Just how important is grass cover?

MARK MORRIS, HR Wallingford, Wallingford, Oxon., UK.
LAURENCE BOORMAN, Lab Coastal, Holywell, Cambs., UK.
JONATHAN SIMM, HR Wallingford, Wallingford, Oxon., UK.

SYNOPSIS. Grass cover on a flood embankment or embankment dam plays an important role in maintaining the condition of the soil structure of the embankment, and in protecting the surface from erosion during overtopping or overflow conditions. But just how sensitive is overall flood embankment or embankment dam performance to the type and condition of grass? Recent studies from different areas of the flood risk management community have identified similar issues and conclusions – namely that the effect of different grass type and condition, in conjunction with soil type and condition, can have a very significant impact on how the embankment or dam performs and potentially fails.

This paper introduces and shows common links between a number of parallel research areas, all of which underpin the assessment of flood embankment and embankment dam performance. Research includes:

1. The development of breach initiation and growth models, under the *European FLOODsite project*;
2. The development of fragility curves for embankment performance (Buijs et al., 2007) supporting performance based asset management;
3. The investigation of grass management activity on erosion performance, under the *Environment Agency grass erosion testing project;*
4. Ongoing research in the Netherlands regarding the performance of vegetation

Consideration is given as to how findings from these recent initiatives fit with the UK CIRIA design guidance produced in the 1980s (Hewlett et al., 1987) and which is commonly used today for both reservoir and flood embankment performance design.

MANAGING DAMS: CHALLENGES IN A TIME OF CHANGE

INTRODUCTION

It has been recognised for a long time that grass cover on a flood embankment or dam can provide protection against erosion from both wave overtopping and overflowing water. In the 1980s research was undertaken to investigate the performance of grass cover leading to the publication of CIRIA Report 116 - Performance of Steep Grassed Waterways (Hewlett et al., 1987). This report contains guidance on the potential performance of grass under varying flow depth and duration. This guide still remains one of the most useful sources of design information some 25 years later (Young, 2005), however recent studies have raised questions as to how these design curves should be used and exactly how reliable grass cover may be considered when used as part of structure performance design.

The question of grass performance reliability becomes increasingly important as climate change effects suggest more extreme loading for dams and flood embankments, with the concept of acceptable overtopping becoming more frequently discussed and accepted. Since grass performance affects the rate of breach, and hence predicted flood hydrographs, this influences the base data used for flood risk analyses and hence asset management and emergency planning decisions.

A series of recent and ongoing projects have independently identified common issues relating to the performance of grass cover. These are introduced and explained in the following sections.

BREACH INITIATION AND GROWTH

Research within the FLOODsite project (www.floodsite.net) included work upon structure performance and failure modes (Task 4) and breach initiation and growth processes (Task 6) (Morris and Samuels, 2006). An early review by Young (Young, 2005) into the performance of vegetation confirmed that the CIRIA Report 116 provided useful design performance guidance, but also suggested that this guidance needed to be extended to cover a wider range of flow and grass conditions. Use of the performance curves was then investigated further as part of the breach initiation and growth model development work (Morris et al., 2008, Morris et al., 2009).

Testing and development of the HR BREACH model (Morris and Hassan, 2009) under FLOODsite Task 6 was undertaken in conjunction with the Dam Safety Interest Group breach modelling project (Wahl et al., 2008), using agreed test data sets. **Figure 1** shows breach model predictions against observed test data for a breach test conducted at the USDA Agricultural Research Service centre at Stillwater, Oklahoma. Seven lines are plotted, comprising the observed breach outflow data and then three predictions made using the CIRIA 116 performance curves and three predictions made using 'Technical Note 71' data. Technical Note 71 (TN71) (Whitehead et al., 1976) was an earlier publication on the grass research work containing the base data that was also used to produce CIRIA 116. CIRIA 116 quotes that it "…incorporates, with minor modifications, the curves originally presented in TN71…" however the results gained when using both for breach analysis can differ significantly.

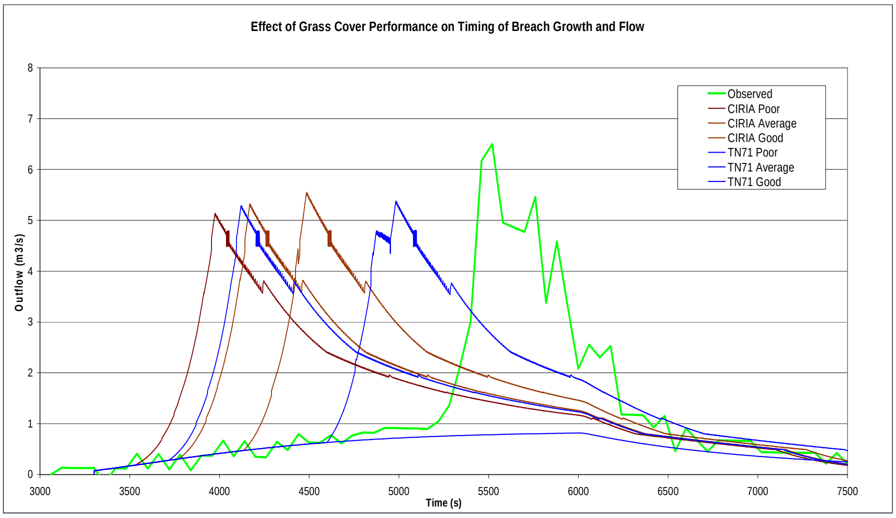

Figure 1. Comparison of breach outflow predictions against observed test data using CIRIA 116 grass performance curves and original TN71 performance data.

The plots shown in **Figure 1** demonstrate a number of issues and trends. Both data sets show consistent performance in terms of an increasing delay in breach initiation as a result of better grass quality and performance. However, in comparison to the observed results, the CIRIA runs all appear to show early initiation. It was for this reason that the data used to generate the CIRIA curves was investigated, leading to the earlier TN71 base data.

Figure 2 shows differences found between the CIRIA and TN71 data. It is possible that a factor of safety may have been added when producing the CIRIA performance curves since they appear to have been made more conservative. Whilst the addition of a safety factor might be considered safe practice for the development of design performance curves, a factor of safety works in the opposite direction when the curves are used for predictive breach modelling or reliability analysis. Hence, when the model predictions in **Figure 1** using TN71 data are reviewed, a considerable difference in breach timing can be seen as compared to the CIRIA based predictions. The three (TN71) curves show a much wider spread in timing and shape, with the 'good cover' result suggesting that breach does not occur at all. Unlike the results obtained using the CIRIA data, these modelling results provide a range of possible scenarios that do ‘straddle’ the observed test condition data. Hence, if the CIRIA curves do incorporate a factor of safety, then care is needed when using the performance curves to ensure that the factor of safety is taken into consideration. Where breach or reliability modelling is being undertaken, it is safer to make best performance estimates before adding any margins for uncertainty.

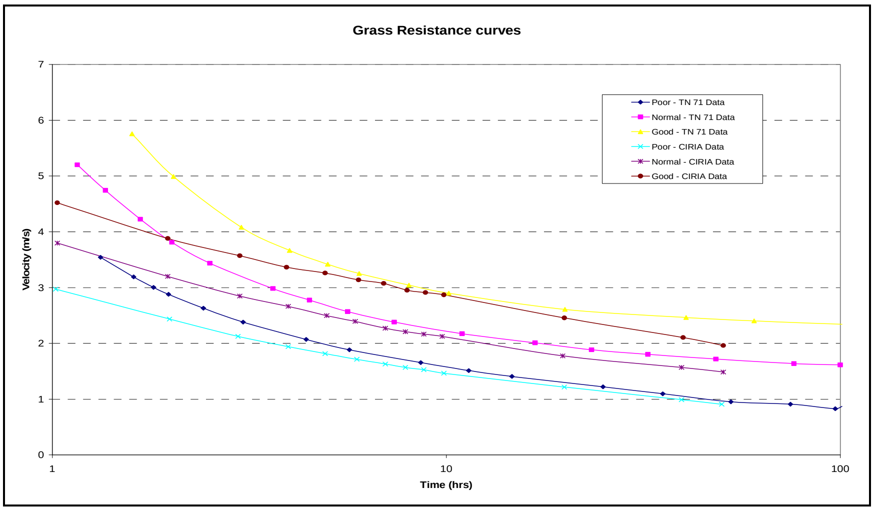

Figure 2. Comparison between CIRIA 116 (Hewlett et al., 1987) performance curves and the original TN71 field test data (Whitehead et al., 1976)

The results in **Figure 1** highlight how dependent the breach predictions are on the performance of grass cover, and hence the need to determine performance as accurately as possible. A change in the timing of breach initiation can result in significant changes to the breach growth process.

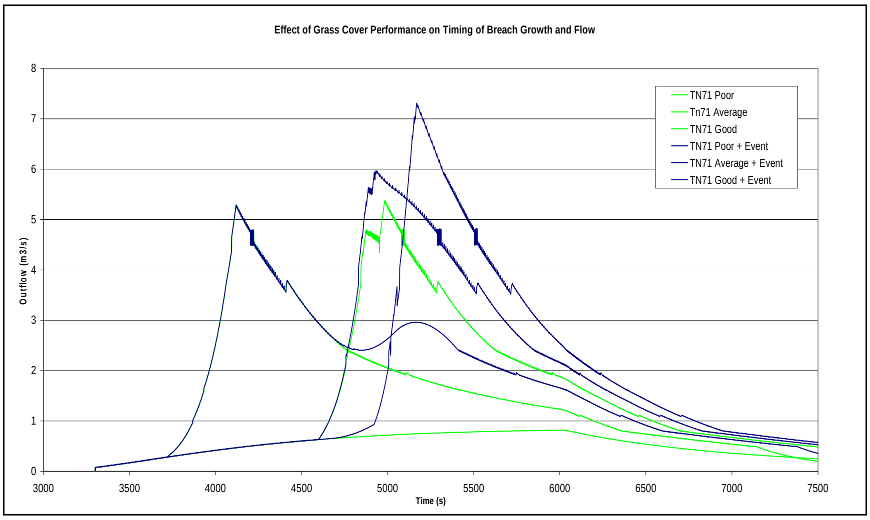

Figure 3. Example of the effect on breach prediction of initiation timing

Figure 3 shows an example of how the breach outflow prediction can vary by varying the breach initiation timing relative to the flood load conditions. The results here show a difference in peak discharge of nearly 40% caused by the breach timing coinciding (or not) with a small surge in the flood loading. For this example, the only difference between the three ‘event’ results is the grass condition.

PERFORMANCE BASED ASSET MANAGEMENT

Over the past decade there has been considerable development of risk based methods for analysing and managing flood risk (Flikweert and Simm, 2008). Reliability or system risk models use fragility curves to represent the performance of flood defences - such as flood embankments – as part of the overall risk system (**Figure 4**). The fragility curve relates the probability of failure of the embankment to the load conditions and hence reflects many different components of an embankment affecting performance, such as grass cover, soil type and state, construction quality etc. Generalised fragility curves for approximately 60 different defence types have been produced for use in UK national flood risk assessment studies as part of the Risk Assessment for Strategic Planning methodology (Hall et al., 2003).

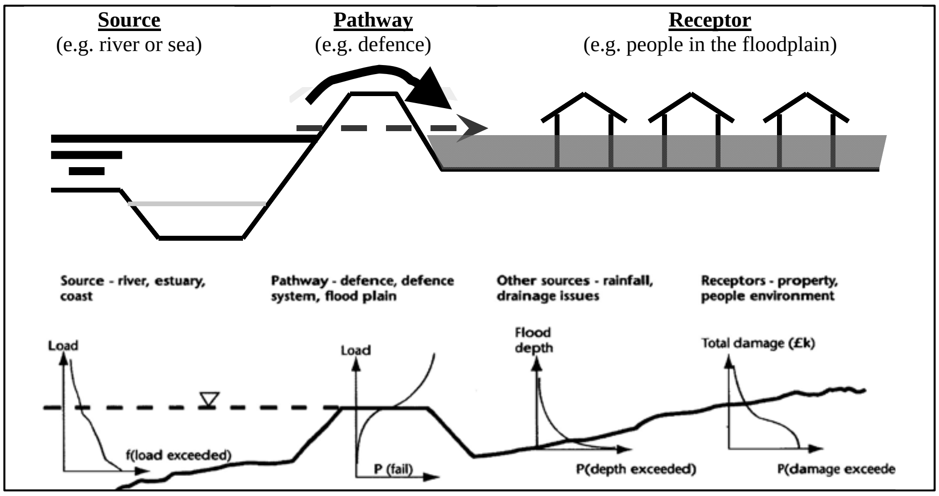

Figure 4. The source-pathway-receptor-consequences model for flood risk (Sayers et al., 2002)

The floods in June and July 2007 were a severe test for the flood defences in England, with about 1000km of embankment being tested with 500km overtopped. Four defences were breached and a specific review of the defences’ technical performance was commissioned by the Environment Agency (Royal Haskoning, 2008). In particular, the review compared the information collected on performance of the defences against the performance predicted by the fragility curves previously generated for the defences; some differences were observed. Three main findings from the review were that:

1. Only four defences actually breached; this figure was very low in comparison to the theoretical performance analysis;
2. Three of the four failures occurred when the water level was still below the crest level, suggesting some form of geotechnical failure;
3. All of the overtopped embankments (possibly but one) withstood significant overtopping.

The third point suggests that the performance of grass cover has been better than expected; this is also consistent with findings from recent Dutch research, as outlined below. For the sites that breached, the fragility curve shows a very small probability of failure (e.g. **Figure 5**), whilst for the embankments that overtopped but did not fail, the fragility curves predict significant probability of breach. The latter is consistent with the conclusions drawn from the earlier breach analyses – namely that a factor of safety within the CIRIA curves may be leading to a pessimistic prediction of defence failure when the data is used as part of a reliability analysis (i.e. to generate a fragility curve).

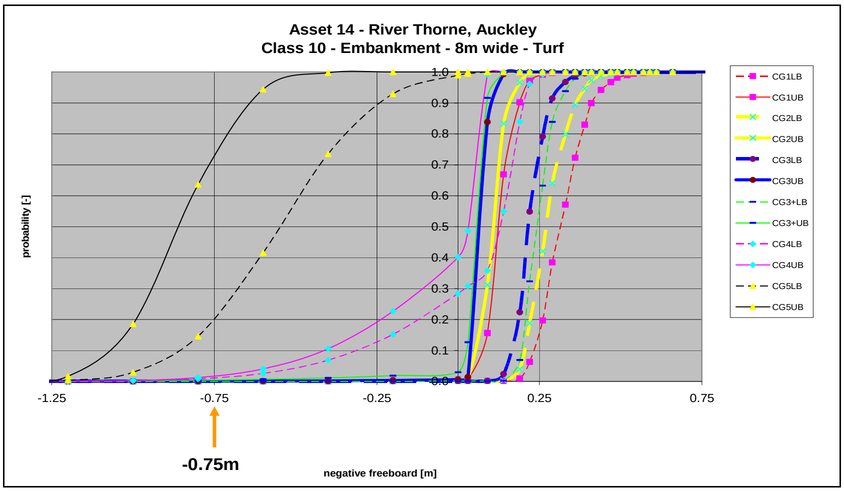

Figure 5. The fragility curve for the breach at Auckley suggested a very low probability of failure at 0.75m below crest when failure actually occurred

GRASS EROSION TESTING

In order to provide a better understanding of the effect of management interventions on the performance of flood banks, the Environment Agency ran Bank Vegetation Management Trials, monitoring a number of parameters relating to vegetation performance under different management Treatment Options at three sites in East Anglia (Ely Ouse, Reach Lode and

Billingborough) between 2003 and 2007. To complement this analysis L A B Coastal, with the support of the Environment Agency, developed and tested a portable erosion measurement device (EMD) which could be used to test the erosion resistance of vegetated grass flood banks by subjecting small test areas to running water (Boorman et al., 2009).

Test areas covering both poor and good quality grass were selected. Each test area was a 150mm square and water from the EMD was run across it at 4m/s for up to a maximum of 30 minutes. Erosion tests were curtailed when excessive erosion occurred and when problems arose further down the bank due to flows of water through faunal burrows and cracks. During the summer series of tests some geotechnical parameters were also measured in the wetted areas after the tests in order to examine the relationship between soil strength, erosion and other variables.

There was positive correlation between the extent of erosion and of bare ground in the test areas. Bare ground occurs for a number of reasons: faunal activity (moles and voles), die-back due to shading by taller plants or by uncut tufts of grass, and by die-back beneath dense clumps of arisings (terrestrial and aquatic) dumped on the bank. In bare areas caused by shading or by faunal activity (e.g. mole hills) the topsoil was often dry and loose, and so it was very readily washed away.

During the course of the erosion tests a number of observation were made on botanical aspects that tied in with the erosion tests in different ways. It became clear that it was the proportion of ground that was covered by living vegetation at ground level that was important; taller grasses often concealed bare ground. However, a good covering of grass or other vegetation did not always result in little or no erosion. Several times it was observed that erosion of the soil surface was occurring under the vegetation canopy even when this was close to the soil surface. In a few of the plots there were stands where the low growing grass species *Festuca rubra* formed a close interwoven cover to the soil and this appeared to be resistant to erosion.

While the extent of bare ground was a relatively good indicator of potential erosion the extent of this was often greatly affected by the quality of the bare ground particularly in relation to the degree of compaction. Test areas with the geotechnically strongest soils generally showed least erosion. The geotechnical measurements indicated that, taking the experiment overall, treatments with frequent mowing were most consistent in having little erosion and strong soils. Under these mowing regimes the soil aggregate particles (peds) remained more tightly packed together and thus more resistant to erosion. The uncut control was by far the weakest area and thus the most liable to erode.

The conclusions were drawn that at least one annual cutting is necessary by way of management. Cutting the grass sward at least once a year significantly contributed to bank performance but there was little direct evidence that more frequent cutting was beneficial. There was some suggestion that with a low frequency of cutting the removal of arisings could be beneficial. This was mainly because the uneven distribution of a dense layer of arisings could lead to the development of bare patches of soil. There was little evidence either that the high frequencies of cutting contributed greatly to erosion resistance. From the point of view of bank erosion, the management of small mammal activity appeared to be a significant factor in some cases although it had to be acknowledged that there were likely to be conservation issues.

The testing methodology had certain limitations; principally that only a single test velocity was used and that the tests were only run for 0.5 hours. The test velocity was appropriate for detecting sources of weakness within the grass cover but some of these weaknesses might have shown up at lower velocities. The work highlights the key issue that theoretically a single weak spot over a kilometre or more of flood bank could be the focus for the initiation of erosion following overtopping, even if the rest of the embankment is well maintained. The management of grassed flood banks needs to be targeted both at the identification and avoidance of points of significant local weakness in the grass cover as well as the general overall standard of erosion resistance of the bank vegetation cover. These objectives both have to be set against the balance between the overall risks of bank failure and its consequences and the costs of the management options involved. The problem is that we have neither the knowledge of what frequency of potential weaknesses is acceptable or the magnitude and details of overtopping that the flood banks may have to withstand.

OTHER GRASS RELATED RESEARCH INITIATIVES

Research into the erosion resistance of grass either requires test facilities big enough to allow controlled testing of prototype scale embankments, or suitable equipment and access to test real structures. Research of this type has been limited in the UK but two notable initiatives overseas are the continued research into the performance of grass on large structures at the USDA test facility at Stillwater, Oklahoma and the recent Dutch research based upon a large scale wave overtopping simulator (Figure 6).

The Dutch wave overtopping simulator (van der Meer, 2006a, van der Meer, 2006b) takes erosion testing to the embankment by applying controlled releases of water across the embankment face. This equipment has the potential to test grass performance ‘in situ’ for both wave overtopping and water overflowing conditions. Findings from the initial Dutch tests report grass performance that often exceeds existing design guidance expectations.

Figure 6. Wave overtopping simulator in action on a dike in The Netherlands

REVIEW OF CIRIA 116 GRASS PERFORMANCE CURVES

There were a number of differences between the erosion tests on steep grassed waterways (Hewlett et al., 1987) and recent tests using the erosion measurement device (EMD) (Boorman et al., 2009). The major differences were that the earlier tests were run at a range of water velocities, durations and depths (up to 10m/s for up to 10 hrs with depth >100mm) while the recent tests were run at a single velocity of 4m/s for a maximum of 30 minutes at a depth of 20mm. Nevertheless there appears to be a good relationship between the two data sets (**Table 1**) that warrants further investigation. The data in brackets are best estimates.

Table 1. Comparison between EMD and CIRIA performance data

Operator	**EMD**	**CIRIA**	**CIRIA**	**CIRIA**
	Duration (hours)			
Condition of sward	0.5	1.0	2.0	5.0
'Good'	(4.7)	4.5	3.8	3.3
'Average'	4.0	3.8	3.2	2.6
'Poor'	(3.2)	3.0	2.4	1.9

The EMD tests provided very interesting new information on the details of the initiation of bank erosion. It is clear that there is a necessity to examine more real time data to select appropriately realistic overtopping scenarios. The CIRIA report (Hewlett et al., 1987) basically considered the grass cover as a single unit with a variable height with the tallest grass having the highest hydraulic retardance. The retardance created by the taller grass swards could be greatly reduced when the grass was flattened by increases in water flow velocities and in depths of water. It was shown that erosion was reduced significantly by the presence of a dense mat of flattened grass. With the slower and shallower flows studied using the EMD the flattening of the grass cover was somewhat reduced. This enabled observation to be made regarding the effect of small differences within the grass cover itself. The most important point which emerged was that with medium to tall grass cover which slowed the water velocity there were often locally high water velocities below the flattened grass sufficient to initiate erosion. The key factor in erosion resistance of a grass sward appeared to be the extent and density of the cover of short, often fine-leaved, grasses near the soil surface irrespective of the overall height of the tallest grasses.

Despite these broad similarities between the two series of erosion tests there was also a notable difference in erosion processes that occurred. In the original CIRIA tests failures were generally initiated in the subsurface layers with water penetration through the grass sward washing out voids in the soil and subsequently the pore water pressure built up forcing a breaking through the grass sward from below. During the EMD tests the initiation of erosion was largely through weaknesses in the grass sward which facilitated the erosion of the soil surface layers. It would appear that these differences could be attributed in part to the greater depths of water flow and the longer run times in the CIRIA tests. Both of these processes would have facilitated the depths of pore water penetration. It is notable that despite these differences the net results in terms of erosion tolerance in relation to water flow velocities are broadly similar.

In terms of flood bank protection, although the results obtained from the EMD tests appear to confirm the general situation they do set some significant further questions. They clearly underline the need to consider the detail of grass cover more closely (such as specific studies on individual grass species and varieties) as well as indicating the desirability for further studies on the time/velocity relationship in the initiation of erosion. The risk posed by the spatial distribution of poor patches of grass in relation to likelihood of overtopping or overflowing also requires consideration.

CONCLUSIONS AND RECOMMENDATION

A number of observations can be made in relation to the use of vegetation for erosion protection, and the current guidance available:

- It is clear that vegetation plays an important role in protecting earth structures from surface erosion. With more extreme loading arising from predicted climate change there will be an increased need to design for and manage acceptable overflowing and overtopping conditions.

- Changes in vegetation performance do affect the timing of breach initiation. These timing changes can lead to significant changes in the magnitude and rate of breach; hence for a reliable estimate of flood risk, a reliable estimate of vegetation performance is also required.
- The design data used in the UK is typically from the CIRIA 116 report. The performance curves within this report appear to be based on a relatively small set of data collected from the 1950s to the 1980s. The curves may include a factor of safety which adversely affects use of the curves for reliability or breach analysis. Use of the original TN71 curves appears to give more appropriate results in this situation, as supported by findings for both breach analysis and the assessment of generic fragility curves against embankment performance during the 2007 floods.
- Recent erosion resistance tests undertaken using the EMD provide results that are generally consistent with the CIRIA data, but the work highlights the need for closer analysis of grass performance in general. The risk of initiation posed by areas of poor grass cover within an otherwise well maintained length of embankment are highlighted.
- All of the recent project work undertaken that links to vegetation performance emphasizes the important role that vegetation plays and the need to reduce the uncertainty in predicting vegetation performance by providing more extensive performance data.

Where from here?

At the time of writing it is understood that further tests of the overtopping simulator are planned in The Netherlands and in the US. In the UK, research into vegetation performance has been recommended from a number of projects, but remains as yet unfunded. One initiative that will allow some initial progress in this area is the European FloodProBE project (www.floodprobe.eu). This project started in November 2009 with a programme of work looking at the performance of the built environment during flooding, and the performance of flood defences. Part of this work allows for an international review of current guidance on vegetation performance and available data, with the aim of identifying how performance guidance may be improved. The need to consider different grass conditions and species, along with frequency and nature of likely load conditions (overtopping and/or overflowing) has been highlighted by a number of projects and should be considered in any future initiatives.

In the absence of further guidance on grass performance, it is recommended that users of CIRIA 116 consider how their analyses might change if using a range of different grass conditions and for breach or reliability analyses, consider the TN71 performance curves as well.

REFERENCES

Boorman, L.A., Hazelden, J., Adams, M., Cotten, J., Denness, D. and Smith, K. (2009) 'Maintaining vegetated flood embankments: a five year experimental approach to understanding best practice', *44th Defra flood and coastal management conference,* Telford, 30th June - 2nd July, 2009.

Buijs, F., Simm, J.D., Wallis, M.J. and Sayers, P.B. (2007) *Performance and reliability of flood and coastal defences, Technical Reports FD2318 TR1 & TR2.* Defra.

Flikweert, J. and Simm, J.D. (2008) 'Improving performance targets for flood defence assets', *Journal of Flood Risk Management,* (No.1), pp. pp. 201-212.

Hall, J.W., Dawson, R., Sayers, P.B., Rosu, C., Chatterton, J. and Deakin, R. (2003) 'A methodology for national-scale flood risk assessment', *Proceedings of the Institution of Civil Engineers - Water Maritime Engineering,* 156 (3), pp. 235-247.

Hewlett, H.W.M., Boorman, L.A. and Bramley, M.E. (1987) *Design of reinforced grass waterways, CIRIA Report 116.* CIRIA.

Morris, M.W. and Hassan, M.A.A.M. (2009) 'Breach modelling research into practice: Cconclusions from the HR Wallingford & European FLOODsite Projects', *ASDSO Dam Safety 09,* Hollywood, Florida, US2009.

Morris, M.W., Kortenhaus, A. and Visser, P.J. (2009) *Modelling breach initiation and growth, FLOODsite Report T06-08-02.* FLOODsite. www.floodsite.net

Morris, M.W., Kortenhaus, A., Visser, P.J., Hassan, M.A.A.M., Geisenhainer, P. and Zhu, Y.H. (2008) 'Modelling breach initiation and growth', In: Samuels, P. G., Huntington, S. W., Allsop, N. W. H. A. and Harrop, J. eds. *FLOODrisk 2008: Flood risk management, research and practice,* Oxford, UK2008. Taylor and Francis.

Morris, M.W. and Samuels, P.G. (2006) 'FLOODsite (Integrated flood risk analysis and management methodologies) - Research relevant to the dams industry?' In: Tedd, P. ed. *British Dam Society 14th Biennial Conference, 2006: Improvements in reservoir construction, operation and maintenance,* Durham, UK2006. Thomas Telford Ltd., pp. pp. 261-270.

Royal_Haskoning (2008) *Technical analysis of defence failures - summer floods 2007*.

Sayers, P.B., Hall, J.W. and Meadowcroft, I.C. (2002) 'Towards risk based flood hazard management in the UK', *Proceedings of the Institution of Civil Engineers Civil Engineering Journal,* Special Edition, Vol. 150., pp. 36-42.

Wahl, T.L., Hanson, G.J., Courivaud, J.-R., Morris, M.W., Kahawita, R., McClenathan, J.T. and Gee, D.M. (2008) 'Development of next generation embankment dam breach models', *US Society of Dams Annual Meeting and Conference 2008,* Portland, Oregon. US.2008.

Whitehead, E., Schiele, M. and Bull, W. (1976) *A guide to the use of grass in hydraulic engineering practice, Technical Note 71.* CIRIA.

Young, M.J. (2005) *Wave overtopping and grass cover layer failure on the inner slope of dikes,* UNESCO-IHE Institute for Water Education, Delft. MSc.