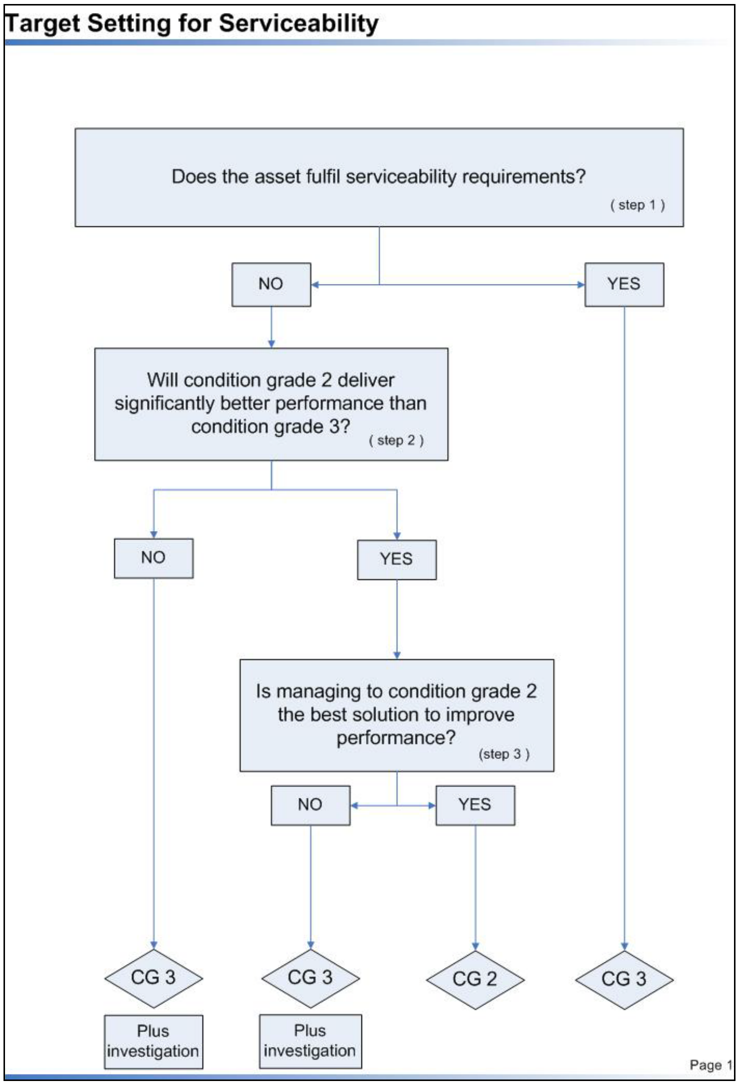

Figure 9: Flowchart to determine assets that require better condition

It is important to note (in step 2) that assets only benefit from a better condition grade if their performance is dominated by visible features. The condition grade can reflect symptoms of failure modes and processes (such as boils at the landward toe that indicate a sensitivity to seepage), but a better condition grade will not reduce the likelihood of seepage. However, the condition grade can also reflect features that are drivers for performance; these are the features through which managing to condition grade 2 can improve the asset's performance. These visible drivers for performance are:

- features related to failure modes that occur on the surface, such as crest degradation and erosion of slopes;
- external features that cause increased susceptibility of the asset to geotechnical failure, such as local presence of burrowing animals, accessibility of the asset to cattle, public and traffic and presence in and around the asset of foreign objects.

There can be cases where managing to a better condition grade to improve these features is justified to improve the so-called serviceability of the asset. Serviceability is defined as the degree to which the asset provides the performance for which it was built, related to the standard of protection. But there can also be cases where a better condition grade is justified to improve the asset's performance during 'exceedence events', aiming to provide more time for emergency response, allowing the public to evacuate or move their furniture upstairs, or for the authorities to protect critical infrastructure.

Improving knowledge can be as effective as improving condition grade
The analysis of the summer floods shows that irregularities or discontinuities were the predominant cause of breach. It is not straightforward to reduce this cause of breach because of the large number of assets and the uncertainty about the type of irregularity that is likely to cause breach. The search for the proverbial needle in a haystack can however be facilitated by focusing on high risk assets and also by learning from historic breaches: focus on areas where breaches have occurred, and focus on phenomena that have been seen to cause breach. A possible example from the summer floods concerns one of the breached defences, for which generally available aerial photography showed that an old meander crosses the defence at the site of both the recent and a historic breach. A more extreme example of improving knowledge being more effective than improving condition grade concerns cases where the crest level or standard of protection is unknown. Such cases are dealt with in the target setting guidance that the Environment Agency is presently introducing.

In addition, other improvement measures can of course also be more effective than improving the condition grade, for example structural or operational measures. Again, the target setting guidance aims to identify such cases.

VISION FOR THE FUTURE & HOW TO GET THERE

Keep moving toward risk based asset management
The need to target flood risk management spending in areas of greatest flood risk, whilst seeking to maximise the overall return on investment and achievement of other targets does not stop at capital works, but also concerns asset management. Decisions about optimal asset management strategies, both at the level of systems and individual assets, have to be directly linked to the impact on flood risk, through asset performance. These concepts are now fully embedded in flood risk management in England and Wales, and this is being reinforced by the currently ongoing introduction of System Asset Management Plans within the Environment Agency. However, the detailed technical application of those concepts is as yet strongly simplified, and limited by shortage of information and knowledge.

Asset management needs to be based on risk, so the associated targets need to be as well. In the longer term it is hoped that asset managers will move towards adopting a methodology such as PAMS (Simm *et al*, 2006), with all required data, performance modelling and deterioration predictions to compare different alternative management scenarios and choose the one that best meets all criteria, particularly reduction in economic flood risk attributable to an asset, over the whole life of the assets. It would still be essential to use indicators and targets for day to day management of the assets based on visual inspection (or, as science progresses, on remote inspection methods that may be able to look inside the asset too). However, these indicators and targets would then be fully linked to the assets' role to reduce flood risk (or perform other functions). This means that they would have to be linked directly to the asset characteristics and parameters that drive performance, such as erosion resistance of slopes. For assets that are less dependent on visible characteristics, there would be a stronger focus on other forms of inspections (different techniques, more expert involvement).

The existing system of condition grades is very valuable for its systematic and consistent structure, so it is important to use it as a basis for future developments. The PAMS project is currently making a step forward by developing a visual condition grading method that still works with the 5 condition grades, but links the inspection process directly to failure modes. The assessment operates through the evaluation of 'performance features' (Figure 10) using structured flow charts (see example in Figure 11). Within this development the primary end result is still a condition grade from 1 to 5. In a next step, the inspection method could be extended to provide direct links to parameters in performance models (e.g. fragility curves) and hence to flood risk, although this will require the ability to measure and instrument assets as well as carrying out visual inspections.

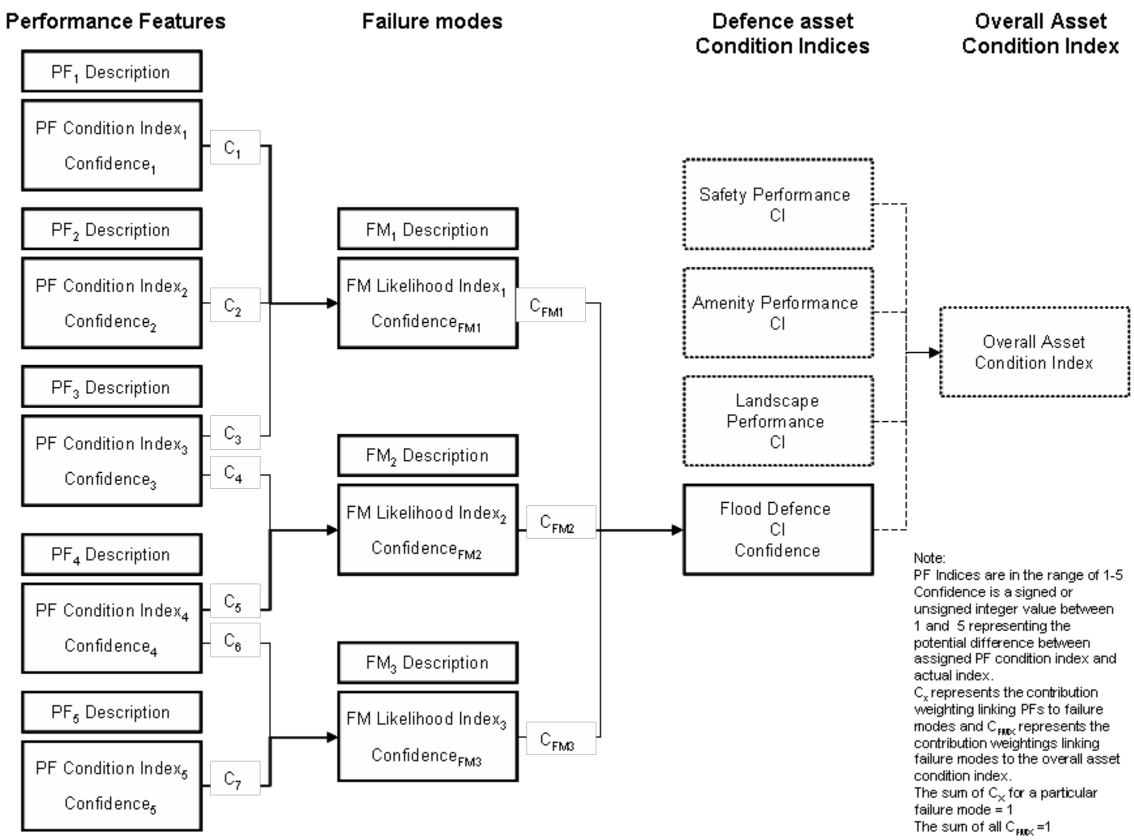

Figure 10: Condition grading system proposed within PAMS

It is interesting to note that current Dutch flood defence management is probably at the other extreme: a strong focus on quantitative performance modelling, but possibly insufficiently related to day to day visual inspection. The Dutch approach of quantitative performance modelling can be part of the vision for the future of flood defence asset management in England and Wales, but only if it is embedded in the context of more limited budgets, a risk based approach and wider objectives, and if it makes optimum use of local knowledge from day to day asset management.

CONCLUSIONS

1. Managing flood defences involves setting crest levels and geometry to limit overtopping, together with ensuring that the structural condition of the defence is resistant to breaching and damage, even when overtopped. For many defence types, visually inspected condition is a very good indicator of deterioration, and hence can also be an indicator of performance. The Environment Agency currently use it as such, but there is a move toward more formalised performance targets, which need to be realistic and balanced with other performance features.

2. An analysis of generic fragility curves using target conditional failure probabilities suggests that in many cases 'good condition' (condition grade 2) is not required for reasonable performance, although 'poor condition' (condition grade 4) was generally inadequate. Whilst the extra cost to maintain to 'good condition' (condition grade 2) when compared with maintaining to 'fair condition' (condition grade 3) can be significant, the analysis suggests that the difference in performance is small.

3. During the floods of Summer 2007 about 1,000km of flood defences were tested and these generally performed well. An analysis of flood defence performance shows that there were only four real breaches, and at least three of these occurred at water levels below the crest, caused by local irregularities. There was no clear correlation between the breaches and the condition grade.

4. It is possible to build on the Environment Agency's existing condition grade target setting methods and keep moving toward a more rational and performance based approach by:

- Using a target of 'fair' condition for most flood defence assets
- Using a higher condition grade target for some assets, where needed, if it improves performance and if there is no better alternative
- Making sure that the condition stays above the level at which performance is significantly affected. If target condition grades are to be lowered and the consequential cost savings realised, it is essential to understand that the target represents a minimum standard to which the defence must comply at all times, avoiding any perspective that suggests the target only represents an aspirational vision.
- Using a target-setting process to identify assets for which other measures are more effective to improve performance. Such measures can include physical improvements but also improvement of knowledge of the assets.

6. Future developments should focus on further improving the link between targets and performance. In the UK context these targets are increasingly likely to be set on the basis of economic flood risk reduction rather than on fixed performance targets. In this regard, the UK is adopting a different path to the standards based approach in the Netherlands. Current developments in research and development (such as the PAMS project) are already providing the framework and tools for this. The current well developed systematic condition grade system should be seen as an important foundation for the next steps.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Environment Agency's Science programme and the Environment Agency's Asset Systems Management and Enforcement team's work as an important basis for this paper.

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Word count: 6,103

Figures: