Dambreak and Emergency Planning: meeting end user needs

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SYNOPSIS. With changes to UK legislation and the European Floods Directive on the point of implementation, dam owners will face more stringent requirements to consider flood risk from reservoirs and to take preparatory steps in terms of dambreak flood risk assessments and emergency planning. Guidance on emergency planning in the UK is under review and a number of significant research projects are underway to advance our understanding and ability to analyse and manage flood risk. With the continued rapid pace in development of computing power, modelling and mapping technology, it is a good time to review current practice and capabilities, and to identify what should be considered as reasonable practice for dambreak modelling and emergency planning.

In reviewing practice, it is essential to consider the range of end user applications that the results of any study might be used for, and to ensure that the uncertainty and resolution of any predictions are suited to such applications. A failure to recognise the significance and magnitude of uncertainty within these predictions, and applications, undermines the value of undertaking and using such studies.

This paper presents a brief history of dambreak and emergency planning development in the UK leading towards the current convergence of a number of projects and drivers. This includes how modelling and data management tools have developed over the last decade, particularly within the field of flood risk management in general, to now provide us with powerful tools for flood risk assessment and management planning. Different approaches for dambreak analysis and emergency planning are considered, leading to a recommended type of approach that steps towards greater integration with wider Environment Agency flood risk management principles and is driven by the practicalities of end user needs and a consistent approach to dealing with uncertainties.

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ENSURING RESERVOIR SAFETY

INTRODUCTION

The UK is going through a very interesting period of change and potential for change at this time. The Reservoirs Act 1975 has served us well for the last 20 years but as with the review of the Reservoirs (Safety Provision) Act, 1930, it is appropriate to review and undertake change. The Water Act 2003 gives the Secretary of State power to direct owners to prepare a flood plan. This direction will specify the matters to be included in the plan to a specification to be advised. These plans will include dam break analysis and inundation mapping and will be used for emergency planning but with revisions planned for the Reservoirs Act 1975 provide an opportunity to develop a methodology which might be appropriate for a number of uses including legislative change, spatial planning, emergency planning and asset management.

DEVELOPMENT OF DAMBREAK AND EMERGENCY PLANNING IN THE UK

The failure of Dale Dyke Reservoir in March 1864 inundated the city of Sheffield after travelling 11 km at an average speed of nearly 30 km/hr. Parts of the city were flooded to a depth of 3 metres and large areas were covered with a thick layer of wood, mud, sand and stones. More than 250 people were killed, 798 houses were destroyed and more than 4000 seriously flooded. Dozens of mills, factories, shops and workshops were totally or partially destroyed (Smith, 1972). At the time the coroner stated that 'by one Act of Parliament dams should be subject to frequent, sufficient and regular inspections'. Unfortunately no legislation was enacted until there had been 3 failures in 1925.

In the 1980's a simple dam break modelling programme – DAMBRK was developed in the United States and this was subsequently modified and adapted to enable it to be used in the UK; indeed the information on time of travel from the Dale Dyke tragedy was used to 'calibrate' the model.

Over the last 20 years there has been a gradual and in recent years impressive improvement in modelling techniques. However, in the UK most of the analysis carried out to date has been fairly crude and rudimentary and have often been carried out without a clear reason for doing the work because the information has not been shared with others. In contrast many other countries around the world have adopted a far more rigorous assessment process often working with 2D modelling, public consultation and emergency planning/rehearsal and publication of maps.

The Water Act of 2003 states that

- 'The secretary of State, by written notice served on the undertakers in relation to a large raised reservoir, direct them to prepare a plan (a

> "flood plan") setting out the action they would take in order to control or mitigate the effects of flooding likely to result from any escape of water from the reservoir'.

The EU Floods Directive seeks to reduce and manage the risks that floods pose to human health, the environment, infrastructure and property. Member States of the EU will have to reduce flood risk where the risk is deemed to be significant. This is done by first determining the extent of flood risk (through hazard mapping and flood risk mapping. Whilst reservoirs are not specifically mentioned, the directive requires that all flood risk be considered and thus it is likely that the flood risk arising from reservoirs will be included.

AN OPPORTUNITY

It is clear that the UK is entering a period of change where opportunities exist to review and update our approaches and specifications and take the UK into the 21st Century. A review of the Reservoirs Act 1975, the Water Act 2003 and the EU Floods Directive all provide reasons and opportunities for improvements.

In reviewing the actions of the past it is clear that many of the studies undertaken in the 1990's lacked consideration of how the data was going to be used, and indeed the suitability of the modelling for the application. It might be that, in the event of failure, such plans could result in unnecessary losses and / or actions.

In moving forward it is essential to consider the various users and end applications of any modelling and mapping that is undertaken. It is essential to ensure that the results are meshed with an overall system supporting a range of applications which might include not only emergency planning but also legislative change, spatial planning and asset management. The data provided and the methods used must be appropriate for those applications and support more detailed analysis, perhaps where the consequences of failure are high, where it is required.

POTENTIAL APPLICATIONS AND END USERS

Historically, dambreak analyses have been undertaken purely for emergency planning purposes. Even then, the results of many studies were locked firmly away, only to be reviewed at the time of an emergency. However, with growing recognition of the range of actions that can be taken to contribute towards overall flood risk management it is becoming more widely recognised that the results of dambreak analyses may be used in a variety of applications, both at a national or local scale. For example, these may include:

ENSURING RESERVOIR SAFETY

- National risk assessment (including risk to Critical National Infrastructure)
- Local (reservoir specific) risk assessment
- National emergency planning
- Local emergency planning (including evacuation planning)
- Asset and business management
- Spatial planning

A *National Risk Assessment* would be undertaken to meet specific government needs and may also facilitate local risk assessments and enforcement of dam safety regulations. Flooding in 2007 highlighted the real risk that infrastructure can pose; identifying the real risk from national infrastructure is a key driver for undertaking such a study. Results from such an assessment would also support any national emergency planning measures (for example, high level provision of large capacity pumps).

Current plans to undertake broad (national) scale modelling of flood risk from reservoirs offers a number of opportunities, but must be undertaken to an appropriate resolution and accuracy in order to underpin the wider range of potential applications and hence be of greater industry value other than providing a 'one off' snapshot of broad scale flood risk.

Reservoir specific risk assessments may be undertaken to meet the requirements of UK and European legislation. Results from such studies will also support more detailed risk management measures, such as *emergency planning*, including evacuation planning, and asset and business management measures. Prioritisation of works to mitigate and manage flood risk (liability) is a key business activity.

Spatial planning uses Environment Agency (EA) guidance regarding flood risk and acceptability for land use. The significance of flood risk in the planning process is recognised and weighting regarding development decisions is likely to grow. Consideration of flood risk from reservoirs needs to be integrated into this process in a logical, transparent and consistent manner.

With such a range of different potential end uses for dambreak analyses it is important to ensure that the accuracy and resolution of an analysis is fit for a particular application, or group of applications. Current modelling and GIS technologies allow for flood plans to be produced overlaying satellite images or ordnance survey plans, but typically fail to reveal the true accuracy of the plans. This can be misleading once the plans pass from the originator on to a variety of users who are remote from the original studies.

Uncertainty is the Key Issue

Uncertainty within the base data, models used and end user application or management processes are key to ensuring that maximum value is obtained from any future dambreak analyses, whether undertaken at a national scale or as more detailed individual reservoir studies.

A series of questions should be addressed in order to ensure that a suitable approach is taken. These include:

1. What do we need (from dambreak modelling)?
2. What have we got (in terms of data and methods)?
3. What could we get (in terms of data and methods)?
4. Can we meet user needs with the available tools, techniques and data?
5. If yes, we can match methods and data as appropriate; if no, we should not proceed with modelling that is not fit for the required application. Instead, we should focus upon refining tools, techniques and data to match our needs. If this cannot be achieved, the results should not be routinely used for that particular application.

Answering these questions properly requires careful consideration of the dambreak analysis processes. The following section provides a suggestion as to what issues may arise. This is intended only as an example and requires more detailed validation before wider use. Values given here as examples should not be used directly to justify existing works or approach.

CONSISTENCY WITH EXISTING ENVIRONMENT AGENCY APPROACH TO FLOOD RISK MANAGEMENT

Defra and the EA are implementing a risk based approach to flood risk management for risks arising from flood and costal erosion). The Flood Risk Management Research Consortium projects (FRMRCI / FRMRCII; www.floodrisk.org) and FLOODsite projects (www.floodsite.net, Morris & Samuels, 2006) support and integrate with this programme. Concepts developed for flood risk management can, and should, be used as a framework for considering flood risk from reservoirs.

The Source – Pathway – Receptor model (Figure 1) is recommended by the EA for considering flood risk. By adopting a risk based approach for each stage (source, pathway, receptor) a true assessment of flood risk may be made. Within this model it is possible to identify the contributions that each component (stage or process) makes to the overall flood risk and to systematically identify uncertainties within the flood risk analysis process.

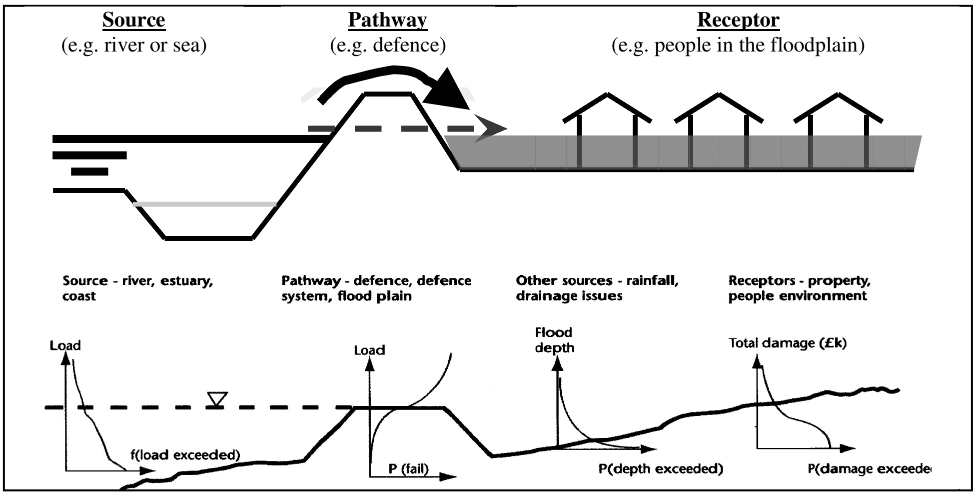

Figure 1: The source-pathway-receptor-consequences model for flood risk (Defra, 2002).

The process of flood risk assessment from dambreak may be considered in a similar way to that shown in Figure 1. The source is formed by the hydraulic loading of the dam, the pathway is represented by performance (failure or not) of the dam, and the receptor is represented by assets and people in the inundation affected areas. The consequences are driven by the speed and extent of flood spreading. The dam break flood risk is formed by the likelihood of the hydraulic loading conditions, the likelihood of the dam break scenarios and the consequences due to inundation.

Historically, dambreak analyses have not dealt rigorously with risk. Assumptions are typically made regarding load conditions (PMF, sunny day failure etc.) and how the dam fails (partial failure, catastrophic etc.). Recent developments in quantitative risk assessment (Brown & Gosden, 2004) consider risk in more detail, but do not offer the complete 'model' as outlined in Figure 1. A particular difference here lies in the representation of pathway (dam) performance – i.e. how it fails under different load conditions. The S-P-R approach represents pathway performance through a fragility curve (HR Wallingford, 2005). This relates the probability of failure to a given load condition. Work is required here to determine to what detail dam performance can be related to load conditions. For example, how far beyond a simple fail – no fail load condition can we reliably predict behaviour and how important is this detail for establishing dambreak flood risk?

The EA adopts a hierarchical approach to flood risk assessment, with high, intermediate and detailed levels of assessment. These broadly relate to national, regional strategic and site specific levels of study. Table 1 below (Sayers et al, 2002, following from Defra, 2002) provides a summary of these approaches in relation to end user ('decision to inform'), data sources and methods for analysis. Similar consideration may be given to national or site specific dambreak studies, and hence appropriate sources of data and methodologies to use in relation to end users (or ‘decisions to inform’). This is outlined in a comparable table (Table 3) later in this paper.

Table 1 shows that risk assessments inform different policy levels, e.g. a national, regional and site specific level. The required detail of the risk assessment models to inform the decisions differs for each policy level. Table 1 illustrates that as the detail of the decision-making increases, the data requirement and the complexity of the applied methodologies increases. It is advantageous, however, for some data sets to be common to all levels of hierarchy. For example, working from a common topographic data set, but using different densities of data, will aid modelling speed without compromising consistency between mapping of flood risk at different hierarchical levels.

Table 1: Tiered hierarchy in objective setting and data supply for fluvial and coastal flood risk assessment (Sayers et al., 2002).

Level	Decisions to inform	Data sources	Methodologies
High	National assessment of economic risk, risk to life or environmental risk Prioritisation of expenditure	Defence type Condition grades Standard of Service Indicative flood plain maps Socio-economic data Land use mapping	Generic prob. of defence failure based on condition assessment and crest freeboard Assumed dependency betwn. defence sections Empirical methods to det. likely flood extent
Intermediate	*Above plus:* Flood defence strategy planning Regulation of development Prioritisation of maintenance Planning of flood warning	*Above plus:* Defence crest level and other dimensions where available Joint probability load distributions Flood plain topography Det. socio-economic data	Prob. of defence failure from reliability analysis Systems reliability analysis using joint loading conditions Modelling of limited number of inundation scenarios
Detailed	*Above plus:* Scheme appraisal and optimisation	*Above plus:* All parameters required desc. defence strength Synthetic time series of loading conditions	Simulation based reliab. analysis of systemSimulation modelling of inundation

Detailed emergency planning, land use planning and asset management requires a detailed representation of hydraulic boundary conditions, dam failure and deterioration, breach formation and inundation scenarios. The source-pathway-receptor consequences and tiered decision-making approach enables modelling multiple failure and inundation scenarios in an integrated way. In flood defence management the possibilities to implement performance based asset management have been explored (Defra / Environment Agency, 2004a, b & c). Such an approach ideally integrates asset management, emergency planning, land use planning and other user needs.

POTENTIAL APPLICATIONS, REQUIREMENTS AND ACCEPTABLE UNCERTAINTY FOR DAMBREAK ANALYSES

The following section details potential end uses of dambreak analyses and indicative measures of uncertainty (in terms of predicted water level) that might be appropriate for such applications. It is recognised that predicted water level is perhaps not the best measure of uncertainty here, given its dependency on site specific factors, however it does provide a practical measure that is widely recognised by all end users. Table 2 provides a summary of indicative levels of accuracy that might be required for different end uses. More detailed consideration is required to refine these values, whilst this initial summary presents the concept.

Table 2: Indicative required accuracy for flood level prediction in relation to potential different end uses

Indicative acceptable accuracy of flood level prediction for different end applications						
National risk assessment	±0.1m	**±0.5m**	±1.0m	**±2.0m**	**±5m**	±10m
Critical national infrastr.	±0.1m	**±0.5m**	±1.0m	±2.0m	±5m	±10m
Emergency planning	±0.1m	**±0.5m**	**±1.0m**	±2.0m	±5m	±10m
Spatial planning	**±0.1m**	**±0.5m**	±1.0m	±2.0m	±5m	±10m
Asset management	±0.1m	**±0.5m**	±1.0m	±2.0m	±5m	±10m

National Risk Assessment at a broad national scale would provide an indication of overall national risk arising from reservoirs through indicative inundation plans to an accuracy of perhaps ±2-5m. However, the risk assessment may also be used to categorise risk in relation to individual reservoirs (i.e. reservoir risk categorisation A, B, C, D etc) and to provide base data for more detailed studies of high risk dams, in which case a greater degree of certainty is required (perhaps ±0.5m). In this case the modelling would need to adequately reflect the resolution between reservoir risk categories which currently differentiates between a threat to a community of more than 10 people, as compared to 0-10 people. Such resolution requires a far more accurate prediction of flood timing, velocity and depth and hence level accuracy of ±0.5m is suggested instead of ±2-5m.

Risk to Critical National Infrastructure can be assessed at both national and detailed individual levels. The cost implications of risk to critical infrastructure are large. When infrastructure is found to be at risk, logical further steps are to establish what measures might be needed to protect the infrastructure. Hence, accuracy of mapping for both initial identification and protection options needs to be better than initial broad national scale modelling, and is suggested as ±0.5m. Assessing the physical threat to infrastructure (which may be above or below ground) can require detailed consideration of flow velocity, damage potential and timing.

Emergency Planning can be implemented in a number of ways, ranging from the broad to the complex. The objective here is to provide predictions of scenarios that will provide maximum value to emergency services during an event. Information that is of value includes inundation extent, timing and damage zones. Damage zones implies prediction of flow depth and velocity to a reasonable resolution. The way in which flow modelling is undertaken affects the accuracy of all of these parameters. For example, if flood wave attenuation is not correctly modelled, not only will flows and water levels be incorrectly predicted, but so too will the timing of the flood wave.

Emergency services are likely to evacuate areas based upon geographical features or zones (i.e. whole streets) rather than the predicted line of inundation. However, the uncertainty in the inundation plan is a function of uncertainty in flow prediction combined with topography. Uncertainty in flat areas relating to ±0.5m can cover large areas in comparison to uncertainty in inundation of populated areas within a valley.

Spatial Planning could make use of reservoir plans to limit risk in the event of a dam failure. The current position is ‘grey’ with some developers, planners, owners and the Enforcement Agency recognising the issues whilst others ignore it. As a dam owner, any construction within the potential inundation zone of your reservoir may (currently) change the risk category of the dam and hence actions needed to maintain the dam. With threat to life being a key issue, required accuracy is likely to be high.

It is the author’s experience that development costs typically dwarf the costs of undertaking reasonably detailed flood risk studies, hence the likely appropriate (cost beneficial) accuracy for such applications is quite fine.

If this suggestion is correct, it raises an interesting moral question in that society would appear to place greater value on establishing true risk for a specific development / planning issue than generally for the emergency planning / evacuation planning of the wider population!

ENSURING RESERVOIR SAFETY

Asset Management requires a risk based approach in order to determine how best to spend limited resources (Defra / Environment Agency, 2004a, b & c). The objective here would be to use dambreak analyses, including full impact assessments, to identify potential risk (liability) and hence to identify what risk reduction or management measures might be appropriate. Portfolio Risk Assessment procedures help to ensure maximum value is obtained in working through various risk management measures. The degree of accuracy appropriate for asset management will depend upon the number and type of dams being considered, and the issues that arise. It might be appropriate to first review indicative risk at a level similar to national broad scale modelling. Subsequently, higher risk dams might be considered in more detail, probably at a level similar to that adopted to assess risk to critical infrastructure.

In conclusion, we can see from this indicative overview of potential accuracy attached to different end user applications, that prediction of flood levels ranging from ±2-5m down to ±0.1-0.5m might be needed. We also see that where results from one application, such as national mapping, are used to inform a variety of decisions, then the required accuracy of the application is dictated by the decision requiring the most stringent conditions.

MATCHING CURRENT DATA AND MODELS TO END USER NEEDS

Having identified different end users and uses for dambreak modelling results the challenge is to now match available data sets and modelling capabilities appropriately.

Topographic Data

Topographic data can pose a significant (cost) barrier to undertaking dambreak analyses. A number of different data sets exist:

- National scale SAR data (resolution 5m grid; accuracy ~±0.5m at best
- LIDAR data (resolution ~2m grid; accuracy ~±0.1m) – not available nationally, but considerable coastline and river valleys covered
- Composite LIDRA/SAR data (resolution 5m grid; accuracy ~±0.1-0.5m depending upon source
- Site specific survey or LIDAR data collected for dambreak studies (resolution as required; accuracy ±0.01-0.1m depending upon method)

If national scale modelling is to be used to support reservoir risk categorisation and more detailed site specific studies (for example, for high risk category reservoirs) then it is likely that national scale modelling will require LIDAR resolution and accuracy data.

Modelling Capabilities

There are many stages to a dambreak assessment, and the potential to use a range of different models at each stage. The importance of various model contributions will vary between dam type and location; for a national assessment however, a single most stringent approach should be adopted to ensure applicability to all.

A good example of analysing and understanding uncertainties within a dambreak analysis is given within Work Package 5 (WP5) of the European IMPACT project (Morris & Hassan, 2005). Here, the Tous Dam failure in Spain was used as a case study and combined breach and flood routing modelling undertaken using a number of models. A practical approach to modelling uncertainty gave a range of predictions for flood levels at a downstream town; a back analysis of the source of uncertainty contribution to flood level was also made, identifying sources such as breach modelling, topographic data, choice of flow model, roughness assumptions etc.

Existing Modelling Capabilities - Hydrology

Research is ongoing here to resolve differences in extreme event prediction between FSR and FEH predictions. Whilst there may currently be uncertainty in both method and prediction, this should not encourage the use of unduly simplified methods elsewhere within the overall dambreak analysis. Instead, the accuracy of methods should be refined to meet specific end user needs.

Existing Modelling Capabilities – Structure failure

Modelling capabilities here vary between different structure types. The need for a consistent approach across structures is recognised and identified within the recent Reservoir Safety R&D Strategy project (Atkins, 2008). Prediction of breach is an area where research has advanced and methods typically fall to predictive modelling versus the use of simple assumptions built around peak discharge equations. The uncertainty attached to peak discharge equations is potentially huge; the accuracy of peak discharge from a predictive model is now in the region of ±20-30%.

Existing Modelling Capabilities – Routing models

There are now a range of flow models available that offer 1D, 2D or even 3D flow simulation. Links to GIS tools for mapping are useful, but can hide the true resolution and accuracy of a simulation. Developments in 2D modelling mean that it is now as easy to produce a 2D model as a 1D; as always, use of appropriate topographic data dictates output, but this is not a reason to differentiate between choice of 1D or 2D approaches. More important is the basis of the model code and suitability for simulation of dambreak flood conditions. Some 2D codes offer a fast but simplified representation of hydraulics. This simplification can introduce large inaccuracies for some applications, particularly where rapidly varying flow conditions occur, as with dambreak. Suitability of a model for fluvial flow modelling and mapping is not a guarantee of suitability for dambreak flood modelling.

Matching Capabilities to End User Needs

Table 3 below starts to match needs to applications. However, the table does not detail conditions other than the two extremes of simple national risk assessment and individual detailed studies. It is anticipated that detailed interim measures should be identified as part of the national broad scale modelling project commissioned by the Environment Agency this year.

Table 3: Indicative tiered hierarchy in objective setting and data supply for reservoir flood risk assessment

Level	Decisions to inform	Data sources	Methodologies
High	National risk	National LIDAR data sets Location of reservoirs within Act Basic type, structure, dimensions etc. Indicative land use	Extreme hydrology Simple – but smart – failure mechanisms Coarse grid, main topographic features – 2D flow simulation
Intermediate	Is this appropriate for reservoir flood risk assessment?		
Detailed	Individual reservoir risk assessment and emergency planning	Local LIDAR data Reservoir bathymetry Dam construction and condition details (survey and sampling if necessary) Land use within impact zone	Detailed hydrology Realistic structure failure mechanisms (predictive modelling) Dynamic modelling of reservoir and routing downstream using integrated 1D and 2D models as appropriate.

CONCLUSIONS, OBSERVATIONS AND SUGGESTED ACTIONS

A key aim of this paper is to highlight the current opportunity (through a range of linked EA/Defra projects) to adopt end user focused approaches to dam break analysis. This will help to avoid inappropriate modelling that can provide results of limited value and application.

Adopting concepts and procedures already used for wider flood risk analysis and management within the EA will help to integrate reservoir flood risk analysis within the developing EA risk management framework. Ultimately, risk from reservoirs should be managed consistently with other flood risks. This approach will also help to ensure that requirements arising from the European Floods Directive are also addressed in a consistent manner.

Ensuring that the chosen methodology for dambreak analysis is suited to a range of different end user needs and applications requires a thorough review and understanding of the uncertainty contributions at each stage of the dambreak analysis process. It is thought likely that the real magnitude of uncertainty inherent in different approaches is far larger than many users appreciate. Also, that the resolution and accuracy required for applications other than a high level indicative risk assessment are more stringent than many users appreciate. However, recent trends in 2D and predictive model development, making more accurate predictions of flood conditions easier and faster, may help to offset this mismatch.

Where a mismatch occurs between user needs and available data and modelling methodologies, it is important to firstly recognise this in any use of existing data and methods, and to secondly focus R&D and national projects towards providing suitable data and methods. At all costs, we should avoid blindly modelling dambreak scenarios and using predictions without a clear understanding of their basis and inherent uncertainty.

REFERENCES

Atkins (2008). *Defra reservoir safety research strategy.* Draft final report, 2008.

Brown, A.J. and Gosden, J.D. (2004). *Interim guide to quantitative risk assessment for UK reservoirs.* Thomas Telford, 2004. ISBN 0 7277 3267 6.

Defra / Environment Agency (2002), *Risk, Performance and Uncertainty in Flood and Coastal Defence – A Review,* SR587, Environment Agency.

Defra / Environment Agency (2004a), *PAMS – Phase 1 Scoping Study, Task 1 interim report: Logical framework for O&M activity*, Environment Agency.

Defra / Environment Agency (2004b), *PAMS – Phase 1 Scoping Study, Task 2 interim report: Review of existing methodologies,* Environment Agency.

Defra / Environment Agency (2004c), *PAMS – Phase 1 Scoping Study, Task 3 interim report: options for performance based asset management systems,* Environment Agency.

HR Wallingford (2005), *Performance and Reliability of Flood and Coastal Defences,* FD2318/TR1, Wallingford.

Morris, M.W. and Hassan M.A.A.M. (2005). *Conclusions and Recommendations from the IMPACT Project WP5: Combined Risk and Uncertainty.* Available via www.impact-project.net. EC Research Project EVG1-CT2001-00037.

Morris, M.W. and Samuels, P.G. (2006). *FLOODsite (Integrated Flood Risk Analysis Management Methodologies) – Research Relevant to the Dams Industry?* British Dam Society 14th Biennial Conference, University of Durham, 6-9th September, 2006.

Sayers, P.B., Hall, J.W., Meadowcroft, I.C., (2002), *Towards risk-based flood hazard management in the UK, Proc. ICE Civil Engineering*, v150, n1, special issue: Floods – a new approach, pp. 36-42.

Smith, N (1972). *A history of dams*. Citadel Press.