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# IMPACT: Investigation of extreme flood processes and uncertainty - a European research project

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# *IMPACT: INVESTIGATION OF EXTREME FLOOD PROCESSES AND UNCERTAINTY - A EUROPEAN RESEARCH PROJECT*

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## Abstract

The IMPACT project, which was completed at the end of 2004, comprised a programme of research investigating a range of aspects common to extreme flood events and in support of improved flood risk management. This paper presents an overview of the state of the art capability and findings for each of these research areas, with an emphasis upon how this research work may be used within the UK flood risk management community.

Research areas included predicting breach formation, modelling extreme flood flows along natural topographies and through urban areas, predicting sediment movement – in both near and far fields and assessing uncertainty in predictive models used for flood risk assessment. A further module investigated the use of geophysics for the rapid integrity assessment of long lengths of flood defence embankment. Research work was undertaken by a consortium of 11 partners, drawn from 10 countries across the EC. Additional organisations and researchers around the world also participated in different aspects of the work.

## The IMPACT Project

The IMPACT project addresses the assessment and reduction of risks from extreme flooding caused by rare natural events or the failure of dams and flood defence structures. The work programme is divided into five main areas, addressing issues raised by the earlier CADAM project on breach formation, flood propagation, sediment movement, modelling uncertainty and geophysical investigation techniques. Research into the various process areas was undertaken by groups within the overall project team. Some work areas interact, but all areas were drawn together through an assessment of modelling uncertainty and a demonstration of modelling capabilities through an overall case study application. The IMPACT project provides support for the flood risk management industry in a number of ways, including:

- Provision of state of the art summaries for capabilities in breach formation modelling, dambreak / extreme flood prediction (flood routing, sediment movement etc)
- Clarification of the uncertainty within existing and new predictive modelling tools (along with implications for end user applications)
- Demonstration of capabilities for impact assessment (in support of risk management and emergency planning)
- Guidance on future and related research work supporting dambreak assessment, flood risk analysis and emergency planning

The core of this paper provides an overview of the work undertaken within the IMPACT work packages. More detailed information on all research may be found via the project website at www.impact-project.net. The project work packages (WPs) comprised:

- WP2: Breach formation
- WP3: Flood propagation
- WP4: Sediment movement
- WP5: Uncertainty analysis

- WP6: Geophysics and data collection

The nature of extreme flood events means that very little reliable data exist through which processes may be understood and models validated. Consequently, a common approach adopted within many of the WPs, was to initial undertake field and / or laboratory work to collate reliable data sets through which model performance may be assessed and subsequent development undertaken. To ensure that model performance was as objective as possible, many of the benchmark tests were undertaken 'blind', whereby the modeller was only provided with test conditions, and no test results until after initial submission of modelling predictions.

## WP2: Breach formation

A range of activities relating to improved modelling of breach formation were undertaken within WPs 2, 5 and 6. Key actions comprised:

- Improvement of the prediction of breach formation
  - 5 large scale field tests (Norway)
  - 22 1:10 scale laboratory tests (UK)
  - Model application, comparison, development (modellers worldwide)
- Analysis of uncertainty within the breach modelling process
- Investigation of factors contributing to breach location
  - Collection and analysis of historic breach data (Hungary / Czech Republic)
  - Numerical modelling approaches for breach location

### Field Tests

A unique test site was established in Northern Norway, just below the artic circle, where an embankment test site was established allowing construction of embankments 4-6m high, approximately 40m wide and retaining 60-100,000m$^3$ water. The location downstream from a dam allowed control of inflow to the test area. In 2002 and 2003 five field tests were undertaken. The tests were designed to provide large scale data on breach formation processes in homogeneous and composite embankments, failing by overtopping and piping. The five tests comprised:

- 6 m high cohesive embankment / overtopping (25 % clay and less than 15% sand)
- 5 m high non-cohesive embankment / overtopping (less then 5 % fines)
- 6 m Composite embankment / overtopping (Rock fill & Moraine)
- 6 m Composite embankment / piping (Rock fill & Moraine)
- 4.5m Homogeneous embankment / piping (Moraine)

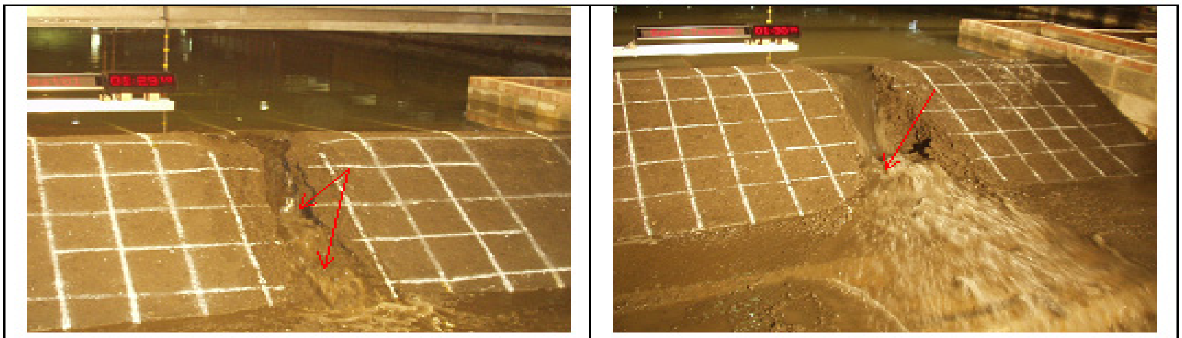
Data collected from each field test included water levels, discharge, pore water pressures, breach development parameters and extensive video footage and still photos. Figure 1 below shows examples of 4 different field tests in progress.

### Lab Tests

A total of 22 laboratory experiments were also undertaken at HR Wallingford in the UK. Most of these tests were undertaken at a scale of 1:10 to the field tests and were designed to allow variation of different parameters that influenced the breach process. These tests were divided into 3 series, as summarised below:

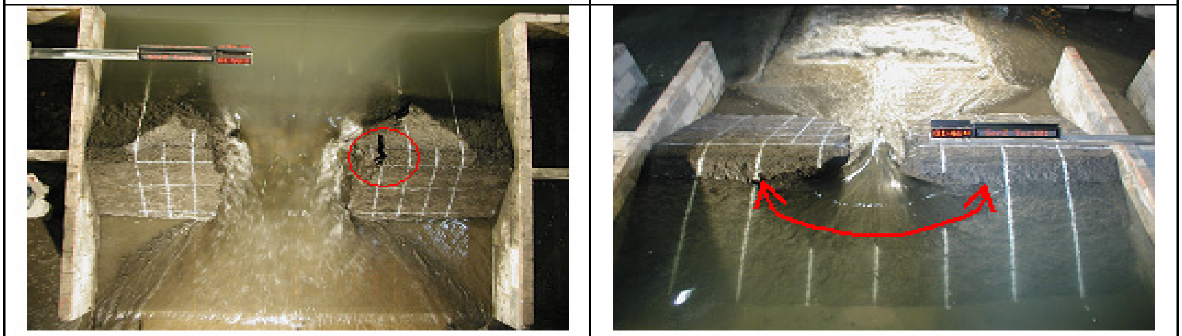
Series #1: 9 tests : Homogeneous embankment; non cohesive material; overtopping failure
Series #2: 8 tests : Homogeneous embankment; cohesive material; overtopping failure (Figure 2)
Series #3: 5 tests : Homogeneous embankment section; cohesive material; piping failure

**Figure 1** **Breach development stages (4 different field tests)**



A) Head cut formation

B) Combined head cut



C) Material slumping

D) Upstream erosion

**Figure 2** **Lab Series 2 tests – breach formation processes**

## Numerical modelling benchmark tests

Modellers worldwide participated in the breach model test programme:

*HR Wallingford* (Mohamed Hassan), UK, HR BREACH, NWS BREACH
*Cemagref* (André Paquier), France, Simple model
*UniBwM* (Karl Broich), Germany, Deich_P
*USDA – ARS* (Greg Hanson), USA, SIMBA
*Delft Hydraulics* (Henk Verheij), Holland, SOBEK rural overland flow
*Ecole Polytechnique de Montreal* (Rene Kahawita), Canada, FIREBIRD

Numerical modelling runs undertaken by the modellers comprised both 'blind' and 'aware' tests for a wide range of the field and laboratory test data. Given the huge number of tests and limitations on resource, priorities were placed upon undertaking model performance comparisons for the field tests, the lab tests matching the field tests and then all other lab tests.

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The data produced from the numerical modelling exercises allowed a comparison of model performance and investigation into breach and modelling processes to understand why models performed better or worse for different situations. Figure 3 below shows an example of modelling results compared against field data from Field Test #1.

The performance of the different models was assessed using a methodology to compare different result parameters such as peak discharge, breach dimensions etc. Scores for each parameter may be determined and overall performance assessed through weighted combinations of these scores, where weight depending upon which aspects of the predicted results were of most interest.

Table 1 below shows a summary of model performance scores – regardless of runs. This is one of a number of such tables. It should be noted that scores are indicative and when considering comparisons, users should be aware of the different model capabilities and the test conditions applied. Nevertheless, the tables do give an indication of which models consistently perform better or worse.

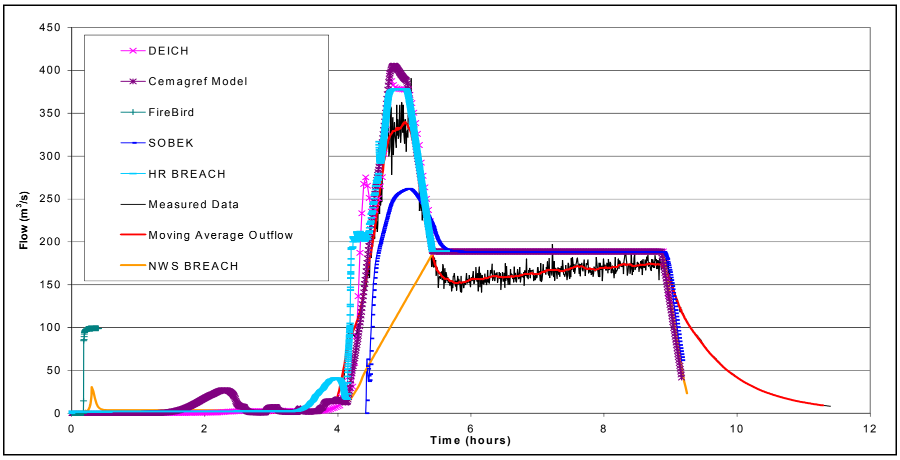

**Figure 3 Predicted outflow vs measured data for Field Test #1**

### Table 1 Overall model performance scores (regardless of number of runs) Breach location

| Average score - all models (regardless of number of runs) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Range of Weighting Factors | | Peak Outflow / Water Level at Peak Outflow | | Peak Outflow / Peak Water Level | | Peak Outflow | | Time to Peak | | Final Breach Width | |
| PO:1 TP:1 WLP:1 PWL:0 FBW:1 | | PO:1 TP:0 WLP:1 PWL:0 FBW:0 | | PO:1 TP:0 WLP:0 PWL:1 FBW:0 | | PO:1 TP:0 WLP:0 PWL:0 FBW:0 | | PO:0 TP:1 WLP:0 PWL:0 FBW:0 | | PO:0 TP:0 WLP:0 PWL:0 FBW:1 | |
| | | | | | | | | | | | |
| HR BREACH | 8.1 | Sobek | 8.1 | HR BREACH | 8.6 | HR BREACH | 8.9 | HR BREACH | 8.7 | Sobek | 7.6 |
| Sobek | 7.8 | HR BREACH | 7.9 | Sobek | 8.2 | Sobek | 8.3 | Cemagref | 8.4 | HR BREACH | 7.1 |
| Cemagref | 7.2 | Firebird | 7.0 | DEICH | 7.3 | DEICH | 8.2 | Simba | 7.9 | DEICH | 5.0 |
| DEICH | 6.9 | DEICH | 6.8 | Cemagref | 6.8 | Cemagref | 8.2 | NWS BREACH | 7.7 | NWS BREACH | 4.7 |
| Simba | 6.4 | Cemagref | 6.7 | Simba | 6.6 | Simba | 6.6 | DEICH | 7.5 | Simba | 3.9 |
| NWS BREACH | 5.9 | Simba | 6.1 | Firebird | 6.4 | NWS BREACH | 6.4 | Sobek | 7.0 | Cemagref | 2.8 |
| Firebird | 4.1 | NWS BREACH | 5.1 | NWS BREACH | 6.3 | Firebird | 4.2 | Firebird | 5.2 | Firebird | 0.0 |

The aim of work here (under WP2 and WP6) was to investigate potential approaches / methodologies for identifying the relative risk of breach occurring along long lengths of flood defence embankment. This problem may be viewed from a number of perspectives, namely:

- Investigation of physical processes and factors contributing to breach formation through an embankment (and hence identification of key indicators or parameters for inclusion within a model framework or asset inspection / management system)
- Development of a framework for assessment based upon 'available knowledge'
- Assessment of flood risk, regardless of specific breach location (i.e. 'what if' approach to modelling inundation from breach

Research under IMPACT WP6 included the collation and analysis of data relating to breach of embankments across Hungary and the Czech Republic. The focus of this work is the collation of embankment condition, material and failure process data to allow identification of key parameters and processes.

Whilst details of a large number of breach events were collated the quality of available data proved to be poor and detailed analysis of any correlation between material properties and breach was not possible. However, correlation between typical breach size and breach location along the river was possible. The collected data base allowed analysis of failures along the Danube River from 77 data series, along the Tisza River using 97 data series, from 288 data related to the tributaries and further 95 of the small rivers of Hungary leading to:

- relations between the length of the breaches vs height of overflow and of the flow rate of the river;
- relations between the length of the breaches and the location of the breach along the river;
- relation between length of breaches and calendar years of occurrence (the role of time).

These relationships are of significant value at a local level, in that typical breach dimensions may be predicted for typical conditions and locations. This is invaluable when trying to repair a breach during a flood event. Further analysis would be required to determine applicability to other catchments and countries.

A framework approach for assessing the relative risk of breach location has been developed through the UK Defra / EA RASP project. The use of fragility curves to represent embankment performance allows the relative risk of failure under variable loading to be determined. Fundamental now, is development and validation of reliable fragility curves. The case study data collected in Hungary could be further analysed to help confirm such embankment performance.

A third approach to looking at breach location was undertaken by Karl Broich of UniBwM. Analysis of a real event where 8 breaches occurred was undertaken and a simple correlation between overtopping flow depth and breach considered. Seven out of eight breach locations were correctly predicted using accurate ground and water level models. The success of this simple approach requires further consideration.

## Value of Breach Formation Research to the UK Flood Risk Management Community

The breach formation research under IMPACT WP2 has significantly advanced the level of knowledge in this field. Researchers within the team are international experts – the models applied are the current state of the art.

The full range of results produced cannot be listed here, but significant points include:

- current modelling accuracy is in the region of ±30% for estimation of <u>peak discharge</u> – accuracy will depend greatly upon the reliability of knowledge regarding embankment materials, construction and condition. Accuracy of predicting breach dimensions and lateral growth is worse; accuracy of predicting breach initiation is considerably worse.
- Performance tables comparing results for six different models applied to a range of tests allows indicative assessment of performance. The NWS BREACH model – one quite widely used worldwide due to public domain availability since the 1980's at minimal cost – consistently performed poorly in comparison to more recent models with better physics. Continued use of this model cannot be considered best practice.
- breach formation processes are complex and vary depending upon the material type and embankment condition. Many existing models predefine growth patterns, which leads to errors. (Many existing so called breach models ask the user to define the growth pattern!)
- Parameters such as material type, grading, compaction and moisture content all significantly affect breach growth rates – some by orders of magnitude. Many models do not include these parameters and hence have little chance of consistently good performance. The integration of soil mechanics and hydraulics theory is essential for further advancement of capabilities in this area
- IMPACT allowed collection of rare and reliable data regarding breach formation, along with analysis and development of models. Further analysis of this data will now allow further refinement of breach model performance.

## WP6: Geophysical investigation

With tens of thousands of kilometres of flood defence embankments in the UK alone, the need for effective monitoring and maintenance is fundamental. Currently, inspection is either a visual inspection or for more information about the embankment construction and materials, the use of detailed geophysics and / or intrusive exploratory work. Whilst visual inspection is relatively quick and inexpensive, it is difficult to learn much about the embankment integrity. Use of intrusive and / or detailed geophysics provides more information, but is relatively slow and expensive. The challenge here is to find an approach that allows the relatively rapid, non intrusive assessment of embankment integrity.

Czech Partners within the IMPACT project undertook a programme of review and testing of different geophysical investigation techniques. Test sites within the Czech Republic were monitored over a period of time in to try and identify changes in embankment condition using various geophysical approaches. Works proceeded in 3 phases, as outlined below:

**Phase 1**: Determination of optimal geophysical methods as well as parameters for monitoring. *Geophysical parameters monitored:*

- volume density (for determination of density model of the given sector of the embankment)
- seismic velocity
- seismic models of elasticity

- porosity
- structure of the embankment
- layering of the embankment (for determination of resistance model of the dam)
- natural electric potential in the space of the dam (identification of places of leakage)

*Geophysical methods used:*
- Geoelectric methods
- Geological radar
- Seismic methods
- Gravimetry
- Magnetometometry

**Phase 2**: Monitoring and analysis of selected geophysical and geotechnical parameters at a test site (Velky Belcicky pond, Czech Republic).

Phase 3: Determination of dependence of modelling results on geophysical measurement in-situ and recommendations for use / implementation of such methods within industry.

## Initial findings

The investigations highlighted a number of opportunities for using geophysics for embankment integrity assessment:

- The comparison of approaches allowed the relative value of each technique to be determined. Geoelectric methods (measuring resistance, conductivity, electric potential) were considered of most value; magnetometry and radiometry of least value.
- Periodic measurement of embankments does allow identification of defects with time and hence if a rapid assessment system is developed, these techniques could allow time varying condition to be determined
- A system (GEM 2) used by US military for alternative applications and only released for public use within the last few years was identified as having potential for rapid assessment application. This system is based upon the application of electromagnetic conductometry (EFM method) and allows for multi frequency monitoring. This was trialled and shows promising results at high productivity (i.e. whilst being moved along the crest of an embankment).

The research undertaken in this area within IMPACT was a preliminary investigation to assess feasibility of approach. This has proved successful. The next step towards a system that might be used in routine embankment monitoring programmes is the development and test application of a more formal prototype. Options for a programme of work and funding to achieve this are currently being considered nationally and within the EC. If workable, such a system would be of significant value to the UK flood risk management community.

## WP3: Flood propagation

Research within IMPACT WP3 was focussed upon the advancement of scientific knowledge and understanding for the development of flood propagation models that could simulate the catastrophic inundation of valleys and flood flows through urban areas. The research divided broadly into two areas: u*rban flood modelling* and f*lood propagation along natural topographies*. Both areas of work were approached in a similar manner, namely by means of a combination of desk, experimental, field and computer work.

Physical modelling of flow around a single building and flow through a ‘mesh’ of buildings was undertaken to provide reliable datasets against which model performance could be assessed. Figures 4a and 4b show numerical model simulation of flow around a single building and the physical modelling of flow through a mesh of buildings.

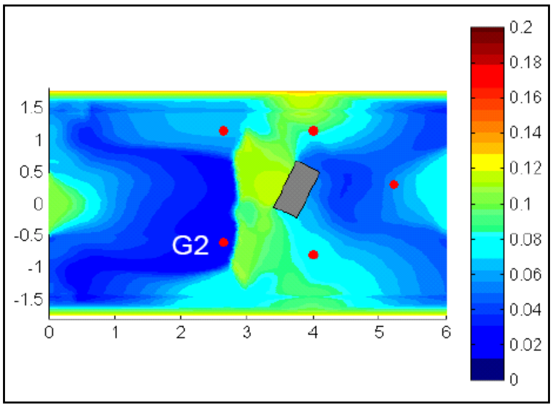

**Figure 4a** **Numerical model simulation of flow around a single building**

**Figure 4b** **Physical modelling of flow through a mesh of buildings**

The Tous Dambreak case study was used extensively to compare model performance for both propagation of a flood wave along a natural valley, and comparison of different flow modelling techniques for predicting flood flow through urban areas. Considerable analysis was also undertaken using the Tous case study to investigate and demonstrate the magnitude and influence of different sources of uncertainty within the flood propagation modelling.

## Findings and Implications

Whilst use of the Shallow Water Equations (SWE) only offer an approximation to true flow conditions, as many SWE assumptions are questionable during extreme flood flows, their use remains an acceptable balance between provision of a mathematical modelling framework that represents most of the physics in flood flows whilst being computationally solvable with current computing power. More complex approaches are not yet practical with current computing power.

Modelling of complex extreme floods at laboratory scale can be accomplished quite successfully. Results are accurate, uncertainty small and run times reasonable. However, when applying such models to real situations two problems arise:

- the spatial and time scales are several orders of magnitude larger, making the computational process too time consuming for practical use
- data availability are typically not complete nor accurate (i.e. boundary conditions, topography, bed resistance etc)

The models tested within IMPACT were mainly complex 2D models. Using current computing power (high end Pentium IV PCs) a practical limit of simulation speed of approximately 10Km$^2$ of catchment scenario per day could be achieved. A key conclusion was therefore that for further refinement in modelling accuracy, efforts should be focussed upon assessing trends resulting from combined improvements in computing power and modelling data density and accuracy, rather than further refinement of numerical modelling solutions.

The comparison of approaches for the simulation of urban flooding showed that the different approaches all performed reasonably, but performance does also depend upon the nature of the flow (i.e. slow inundation, fast flowing etc.). Four approaches were considered:

- 1D channels simulating streets between buildings
- 2D channels simulating streets between buildings
- 2D bottom elevation; a solid 2D mesh incorporating buildings etc. into the grid

- 2D bottom friction; increased local friction to simulate obstructions such as buildings

Each approach offers advantages and disadvantages that cannot be detailed here. The detailed meshing approach whereby buildings are represented as solid walls and the streets of the city are meshed in 2D, appears to be the best choice from the view point of accuracy regardless of the type of flooding conditions.

## WP4: Sediment movement

Dambreak case studies from the US and many examples of extreme flood events (such as the recent Boscastle event) show that significant amounts of sediment are moved during an extreme flood (Figure 5). To date, much of our modelling capabilities have been focussed upon refinement of the prediction of flood water level whilst ignoring the effects of sediment movement. Resolving water level predictions to within centimetres when bed levels may vary by metres is not consistent!

WP4 in IMPACT focussed research on the basic processes of sediment transport that occur during extreme events. Two aspects were considered in detail:

- Near field effects: what happens just downstream of a breach or dambreak
- Far field effects: what happens to a river valley when subjected to an extreme flood event

Research was undertaken through laboratory tests to collate data and then benchmark tests to assess the performance of models. Figures 6a and 6b show laboratory tests monitoring entrainment of sediment under flood surge (near field) and lateral erosion of banks (far field).

(a) Deposition (b) Widening (c) Bed-rock effect

**Figure 5 Typical morphological evolutions - Lake Ha!Ha! dambreak wave (Brooks 2003)**

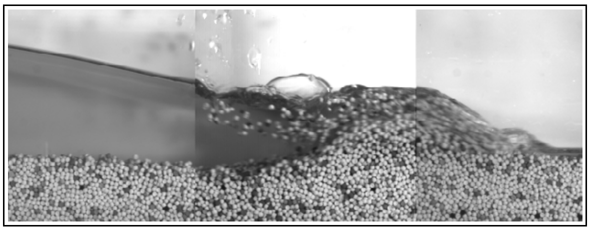

**Figure 6a Near-field geomorphic flow (UCL)**

**Figure 6b Bank erosion resulting from intermittent block failure**

Since the majority of existing 'sediment' models utilise long term steady state sediment transport functions, some of the models developed within IMPACT used new relationships and approaches.

## Findings and Implications

The level of science and understanding of sediment processes during extreme floods is at a significantly lower level than that, say, for predicting breach formation or flood propagation. The research undertaken concluded that:

- Sediment entrainment does significantly affect propagation of a dambreak or extreme flood event flood wave. A sediment 'plug' (as in Figure 6a above) will slow the rate of propagation and potentially reduce the rate of attenuation. This may also explain the "wall of water" observed during many flash floods
- The level of science, understanding and modelling capability is relatively young. Whilst a number of modelling approaches were investigated, all approaches showed a relatively poor performance when applied to the Lake Ha!Ha! case study.
- Significant further research and development is required in this area before models will be suitable for practical application within industry

## WP5: Uncertainty analysis

The objectives of this part of the research project were to investigate uncertainty within the modelling process, develop and apply an approach to demonstrate uncertainty within a case study and to consider implications for end users.

Assessing uncertainty within models is difficult. The process is further complicated by the need to transfer measures of uncertainty between models, when multiple models are used within an assessment (for example, breach models, sediment and flood propagation models). The scope of work and focus meant that the desired approach was to adopt a practical solution that perhaps gave indicative rather than statistically rigorous results.

Early within the work programme it became clear that the level of science and understanding within the sediment movement area was significantly less mature than for breach and propagation modelling. It was concluded that with large degrees of uncertainty in understanding of the basic processes and modelling capabilities it was meaningless to attempt to quantify uncertainty for sediments. The focus was therefore shifted to uncertainty within breach and flood propagation modelling only.

With the aim of a practical approach, the method adopted was to generate upper, mid and lower flood hydrograph scenarios from the breach models, which could then be fed into upper, mid and lower scenario models for flood propagation, in turn producing 9 potential result scenarios which provide indicative upper to lower type events.

It was recognised that this approach would not necessarily provide true upper and lower bound limits, but would given an indication of the potential range of uncertainty. The approach was applied to breach and propagation models for the Tous Case study and breach modelling results did actually demonstrate that the breach hydrograph with the highest peak discharge did not give the worst case water levels downstream. This demonstrates the need for breach modelling to provide a full hydrograph shape, not just peak values, and reminds that flood levels downstream are a function of the flood hydrograph (i.e. flow volume, timing) and local topography.

The process for identifying uncertainty comprised:

- Initial sensitivity analysis of the model to modelling parameters; prioritisation of key parameters to identify those that most influence modelling results
- Allocation of realistic parameter value distributions (based upon expert judgement)

- Monte Carlo (MC) simulation of results varying the top 3 or 5 model parameters
- Selection of upper, mid and lower scenario results

A key issue within this approach is the speed of model runs. Whilst MC analysis could be undertaken for breach modelling, this approach was not practical for detailed 2D propagation modelling. Instead, model scenarios for upper, mid and lower cases were run with modelling parameters selected through expert judgement.

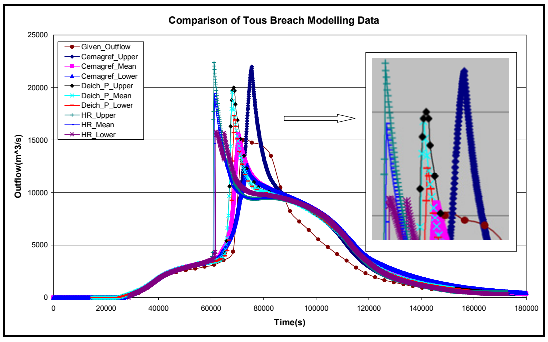

**Figure 7a Breach hydrographs - all scenarios**

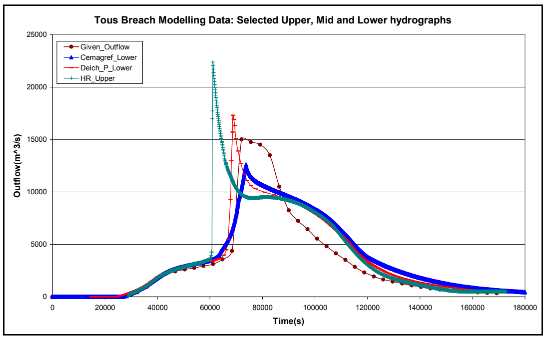

**Figure 7b Selected breach hydrograph**

The uncertainty analysis process highlighted two interesting features within the breach modelling work (Figures 7a and 7b). The first was that modelling the breaching of a composite structure by assuming that the structure could be represented by a homogenous structure with averaged soil properties showed that results could vary by hundreds of percent (Figure 8a). Composite structures should be modelled using breach models capable of simulating such structures! Secondly, that when considering a range of various parameters, a realistic scenario is that the structure does not breach at all (Figure 8b)

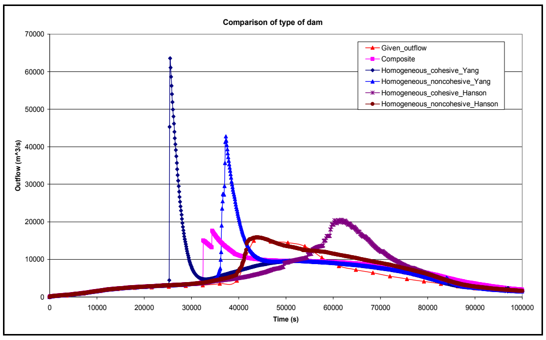

**Figure 8a Potential variation in breach hydrograph - ignoring composite structure**

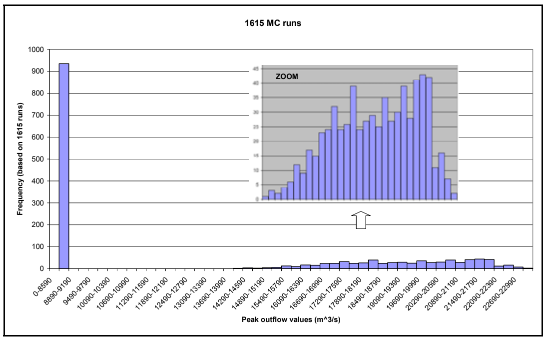

**Figure 8b MC results for breach analysis showing non failure on left hand side**

Analysis of flood propagation model uncertainty highlighted 4 key areas:

- Differences between models in predicting ground level conditions (i.e. model grid generation)
- Differences between model hydraulic calculations
- Uncertainty in predictions arising from uncertainty within the inflow (boundary) conditions
- Uncertainty in predictions arising from uncertainty in assumed roughness values

By undertaking multiple model runs, using different models and different parameter assumptions, the overall magnitude of uncertainty and the contribution to it arising from each of these parameters could be determined. The magnitude of uncertainty was surprisingly large, ranging from 30-50% in flood depths of 5-10m. These uncertainty bands were seen throughout the model, not just at the upper boundary condition. For the Tous Case Study, the contribution appeared to be in the order of:

- ~50% arising from uncertainty in the breach hydrograph
- ~35% arising from selection of friction values within the model
- ~15% arising from differences between modelling approach

## Findings and Implications

Application of the uncertainty analysis approach clearly demonstrates the large degrees of uncertainty that exist within the flood modelling process. Whilst the process adopted was not statistically rigorous, it does provide a practical and indicative approach to assessing the likely magnitude of uncertainty. Even with this approach, the extent of numerical modelling work required was considerable. The breach modelling work highlighted:

- There is considerable uncertainty in hydrograph prediction; this may be reduced by reducing uncertainty in model parameters such as soil type, cohesion etc. The accuracy of predicting peak discharge was in the order of ±30% (or +50% -17% for this specific case)
- Expert judgement on parameter value selection is more reliable than simple average range parameter values
- Composite structure should be simulated using models capable of simulating the structure and not through assumption of a homogeneous structure with modified parameters. The risk of uncertainty in this approach is very large
- Analysis of different scenarios highlights that breach formation may not always occur. When comparing to a case study it is impossible to know just how close to the failure / non failure 'line' the event was

The flood propagation modelling highlighted:

- Uncertainty can be significant – 30-50% uncertainty in water level prediction for the Tous case
- Key contributors to uncertainty (in reducing order of magnitude) were boundary conditions, friction assumptions and model type. A further significant factor is the ground model generated within the flow model, which can contain significant errors before any hydraulic calculations are undertaken!
- Limitations in computational resources mean that MC analysis is not yet practicable for 2D models applied to real scenarios

## Overall conclusions and recommendations

The IMPACT Project has significantly advanced science and understanding in a range of key areas relating to extreme flood processes. Work has been undertaken on breach formation, flood propagation, sediment movement, geophysical investigation and model uncertainty analysis. By working as part of a European Project team on these issues, knowledge, expertise and modelling approach from across Europe, and indeed worldwide, has been pulled together, hence the results and conclusions drawn provide international state of the art expertise in this area.

Key actions or issues have been identified for each research area, through which science and modelling capability may be improved. These recommendations should be taken into consideration when prioritising research and development work in the field of flood risk management.

## Key Messages for UK Flood Defence Practice and Dam Safety Enforcement

Breach modelling: The state of the art modelling of breach formation through embankments and dams has been significantly advanced through the IMPACT project and indicative model performance tables have been provided. Further improvement to models could now be made by focussed use of the field and laboratory data collected. Analyses show that use of peak breach discharge values rather than a breach flood hydrograph does not necessarily provide worst case flood conditions downstream of a breach. The focus of work within IMPACT has been on breach formation processes. Similar efforts are now required to analyse breach initiation processes to allow prediction of when a breach may occur as well as how the breach will form.

Flood modelling: A comparison of modelling approaches for simulating urban flooding has been undertaken and recommendations provided. Limitations on the accuracy and practicability of 2D flow modelling appear to arise more from the magnitude of uncertainty within data provided for modelling and limitations in computing power, rather than the physics of the numerical modelling approaches.

Sediment movement: Research under IMPACT has advanced knowledge in this area sufficiently to confirm that sediment movement does significantly affect flood behaviour during extreme events and should be taken into consideration when trying to predict extreme flood conditions. However, the magnitude of uncertainty within the science and modelling capability means that we are still some distance from being able to provide practical models for use in industry. Further research into the morphological processes and optimal modelling approaches is required as a first step.

Uncertainty analysis: A practical approach to assessing the potential magnitude of uncertainty within the flood modelling process was developed. Application to a case study showed uncertainty in predicted water levels in the order of 30-50%. This range of uncertainty is significant and should be taken into consideration when using modelling data for end applications. Naturally, the implications for end user application vary between the different areas of research and the nature of the end user.

Geophysical investigation: Initial research and trials into the use of geophysical techniques for the rapid integrity assessment of flood defence embankments have identified a possible approach that may allow 5-10km of embankment to be assessed / day. The approach is at the early stages of development and requires further field testing and development to demonstrate suitability for wider use within industry. However, initial results are promising and the longer term benefits tantalising!

## Using Knowledge from IMPACT

The contents of this paper offer only a sample of the research work undertaken through the IMPACT project. Full results of the research work are available through a number of routes. Final project reports may be accessed via the project website at www.impact-project.net and reports and papers from the 4 project workshops are also available via the website and CD ROM. A book containing details of the various benchmark tests that were undertaken throughout the project will also be available during 2005. Access to field, laboratory and numerical modelling data is available on a case by case basis. In some areas research work continues to further improve model capabilities, hence data may not be immediately available in the public domain.

## Some Related EC Research Projects

Two EC funded research projects which relate to these topics and are currently active are the FLOODsite Project and the ERANET CRUE project.

FLOODsite is an integrated project under the EC 6th framework programme. It is the largest single funded project that the EC has initiated looking at flood risk management for rivers, estuaries and coasts. The structure of this project has been developed to align with the EA/Defra joint research programme needs and the FRMRC research programme. Some aspects of the work under IMPACT, such as breach initiation, modelling uncertainty etc. will be further addressed within FLOODsite. More information on

FLOODsite may be found at www.floodsite.net and Samuels et al, 2004.

The ERANET-CRUE project is investigating how nationally funded R&D programmes relating to flood risk management may be more closely integrated to gain added value from the research effort. More information on this project may be found at www.crue-eranet.net

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  Mark Morris, HR Wallingford Ltd, UK
- WP3 Flood Propagation
  Francisco Alcrudo, University of Zaragoza, Spain
- WP4 Sediment Movement
  Yves Zech, Université Catholique de Louvain, Belgium
- WP5 Uncertainty
  Mark Morris, HR Wallingford Ltd, UK
- WP6 Geophysics
  Zuzana Boukalova, Geo Group, Czech Republic

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HR Wallingford Ltd (UK), CESI (Italy), Universität Der Bundeswehr Műnchen (Germany), SWECO (Norway), Université Catholique de Louvain (Belgium), Instituto Superior Technico (Portugal), CEMAGREF (France), Geo Group (Czech Republic), Università di Trento (Italy), H-EURAqua (Hungary), University of Zaragoza (Spain)

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For further information see the project website at www.impact-project.net

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