delivering benefits through evidence

Broad-scale modelling and scenario analysis for long-term planning – Knowledge transfer from Chinese Flood Foresight Project

Project: SC090034

Flood and Coastal Erosion Risk Management Research and Development Programme

The Environment Agency is the leading public body protecting and improving the environment in England and Wales.

It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

This report is the result of research commissioned by the Environment Agency's Evidence Directorate and funded by the joint Environment Agency/Defra Flood and Coastal Erosion Risk Management Research and Development Programme.

Published by:
Environment Agency, Horizon House, Deanery Road, Bristol, BS1 5AH
www.environment-agency.gov.uk

ISBN: 978-1-84911-238-3

Further copies of this report are available from our publications catalogue: http://publications.environment-agency.gov.uk or our National Customer Contact Centre: T: 08708 506506
E: enquiries@environment-agency.gov.uk.

Author(s):
EP Evans
JW Hall
R Lamb
EC Penning-Rowsell
NS Reynard
PB Sayers
JD Simm
SS Surendran
CR Thorne
AR Watkinson
JM Wicks

Dissemination Status:
Publicly available

Keywords:
Flood risk modelling, Foresight, China, scenario, socio-economic

Research Contractor:
Professor Edward Evans
School of Geography, University of Nottingham, Nottingham NG7 2RD

Environment Agency's Project Manager:
Jacqui Cotton, Evidence Directorate

Project Number: SC090034

Product Code:
SCHO0811BUCA-E-E

Evidence at the Environment Agency

Evidence underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us, helps us to develop tools and techniques to monitor and manage our environment as efficiently and effectively as possible. It also helps us to understand how the environment is changing and to identify what the future pressures may be.

The work of the Environment Agency's Evidence Directorate is a key ingredient in the partnership between research, guidance and operations that enables the Environment Agency to protect and restore our environment.

This report was produced by the Research, Monitoring and Innovation team within Evidence. The team focuses on four main areas of activity:

- **Setting the agenda**, by providing the evidence for decisions;
- **Maintaining scientific credibility**, by ensuring that our programmes and projects are fit for purpose and executed according to international standards;
- **Carrying out research**, either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available.

Miranda Kavanagh

Director of Evidence

Executive summary

Flood and coastal risk management (FCRM) is a complex process. Changing climate, land use, socio-economic and environmental aspects mean that flood risk will increase in many areas and managing this is a challenge. A risk-based and system-based approach using scenarios in planning and investment is essential to manage this risk. The Government's Foresight Future Flooding Project, completed in 2004, was a major driver for long-term planning particularly for the Government's *Making Space for Water* strategy and the Long-Term Investment Strategy.

The Taihu Basin project has its origins in the UK Foresight project, and was a cooperative project between the governments of UK and China aimed at developing and adapting the Foresight methods to China. The study area selected was the Taihu Basin, one of the most important regions of China, containing Shanghai and a number of other major cities.

The Taihu Basin is located in the delta region of the Yangtze River with a total area of 36,895 km^2 (for comparison, England covers 130,795 km^2). Although its area is only 0.4 per cent of the national territory, the population of 36.8 million and the gross domestic product (GDP) of 1,890 billion Yuan (£10 billion) in 2003, represent about three and 13 per cent of the nation's totals respectively. It has one of the highest speeds of social and economic development in China today.

The Taihu project involved a complete 'end-to-end' flood risk analysis, from the generation of climate and socio-economic scenarios, through hydrological, hydraulic and damage modelling to a final GIS system, the Taihu Basin Risk Assessment System (TBRAS).

The results show flood risk multiplication factors for the period 2005-2050 of around five times for both climate and socio-economic factors taken separately. When they are combined and sea level rise and land subsidence are added, the multiplication factors rise to 25 to 35 times, even higher than in the UK owing to the extreme socio-economic drivers.

What lessons can we learn from the Chinese project?

The Chinese fielded a highly capable team to complement the UK experts, and unlike the UK project we started with a nearly clean sheet. Significant differences in methods emerged as the Taihu project progressed, from which we in the UK can learn useful lessons. The key lessons which emerged are as follows:

Improving project planning and execution by carrying out a preliminary screening analysis using qualitative analysis (expert knowledge) techniques.

Using spatial and temporal event modelling to obtain insights into the patterns and impact of real, complex events as an aid to emergency planning and other non-structural FCRM responses. Although done rather crudely by scaling real, extreme, recorded events its value was clearly demonstrated.

Socio-economic issues. The socio-economic dimension of scenarios has been given little attention compared with climate change, yet we know from both the Taihu and UK that such drivers are of the same order of magnitude.

End-to-end modelling systems for long-term large-scale FRM planning that encompass the full range of scenarios, drivers, pathways and responses within a linked system of computational models. This has not been carried into practice in the UK despite the example of the 2004 Foresight project. Associated issues include the long run-times of computer models such as the Risk Assessment for System Planning (RASP) and the Long Term Investment Strategy (LTIS) model compared with the TBRAS.

How can we transfer the lessons to the UK?

Suggested actions for knowledge transfer include producing good practice manuals to improve current UK practice, instigating applied research projects and development of end-to-end modelling:

Short-term actions include incorporating the practical lessons learned in the course of the Taihu project into UK practice. Information sheets could be published setting out key principles rather than in-depth analysis of what should or should not be done.

Development actions include improving tools and techniques used in national studies such as the National Flood Risk Assessment (NaFRA) and large-scale plans such as Catchment Flood Management Plans (through the development of the Modelling Development Service Framework; MDSF2).

Research activities; one key lesson from Taihu is the value of using realistic spatial and temporal event patterns. To do this, the underlying science must be further developed for practical business application.

Although actions, developments and research would be led by different parties, there is great advantage in carrying these out within an integrated framework, with the research councils and the Environment Agency's FCRM functions and research programme acting in partnership.

Acknowledgements

We are grateful to the Environment Agency for sponsoring the projects. The members of the SC090034 Project Board and Steering Group are thanked for their helpful contribution during the partners workshop. The authors' special thanks go to I. C. Meadowcroft, M. Steel, R. Caudwell, J. Rees, O. Tarrant, J. Cotton and S. Longfield for their support.

Contents

1 Introduction

This report was commissioned by the Environment Agency to explore knowledge transfer from the Chinese Flood Foresight Project. The project aims are given in Appendix 1.

Section 1 of the report briefly reviews the Environment Agency's long-term strategies, large-scale plans and the Chinese methods, models and processes developed under the project. A sister US project, also included in the scope of the project, has not progressed beyond a scoping document (Thorne *et al.,* 2008) and hence is mentioned only sparingly in this report.

Section 2 looks at the potential lessons for the Environment Agency and its partners for the future development and improvement of tools for scenario-based broad-scale modelling for flood and coastal risk management (FCRM) long-term large-scale planning and investment..

Section 3 draws the key lessons into a number of themes summarising what knowledge could be transferred to the UK and to the Environment Agency in particular, and discusses what work is needed to transfer the knowledge to the UK. The formulation of these has benefitted from a joint workshop of Taihu team experts and interested groups and professionals.

Section 4 groups the key knowledge transfer actions under three headings and formulates a cost-effective tiered programme of work and actions. This proposed programme will help the Environment Agency and others transfer the lessons learned into UK practice.

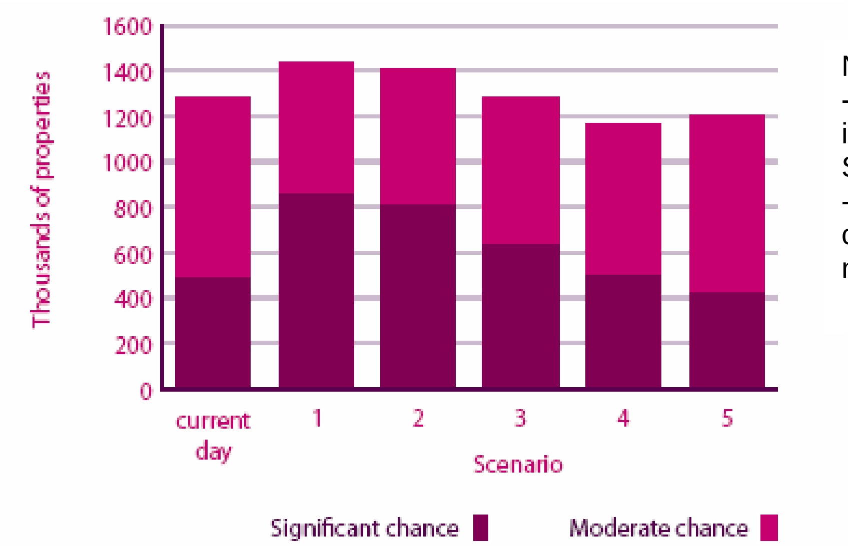
1.1 Background - the Environment Agency's long-term strategies, large-scale plans and the need for improvements

Flood and coastal risk management (FCRM) is a complex process. Changing climate, land use, socio-economic and environmental aspects mean that the risk of flooding will increase in many areas and managing this is a challenge. A risk-based and system-based approach using scenarios in planning and investment is essential to manage this risk. The Government's Foresight Future Flooding Project (Evans *et al.* 2004) completed in 2004 was a major driver for long-term planning, particularly for the Government's *Making Space for Water* strategy and the Long-Term Investment Strategy – LTIS (Environment Agency 2009a,b). The Environment Agency and Department for Environment, Food and Rural Affairs (Defra) have played a major part in developing and implementing this.

The LTIS provides an evidence base for future flood and coastal risk and the associated investment needs. The strategy describes:

- the present scale of flood and coastal erosion risk, and the achievements in managing it so far;
- the investment needed to adapt to climate change and manage the risk over the period 2010-35;
- the ways to manage flood and coastal erosion risk more efficiently;
- the benefits of investment and the potential to broaden the sources of investment.

Today, around 5.5 million properties in England and Wales face a risk of all forms of flooding. Within England about 490,000 properties face significant likelihood of flooding. By considering the impacts of climate change using the data from the UKCIP09 climate projections (Jenkins *et al.,* 2009), the LTIS made projections of flood risk outcomes resulting from various levels of investments between now and 2035. If investment is kept at current levels (in 'cash terms'), there will be 350,000 more properties in England which have a significant chance of flooding by 2035 (Figure 1.1). If asset investment is increased to £1,040 million by 2035, as suggested by Scenario 4, from the current level of £570 million, this increase of risk to properties is prevented.



Note:
- The most favourable investment scenario is Scenario 4
- Properties with a low chance of flooding are not shown

Figure 1.1: properties at risk of flooding in 2035 for five investment scenarios (Source: LTIS, Environment Agency, 2009a)

Figure 1.1 shows that while investment must rise significantly, the benefits of increased investment will substantially outweigh the costs. The production of these future risks, benefits and cost are all derived from different scenarios based on best available science and tools such as FACET (Flood And Coastal Erosion Tool). However, to keep up to date with new evidence and innovation on risk assessment, futures studies and option appraisals based on social, political, economic, climatic and environmental circumstances, investment strategies will need to be periodically reviewed and improved. Learning lessons on these and transferring new knowledge into everyday practice is therefore crucial.

Defra and the Environment Agency are adopting a risk-based approach to FCRM. Risk modelling and decision making therefore has a key role in the Environment Agency's large-scale strategic policy planning at national level (National Flood Risk Assessment -NaFRA), and at catchment (Catchment Flood Management Plans - CFMPs), shoreline (Shoreline Management Plans -SMPs) and estuary (Estuary Strategies - ESs) level.

To provide a more integrated and consistent risk-based decision support tool to those dealing with FCRM at a large scale, the Environment Agency is developing the Modelling Decision Support Framework Version 2 (MDSF2). This is being built on the existing version of the MDSF(1) and Risk Assessment for Strategic Planning (RASP) system, with improvements and new additions. However, there is scope for further improvements in broad-scale modelling and scenario analysis.

The Environment Agency has recognised the potential to learn lessons from the recent flood risk Foresight project in the Taihu Basin, China, just such a modelling exercise. This small, focussed 'knowledge transfer' project was set up to improve our broad-scale modelling and scenario analysis for long-term large-scale planning.

1.2 *Background – the original Taihu Basin Foresight project*

The original Taihu Basin project (China/UK scientific cooperation project: Scenario analysis technology for river basin flood risk management in the Taihu Basin) has its origins in the Foresight Future Flooding project (Evans *et al.* 2004), commissioned by the Chief Scientific Advisor to the British government.

Following discussions between the UK and Chinese governments a planning mission visited China in 2005 and drew up a joint proposal for a Chinese Foresight flooding project. Funding was provided by the UK and Chinese governments and UNDESA (United Nations Department of Economic and Social Affairs) and the project was launched under the auspices of the China-UK Science and Technology Commission in 2006. The study area selected by the Government of China was the Taihu Basin, one of the most important regions of China, containing Shanghai and a number of other major cities. The Taihu Basin project was declared as a flagship project by the Chinese Minister of Science and Technology, and work commenced on the project in 2007.

The project aimed to consider:

- How might the risks of flooding change in Taihu Basin over the next 50 years?
- What are the best options for Government and other agencies for responding to the future challenges?

This section gives a brief overview of the Taihu Basin project.

1.2.1 Where is the Taihu Basin and what is it like?

The Taihu Basin is located in the delta region of the Yangtze River in East China with total area of 36,895 km^2 (for comparison, England covers 130,795 km^2 ; the Thames basin 12,935 km^2) involving the southern part of Jiangsu province, the northern part of Zhejiang province and the continental part of Shanghai Municipality (Figure 1.2).

The basin is an important region for the social and economic development of China. Although its area is only 0.4 per cent of the national territory, the population of 36.8 million and the gross domestic product (GDP) of 1,890 billion Yuan (£10 billion) in 2003, represent about three and 13 per cent of the nation's totals respectively. It is one of the regions with the fastest social and economic development in China today.

The basin lies in the sub-tropical zone and has a monsoon climate with an average annual precipitation of 1,177 mm, concentrated in summer. Plain areas cover about 80 per cent of the basin with elevations between three and four metres above mean sea level, which is two to three metre lower than the highest water level at the river mouth of the Yangtze, and five to six metres lower than the highest tide in Hangzhou Bay. Since it is so flat with slow flow velocities and a drainage system blocked by high tide, the area is prone to river flooding, storm surges and internal floods caused by local heavy rainfall.

Figure 1.2: The Taihu Basin. Shanghai is the large red area on the east side of the basin; the Tai Hu (lake) can be seen in the centre and the Yangtze forms the northern boundary.

During the 1991 flood, the water level of the Tai Lake reached a historical record. Heavy damages were caused to life and property. Following this flood eleven key projects for flood control were constructed, establishing a framework for flood control in the basin, retarding and storing floodwater in the Tai Lake, and draining it northward to the Yangtze, southward to Hangzhou Bay and eastward to the East China Sea.

The new flood control system in the Taihu Basin experienced a severe test in the 1999 flood. Even though the flood control system played an important role in mitigating flood damage and saving life, the 1999 flood brought a loss of 13 billion Yuan to the basin economy. It was timely and important, therefore, to re-examine the regulation of the water system, as well as the relation between flood storage and discharge, flood control in the overall basin and flood discharge in each district.

1.2.2 What was the scope of the Taihu Basin project and how was it carried out?

The Taihu Basin project involved a complete ‘end-to-end’ flood risk analysis, from the generation of climate and socio-economic scenarios, through hydrological, hydraulic and damage modelling to a final GIS system, the Taihu Basin Risk Assessment System (TBRAS).

In the Taihu Basin project, in contrast to the UK Foresight project, a “foundation” stage was necessary to assemble data and set up the necessary models. The overall phasing of the project, with the headline scope of each phase, is shown below:

Phase 1 – Project foundations
Draw up detailed work plan and task specifications
Assemble data, digitise and/enter
Set up models
Generate climate and socio-economic scenarios
Qualitative analysis of drivers and responses and sustainability framework

Phase 2 – Driver and responses analysis
Quantitative analysis of drivers and responses
Sustainability analysis

Phase 3 – Final synthesis
Update qualitative analysis in light of quantitative results
Final reporting

The Taihu Basin project was carried out over a three-year period, 2007-09.

The UK team provided project management, analysis and training but the bulk of the work was carried out in China by the Institute of Water and Hydro-power (IWHR), other national and local research institutes, and the Taihu Basin Authority (TBA), one of the seven river basin management authorities in China.

There are a number of essential functional requirements that the risk assessment system must fulfil, arising from the problems that concern the people of the Taihu Basin. With these in view a logical framework was adopted, based on the Pressure-State-Impact-Response (PSIR) and Source-Pathway-Receptor (SPR) models but adapted to Chinese conditions and ways of thinking, and a system of linked work packages was designed.

Figure 1.3 shows the logical relationships and main information flows between work packages. The links, feedback loops and well-structured connectivity between the work packages are as important as the work packages themselves and proved invaluable to the success of the project.

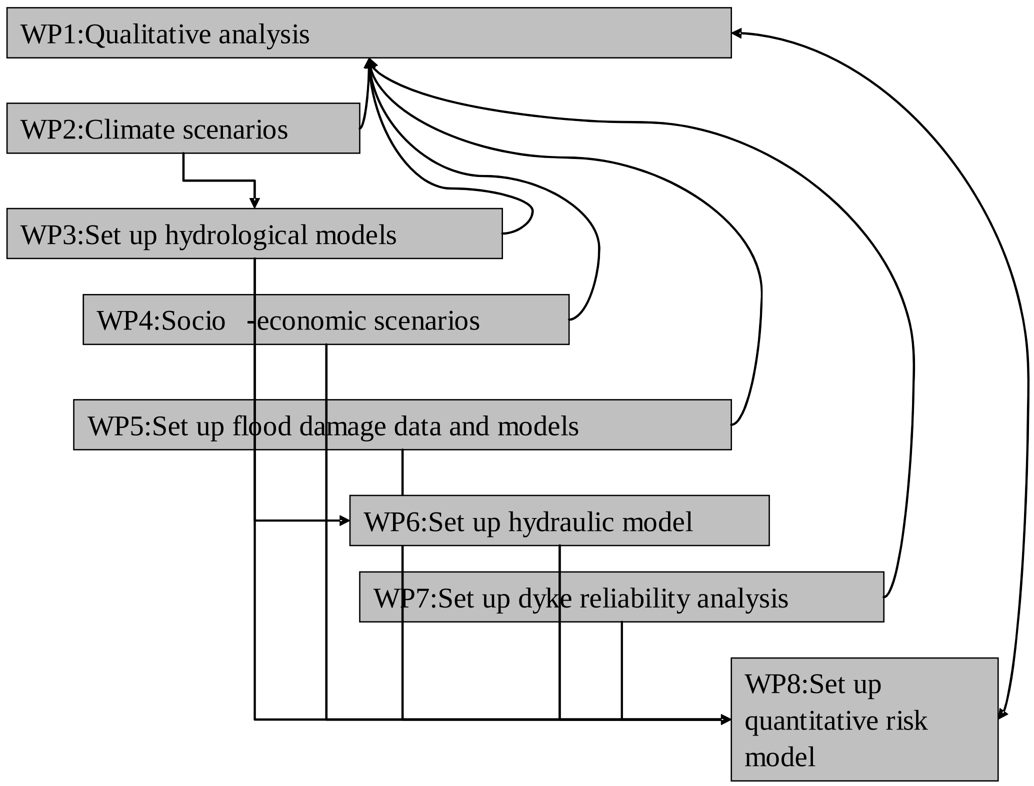


Figure 1.3: Work packages and their links

1.2.3 Early results of the Taihu Basin modelling system

The modelling approach adopted in the Taihu Basin project was to first evaluate the impact of climate change and socio-economic change on basin flood risk separately, then evaluate the impact of these changes in combination. Having established these baseline changes, the final step was to evaluate the impact on basin flood risk of implementing various structural and non-structural flood control measures.

The runs carried out were all 'driver' runs, with the flood defence system assumed to be in its baseline condition in all cases (as in the 2004 Foresight Future Flooding project). The runs and the key results are summarised in Figure 1.4 as ratios of the 2005 baseline estimated annual damages (EAD). In this figure 'CC' indicates the climate change scenario, SE the socio-economic scenario and SL the sea-level rise scenario.

The first two runs compared losses under the baseline present-day conditions in 1999 and 2005. The second group of four runs were carried out with 2030 and 2050 socio-economic drivers alone and the next group of three runs with 2050 climate change drivers alone. These allowed us to understand the relative importance of socio-economics and climate change as drivers of future flood risk. The reality, however, is that they would not act alone, so in the next four runs they were combined. In the final two runs sea-level change was further added into the set of future drivers of flood risk.

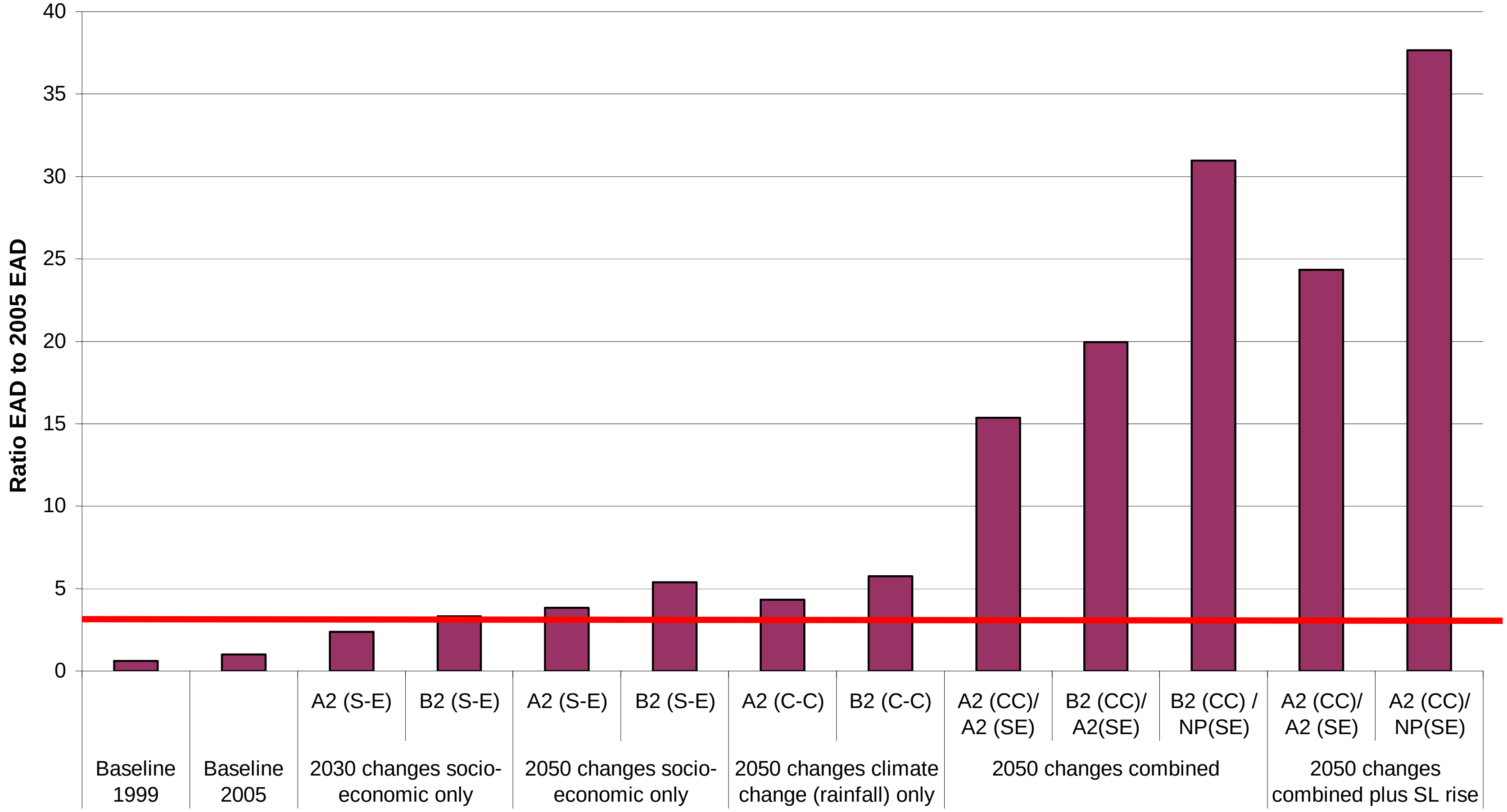


Figure 1.4: Summary of runs and results as ratios to 2005 baseline EAD

The results show flood risk multiplication factors for the period 2005-2050 of around five times for both climate and socio-economic factors taken separately. When they are combined and sea level rise and land subsidence are added, the multiplication factors rise to 25 to 35 times.

One novel aspect of the TBRAS was the introduction of a breach/no-breach switch, permitting the direct comparison of cases with and without breaching. Results from the risk analysis demonstrated this starkly. As Figure 1.4 shows, including breaches leads to more than double the calculated expected annual damages.

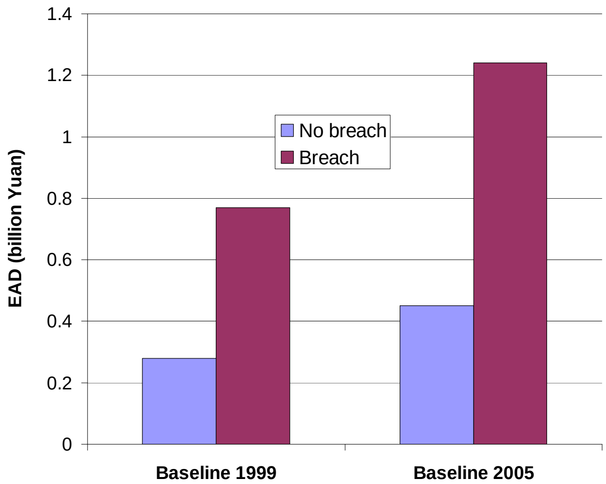


Figure 1.5: Expected annual damages in the Taihu Basin with and without breach

The results have been met with great interest by Chinese experts and authorities, and the method has been endorsed by senior officials in the Chinese Ministry of Water Resources.

In the words of Professor Cheng Xiaotao, the leading Chinese expert on flooding and co-director of the project:

A large number of difficulties, expected and unexpected, have been overcome in carrying out the project. The advanced philosophy and practical experience have been transferred successfully from the UK Foresight Future Flooding project to the Taihu project. An initial framework of flood risk scenario analysis technology has been formulated that provides a sound foundation for further work including responses analysis. The China-UK Scientific Co-operation project has so far proved a highly effective means of communicating UK developments in flood risk assessment, adapting methods and concepts, and addressing the different sets of flood risk drivers and responses which are relevant to the Taihu Basin.

2 Potential lessons for the Environment Agency from the Taihu Basin project

We now discuss the lessons learned from the Taihu Basin project which have potential application for the Environment Agency and its UK partners. We group these in the first place according to the Taihu Basin work packages. In each case we give a thumbnail sketch of the work package before proceeding to examine the work and draw out lessons.

2.1 *Qualitative analysis of flood risk drivers and responses*

> The aim of Work Package 1 was to identify, describe and rank the relative importance of drivers of flood risk and responses to changes in flood risk that are in future likely to affect the flooding system in the Taihu Basin.
>
> In order to do this, WP1 adopted a process of structured expert knowledge elicitation. Conceptual models and the way in which climate change and socio-economic scenarios were combined were also derived within this work package. The UK sustainability analysis was adapted to Chinese ways of thinking.
>
> WP1 had strong interactions with the other work packages and required input from various experts from the other work packages. It very much defined the direction of the model building and quantitative analysis.

The Taihu Basin study reinforced the value of qualitative analysis using local and national expert knowledge elicitation before proceeding to the quantitative modelling. Such techniques are well established in many fields of science and engineering (for example, Cooke, 1991; Vick, 2002). The techniques are widely used by the World Bank as exemplified in Figure 2.1.

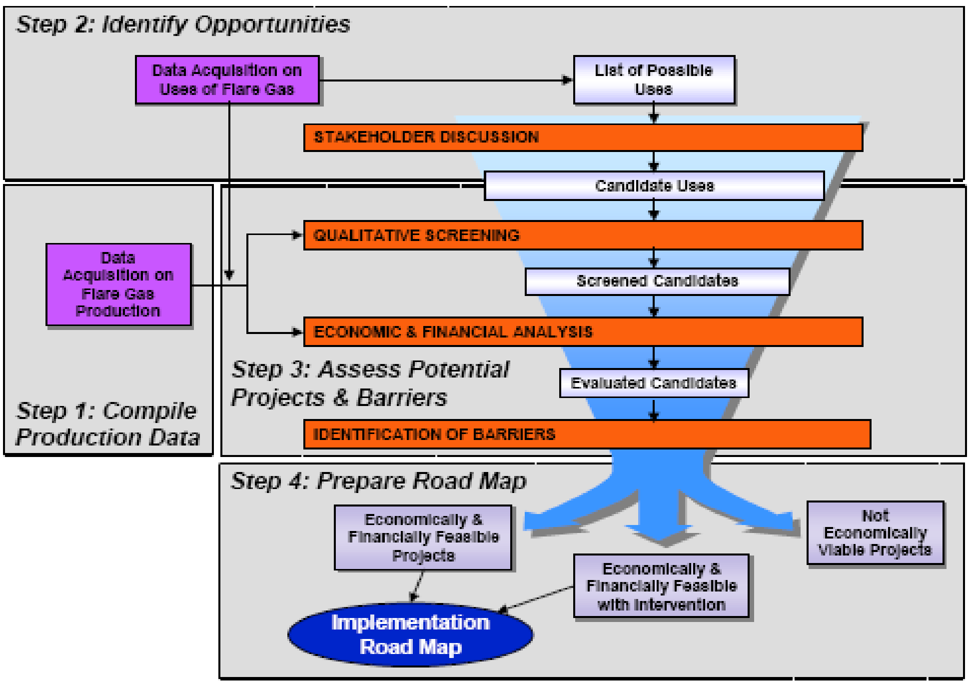


Figure 2.1: Approach overview (from Crosetti and Fuller, 2006)

It was essential to grasp the conceptual form of the river systems, flood storage areas, coastal, river and city ring dykes before moving into modelling (Figure 2.2).

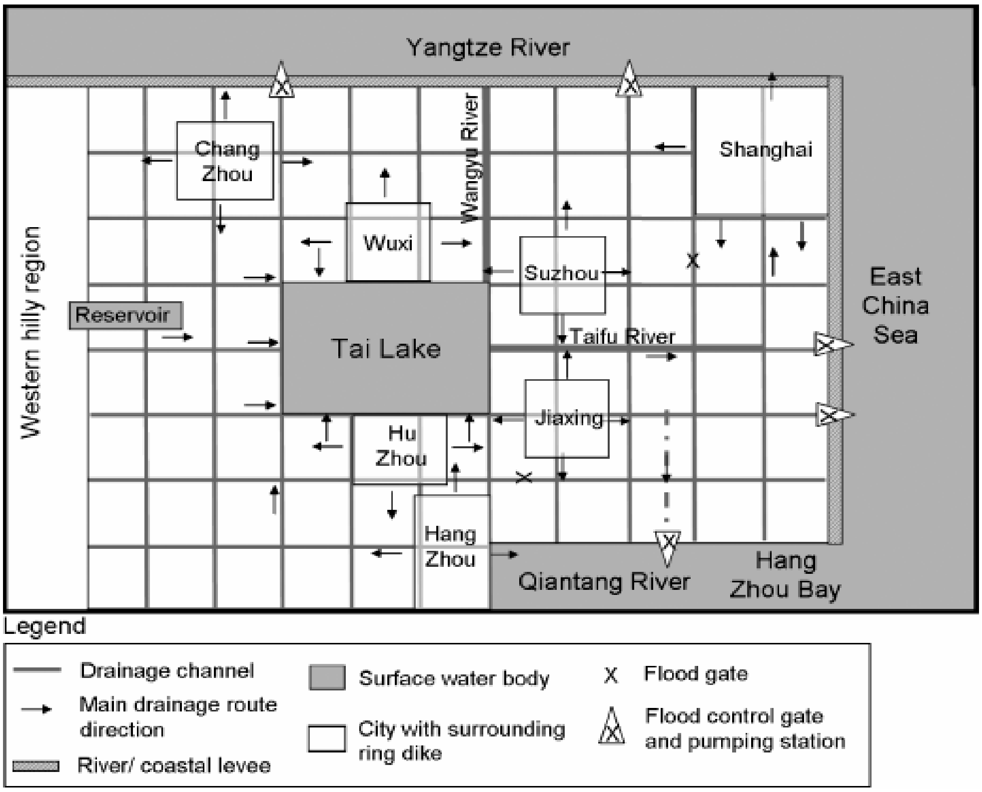


Figure 2.2: Conceptual model of the Taihu Basin flood system

The importance of breach and overtopping and the impact of uncoordinated construction or improvement of city dykes and pumping schemes was rapidly recognised as having a major impact elsewhere in the flood plain. This led to a conclusion of the need for a modelling system that did much more than simply model the river system itself as an "in-bank", as an existing Chinese model (HOHY2) was doing. Coming to this situation as external experts, it was easy to see the inadequacies of the current modelling approach and the need for a new start, making use of the existing modelling data. However, in the UK context, we often become too tightly linked to existing modelling systems or perceived needs for a system that are not adequately underpinned by a proper expert analysis of the real problems.

We must learn this lesson for ourselves in the UK and avoid moving to modelling too quickly, allowing ourselves to be locked into past assumptions and prevailing thinking. Instead, adopting appropriate pre-modelling screening analysis is highly desirable, especially given the Environment Agency's new strategic overview role. It echoes closely the thinking in current work in the Environment Agency project on *Developing the next generation of surface water flood risk assessment* (Science Project SC070059). Here, extensive consultation has revealed a need for tools and processes to capture layers of information that include just this type of expert knowledge in order to provide confidence-building auxiliary data to support the more quantitative types of outputs such as EAD.

Expert elicitation

A related issue which emerged from discussions with the United States was the use of the term qualitative, as if this was in some way inferior to quantitative. The

Americans preferred the term “expert elicitation”. This helps to reinforce the notion that this is a quality analysis based on all available data.

Listening to local groups and professionals

Listening to interested and affected groups is important for two reasons. Clearly, it has a value in terms of ensuring that the subsequent process continues without difficulty. A classic example of this was engagement with a senior retired engineer who was held in great respect by the Chinese. The opportunity that he had at an early workshop to articulate his views and feel that they were being recognised meant that subsequently he was supportive of the process.

Listening also has a direct impact on the outcome of the study, improving the chance of the emerging conclusions being appropriate to the prevailing local situation. A good example of this arose when trying to define the sustainability criteria against which response options were to be assessed. The UK team brought the rather Western and individualistic perspective of social justice as one criterion; as a result of the workshops this criterion was changed to the term district harmony, which represented a more Chinese and communitarian perspective on what was essentially the same issue.

Significant differences of physical geography and social structures exist between the UK and China. There may therefore need to be more flexibility with some of our decision-support metrics and processes, adapting them to the specifics of the region. These differences might be drawn out, for example, by a comparison between the outcomes of CFMPs and SMPs produced in different parts of England and Wales.

Understanding flood response measures as potential drivers of flood risk

In the UK Foresight study, it was generally assumed that flood response measures would reduce flood risk and would not impact on it negatively. The only exceptions out of the 18 main response groups were the various coastal defence measures and only when these were assessed under the Local Stewardship scenario; here, it was recognised that uncoordinated local measures in one location could have adverse geomorphological impacts in another.

In the Taihu Basin, the negative impact of flood response measures was recognised as a much more serious issue. In particular, as indicated in Figures 2.3 and 2.4 below, urbanisation processes were encouraging the construction of massive city ring dykes and associated pumping schemes. These raise water levels in other parts of the basin and thus increase flood risk there.

Although the Taihu Basin example is rather extreme, there remains the danger that well-intended intervention measures or policy instruments can have unintended consequences. The Environment Agency is vigilant in terms of development control in seeking to limit loss of floodplain storage, but proper analysis of the impact of the plethora of measures and instruments on the existing flooding system is not always carried out. This point would appear to become all the more relevant when we consider larger scales and also for flooding from multiple sources (for example in a situation where surface drainage discharges into floodplain storage cells).

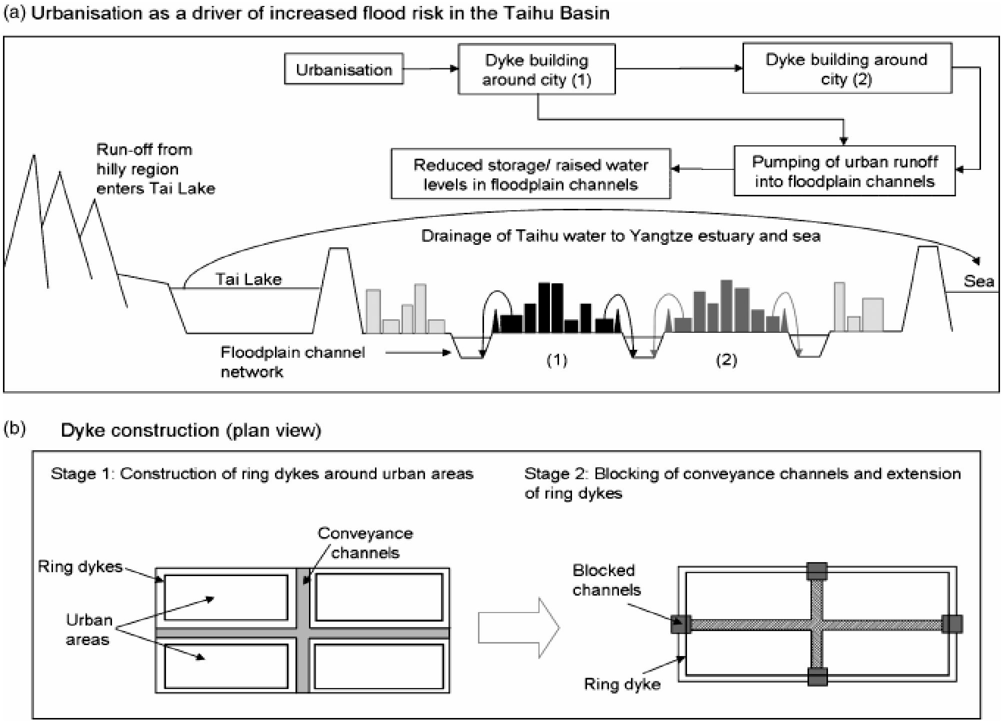


Figure 2.3: Urbanisation and dyke construction as a driver of increased flood risk

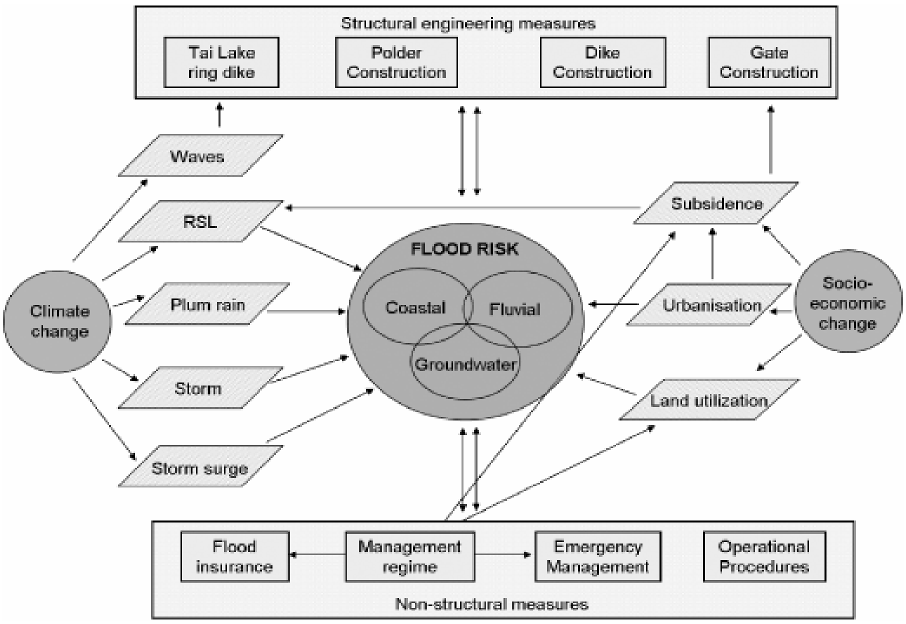


Figure 2.4: Conceptual model of the interaction between climatic and socio-economic factors driving future flood risk in the Taihu Basin

Furthermore, it is increasingly recognised that not all forms of adaptation to climate change are exogenous to the flooding system. What is sometimes known as autonomous adaptation, often occurring at a small scale, can take place without being recognised and can have both positive and negative impacts. For example watercourse management by farmers and communities can improve or worsen flooding depending on the locations and manner in which such activities are carried out.

Sustainability of responses

Each set of responses was ranked according to five sustainability criteria appropriate to Chinese conditions and culture (decrease in flood risk, district harmony, environmental impacts, economics, and use of resources). It is interesting to note the differences from the UK criteria adopted in the 2004 Foresight project (effectiveness in reducing flood risk, social justice, environmental quality, cost-effectiveness, robustness, precaution),

Consideration of extreme/exceptional events

In the Taihu Basin not all extreme or exceptional events were tested using the modelling system. Several reasons exist for this: the complexity and severity of the event or events identified; the capacity of modelling systems to describe these events; and simply a lack of knowledge about the event. It is traditionally supposed that this issue can be tackled by including an extreme scenario; for example, in the TE2100 project the so-called High ++ climate change scenario was examined in the modelling. However, not all events can be tackled in this way and indeed it may be decided, if only because of resource constraints, not to do so. The lesson of the Chinese experience is that conceptual ideas and data about such extreme and exceptional events should none the less be captured and used for qualitative assessment of an appropriate management response.

Event type	Extreme event	Flood risk impact
Climatic	Super-strong typhoon	Overtopping of, or damage to, the coastal levee combined with intense rainfall causing flooding of a large part of the basin
	Super local rainstorm	Local water logging and flooding
	Combined astronomic high tide, typhoon and inland flood	Flood drainage system overwhelmed by the magnitude of the combined events
	Excessive sea level rise	Permanent inundation of low-lying coastal areas and general increase in coastal flood risk
	Tsunami	Potential for wave over 100 m in height. Widespread inundation of coastal and inland areas
Structural	Structural failure of reservoir dam	Catastrophic flooding downstream of reservoir
	Combined structural failure of the Tai Lake ring dyke, river dykes and coastal levees	Inundation of large areas surrounding the lake, rivers and coast
Environmental	Invasion by exotic vegetation	Vegetation growth reduces conveyance capacity, leading to increased flood risk from lower intensity rainfall events
	Environmental health	Health dimension of flood risk increases disproportionately, requiring new and radical approaches to public health provision and responses

Table 2.1: Taihu Basin: extreme and exceptional events

2.2 Climate change scenarios

The Hadley Centre PRECIS regional climate model, previously installed in China under a Defra project, was used to simulate long return period extreme rainfall events. A set of tables was produced giving future changes in long return period extreme rainfall, with various durations representative of natural climate variability and projected future climate change over the basin.

Mean sea level rise scenarios for Chinese coastal waters were also derived.

The method for applying regional climate change projections is described in the Taihu summary report. The approach was to analyse precipitation extremes in data simulated by the PRECIS climate model. The difference in estimated rainfall depth and duration exceedance probabilities between baseline (1961-1990) and projected future climate were derived from the climate model outputs. These differences were then applied as an adjustment to the corresponding statistics derived from observed rainfall records. This technique was adopted as a way to remove, or at least reduce, the influence of any systematic bias in the climate model simulations whilst accepting the relative changes.

The approach allows for relatively simple adjustments of rain storm total precipitation to represent projected future climate. However, it is not based on a full analysis of possible changes in the temporal sequencing or spatial pattern or rainfall, all of which can influence the hydrological response of a catchment. To represent the effects of such changes, along with correlated changes in evaporation, requires analysis of the output from the climate model simulation. For the UK, this is not automatically provided by the UKCP09 climate projection outputs. While the UKCP09 projections offer several advantages over previous climate projections, including probabilistic treatment of uncertainties and greater spatial resolution, the information has been packaged for ease of use to include data such as projected changes in rainfall accumulations. To understand the hydrological implications requires analysis of the primary climate model outputs that underlie the UKCP09 products such as that carried out as part of the Defra R&D project FD2020 (Defra, 2009).

While UKCP09 represents a major advance, there is uncertainty over changes in the short duration extreme rainfall events that drive, particularly, summer flooding. As in the Taihu Basin, indications from UKCP09 are that despite projected reductions in summer rainfall totals, summer rain storms might be more intense events increasing the risk of surface flooding. Catchment and national studies are required to understand the implications for these sources of flood risk from the UKCP09 projections. In an approach based on realistic hydrological event scenarios, it is therefore important to consider what is realistic for the future, as well as for recent climate conditions, in constructing the event scenario data. In this context, probabilistic information about uncertainty in modelled future climate data may be particularly useful, provided that it is analysed in the light of understanding the importance of spatial, temporal and cross-variable correlation.

2.3 Hydrology

The hydrology work package developed rainfall series and rainfall-runoff models and produced boundary data for the broad scale hydraulic model.

The Variable Infiltration Capacity (VIC) model was selected as the rainfall-runoff model for the upland areas. For the floodplain areas an SCS (US Soil Conservation Service) method was used to generate net rainfall.

Examination of the 1999 rainfall records, Tai Lake water levels and damage distribution showed that there was strong interaction between a rich spatial and temporal pattern of rainfall and tidal boundary levels, and the equally complex hydraulic system of the basin which had numerous characteristic response times. This is illustrated in Figure 2.5. It was obvious that there was no simple solution to the problem of producing boundary conditions to feed into the broad-scale hydraulic model. What was needed was a method which would preserve the spatial and temporal distribution of the rainfall, thus leading to realistic simulations of flood risk.

There was no provision in the project for a major exercise in continuous rainfall series generation. Instead, rainfall inputs were based on the spatial and temporal pattern of the 1999 event, scaling the observed rainfall profiles to produce rainfall inputs for different return periods using TBA relationships between depths for different return periods and durations.

Further "growth factors", derived from the PRECIS modelling, were used to simulate the effect of climate change

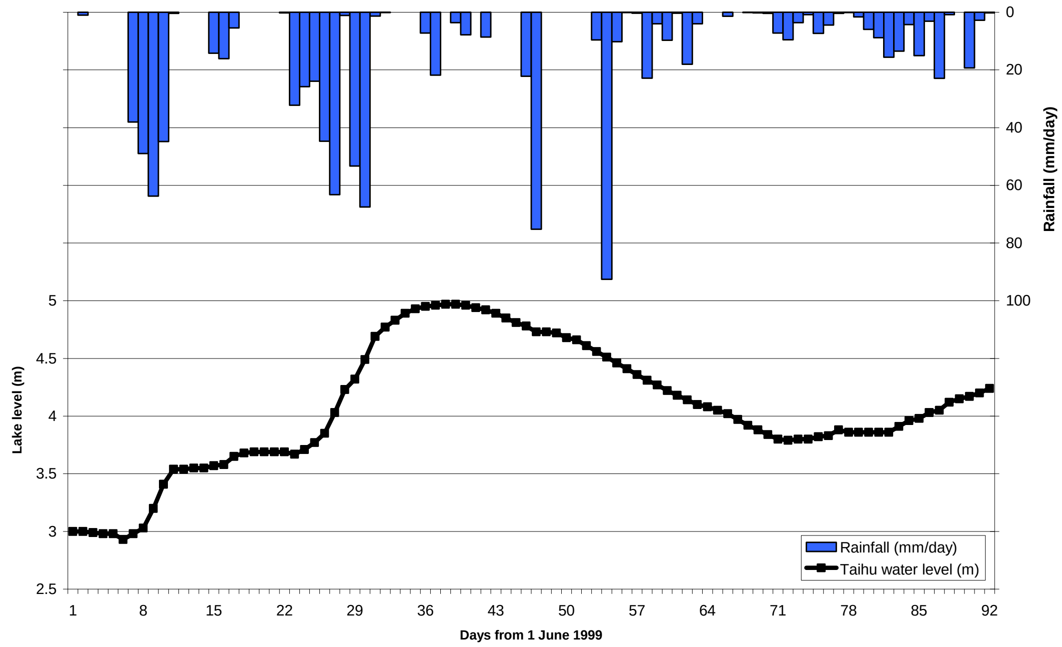


Figure 2.5: Rainfall and Tai Lake levels as recorded in the 1999 flood event

Understanding event risks

Owing in part to the approaches to flood management taken in China, the Taihu study highlights how understanding potential event losses helps in thinking about the planning and resources needed to respond to flooding, including the capacity of a large-scale drainage system, emergency responses and other non-structural measures. Understanding annual average flood losses can inform the investment that may be needed over 20, 50 or even 100 years.

The Taihu study established the probabilities of rainfall over the basin, derived from historical data. The decision to use a real event which caused large-scale flooding as the basis of a set of source inputs to the hydrological and hydraulic modelling process, scaling it to give rainfall events of different probabilities and climate change scenarios, was driven by the large scale and complex nature of both the rainfall and the hydraulic system of the catchment. With the catchment's multiple periodicities of response it was not possible to envision any simpler approach which would stress the system in a realistic way. The notion of simply scaling this real event then followed as a consequence of constraints of time, skills and tools. Thus, whilst the benefit of understanding probability and consequence of the modelled flood scenarios has been demonstrated, the size of the Taihu Basin meant that spatial patterns of flooding were greatly simplified in the scenario analysis. One event (the 1999 flood) formed the basis for all of the modelled scenarios; other well-recorded monsoon-season events of significant magnitude (1954 and 1991) were also available but were not used owing to the above-mentioned constraints.

There is no certainty that major flooding in the future will have the same pattern. The monsoon rainfalls over the Taihu Basin create long duration, broad-scale rainfall events in the summer months (the "plum rains") which may be more consistent in their spatial patterns than weather systems typical in the UK. In addition to the plum rains, the Taihu qualitative analysis showed that more localised, intense typhoon-season rain storms can also contribute to flood risk in the basin. However, work focussed on the plum rain hazard as this was seen by the Chinese researchers as the most threatening. Similarly the potential combination of typhoon rain and storm surges was not addressed. Scientifically, this was accompanied by an inability to quantify these risks for lack of convenient tools to implement statistical and modelling techniques. The impact of variation in spatial patterns of flooding, now and in particular for a future climate, was regarded as an un-quantified source of uncertainty, an "unknown unknown".

This point is illustrated by the spectrum of spatial patterns that may characterise any particular flood, expressed in terms of spatial scale and severity, as illustrated in Figure 2.6.

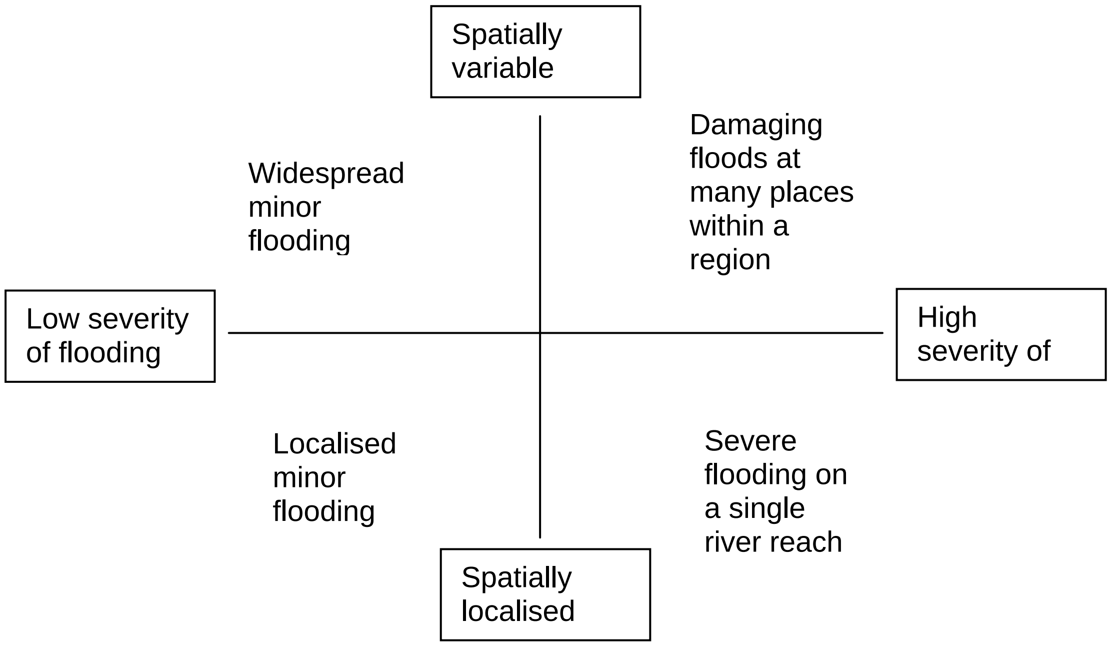


Figure 2.6: A spectrum of flood events with variation in spatial patterns and severity

Thus, flood risk over a large basin or region is a function not only of the hydrological responses and performance of flood management systems at any given location, but also of the combinations of events that may occur at different scales and with different levels of severity at any one location. Without a proper statistical framework to analyse these patterns, it is also difficult, if not impossible, to assess the chance of experiencing any particular flood now or in the future. This affects the confidence with which a single historical event (or indeed any small number of such events) can be adopted as a prototype for scenario analysis.

A shift in thinking is thus required to recognise that at a large scale there can be many possible flood events, all consistent with a specified probability of occurrence or consequence. For example, Figure 2.7 shows three different river flood scenarios, all of which have approximately the same 1 in 100 year annual probability.

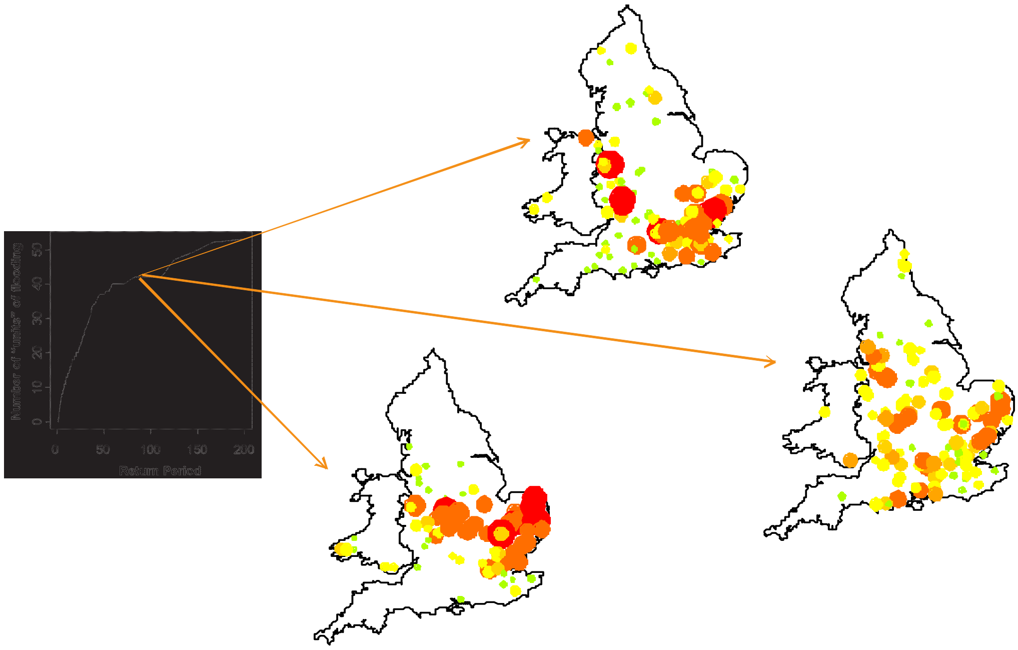


Figure 2.7: Three different extreme river flow event scenarios, each with a one in 100 chance in any given year when assessed on the basis of the combined severity of flooding. The discs indicate river gauges; small green discs indicate less extreme flows, large red discs indicate more extreme flows - pilot study results from Environment Agency project SC060088.

The scale of the Taihu Basin, the complexity of its drainage system, rapid economic growth and population shifts all serve to emphasise that very different consequences could follow from floods with different spatial characteristics.

What is therefore needed are models for spatial extremes which can provide scientifically well-founded answers to questions such as "What is the expected 1 in 100 years economic loss from flooding for a catchment, region or country?" and "What is the probability of previous major notable floods?" As well as providing additional evidence to support investment decisions about flood management, this type of information can also help communicate risk in a way that relates to specific events rather than long-term averages.

Advances in continuous simulation and extremes analysis

Advances in continuous simulation and large-scale multivariate extremes have only been taken up slowly in practice within flood risk management. In contrast, advances in the analysis and modelling of flood defence systems have been incorporated successfully into practice. This has been driven by the need for information to inform investment planning where long-term averages are important. However, to understand fully our exposure to individual, widespread floods (such as those in autumn 2000 or summer 2007) we need to be able to assess the risk of events, including potentially catastrophic future scenarios that have not yet been quantified. This is particularly important in understanding resource needs for emergency planning and non-structural measures. The Taihu Basin study shows the importance of capacities in flood management including flood control and emergency response.

The scaling of the single event in the Taihu Basin study may be compared with the approach adopted on FRACAS, a Natural Environmental Research Council (NERC) Flood Risk from Extreme Events (FREE) project. Here, a systems analysis approach uses the principles of RASP but within a continuous analysis framework, driven by temporally and spatially distributed rainfall (though the qualification noted above in relation to methods for generating spatially and temporally correct rainfall patterns applies equally). It is important that the lessons from the Taihu analysis and the FRACAS work are combined to make the most of both.

Summarizing the lessons from the Taihu Basin

The Taihu Basin study provides an opportunity to reflect on how the emphasis placed in the UK on long-term investment planning has helped to drive a probabilistic method for modelling structural flood management systems within Foresight scenarios. In contrast, when faced with a need to understand the probabilities and consequences of possible flood scenarios, which may vary spatially in severity and in social/economic vulnerability, it has been necessary to make simplifications that bring with it significant uncertainty.

For capacity planning, there is currently a gap in knowledge about questions such as "What is the probability of two or more critical infrastructure facilities being flooded at the same time?" and "What resources are we likely to need in a 'worst case' flood event?" Being able to provide consistent answers should aid strategic thinking about the resources needed to recover from flooding. It should also help us to set realistic scenarios for emergency planning exercises.

In summary, the lesson from the Taihu study is the value and effectiveness of driving the broad-scale flood risk assessment by realistic hydrological events. The crucial issue is how to develop methods to generate and quantify those events, and where they should be used in UK flood risk management. As the Taihu summary report puts it:

"The scaling procedure for generating rainfall profiles for different return periods and climate change scenarios while useful is crude. There is much attraction in placing the idea in a proper statistical framework."

We review potential approaches in Section 6.

2.4 Socio-economic scenarios and issues

Whereas the aim of WP4 was to generate a set of socio-economic scenarios to accompany the climate change ones, the aim of WP5 was to assess potential flood impacts on economic assets, economic activity and the people of Taihu Basin under different scenarios. The resulting flood damages assessment model, created in conjunction with WP4, is implemented as a sub-system of the TBRAS.

We now turn to the second set of scenarios and more general issues of socio-economics in flood risk management, but first summarize the vision of scenarios derived in China.

The three functional groups of drivers and responses (climate change, socio-economic development, and flood control system measures) gave rise to a 3-D 'scenario coordinate' picture of future basin flood risk. This could potentially lead to many combinations, so the 3-D scenario was simplified by linking climate scenarios to socio-economic ones. Two combined scenarios emerge, with A2/A2 and B2/NP climate/socio economic combinations. The first is characterised by low government regulation, open market and high competition, the second by harmony and sustainability. These are illustrated in Figures 2.8 and 2.9.

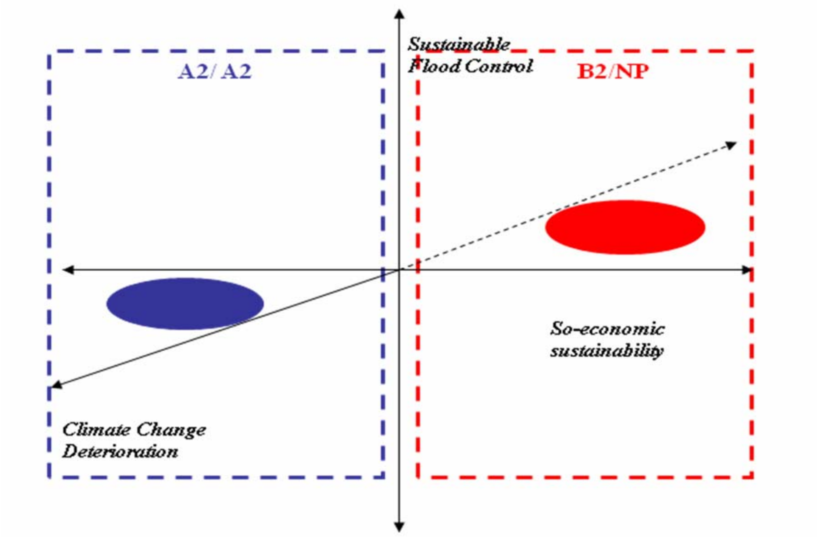


Figure 2.8: 3-D scenario coordinates of future flood risk

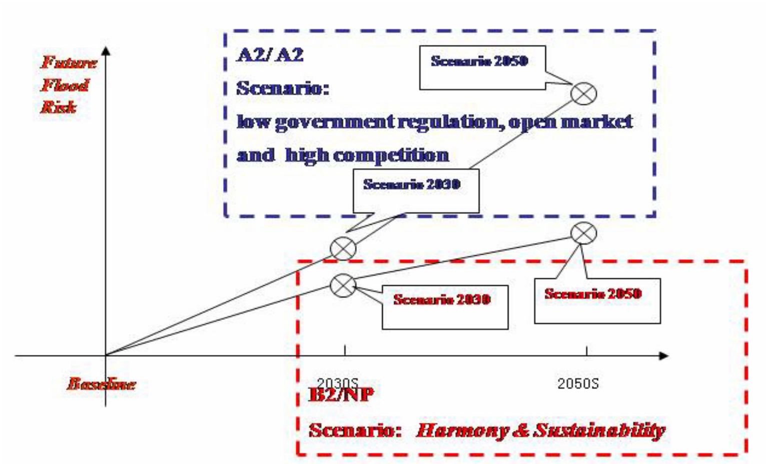


Figure 2.9: 2-D representation of flood risk change under two scenarios

The use and refinement of scenarios

Results of Foresight-type flood risk studies are fundamentally scenario-dependent and a key lesson here is that the scenarios must be carefully chosen and need to lend themselves to quantification (in terms of population numbers, economic growth rates and so on).

The Taihu project shows the use of scenario analysis to explore the implications of future changes such as climate change and socio-economic change. One innovation here uses the Chinese National Plan as one scenario, meaning that this scenario could be firmly grounded in all the research and forecasts that have been done to construct that plan. This advantage is somewhat outweighed (or balanced) by the fact that the National Plan only goes to 2030 (though some projections go to 2050).

Nevertheless, with each study of future flood risk scenarios (in the UK; China) we gain confidence in their use. In this respect it might be useful for the Environment Agency to use more ambitious scenario analysis in its longer term projects, including in the Long Term Investment Strategy (LTIS) and related work on asset management. The Environment Agency and Defra should continue to look far ahead when developing their policies and funding strategies, and the use of scenarios can help here, not least by forcing a consistency of approach across different types of studies or sectors of government policy and investment.

New thinking

The Taihu project has shown how understanding potential event losses helps us to establish the preparedness, emergency response arrangements and other non-structural measures required, while annual average flood losses give insight into the investment that may be needed over 20, 50 or even 100 years.

The difference between considering event and annual average losses is important. Numerically identical averages of losses can be made up of different combinations of events. This average is important for sizing investment decisions, but those making decisions about how to manage events also need to know the distribution of values: strategies for managing rare extremes can be radically different from managing a regular sequence of smaller events.

In the UK we tend in project appraisals and risk assessments to focus on annual average damages, because these sums drive investment decisions, and it is those decisions that lead from potential damage assessments to benefit:cost tests. These tests are rigorously imposed, guided by the Treasury Green Book (HM Treasury, 2003) and Defra's Project Appraisal Guidance series as originated in the late 1990s (MAFF, 1999).

On the other hand, policy measures that relate to flood events (as opposed to annual averages) are not subject to the same level of economic analysis in the UK. For example, the justification to improve flood forecasting and warning systems is only loosely based on economic analysis; the emphasis is on minimising loss of life and injury in floods. Emergency response efforts of the Environment Agency and others (such as local authorities) are not tailored to their effectiveness or efficiency in damage-saving, and hence are not judged by economic metrics.

The Taihu analysis therefore provides a useful comparison with the UK scene, from which we can learn. Moreover, the modelling done for the Chinese case, in serving to emphasise event losses, perhaps reminds us that the needs of capital investment are just one dimension of flood risk management.

Climate and socio-economic change: important results

The relation between climate and socio-economic drivers of future flood risk is under-researched. Moreover, compared with research into climate change, that into socio-economic change has been neglected. Since the UK Foresight project, there has been a general uncoupling of the link between emissions (climate) scenarios and socio-economic scenarios.

The Taihu results are obviously location-specific, but show interesting parity of impact of the two drivers in arriving at the combined future risk. Socio-economic growth in China by 2050 will result in risk increase wealth/assets factors of about five times. The scenario National Plan leads to the greatest rate of increase in risk, reflecting the rapid rate of economic development in the Taihu Basin. The increases in risk due to climate change alone are of the same order as the increases due to this socio-economic change.

When the socio-economic and climate change factors are combined their effect is geometric, as risk is a product of probability and consequence, so the factors of increase on probability (climate change) and consequence (socio-economic change) simply multiply. Thus for combined climate and socio-economic change, with each seeing multiples of around five times, the increase in risk is of the order of 20-30 times. While logically justified, these values are surprisingly high but are comparable to the UK Future Flooding results.

What we can learn from these results is that in areas of the world where economic growth rates are high (as in China) the impact of socio-economic drivers rises to match climate change effects. Even in the UK, the 2004 Foresight study, through the one run carried out with World Markets (high growth) and low climate change, suggested that climate and socio-economic impacts were of the same order. Clearly, this requires more research to establish the full nature these relationships.

Risk transfer from old to new areas

One of the features highlighted by modelling is the transfer of risk from the Tai Lake to areas outside the polders that now circle many of the larger urban areas in the region. Thus, a presumably unintended consequence of the success of the diversion canals built in the last decade to take water from the lake to the estuaries and sea is to render the risks of flooding greater in areas that were once relatively flood-free.

This transfer of risk means that it is now unambiguously human-driven. This has echoes of the recently articulated concept of the "risk society", a term that emerged during the 1990s to describe the manner in which modern society organises itself in response to risk. The term is closely associated with several key writers on modernity, in particular Anthony Giddens and Ulrich Beck.

According to sociologist Anthony Giddens, a risk society is "a society increasingly preoccupied with the future (and also with safety), which generates the notion of risk", whilst the German sociologist Ulrich Beck defines it a systematic way of dealing with hazards and insecurities induced and introduced by modernization itself. These authors argue that whilst humans have always been subjected to a level of risk - such as natural disasters - these have usually been perceived as produced by non-human forces. Modern societies, however, are exposed to risks such as pollution, newly discovered illnesses and crime as a result of the modernization process itself.

Giddens defines these two types of risks as ‘external risks’ and ‘manufactured risks’. Manufactured risks are marked by a high level of human involvement in producing and mitigating such risks. The Taihu Basin appears to be a nice example of this, where increased risk is being generated by National Plan modernisation proposals (with its increasing GDP in the flood plain areas) and is being redistributed according to the effects of human intervention, rather than processes that could be termed “natural”. This is an interesting and important result that has echoes in other parts of the rapidly developing (or modernising) world.

Demographic factors

One of the important lessons to be learnt from Taihu is that demographic changes need to be incorporated into the kind of “futures” work that characterises the UK Foresight Futures work. This is indeed one of the innovations in Taihu. Although future population changes are difficult to assess, capturing the scale of these changes is crucial to the success and credibility of this kind of long-term modelling. Urbanisation trends are similarly difficult to anticipate and hence model.

In Taihu, this was helped by the fact that one of the scenarios used was the National Plan. This includes changes in population as a central data input, whereas the UK Foresight Futures flooding project crudely assumed a static population (shown

subsequently to be incorrect, as net immigration is significant in the UK). Whether the National Plan fully captures the massive increases in population in the Shanghai area is a moot point (see Figure 2.10 below, from photographs taken just two years apart in December 2003 and December 2005). But at least the National Plan scenario assumes some inward migration and the model results reflect that and the increase in urbanisation that would result.
This increase in urbanisation in the Taihu case was modelled assuming that each urban area would expand spatially in proportion to its current size. This could be refined in the future, and reflect spatial plans rather than simple organic growth. Indeed that could be one of the interventions modelled, rather than remain an assumption. The impact of interventions should provide a feedback loop in the modelling (especially spatial planning and changing governance), but this cannot yet be done with ease.

The overall lessons learnt here from the Taihu case for the UK are that demographic changes must be built into this kind of future risk modelling, as they are both a key element of change and a factor that can be affected by interventions.

Figure 2.10: Photographs of an area of Shanghai taken just two years apart in December 2003 and December 2005

Interdisciplinary issues

The Taihu study brought some Chinese research into the international arena. This included flood damage modelling, where good work preceded the Taihu study, focused on flood damage in Shanghai. The researchers involved thus had the advantage of working with a larger team with substantial international experience.

The Taihu study also brought the involvement of the Chinese Academy of Social Sciences (CASS). As a major focus of social science expertise in China, CASS brought a new dimension to the research, notably a strong link with the Chinese National Plan (with which CASS is centrally involved). Developing strong links between engineers and social scientists was a feature of the Taihu study.

This kind of link is not common in the UK. The Environment Agency and Defra both have strong teams of economists, but other social sciences are poorly represented. It is likely that both organisations could benefit from more exposure to other disciplines - such as demography – so that their longer term scenario or forecasting work is more strongly grounded in these other social sciences, perhaps through better links with the Office of National Statistics (ONS) or organisations aligned to and funded by the Economic and Social Research Council (ESRC).

2.5 Broad-scale hydraulic modelling

The aim of this work package was to develop a broad-scale hydraulic model of the Taihu Basin and to use it to help the scenario analysis. By this we mean not a fully detailed, relatively localised model such as would be used for design purposes, but a wide-area, sparse-data model fast enough to permit the running of many cases needed for scenario analysis, reproducing at a sufficient level of accuracy the broad features of flooding and approximate flood levels and extents.

The model uses inputs of direct net rainfall, upland inflows, Yangtze and coastal tide levels, Tai Lake initial water levels, sluice gates control rules and polder pumping rules. Simulations take about 30 minutes to run a 90-day period. Outputs include channel water levels and flood volumes in the floodplain cells; these data are passed to the TBRAS for use in the estimation of risk.

The schematic of the system is shown in Figure 2.11.

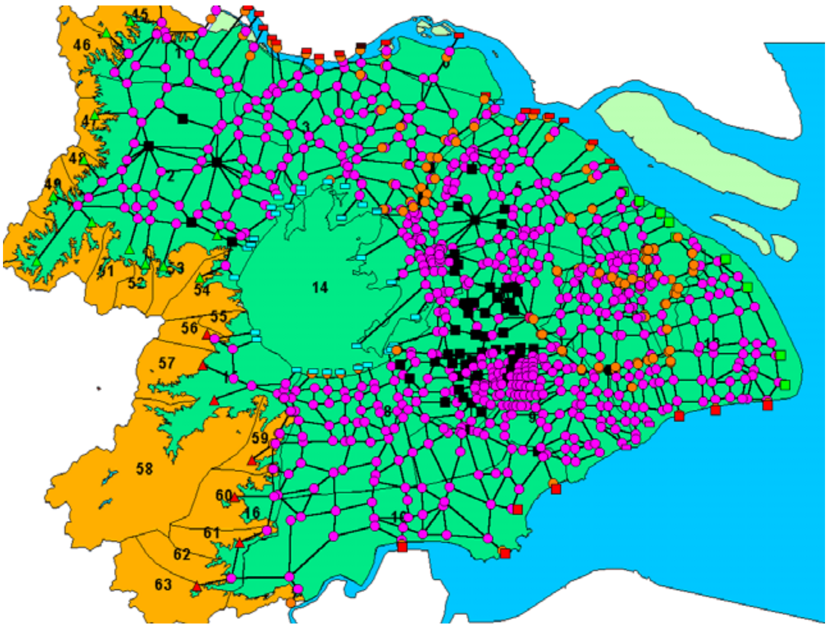


Figure 2.11: Broad-scale hydraulic model; overview of schematisation

Not all channels were explicitly included in the model as the HOHY2 model uses a process in which smaller channels are concatenated into equivalent channels. The concatenated channels have the same capacity as their component channels and thus the overall conveyance capacity is preserved.

The (in bank) HOHY2 model did not contain bank top data and surveyed or design bank top data were not available for many parts of the network. Where the data were not available, approximate levels were inferred based on calculated extreme water levels, with freeboards supplied by TBA. Despite this, a reasonable calibration was achieved, which gave Chinese officials and researchers confidence in the model:

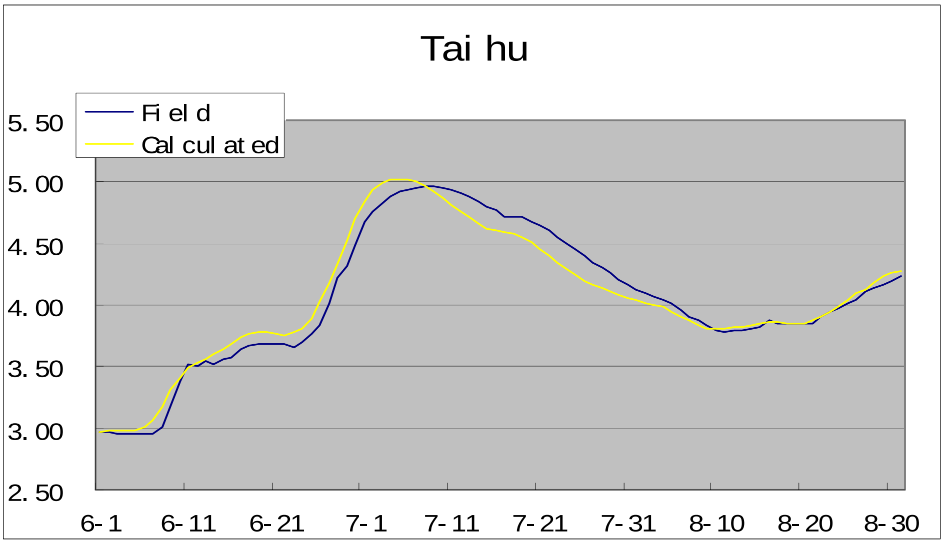


Figure 2.12: Tai Lake water levels, metres above mean sea level, for June-August 1999 (blue-observed; yellow-calculated)

Designing fit-for-purpose modelling studies

The Environment Agency invests around £17 million a year in flood modelling and mapping, so ways to improve the efficiency and effectiveness of the modelling could lead to major cost savings. The Environment Agency's new FCRM Modelling Strategy states that the 'modeller should decide on the most appropriate method based on outcomes required and risk, but provides no guidance on what are the most appropriate methods. Are there lessons that that could be learnt from the Taihu project on designing 'fit-for-purpose' modelling studies?

The modelling approach for the Taihu project consisted of three steps. Firstly, a qualitative analysis step to identify the most significant processes that needed to be included in the modelling framework. Here, 'significant' meant those processes that required simulating because they were sensitive to the drivers of change or management responses, and those linking processes which transfer flooding information to the receptors. Thus it was necessary to simulate rainfall (sensitive to climate change), runoff (a linking process), hydrodynamic flows in channels/lakes (primarily a linking process), spills into flood cells (primarily a linking process), pumping from flood cells (management response and linking process), flood water distribution within flood cells and receptor impacts.

Secondly, once the processes were identified, the modelling tools best suited to each process were chosen. Where it was not appropriate to use existing modelling tools, data were extracted from the existing tools and transferred into more suitable ones. For example, due to the need to simulate overtopping of flood defences and to represent a range of management responses, it was not possible to reuse the existing HOHY2 hydraulic model of the network. Existing data and schematisation held in the HOHY2 model were extracted and used to build an ISIS model of the network.

Thirdly, a modular approach was used and, where necessary, writing data transfer utilities to automate transfer of data between modules. In general process building blocks (such as rainfall-runoff, defence breaching) were constructed in isolation and 'joined together' later in the project. This allowed parallel working early in the project and enabled individual teams to verify their component before system integration (although further calibration/verification was required once the system was integrated). The writing of data manipulation utilities meant that data transfer errors during manual data transformations were largely eliminated and the scenario analysis was speeded up by the use of bulk editing facilities to model responses such as doubling the polder pumping rate.

Much of the Environment Agency's flood modelling programme is well optimised to use efficient 'fit-for-purpose' modelling approaches. However, improvements could be obtained by applying the processes highlighted above.

Hydrodynamic modelling at a regional scale

The ISIS hydrodynamic modelling software was used to build a broad-scale model of the whole Taihu Basin.

Simulating such large areas (over 30,000 km^2 and some 4,500 km of channel) hydrodynamically is unusual. However, it was necessary for the Taihu Basin because of the hydraulic interconnectivity of the channel, lake and polder systems. UK rivers are less connected at this kind of large geographical scale and therefore it is unlikely that models of such large areas and/or channel lengths would be required, but complex connectivity may occur in more detailed models of smaller basins, and may also be a feature of models that seek to combine surface and subsurface drainage systems at a catchment scale. There are instances where large broad-scale models would be beneficial, such as in strategic studies of the Severn, Trent, Thames or Norfolk Broads or for integrated studies of water transfer via linking river and canal systems. Consideration should also be given to the use of broad-scale hydraulic simulation for studies linked to the Long Term Investment Strategy where interaction between response options can be important. The Taihu model suggests that such hydraulic models are feasible and should be considered when designing modelling approaches for large areas.

Nested models (models within models) help to resolve scale issues

The modelling approach for the channel flows and flooding in the floodplain area of the Taihu Basin consisted of a broad-scale ISIS model of the channels, lakes and polders, together with a GIS-based flood risk analysis (TBRAS). In effect, the ISIS model provided a very broad-scale simulation of the polders, with TBRAS providing a more detailed simulation of the distribution of flooding within the polders – a nested approach to modelling. This approach was used because different processes are significant at different scales. At the basin scale, it is necessary to hydraulically simulate the interconnected channel/lake system to enable channel water levels to be predicted throughout the system, but it is not necessary to simulate within-polder hydraulics. At the scale of cities and other groups of main receptors, it is necessary to simulate the distribution of flood waters within polders, taking account of city-level ring dykes and pumping, but it is not necessary to simulate the hydraulics of the main channel system as long as channel water levels are known. To simulate both these sets of processes within a single model would have been possible in theory, but would have resulted in an impractical modelling system.

There are similar scale challenges in the UK and it is worth reflecting on the approach taken in China. In essence, the lesson is to use the most appropriate tool for each element of the particular job, and not allow the need to simulate one process lead to unsuitable methods used on other processes. For example, it could be argued that while the MDSF2 system will introduce appropriate methods for defence reliability, it may also result in retrograde steps in simulating hydraulic interactions between the channel and floodplain. An alternative architecture similar to the ISIS-TBRAS nested models may be more appropriate.

Calibrate/verify at a range of points in the calculation sequence

The modelling approach for the Taihu Basin resulted in a set of calculation modules constructed in parallel (such as rainfall-runoff, hydraulics, defence reliability, flood risk assessment) before being linked to form an integrated system model. Each module was calibrated/verified (where possible) in isolation before integration (when further calibration/verification was made). This disaggregated approach enabled the experts in each module to assess the confidence in their module. It also forced what would later become intermediate outputs (such as flow hydrographs from the upland catchments and defence reliability) to become 'exposed' to scrutiny.

In the UK there is a move towards integrated modelling in which single-supplier software frameworks are used to simulate most (sometimes all) of the processes. This can bring advantages in time savings for the modellers (sometimes permitting modelling that was previously not possible). But it risks introducing 'black box' approaches in which only the main outputs are thoroughly checked. Emphasis should remain on the need for calibration/verification at a range of points in the calculation process, with modelling systems enabling intermediate results to be efficiently assessed. 'Sector' experts need to help assess the intermediate results.

2.6 Reliability analysis of the dyke system

This task included assembling information on the dyke system into a structured and accessible GIS/database format to support the reliability model, and the characterisation of dyke reliability by type, determining the relationship between load and the probability of structural failure for each dyke type. European fragility curves were used in the absence of Chinese equivalents.

The discharge into each flood area in the event of a single dyke breach was estimated, and incorporated in a simple spreadsheet which was implemented as a sub-system of the TBRAS. A "switch" was introduced to allow "breach" and no-breach" runs to be carried out.

Defence classification

The geographical classification of the Taihu defences was as follows: lake, coastal, tidal, fluvial primary and secondary, and fluvial minor defences. However, for the classification of defence structure type (coastal/fluvial, vertical/sloping and so on) and material, the Chinese team were happy that the UK approach embedded within the National Flood and Coastal Database (NFCDD) was directly transferable (Figure 2.13). This is not to say that there were not significant variations in the forms of defences, particularly with composite defences which are not really covered by the classification system.

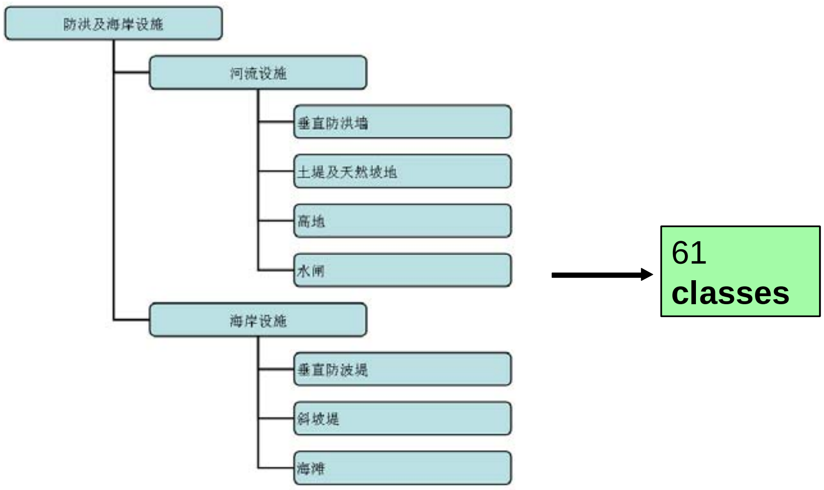


Figure 2.13: Classification of defence structure types - Chinese adopt UK system

Significance of defence breach in risk assessment

There was nervousness in China about classifying the Taihu Basin defences in the TBRAS owing to lack of data. Eventually, it was acknowledged that defence breach was in fact possible and indeed data was supplied for major defences in one district which enabled the distribution of various defence breach widths to be collated. Figure 2.14 shows this data in histogram form; this provides a useful insight for UK practice and dialogue with Chinese researchers on this issue is continuing.

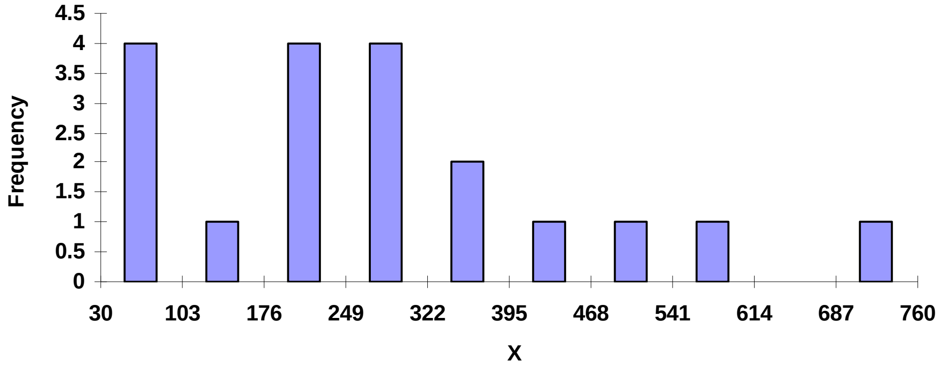


Figure 2.14: Frequency of different breach widths x(metres) – Chinese data for major defences

As noted earlier, the impact of including breaches was to more than double the calculated expected annual damages. In terms of UK practice, the lesson learned is the importance of breaches in flood risk assessments and management of defence condition as a key part of the ongoing asset management strategy. The Chinese data and recent experiences in France reinforce UK experiences of the 2000 Gowdall breach and problems on the Jubilee River and indicate that the small number of failures in summer 2007 (four failures in 500 km) should not be taken as a guide to long-term performance in extreme events.

Innovative approaches to resolving lack of data

The issue of data scarcity seems to be common throughout the world (such as breach failure mode/mechanism, breach size); this means that in many cases such as the Taihu basin study, simplified approaches are necessary. In the Taihu case this included distribution of condition grades along dykes. Here, it was only possible to estimate the percentages of different dyke lengths that were in different conditions. These estimates were then used to assign different condition grades to different proportions of a defence length. Assumptions about breach width were made using the data described above. UK generic fragility curves were used in the absence of better information/science in China.

Other than recognising the value of UK generic fragility data, the main lesson learned here is the considerable value in maintaining links with Chinese researchers. Now that there has been acceptance in China that breach is something to be managed actively, there may be a rich body of data and experience to be mined if permissions can be secured from Chinese authorities. For example, a review of UK generic fragility curves with Chinese researchers has suggested some useful improvements.

Simplified methods of reliability analysis

During the course of the Taihu study, work was carried out on spreadsheet-based reliability assessments and first-pass assessments of defence reliability (using individual defence analysis). Whilst the full RASP methods are superior for systems analysis, some of these ideas have now been incorporated into the Environment Agency's simplified Risk Attribution a Field-based Tool (RAFT) tool.

To estimate the probability of an asset failure, RAFT uses a library of high level fragility curves and user-defined asset type and surface protection to select a fragility curve from the built-in library. It then automatically calculates flood risk as the product of the annual probability of asset failure at its current condition grade and the number of properties that would be affected by a breach.

The RAFT tool is now being widely used in the Environment Agency to provide a useful first assessment of the criticality of individual assets through a simple field-based activity. RAFT could be improved usefully by some of the lessons from the Taihu basin experience.

2.7 Quantified risk analysis - the Taihu Basin Risk Assessment System

The Taihu Basin Risk Assessment System (TBRAS) is a GIS-based flood-risk analysis tool which integrates the components of quantified risk analysis established in the preceding work packages, and performs risk calculations for scenario analysis.

TBRAS has a number of interesting features. The spatial and temporal footprint of rainfall events originating from the hydrological modelling is preserved though TBRAS. It thus enables direct examination of the impacts of large, realistic flood events. The model combines probabilistically the flood volumes from these events with estimates of breach volumes. A simple but effective broad-scale model of the internal polders has been developed. As noted previously, a "breach" and "no-breach" switch is incorporated. The model is fast enough to enable large numbers of runs to be carried out and the space-time changes of flood risks in different scenarios displayed, as individual events and as EADs.

While much simpler than RASP and MDSF2 in many ways, TBRAS nevertheless provides food for thought on their future development.

2.7.2 Internal ring dykes: Pump capacity and flood depths

Analysis of flood risk in the Taihu basin involved hydraulic analysis of water levels in the main channels, which determined the probability of flooding by overtopping and/or breaching in the large flood cells (approximately 10x10 km) bounded by these channels. However, within these flood cells, flood depths are strongly determined by pumping arrangements and internal secondary dykes, termed polders by the TBA. Pumping is of significance even in the absence of inflows from the main channels, in order to evacuate pluvial floods. A method based on a simple mass balance equation that accounts for inflows from the main channels, rainfall, local storage and internal dykes was established. This was implemented separately from hydraulic modelling, as part of the flood damage calculation. It illustrates how simple physical principles can be used to generate reasonable approximations to flood depths in complex systems. It has also been used to illustrate the sensitivity of flood depths to the rate of pumping.

2.7.3 Multivariate boundary conditions

Flood risk in the Taihu basin is a function of direct rainfall into the system, inflows from rainfall in the hills to the west, and tide levels at sea and in the Yangtze.

Hydraulic modelling has also illustrated sensitivity of the flooding probability to the sequencing of rainfall. Thus, the risk calculation involves integration over a multi-variate joint probability distribution. Some simplification is feasible as the season of storm surges is different to the season of “plum rainfall” directly into the system. Nonetheless, carefully attention has to be paid to the joint probability of boundary conditions. Calculations of this type do form part of UK flood risk analysis, and the TE2100 project was notable in taking account of joint fluvial flows and surge tide levels. Thus, the analysis in the Taihu basin cannot be considered in this sense to be a major advance on UK practice. It does, however, underline the importance of being able to flexibly bring together different sets of joint boundary conditions on a case-by-case basis. Section 2.3 discusses some recent advances in generalised statistical methods for joint probability analysis of the extremes of multiple variables that have complex inter-dependencies.

2.7.4 Validation

Validation of the flood risk calculation was a significant aspect of the Taihu study. Of course, risk estimates can only be validated in probabilistic terms. However, in the Taihu study, particular attention was paid to the capacity to reproduce flood outlines and damage estimates from observed events. Having to reproduce observed events helped to refine the hydraulic model and damage calculation. This process of reproducing events did not validate the exceedance probability estimates associated with those events. However, it helped to convince partners in the work that the model results were trustworthy.

2.7.5 Socio-economic scenarios

China is a challenging location in which to conduct socio-economic scenario analysis. The rates of change in economic development, and consequent vulnerability to flood damage, are remarkable. Analysis of socio-economic change has relied on data from Chinese counterparts, and is discussed elsewhere in this report. Also remarkable are the patterns of socio-economic change, illustrated strikingly in the LANDSAT images below, in which cities in the Taihu Basin can be seen to grow rapidly (Figure 2.15).

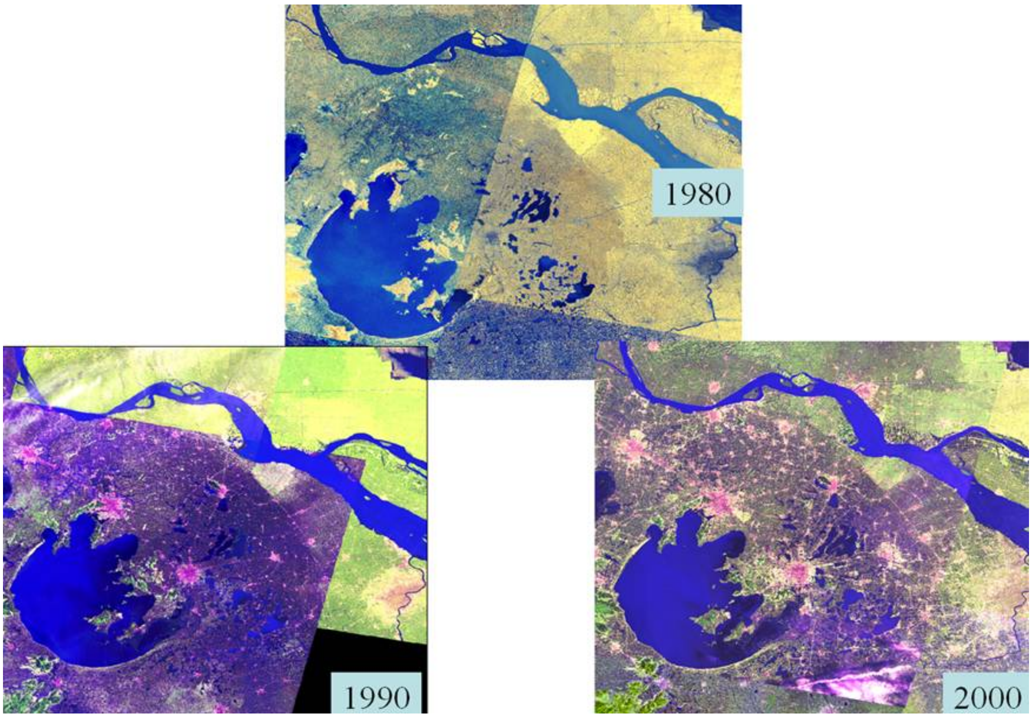


Figure 2.15: Growth of cities in the Taihu Basin 1980-2000

Development of this type is amenable to land use modelling, such as the spatial interaction modelling developed by the Tyndall Centre to look at long-term land use (and changing vulnerability) for London and the Thames Gateway (Figure 2.16).

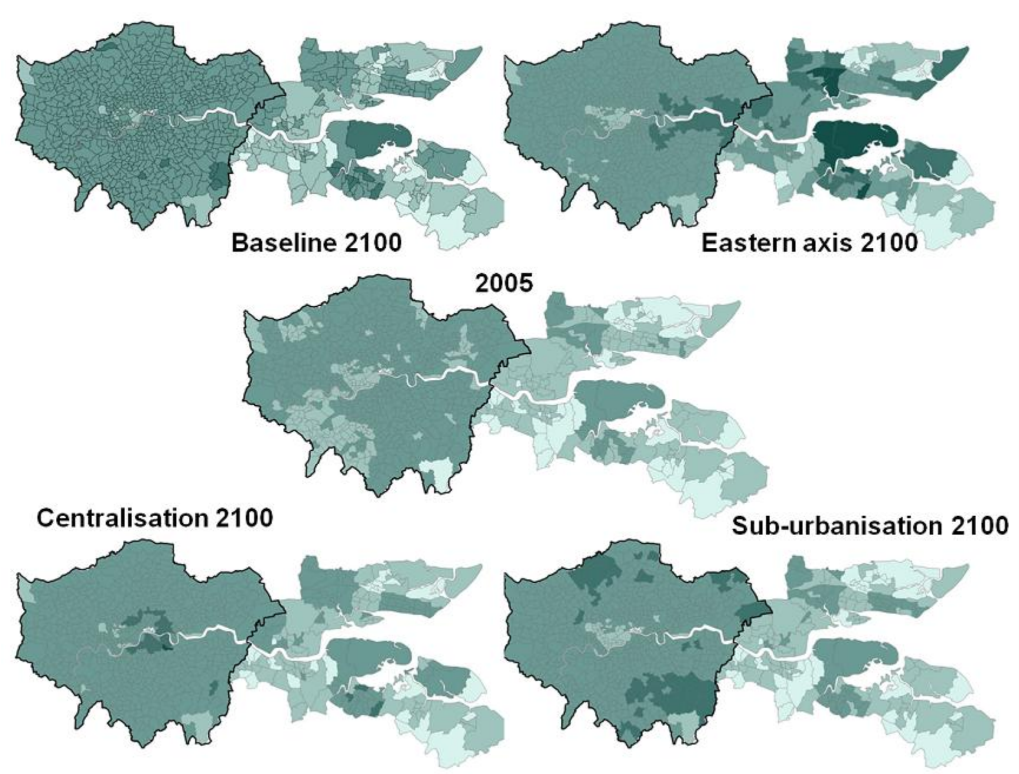


Figure 2.16: Ribbon development in London and the Thames Gateway

Whilst there was no opportunity to conduct this type of spatial analysis of long-term changing patterns of urbanisation in the Taihu Basin, it is clear from our studies that changing spatial patterns of vulnerability are one of the main determinants of future flood risk, and so merit careful attention. This also emphasises the importance of generating event scenarios that can represent and extrapolate feasible spatial patterns of flooding.

2.7.6 Putting risk analyses together

As is often the case, the most revealing and testing lessons from the China Foresight project have been the human process of putting the risk analysis together and generating the results. Communication at a conceptual level is essential and, for obvious reasons, was not straightforward for the UK team in China. Generation of any results at all, and above all credible results, depends on human capacity. Fortunately, within the Taihu study we were able to rely upon individuals who understood the problem and the analysis.

The Taihu project has reinforced the importance of conducting the fastest possible "first pass" through the risk calculation and then progressively refining the risk estimate. The first pass helps to build confidence and identify uncertainties that should be subject to more detailed analysis. There is no one-size-fits-all in flood risk calculations. The Taihu Basin risk analysis had to be customised to deal with the characteristics of the system in question (a complex low-gradient network of channels), fluvial inflows from neighbouring mountains, direct rainfall, flood defences with a finite probability of failure, secondary internal dyke systems and significant pump capacity. The starting point was an engineering evaluation of the dominant modes of behaviour of the system, leading to an analysis that sought to reflect those modes. This required good understanding of the behaviour of the system and capacity to develop a good model representation. Construction of the analysis was, as ever, limited by scarcity of data, so the method had to be adapted to cope with these data limitations.

Given these limitations, it was important for assumptions to be transparent and results to be readily available for scrutiny. Intermediate results have to be available to be extracted and scrutinised. Moreover, various aggregations and statistics of these results (short of the final risk estimate) are necessary to understand large numbers of model runs. An open and flexible modelling framework is thus needed, from which sets of results can be extracted, manipulated and scrutinised. Consultation for the Environment Agency's project, *Next generation of surface water flood risk assessment (SC070059)*, would support this. We could argue that the Taihu study is exemplary here, even though it is not specifically to do with "surface water" as understood in the Environment Agency's strategic overview role.

As in any country, availability and sharing of data for flood risk analysis was a delicate issue in China. However, it became clear to all involved that progress could only be made with some degree of openness about the fundamental data on which the analysis was based. Where this was not feasible, the analysis was impeded.

2.8 Summary of lessons from the Taihu project

2.8.1 Key lessons for transfer

The Taihu project generated a considerable number of potential lessons for the UK. The key groups or themes which emerged are as follows:

Improving project planning and execution by carrying out a preliminary screening analysis using qualitative analysis (expert knowledge elicitation) techniques.

Using spatial and temporal event modelling to obtain insights into the patterns and impact of real, complex events as an aid to emergency planning and other non-structural FRM responses, as well as the conventional statistical outputs such as EAD which are required for economic analysis.

Socio-economic issues. The socio-economic dimension of scenarios has been given little attention compared with climate change, yet we know from both the Taihu and UK that such drivers are of the same order of magnitude.

"End-to-end" modelling systems for long-term large-scale FRM planning that encompass the full range of scenarios, drivers, pathways and responses in a linked system of computational models. This has not been carried into practice in the UK despite the example of the 2004 Foresight project. Associated issues include the run-time of RASP and LTIS compared with the TBRAS and the question of continuous simulation versus event-based modelling.

We now discuss these briefly. In each theme, we preface the discussion with a table of extracts from earlier in Section 2 to provide a set of references for the reader.

2.8.2 Improving project planning and execution

Planning for efficient studies
Qualitative analysis or to use the term preferred by the US Army Corps of Engineers (USACE), "expert elicitation", need not be inferior to quantitative methods and can be a high quality analysis when based on reliable data, which wherever possible is quantitative. The conclusions provide a credible evidence base on which to make some decisions, even without subsequent quantitative flood systems analysis.
Avoid moving to modelling too quickly, allowing ourselves to be locked into past assumptions and prevailing thinking. Instead, adopting appropriate pre-modelling screening analysis is highly desirable, especially given the Environment Agency's new strategic overview role.
Listening to interested parties and affected groups was important.
The danger that well-intended intervention measures or policy instruments can have unintended consequences.
Thinking innovatively about extreme/exceptional events
Efficient modelling strategies
The Environment Agency's new FCRM Modelling Strategy states that the 'modeller should decide the most appropriate method based on outcomes required and risk' but provides no guidance. Some detailed suggestions for this are made.
Hydrodynamic modelling can be used at a regional scale. Consideration should be given to the use of broad-scale hydraulic simulation for studies linked to the Long Term Investment Strategy where interaction between response options can be important. The Taihu model suggests that such hydraulic models are feasible and should be considered when designing modelling approaches for large areas.
Nested models (models within models) help to resolve scale issues.
Simple physical principles can be used to generate reasonable approximations to flood depths in complex systems.

The project was successful in producing credible flood risk assessments from a complete, end-to-end modelling system in three years, starting from a much lower base in terms of data and tools than was the case for the 2004 UK Foresight project. Furthermore the way the project was carried out built up familiarity and confidence among partners who initially had low expectations in the outcomes.

One key to this was the qualitative (expert elicitation) analysis, started early in the project. The second ingredient was clear and efficient packaging of the work and management of the links between different packages. This used the initial qualitative analysis carried out as part of the scoping work of the planning mission. It is not always the case in the UK that people engaged on one part of a project know why it is being done and how it links to other parts of the study.

In any risk assessment, a great deal of time and energy is spent setting up models to simulate the floods that are the basis of that assessment. Why this is the case is not always clear. Sometimes the modelling is over-ambitious, and tackles the issues with too much detailed data (for example, using every individual property in the National Property Database within the UK NaFRA/MDSF framework, rather than using, say, hectares of built-up urban area). In other cases there are ‘blocks’ that cannot easily be anticipated (such as a lack of crest-level data in embankment datasets for Taihu).

The inclusion of an early qualitative stage, before quantitative modelling started, was not done in the TE2100 study recently completed in the UK, leading arguably to more data being collected than was necessary and more complex geomorphological modelling than was essential to the project’s conclusions. Whatever the reason, it is often the case that insufficient time is available to project teams to assess and interpret the final results of the modelling, thus leading to an unfortunate compression of that stage of the work. We must learn to be more disciplined in this respect.

There is also the human dimension to flood risk projects. Qualitative analysis allows involvement of those affected by the issues in problem identification before trying to select solutions. This can lead to broad-scale modelling – perhaps leading to refined modelling, if needed. At that point possible solutions can be reconciled with the wishes and feelings of both public and professional groups as expressed in the qualitative analysis. Keeping all parties involved from qualitative analysis to modelling will save money, and sets the basis for the team driving the modelling rather than the modelling driving the team and the project.

Unintended consequences from well-intended intervention measures or policy instruments can arise. The use of a Foresight-type sustainability analysis, adapted to Chinese culture and conditions, was a useful tool in highlighting this to those involved.

2.8.3 Spatial and temporal event modelling

Spatial and temporal event modelling
Understanding potential losses helps when thinking about the preparedness, emergency response arrangements, and other non-structural measures needed. Using a rich and realistic event as the basis for risk assessment was therefore appealing.
The scaling procedure to generate rainfall profiles for different return periods and climate change scenarios, while useful, is crude. Whilst it is attractive to drive the risk assessment with realistic temporal and spatial patterns, the way to do this is crucial.
The methods used in the UK to assess hydrological sources of flood risk continue to apply engineering design approaches developed in the 1970s and much earlier. They cannot represent the likelihood of flooding experienced in multiple localities. Yet when we look at our exposure to floods at a large scale, it is clear that there is a spatial dimension to the most damaging floods.
Advances in continuous simulation and large-scale multivariate extremes have only been taken up slowly. In contrast, advances in the analysis and modelling of flood

defence systems have been incorporated successfully into practice.
The lesson from the Taihu Basin study is the value and effectiveness of driving the broad-scale flood risk assessment by realistic hydrological events.

The Taihu project has shown how understanding potential losses leads to an awareness of the preparedness, emergency response arrangements and other non-structural measures that may be needed. It also answers such questions as “what would happen if we experienced another flooding like 2007 but even bigger?”

This presents a major challenge, particularly to hydrology. Flood risk over a large basin or region is a function not only of hydrological responses and performance of flood management systems at any given location, but also of the combinations of events that may occur at different scales and with different levels of severity at any one location. Using a rich and realistic event as the basis for risk assessment is therefore attractive. However, without a proper statistical framework to analyse these patterns it is difficult, if not impossible, to make statements about the chance of experiencing any particular flood now or in the future.

One difference between China and the UK is the importance of locality in UK flooding – the area, size and intensity of weather/climate conditions has a big impact on risk.

Thus, while the attraction of driving the risk assessment with events of realistic temporal and spatial patterns has been shown, the way to do this becomes crucial. The scope of a suggested research programme is outlined in the next section.

2.8.4 Socio-economic issues

Socio-economic issues
The Taihu project has again demonstrated the use of scenario analysis to explore the implications of possible future changes. The Environment Agency and Defra should continue to look far ahead when developing their policies and funding strategies, where the use of scenarios can help this process.
The relation between climate and socio-economic drivers of future flood risk is under-researched. Moreover, compared with research into climate change, that into socio-economic change has been neglected.
Demographic changes need to be incorporated into the kind of “futures” work that characterises the UK Foresight Futures work.
The Environment Agency and Defra could benefit from more exposure to other disciplines - such as demography – so that their longer term scenario or forecasting work is more strongly grounded in social sciences.
One of the features highlighted by the modelling is the transfer of risk from around the Taihu Lake to areas outside the polders that now circle many larger urban areas.
Changing spatial patterns of vulnerability are one of the main determinants of future flood risk. This emphasises the importance of generating event scenarios that can represent and extrapolate feasible spatial patterns of flooding.

The most obvious lesson here was the value of taking a systematic scenario approach to questions of large-scale long-term flood risk and its management in China. Although TE2100 (Thames Estuary 2100) employed some elements of a scenario approach, there is no consistent use of such methods in the UK. In the UK there may be reluctant to consider a wide range of possible socio-economic futures – political issues can add to the complexity of a project. Socio-economic and other scenarios are important in setting the terms of reference for a project and early agreement is vital.

Even in the UK, the 2004 Foresight study suggested that climate and socio-economic impacts were of the same order, yet compared with research into climate change, that into socio-economic change to support such an approach has been neglected.

We have not in the UK included changing demography and development patterns in our long-term studies of flood risk, though an elementary attempt to do this was included in the 2004 Foresight study. Development of this type is amenable to land use modelling, such as the spatial interaction modelling developed by the Tyndall Centre to look at long-term land use future possibilities(and changing vulnerability) for London and the Thames Gateway. Whilst there was no opportunity to conduct this type of spatial analysis of long-term changing patterns of urbanisation in the Taihu Basin, it is clear from our studies that changing spatial patterns of vulnerability are one of the main determinants of flood risk, and so merit careful attention in long-term UK planning.

2.8.5 "End-to-end" modelling systems for long-term large-scale FRM planning

In this section we refer to a range of FCRM planning tasks including future CFMPs, SMPs and strategies, regional studies such as TE2100, and the LTIS.

"End-to-end" modelling systems
The project involved a complete 'end-to-end' flood risk analysis, from the generation of climate and socio-economic scenarios, to the final Taihu Basin Risk Assessment System (TBRAS).
The introduction of a "breach", "no-breach" switch in TBRAS permitted direct comparison of cases with and without breaching - the impact of including breaches was to more than double the calculated expected annual damages.
The importance of being able to flexibly bring together different sets of joint boundary conditions on a case-by-case basis.
The importance of conducting the fastest possible "first pass" through the risk calculation and then progressively refining the risk estimate.
Assumptions needed to be transparent and results readily available for scrutiny. Intermediate results needed to be available to be extracted and scrutinised.
There is a risk of introducing 'black box' approaches in which only the main outputs are thoroughly checked. Emphasis should remain on the need for calibration/ verification at a range of points in the calculation process, helped by modelling systems enabling intermediate results to be efficiently assessed.
As is often the case, the most revealing and testing lessons from the China Foresight project have been in the human process of putting the risk analysis together.

In the Taihu Basin case we developed a single-pass "end-to-end" modelling system that encompassed the full range of scenarios, drivers, pathways and responses within a linked system of computational models. The system included rainfall (sources) and its spatial and temporal characteristics, routing of that flood water through the many rivers, canals and sub-basins (pathways), to reach urban areas and their property and populations at risk (receptors). This supported the systematic scenario approach referred to above.

A minor innovation was the introduction of a "breach", "no-breach" switch in TBRAS permitting direct comparison of cases with and without breaching - the impact of including breaches was to more than double expected annual damages. This communicated graphically the importance of dykes as opposed to the enormous pumping and control structures they have been building.

This continuous single-pass system has not been done before on this scale. No doubt there are simple rainfall-runoff-impact assessments at a sub-catchment or similar scale, but not on the regional scale characteristic of the Taihu Basin. The advantage is that one can change assumptions at any stage in the “pass” through the model, and assess their effects (on breach incidence, or from spatial planning measures and so on). This means that interventions can be studied one by one, rather than combinations being evaluated (owing to constraints in project timing or resources) that conceal the impact of individual actions. But the approach has complications as well as advantages. The modelling is complex, and while run times are reasonable, the process of editing the files to model driver and responses needs to be developed further to make them transparent and convenient.

Given the limitations of data, assumptions needed to be transparent and the results readily available for scrutiny. Intermediate results need to be available to be extracted and scrutinised. Moreover, various aggregations and statistics of these results (short of the final risk estimate) are necessary to understand large numbers of model runs. An open and flexible modelling framework is thus needed, from which sets of results can be extracted, manipulated and scrutinised. This is an important lesson in view of the Environment Agency’s need to integrate surface water into flood risk assessment as part of its strategic overview role.

A number of lessons or issues arise for the RASP family of products and the LTIS. The issue of run-time is important to the LTIS and ideally should be more like the minutes of the TBRAS than the days of NaFRA. Otherwise, the scope of studies is limited by the model, not by the questions posed or need for knowledge. This may also be a limitation in the case of MDSF2. The systems are of course very different, but nevertheless the issue must be raised.

Another issue is whether the more event-based approach of TBRAS contains lessons for the next generation of MDSF/NaFRA models. Again, we do not say that one is better than the other, but merely point out the need to ask the question. This is also tied to the associated question of continuous simulation versus event-based (stochastic simulation) which both have advantages, but first we need to clarify the problem - could tools offer both, for instance?

Other important lessons for LTIS are the modelling of interventions; developing ways of simulating demographic change within the model behind the LTIS and in RASP systems, so that they are more realistic in their characterisations of the future; finding a way for business tools to examine how risk is redistributed by the profile, amount and geography of spend. For example, if budget is reduced, what will the impacts be on different people and places? The ‘rules’ steer investment and hence the distribution of risk between the rich and poor.

Finally, the measured process of the project, pre-declared in the inception report, its transparency and its listening process carried with it some senior and initially sceptical Chinese officials. Human factors are not the least important in designing and carrying out complex projects.

3 What work is needed to transfer the knowledge to the UK?

Key lessons from the Taihu project are described and summarised in Section 2. However, further work is needed before these lessons can be applied in the highly-developed flood risk management environment in the UK.

3.1 Improving project planning and execution

3.1.1 Introduction

This topic draws together the discussions in Chapter 2 on qualitative analysis of flood risk drivers and responses and on broad-scale modelling. We propose the creation of user-focussed guidance covering the following:

Early qualitative analysis: Involving all interested parties in this process is vital, not just to be seen to be fair and accountable, but to ensure that valuable information and opinions are brought into the thinking process. The process prevents moving to modelling too quickly or allowing teams to be locked into past assumptions and prevailing thinking. An integral part of this process is scenario analysis and the need to include some examination of extreme and exceptional events as well as more likely scenarios.

Sustainability analysis: The danger of well-intended intervention measures or policy instruments having unintended consequences was starkly evident in the complex and interconnected flood system in the Taihu Basin. Sustainability analysis touches on components of procedures for Treasury Green Book-based project appraisal and Strategic Environmental Assessment, but examines the impact of proposed individual solutions or portfolios of measures on flood risk and issues such as social justice, environmental quality, cost-effectiveness and precaution.

Efficient modelling strategies: These need to be designed to meet the specific needs of a given project and should be strongly shaped by the qualitative analysis, to support the sustainability analysis.

3.1.2 Benefits and beneficiaries

Users who would benefit from guidance in these areas are those involved in flood risk analysis and management at a range of spatial scales, mainly from the catchment/coastal cell scale down to individual asset systems and local projects and measures. Offering guidance to these professionals means that the overall approach to finding solutions is more coherent, solutions with undesirable feedback mechanisms are avoided and the resulting modelling is targeted and carried out at an appropriate degree of granularity/complexity.

3.1.3 Overview of potential knowledge transfer actions

Three main project components are envisaged. If desired, these could be combined into a single project.

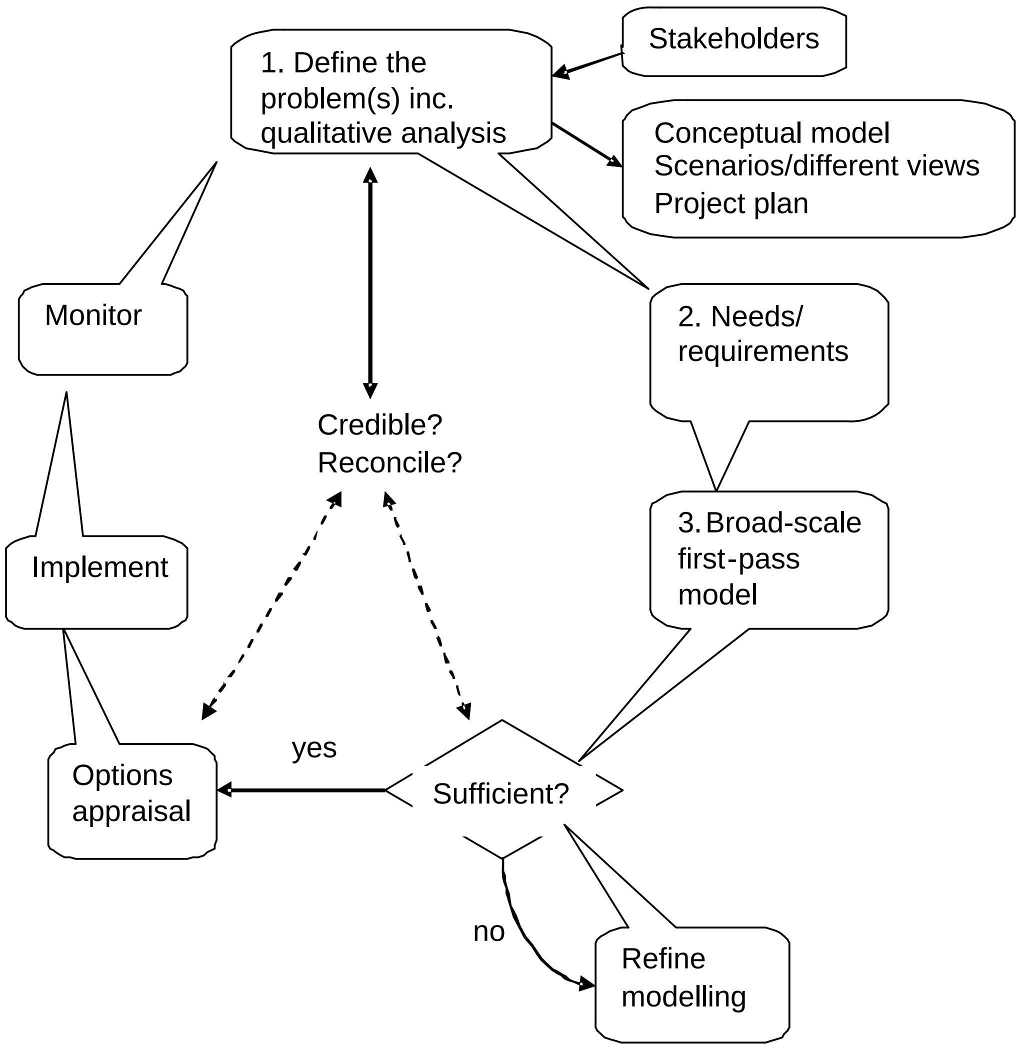
1. **Guidance on qualitative analysis procedures and links to modelling procedures.** Guidance is required which sets out simply and briefly the process for qualitative analysis (see box below), how people are involved in the development of conceptual model(s) and working with experts to agree how these should, if necessary, be implemented in broad-scale or more refined

models. Guidance should explain how scenario analysis is used in this process and how extreme and exceptional events should be taken into account as well as more likely scenarios. Guidance should be set out in terms of guiding principles, together with examples of how these might be used in practice. It should complement rather than supplant existing guidance for management plan production or project appraisal, but future revisions of these could take the new guidance into account.

2. **Guidance on sustainability analysis.** Similar guidance is required which sets out how sustainability analysis should be carried out in the context of flood and coastal erosion risk management. Sustainability analysis touches on components of procedures for Treasury Green Book-based project appraisal and Environmental Impact Assessment and there is no intention to supplant these. The guidance should therefore be set out in terms of guiding principles, together with examples of how these might be implemented in practice. The role and importance of feedback mechanisms should be described, along with how a range of scenarios could be used to assess intervention measures for their impact on flood risk, social justice, environmental quality, cost-effectiveness and precaution, identifying any cases of unintended consequences.

3. **Guidance on efficient modelling procedures.** This guidance should build on the foundations of the two documents proposed above. It should stress the need to design the modelling system to meet the specific needs of a given project, with component process inclusion as prioritised during the qualitative analysis. The use of nested modelling should be explained and promoted. The importance of validation should be stressed and there should be descriptions of the various techniques available to help build confidence in the modelling. The advantages and disadvantages of different types of flood modelling should be described to encourage selection of the most suitable modelling approach leading to 'fit-for-purpose' modelling studies. The overall aim of the guidance should be to help improve the efficiency and value of the modelling components of projects.

Qualitative analysis (see figure below) allows the involvement of all partners in conceptual model generation and problem identification before trying to find solutions. All interested parties can work with experts in choosing scenarios, models, boundary conditions and during the reconciliation loop, the validity of those choices can be tested and explored. The models can prove or disprove fixed ideas of partners about the conceptual model, provided that they are credible and reconciled with all involved. More refined modelling can then follow, if required. At that point possible solutions can be reconciled with the wishes and feelings of those affected as expressed in the qualitative analysis. Keeping people involved in qualitative analysis to modelling will save money; excluding them at any stage costs money and de-motivates the technical staff. Qualitative analysis sets the basis for the team driving the modelling rather than the modelling driving the team and the project.



3.2 *Spatial and temporal event modelling*

3.2.1 Introduction

The appeal of driving risk assessment with events of realistic temporal and spatial patterns has been demonstrated on the Taihu: the question of how to do this becomes crucial. We review potential approaches below.

3.2.2 Benefits and beneficiaries

A number of business users and benefits can be foreseen from adoption of realistic temporal and spatial patterns in event analysis for risk assessment at large scales.

Spatially aggregated risk assessment presents opportunities for a new view on economic risk assessment to support investment planning. Assessment of the probability of economic losses (or other measures of consequence) anywhere within a region, or nationally, provides a basis for planning for severe, widespread flood events that are currently ‘hidden’ within long-term averages. This type of analysis would allow consideration of the resilience of investment decisions and understanding exposure to risk of damaging widespread events, whether for an individual event or aggregated over any given year, and so on.

Realistic event-based risk assessment would allow, for the first time, scientific understanding of the effect of large-scale exposure to flood risk on emergency response planning (for example, how likely are current arrangements to ‘fail’?). This would provide information to support strategic thinking about the deployment and overall level of resources to recover from flooding, for example quantification of realistic scenarios at different levels of risk for emergency planning exercises. Beneficiaries include emergency planners, Defra and the Cabinet Office.

There is a continuing need for methods of setting inflows to catchment flood models to deal with the joint probability of multiple inflows. A consistent, scientifically well-founded method is required to set inflows probabilistically, and to include temporal sequences to allow dynamic aspects of flood management systems (such as the operation of hydraulic structures) to be represented, as has been highlighted in the broad-scale modelling of the Taihu Basin.

3.2.3 Technical background and options for solutions

Methods for generating realistic spatial and temporal rainfall

The methods used in the UK to assess hydrological sources of flood risk (NWC, 1983; Institute of Hydrology, 1999; Kjeldsen, 2007) are based on historic data. In terms of their fundamental principles, these methods continue to apply engineering design approaches developed in the 1970s (Natural Environment Research Council, 1975) and much earlier. Approaches such as flood frequency curves and unit hydrograph models were developed as localised methods, essentially treating the analysis at each location as independent in space. Thus, when we come to carry out risk assessments at the catchment scale or over wider areas, the methods currently used cannot represent the likelihood of flooding experienced in multiple localities. Yet when we look at our exposure to flood events at a large scale, there is a clear spatial dimension to the most damaging floods. This is illustrated in Figure 4.1, which shows the variation in pattern between four recent flood events in England and Wales.

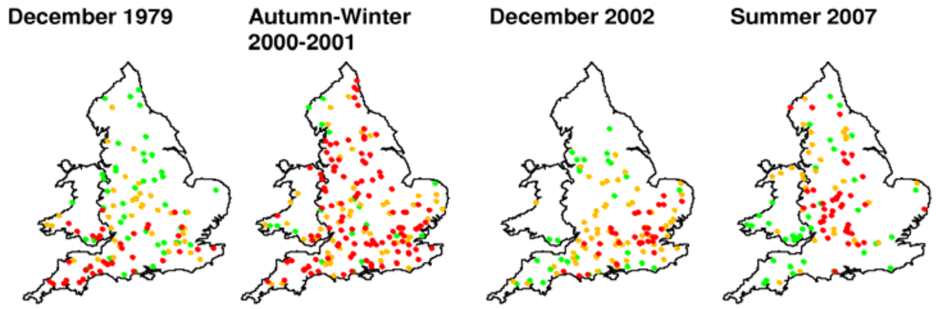


Figure 4.1. Gauged river flows for four severe, widespread flood events illustrating that no two events have the same pattern. Dots indicate gauging stations where the maximum daily mean flow for the event was within the largest 0.33% (approximately the largest 50 events for sites with a 40-year record) of daily mean flow values on record. The red dots are stations where the gauged flow was within the largest 0.033% (the largest five out of 40).

Recent developments in statistical science (Heffernan and Tawn, 2004) have made new techniques available to model the spatial structure in extremes of important sources of flood risk such as river flows, rainfall and sea surge in a way that represents important features of the observational data. The key advances here have been developments of multivariate extreme value models that can help in assessing the probability of a given hydrological event within a proper statistical framework. Methods have been developed over the past ten years or so to model temporal sequences of runoff in order to represent changes such as climate and land management (Calver *et al*., 1999, 2005), as well as the responses of complex flood management systems. This family of techniques is known in hydrology as "continuous simulation". Table 4.1 summarises the approaches.

Table 4.1: Families of methods for simulating hydrological scenarios

Method	Relevant applications
Continuous simulation methods	Simulation of temporal sequences of runoff. Inflows to model hydraulic interactions at catchment scale, such as flood storage systems. Climate or catchment change impacts modelling. Based on models for generating synthetic rainfall data, such as UKCP09 weather generator.
Multivariate extreme value methods	Modelling spatial dependence within or between variables. Statistical assessment of risk of catastrophic flooding over a region. Basin-wide event specification.

In continuous simulation methods, the emphasis has been on temporal extrapolation to generate long, realistic sequences of pseudo-weather or runoff data that conform to historical records but also include more extreme conditions than observed. Models applied in practical situations (such as Faulkner and Wass, 2005, Kilsby *et al*., 2007) have generally been spatially localised. Much research has been done to develop models that represent the spatial structure of rainfall (for example in the UK, Cowpertwait *et al*., 2002, Wheater *et al.,* 2006). It has proved difficult to capture in one model all aspects of the spatial correlation structure and temporal sequencing of rainfall patterns; indeed, this continues to be an active area of academic research internationally (Hundecha *et al.,* 2009, Zheng *et al.,* 2010). The strength of the continuous simulation approach is in dealing with features such as sequences of storm events and the operation of sluices and flood storage so that temporal variation can be factored into the risk model, rather than relying on a single storm profile (as was necessary in the Taihu study).

The continuous simulation approach means that the impacts of possible temporal changes in climate, such as changes in the seasonality of storms, can, in principle, be modelled. Defra's research project FD2113 (Defra, 2007) developed methods to do this based on spatial analysis of daily rainfall and a time-disaggregation approach. The study found that an individual climate model could not be relied on to represent properties of daily rainfall sequences relevant to flood risk, although an ensemble could be used to provide a range of rainfall properties "more or less consistent with observations". Recent research in project FD2020 (Defra, 2009) has adopted a flexible approach based on continuous simulation analysis of the sensitivity of catchments to changes in climate, including spatial and temporal patterns.

Spatial models based on the statistical theory of extremes provide the capability to model the occurrence and magnitude of sources of flooding at many locations simultaneously. The emphasis in these is on representing the spatial pattern within events, rather than long continuous sequences. In a spatial model, it is critical to represent the degree of statistical dependence between locations. Variables are statistically dependent if the observed value of one affects the likely values of the other. For flood risk, the strength of the dependence varies between variables according to factors such as distance and geology, and also with the level of extremeness. Any model should provide a theoretically sound basis for extrapolation to more extreme levels than experienced in the observations. Many studies have considered aspects of dependence in flood risk (Buishand *et al.,* 2008; Hawkes, 2008; Svensson and Jones, 2002, 2004; Tawn, 1988; Tawn and Vassie, 1989; Troutman and Karlinger, 2003) but not all of the above factors. The model developed by Keef *et al.* (2009a,b), based on Heffernan and Tawn (2004), has the flexibility to represent the range of dependence patterns seen in observations of river flows and sea surge, and provides a theoretical basis for extrapolation of spatial patterns. It has been shown to be effective in assessing the probability of flood events at large scales. The model can incorporate some aspects of temporal patterns, although this needs more work.

At a theoretical level, the two families of methods discussed here (continuous simulation and multivariate extremes) are based on closely related statistical ideas such as extreme value distributions, dependence models and Monte Carlo simulation. The way in which these basic ideas have been developed for use tends to emphasise either spatial or temporal variation. However, the commonality of basic principles suggests that it will be a combination of approaches that permits the variability in temporal and spatial patterns to be accounted for properly in risk assessments at a range of scales.

The benefits of the simulation approaches discussed above stem from representing dependencies (spatial and temporal, and between variables) within a probabilistic framework. In particular the hydraulic interactions that can influence risk within a large flood management system can be difficult to incorporate within a probabilistic analysis. Each dependency that exists with the system multiplies the number of possible system responses that must be evaluated to capture all of the contributions to the overall risk. One of the points raised by the Taihu study is that there may be links between climate or catchment change and social or economic responses. Such dependencies are difficult to incorporate into risk assessments probabilistically.

3.3 *Socio-economic issues*

3.3.1 Introduction

The Taihu project has again demonstrated the use of scenario analysis to explore the implications of future changes such as climate change and socio-economic change. Realistic modelling of potential losses leads to an understanding of the preparedness, emergency response arrangements and other non-structural measures that may be needed. Similarly, understanding annual average flood loss values gives insight into the investment needed. The relation between climate and socio-economic drivers of future flood risk is under-researched. Moreover, compared with research into climate change, that into socio-economic change has been neglected. Risk transfer to new areas is an important policy dimension.

3.3.2 Benefits and beneficiaries

Users who would benefit from increased socio-economic direct actions and research in these and related areas are those who seek to develop holistic methods of risk analysis, so that sustainable policies can be promoted. The benefits of such an approach are that policies and strategies meet the needs of the population and societies at risk. The technical background to the proposed work is a relative immaturity in this area of science, compared for example with the sciences of meteorology or hydraulics, and options for solutions involve a range of approaches including modelling, concept development, scoping and economic analysis.

3.3.3 Overview of potential actions

1. **Scenario development**. The use of scenarios in Environment Agency forward planning is not at all well developed and in parts is rudimentary (such as the LTIS scenarios which are, in effect, just budget target amounts). This situation could be improved with research to investigate the different types of scenario that have been used in cognate policy areas, followed by some trialling of a range of scenarios in Environment Agency policy development.
2. **Risk transfer and residual risk analysis.** All FCRM interventions redistribute risk. The extent of this redistribution is not well recognised in the UK, yet it is important in policy terms. Approaches and techniques need to be developed to explore explicitly this redistribution, which will involve the analysis of residual risk after interventions that change risk profiles. Issues of social justice and equity need to be factored into this analysis, building on projects that have been recently completed in the UK (FD2605 on social justice and FCRM; Defra 2008a) and projects on who benefits from FCRM investment (FD2606; Defra 2008b).
3. **Demographic change impacts, including urbanisation trends**: modelling urban development. The Taihu work has shown that population change can affect the impacts of flooding, yet this is not considered at all in UK investment and project appraisal methods. A project should investigate the nature of population change in UK floodplain and other at-risk areas, and develop datasets and modelling techniques to predict the nature of urban and demographic change.
4. **Large-scale flood events: exploring the multiplier effects**. Conventional analysis of flood risk involves quantification of potential flood impacts on a range of individual properties and the links they have within the local economy. But when one analyses the types of large-scale floods as in the Taihu Basin, it raises the hypothesis that large floods lead to impacts of a different scale, involving a longer and more extensive effect on the regional economy. Behind this is the idea that there is a multiplier effect from each individual flood loss into the wider economy. A project could usefully explore this type of multiplier, including examining in more detail this aspect of the 2007 floods in the UK.

3.4 End-to-end modelling systems for long-term, large-scale FCRM planning

3.4.1 Introduction

The Taihu project involved bringing together a system of models and datasets in order to estimate flood risk, for the present day and in the future:

- rainfall simulations in present and future climates;
- rainfall-runoff modelling;
- hydraulic modelling;
- socio-economic scenarios and modelling;
- flood defence reliability;
- analysis of vulnerability to flooding, at present and in future socio-economic scenarios.

This type of analysis is central to long-term planning of flood risk management, including climate change adaptation planning. Versions of this analysis (or parts of it) have been conducted in many settings. For example:

- The UK Foresight Future Flooding project adopted an S-P-R framework, but did not involve rainfall, runoff or hydraulic simulation.
- The NERC FRACAS project is coupling continuous simulation of rainfall and runoff with hydraulic modelling and flood defence reliability, but is not focussing upon socio-economic change.
- The TE2100 project involved rainfall-runoff modelling in the Thames catchment as well as marine climate drives, hydraulics and flood defence reliability. Subsequent Tyndall Centre research has incorporated a high resolution model of land use change. However, this has all been applied at a spatial scale smaller than the Taihu Basin.

Systems modelling needs to match the characteristics of the physical situation and decisions to be informed by the analysis. This entails the need for flexible approaches. A balance must be struck between flexibility (which implies greater technical competence in order to wisely exploit that flexibility) and usability (which implies constraining the amount of flexibility).

We focus upon end-to-end flood systems modelling because these are increasingly becoming the cornerstone of flood risk management, in particular strategic planning, including national-scale investment planning (LTIS), Catchment Flood Management Planning (MDSF2) and adaptation planning on the coast. The reasons for the prevalence of these system modelling approaches are because:

1. The models compute risk, in economic and other terms, which is needed to justify investment and asset management decisions, as well as providing risk information for the EU Floods Directive and other types of risk communication.
2. Being process-based, the models can be used to test scenarios of future change, for example due to physical interventions in the flooding system and non-structural responses. Moreover, as they are driven by climate variables (such as precipitation, sea level rise) they can be used to test scenarios of climate change.

The need for advanced tools to analyse the risks associated with long-term changes was identified in the review of broad-scale modelling by Wheater *et al.* (2007) Approaches to computing flood risk have existed for many years and a variety of studies have examined future changes in flood risk (a few were mentioned above). Indeed, the basics of risk calculations are now very well established. Thus, the actions proposed here are to do with refining what are now the central tools of flood risk management, rather than proposing a radical change of direction. However, our experience in Taihu and elsewhere has revealed important lessons about the use of end-to-end flood systems models. Here, we propose research that may address some of these outstanding issues.

3.4.2 Benefits and beneficiaries

As indicated above, flood system models have become central to the business of managing flood risk in the UK and worldwide. They provide information to inform a whole range of flood risk management decisions, from asset management decisions where maintenance resources need to be targeted in proportion to their benefits in terms of risk reduction, to flood warning decisions which are increasingly being informed by consideration of probabilities and consequences. However, our focus here is on strategic planning decisions which need to take explicit account of, and adapt to, processes of long-term change. This was the objective of the UK Foresight Future Flooding project and similarly has been the aim of the Taihu collaboration. Within the Environment Agency's work, the main classes of decision that end-to-end system modelling could be used to inform are:

- Catchment Flood Management Planning
- Shoreline Management Planning
- Urban flood risk management
- Long Term Investment Strategy
- Future generations of Foresight studies.

Flood risk modelling is already being used to inform the classes of decisions listed above. The research proposed below is not intended to radically change the way in which risk information forms part of the decision-making process. In further research we do, however, hope to achieve the following benefits:

- Greater transparency in the way in which risk calculations are constructed, enabling better scrutiny of results and transferability between teams involved in flood risk analysis.
- Greater credibility in the results from flood risk analysis. This is closely linked with the issue of transparency, as it relies on the capacity to scrutinise final and intermediate results and compare them with observed evidence.
- Greater flexibility in assembling models for particular circumstances and testing a wide range of future changes and intervention options.
- Improved accuracy, through the proper treatment of probabilistic boundary conditions and better representation of salient physical processes (where these are not already well represented).

3.4.3 Overview of potential actions

Research is already underway to address a number of the issues listed above. Within Phases 1 and 2 of the Flood Risk Management Research Consortium (FRMRC) as well as FLOODsite there have been major initiatives on uncertainty in flood risk calculations, which has led to better understanding of how these computations should be structured to improve flexibility and transparency. Research project SC090008 (Improving Probabilistic Flood Risk Modelling Capabilities Through Improved Model Validation and Reuse of Existing Models; part of the Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme) has developed a validation framework to improve the credibility of probabilistic flood models. However, we do not believe that the benefits outlined above have yet been fully realised. Doing so requires sustained research. In the following recommendations we seek to build upon recent and ongoing initiatives.

1. **LTIS improvements.** A central need for the Environment Agency is to improve modelling behind the Long Term Investment Strategy (LTIS) in the speed of analysis, types of interventions that can be implemented, scope of scenarios that can be analysed and metrics of consequence, together with a clear grasp of the level of confidence in the outputs. This will allow more time for interpretation, more analysis of interventions, and in this regard more attention on assessing the factors that most influence the results in a systematic way.
2. **Probabilistic boundary conditions: getting the most out of continuous simulation and multi-variate event-based approaches**. Major improvements have been made in recent years, in continuous simulation of rainfall and flow and in the spatial statistics of extremes. Understanding the ways in which these two approaches should in future be combined for broad-scale flood risk analysis needs to be improved.
3. **Risk models: flexibility versus usability.** Flood risk analysis is carried out with a combination of Environment Agency tools (NaFRA, MDSF and so on), commercial tools that have increasing capacity for risk calculations, and custom-build systems that are assembled for particular localities. The Taihu project falls into the latter of these categories. Can we develop more systematic understanding of the circumstances in which these approaches are best used? We propose a review of approaches to help reinforce the Environment Agency's modelling strategy with regard to flood risk.

4 Knowledge transfer: potential actions

The actions for knowledge transfer encompass all the key lessons outlined in the previous sections and range from producing good practice manuals to improving current UK practice, to applied research and development into the end-to-end modelling for long-term large-scale planning (LTIS, CFMP, SMPS and improving existing tools and techniques such as RASP, MDSF2 and FACET), and more basic research on social and hydrological topics.

In order to formulate a cost-effective and streamlined programme of work, we group the key knowledge transfer actions under three categories:

Short-term actions for immediate benefits, by incorporating the practical lessons learned in the course of the Taihu project into UK practice. The outputs would be in the form of information sheets setting out key principles rather than in-depth analysis of what should/shouldn't be done. They may need some short-term reviews, minor refinement and guidance. The sheets are relatively low budget and could be commissioned and implemented quickly.

Development to bring benefits in the medium term by improving the tools and techniques used in national strategies such as LTIS (FACET) and other large-scale plans such as CFMPs, SMPs (MDSF2) and national risk assessment studies such as NaFRA (RASP). This would boost the efficiency of long-term and large-scale FCRM planning and investment studies by making them faster and more inclusive of wider social and economic issues.

Research to provide benefits in the medium to long term - one key lesson from Taihu is the value of simulating realistic spatial and temporal event patterns. To do this properly, however, the underlying science must be further developed and tested for practical business application. Research and applied development will improve the underlying probabilistic methods to enable a move to continuous simulation and event-based modelling, with huge benefits outlined in the preceding sections arising from a better understanding of long-term large-scale extreme risk.

Although the actions, development and research would led by different groups, there is great advantage in carrying these out within an integrated framework, with the research councils and the Environment Agency's FCRM Business functions and R&D programme acting in partnership.

Another important consideration is timeliness. It is not sufficient to ask users and those affected by flooding to wait for years while researchers perfect a new method. We have pioneered in a number of projects, such as PAMS and the original MDSF1, the concept of "parachuting down" best practice to users as early as possible. Many of the lessons learnt from Taihu could be implemented quickly. Improving project planning, for instance, does not need further work.

The three groups of actions are summarized in the following tables. We have given indicative effort expressed as resource days required and overall duration but do not suggest any overall time-scale for the programme or delivery mechanism.

The resulting projects are described in thumbnail project descriptions in Appendix 2.

4.1 Benefit realisation in the short-term

Ref	Title	Lessons learnt from Chinese Foresight Project	Scope for knowledge transfer action	FTE days and dur'n
1.1	Guidance on qualitative analysis and links to modelling	Qualitative analysis can be a high quality evidence-based tool using all available data. Avoid moving to modelling too quickly, locking in past assumptions and prevailing thinking. Instead, adopt appropriate pre-modelling screening analysis.	The process of qualitative analysis, partner involvement. Identification of system drivers, FCRM options, uncertainties in conceptual models. How these can be put into broad-scale or more refined models.	10 days 3 mths
1.2	Guidance on sustainability analysis	The danger that well-intended intervention measures or policy instruments can have unintended consequences.	How sustainability analysis should be carried out within the context of FCRM.	10 days 3 mths
1.3	Guidance on efficient modelling procedures	Hydrodynamic modelling can be used at a regional scale. The Taihu suggests that this is feasible and should be considered when designing modelling for large areas.	Procedures for efficient modelling of flood risk systems, with a focus on broad-scale modelling for LTIS, strategic FCRM.	10 days 3 mths
1.4	Guidance on scenario development	The Taihu project has again demonstrated the use of scenario analysis to explore the implications of future changes.	Developing guidance for the more systematic use of scenarios in FCRM planning.	90 days 6 mths

4.2 Benefit realisation in the medium-term

The LTIS has become a key tool in national FCRM investment planning. The improvements needed to transfer the Taihu lessons have been grouped into a small cluster of potential projects or sub-projects. These will benefit other large-scale planning studies, and will bring benefits to the efficiency of future large-scale FCRM planning and investment studies by making them faster and more inclusive of wider social and economic issues.

Ref	Title	Lessons learnt from Chinese Foresight Project	Scope for knowledge transfer action	FTE days and dur'n
2.1	Accelerating risk assessment engines used in LTIS	TBRAS runs much faster than RASP. We need to speed up the models in LTIS to widen analyses that can be run.	Identify ways of improving the speed of LTIS risk analysis by an order of magnitude whilst not unduly sacrificing accuracy.	150 days 1 yr

2.2	Enhancing the modelling of interventions/ responses	An important lesson for LTIS is the modelling of interventions.	Enhance modelling of FCRM responses in the models behind the LTIS so that policy choices are better represented	150 days 1 yr
2.3	Enhance the modelling of (spatial) socio-economic scenarios and consequences	Changing spatial patterns of vulnerability are one of the main determinants of future flood risk.	Develop ways of simulating demographic and urban change in the model behind LTIS and in RASP systems so that they are more realistic in characterisations of the future.	150 days 1 yr
2.4	Risk transfer and residual risk analysis	One feature highlighted by Taihu is the transfer of risk from around the Taihu Lake area to other areas.	Develop methods to assess risk transfer, including social justice and efficiency and the contribution of governance issues, Add a GIS element to show the effect on risk reduction and risk transfer of different responses.	90 days 6 mths
2.5	Large-scale flood events: exploring the multiplier effects	Large-scale floods may have impacts of a different scale, with a longer and more extensive effect on the regional economy.	Develop methods and data to determine if there are "step changes" in the impacts from major floods as opposed to those that affect a small number of properties or communities	150 days 1 yr

4.3 Benefit realisation in the medium to long-term.

One key lesson from Taihu is the value of simulating realistic spatial and temporal event patterns. To do this properly, however, the underlying science must be further developed and applied. We have grouped the proposed work into two projects.

Ref	Title	Lessons learnt from Chinese Foresight Project	Scope for knowledge transfer action	FTE days and dur'n
3.1	Increase the utility of event analysis in long-term capacity planning	Understanding potential losses leads to a better grasp of emergency responses and other measures needed. It also answers such questions as "what would happen if we got another event like 2007 but bigger?"	Improve modelling of events from RCMs and catchment or flood-defence system changes. Build multivariate approaches for event specification and develop hybrid temporal/spatial approaches. Show applicability with case studies from, flood incident planning or emergency planning for example.	200 days 18 mths
3.2	Build realistic hydrological scenarios and alter these to account for		Improve modelling of spatio-temporal patterns of change in extreme events. Tools to enable realistic hydrological scenario development, particularly for use	200 days 18 mths

	environmental change		in probabilistic flood risk modelling	

4.4 Conclusion

The Chinese Taihu project was a follow-up to the 2004 UK Foresight Future Flooding project, and was designed to transfer the technology to China. In the event, different scientific and cultural approaches and novel thinking from researchers new to the concepts have lead to new or different ways of doing things.

We have shown that there are valuable lessons to be learnt for the UK. We hope that this report will help in transferring these to the UK and realising their benefits.

References

Arnell, N.W. and Chatterton, J. (2007) Reducing flood losses. In Thorne, C.R., Evans, E.P. and Penning-Rowsell, E. (Eds*.), Future Flooding and Coastal Erosion Risks*. London: Thomas Telford.

Buishand, T. A., de Haan, L. and Zhou, C. (2008) On spatial extremes: With application to a rainfall problem. *Annals of Applied Statistics* 2, 624–642.

Calver, A., Lamb, R. and Morris, S.E. (1999) River flood frequency estimation using continuous runoff modelling. *ICE Proceedings, Water Maritime and Energy* 136, 4 (12), 225-234. doi:10.1680/iwtme.1999.31986

Calver, A., Crooks, S., Jones, D. Kay, A., Kjeldsen, T. and Reynard, N. (2005) *National river catchment flood frequency method using continuous simulation modelling*. R&D Technical Report FD2106/TR, Department for Environment, Food and Rural Affairs, London, UK.

Carter, T.R., Parry, M.L., Harasawa, H. and Nishioka, S. (1994) *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations*. Geneva: Intergovernmental Panel on Climate Change.

Chen, L.X., Li, W.L., Zhu, W.Q., Zhou, X.J., Zhou, Z.J. and Liu, H.L. (2006) Seasonal trends of climate change in the Yangtze Delta and its adjacent regions and their formation mechanisms. *Meteorology and Atmospheric Physics* 92(1-2), 11-23.

Chen, X. and Zong, Y. (1999) Major impacts of sea-level rise on agriculture in the Yangtze delta area around Shanghai. *Applied Geography* 19(1), 69-84.

Cooke, R.M. (1991) Experts in Uncertainty: Opinion and Subjective Probability in Science. New York: Oxford University Press.

Cowpertwait, P.S.P., Kilsby, C.G. and O'Connell, P.E. (2002) A space-time Neyman-Scott model of rainfall: Empirical analysis of extremes. *Water Resources Research*, 38. 1131-1145

Crosetti, M. and Fuller, R. (2006) The World Bank/GGFR Indonesia Associated Gas Survey – Screening & Economic Analysis Report. PA Consulting Group.

Department of the Environment, Transport and Regions, Environment Agency, Institute for Environment and Health (2000) *Guidelines for environmental risk assessment and management*. The Stationery Office, London.

Defra (2005) Making space for water. Taking forward a new Government strategy for flood and coastal erosion risk management in England. Defra, London

Defra (2006) *Flood and Coastal Defence Appraisal Guidance*. FCDPAG3 Economic Appraisal. Supplementary Note to Operating Authorities – Climate Change Impacts.

Defra (2007) *Spatial-temporal rainfall modelling with climate change scenarios*. R&D Technical Report FD2113/TR. Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme

Defra (2008a) Social Justice in the Context of Flood and Coastal Erosion Risk Management: A Review of Policy and Practice. R&D Technical Report FD2605/TR. Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme

Defra (2008b) Who Benefits from Flood Management Policies? R&D Technical Report FD2606/TR. Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme

Defra (2009) *Regionalised Impacts of Climate Change on Flood Flows*. R&D Technical Report FD2020/TR. Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme

Djen, C.S. (1992) The urban climate of shanghai. *Atmospheric Environment* 26B(1), 9-15.

Dixon, J.M., Tawn, J.A. and Vassie, J.M. (1998) Spatial modelling of extreme sea-levels. *Environmetrics*, 9, 283-301.

Environment Agency (2004) Risk Assessment of Flood and Coastal Defence Systems for Strategic Planning (RASP). R&D Technical Report W5B-030/TR by HR Wallingford.

Environment Agency (2009a) Investing for the future. Flood and coastal risk management in England: A long-term investment strategy.

Environment Agency (2009b) Flooding in Wales: A national assessment of flood risk.

Environment Agency (2009c) *MDSF2 Detail System Design Report*. SC050051/SR3.

Environment Agency (2010) *Broad-Scale Modelling and Scenario Analysis for Long-Term Large-Scale Planning - Knowledge Transfer from Chinese Flood Foresight Project. Interim Report: Review and Lessons Learned*. R&D Project SC090034.

Evans, E.P., Ashley, R., Hall, J., Penning-Rowsell, E., Sayers, P., Thorne, C. and Watkinson, A. (2004) *Foresight Future Flooding*, Volume I and Volume II. Office of Science and Technology, London.

Evans, E.P., Wicks, J.M., Whitlow, C.D. and Ramsbottom, D.M. (2007) The evolution of a river modelling system. *Proc ICE, Water Management* 160, 3-13.

Evans, E.P., Simm, J.D., Thorne, C.R., Arnell, N.W., Ashley, R.M., Hess, T.M., Lane, S.N., Morris, J., Nicholls, R.J., Penning-Rowsell, E.C., Reynard, N.S., Saul, A.J., Tapsell, S.M., Watkinson, A.R. and Wheater, H.S. (2008) *An update of the Foresight Future Flooding 2004 qualitative risk analysis.* Cabinet Office, London.

Faulkner, D. and Wass, P. (2005) Flood estimation by continuous simulation in the Don catchment, South Yorkshire, UK. *Journal of the Chartered Institution of Water and Environmental Management*, 19(2), 78-84.

Gaffin, S.R., Rosenzweig, R.C, Xing, X. and Yetman, G. (2004) Downscaling and geo-spatial grid of socioeconomic projections from the IPCC Special Report on Emissions Scenarios (SRES). *Global Environmental Change*, 105, 1233.

Green, C.H. and Penning-Rowsell, E.C. (2007) Socio-economic drivers, cities and science. In*: Future Flooding and Coastal Erosion Risks*, Thorne, C.R., Evans, E.P. and Penning-Rowsell, E. (Eds.). Thomas Telford: London.

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

Harvey, G., Thorne, C., Cheng, X., Evans, E., Han, S., Simm, J. and Wang, Y. (2009) Qualitative analysis of future flood risk in the Taihu Basin, China. *J Flood Risk Management*, 2, 85-100.

Hawkes, P.J. Gonzalez-Marco, D. Sanchez-Arcilla, A. and Prinos, P. (2008) Best practice for the estimation of extremes: A review. *Journal of Hydraulic Research*, 46 (2). 324-333.

Heffernan J.E. and Tawn J.A. (2004) A conditional approach for multivariate extreme values (with discussion). *J. R. Statist. Soc. B*, 66, 497-546.

HM Treasury (2003) The green book: appraisal and evaluation in central Government. HM Treasury, London.

Hulme, M., Jenkins, G.J., Lu, X., Turnpenny, J.R., Mitchell, T.D., Jones, R.G., Lowe, J., Murphy, J.M., Hassell, D., Boorman, P., McDonald, R. and Hill, S. (2002) *Climate Change Scenarios of the United Kingdom: The UKCIP02 Scientific Report.* Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK. 120pp.

Hundecha, Y., Pahlow M. and Schumann, A. (2009) Modelling of daily precipitation at multiple locations using a mixture of distributions to characterize the extremes. *Water Resources Research*, 45, W12412. doi:10.1029/2008WR007453

Institute of Hydrology (1999) *Flood Estimation Handbook*. Institute of Hydrology: Wallingford.

IPCC (2007) Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

Jenkins, G.J., Murphy, J.M., Sexton, D.S., Lowe, J.A., Jones, P. and Kilsby, C.G. (2009) *UK Climate Projections: Briefing report*. Met Office Hadley Centre, Exeter, UK.

Jones, R.G., Noguer, M., Hassell, D.C., Hudson, D., Wilson, S.S., Jenkins, G.J. and Mitchell, J.F.B. (2004) *Generating high resolution climate change scenarios using PRECIS.* Met Office Hadley Centre, Exeter, UK.

Junfeng, G., Lorenx, K., Tong, J. and Wang, R. (2003) Flood risk analysis and flood potential losses assessment. *Chinese Journal of Oceanology and Limnology* 21(1), 1-9.

Keef, C., Tawn, J. and Svensson, C. (2009a) Spatial risk assessment for extreme river flows. *Applied Statistics* 58(5), 601-618.

Keef, C., Svensson, C. and Tawn, J.A. (2009b) Spatial dependence in extreme river flows and precipitation for Great Britain. *Journal of Hydrology*, 378(3-4), 240-252.

Kilsby, C.G., Jones, P.D., Burton, A.A., Ford, C., Fowler, H.J., Harpham, C., James, P., Smith, A. and Wilby, R.L. (2007) A daily Weather Generator for use in climate change studies. *Environmental Modelling and Software*, 22, 1705-1719.

Kjeldsen, T; Surendran, S (2007) Revitalised flood estimation research. Flood and Coastal Erosion Risk Management R&D Research News (12). 13-14.

Liang, X., Lettenmaier, D.P., Wood, E.F. and Burges, S.J. (1994) A simple hydrologically based model of land surface water and energy fluxes for general circulation models. *Journal of Geophysical Research*, 99(D7), 14415-14428.

Lin, Z.X. (2002) Construction of flood control engineering and Disaster Reduction Policy in Taihu Basin. *Science of Lakes* 14(1), 12-18.

MAFF (1999) Flood and coastal defence project appraisal guidance (3): economic appraisal (FCDPAG3).MAFF, London.

National Development and Reform Commission (2007) *China's National Climate Change Programme.* People's Republic of China

Natural Environment Research Council (1975) *Flood Studies Report* (in five volumes). Natural Environment Research Council: London.

Nienhuis, P.H. and Leuven, R.S.E.W. (2001) River restoration and flood protection: controversy or synergism? *Hydrobiologia,* 444, 85-99.

NWC (1983) Design and analysis of urban storm drainage, The Wallingford Procedure, Standing Technical Paper No 28, National Water Council, 173pp, ISBN 0901090 271

OECD (2002). Frascati Manual. Proposed Standard Practice for Surveys on Research and Experimental Development.

Office of Science and Technology (2002) *Foresight Futures 2020: Revised Scenarios and Guidance.* Office of Science and Technology, London.

Office of Science and Technology (2004) *Foresight Future Flooding. Executive Summary.* OST, London.

Petts, G.E. (1980) Implications of the fluvial process-channel morphology interaction below British reservoirs for stream habitats. *Science of the Total Environment,* 16, 149-163.

Rapport, D. and Friend, A. (1979) *Towards a comprehensive framework for environmental statistics: a stress-response approach*. Statistics Canada Catalogue 11-510. Ottawa: Minister of Supply and Services Canada.

Shi, P., Ge. Y., Yuan, Y. and Guo, W. (2005) Integrated Risk Management of Flood Disasters in Metropolitan Areas of China. *Water Resources Development,* 21(4), 613-627.

Surendran, S., Linford, T., Evans, E., Mcgahey, C., Sayers, P. and Wicks, J. (2008) System-based risk modelling and decision support for the UK's catchment, coastal and estuary flood management planning. *Forty-second Environment Agency/Defra FCRM Conference*, Manchester University, 1-3 July 2008.

Surendran, S., Evans, S., Benn, J., Heron, E., Jackson, V. and Marks, K. (2009) *Modelling and Risk Theme Review, Vision and Work Plan*. Update summary (September 2005 - March 2009). http://evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Documents/marworkplan.sflb.ashx

Svensson C and Jones D.A. (2002) Dependence between extreme sea surge, river flow and precipitation in eastern Britain, *International Journal of Climatology* 22, 1149–1168.

Svensson C and Jones D.A. (2004) Dependence between sea surge, river flow and precipitation in south and west Britain, *Hydrology and Earth System Sciences* 8 (5), 973–992.

Taihu Basin Authority (2001) The 1999 flood in the Taihu Basin.

Tawn J.A (1988) An extreme value theory model for dependent observations. *Journal of Hydrology* 101 pp 227–250.

Tawn, J.A. and Vassie, J.M. (1989) Extreme sea levels: the joint probabilities method, revisited and revised. *Proceedings of the Institution of Civil Engineers,* Part 2, 87, 429-442.

Thorne, C.R., Evans, E.P. and Rabbon, P. (2008) *Flood Foresight USA: Scoping Document*. Report to the UK Department for Innovation, Universities and Skills, UK Government Office for Science, UK Foreign and Commonwealth Office, and US Army Corps of Engineers, University of Nottingham, UK, 23p.

Troutman, B.M., and Karlinger, M.R. (2003) Regional flood probabilities: *Water Resources Research*, 39, 1095-1110.

Turner, R.K., Lorenzoni, I., Beaumont, N., Bateman, I.J., Langford, I.H. and McDonald, A.L. (1998) Coastal management for sustainable development: analysing environmental and socioeconomic changes on the UK coast. *Geographical Journal*, 164, 269-281.

Vick, S.G. (2002) Degrees of Belief: Subjective Probability and Engineering Judgement. Reston VA: ASCE Press.

Wheater, H.S., Isham, V.S., Chandler, R.E., Onof, C.J., Stewart, E.J., Bellone, C., Yang, C., Lekkas, D., Lourmas, G., Segond, M-L., Frost, A.J., Prudhomme, C., Crooks, S. (2006) *Improved methods for national spatial temporal rainfall and evaporation modelling for BSM*. Technical Report FD2105/TR, Defra, London

Wheater, H.S., Beven, K., Hall, J.W., Pender, G., Butler, D., Calver, A., Djordjevic, S., Evans, E.P., Makropoulos, C., O'Connell, P.E., Penning-Rowsell, E.C., Saul, A., Surendran, S., Townend, I.H., Watkinson, A.R. (2007). *Broad-Scale Modelling. Scoping a Vision for Flood Modelling and Risk Science.* Technical Report FD2118/TR. Defra, London.

Wood, E. F., Lettenmaier, D.P. and Zartarian, V.G. (1992) A land surface hydrology parameterization with sub-grid variability for general circulation models. *Journal of Geophysical Research*, 97(D3), 2717-2728.

Xu, Y.-S., Shen, S.-L., Cai, Z.-Y. and Zhou, G.-Y. (2008) The state of land subsidence and prediction approaches due to groundwater withdrawal in China. *Natural Hazards* 45, 123-135.

Xue, B., Yao, S. and Xia, W. (2007) Environmental changes in Lake Taihu during the past century as recorded in sediment cores. *Hydrobiologia*, 581, 117-123.

Zhang, Y., Xue, Y.-Q., Wu, J.-C., Ye, S.-J., Wei, Z.-X., Li, Q.-F. and Yu, J. (2007) Characteristics of aquifer system deformation in the Southern Yangtze Delta, China. *Engineering Geology,* 90,160-173.

Zheng, X., Renwick, J. and Clark, A. (2010) Simulation of multisite precipitation using an extended chain-dependent process. *Water Resources Research*, 46, W01504, doi:10.1029/2008WR007526

Zong, Y.Q. and Chen, X.Q. (1999) Typhoon hazards in the Shanghai area. *Disasters* 23(1), 66-80.

Appendix 1: Project objectives

Objective 1: To review the Chinese and US Foresight methods, models and processes, and draw out lessons for the Environment Agency and its partners for the future development / improvement of the Environment Agency's Tools and Techniques for scenario based broad-scale modelling for the FCRM long term large scale planning and investment.

Objective 2: To conduct a technical / user workshop to disseminate the output from the above review / lessons learnt activities. Consult to identify what and how this know-how could be transferred to long-term large scale planning (investment planning, strategic policy planning, land use planning) in the UK and the EA in particular.

Objective 3: To recommend how to transfer the above knowledge into the Agency's own tools and techniques (such as RASP, NaFRA, MDSF2, FACET and other tools and techniques under development within the Joint Environment Agency / Defra FCERM R&D programme) for long term large scale planning and investment.

Objective 4: To scope future research and development needs related to long term large scale planning for strategic policy and investment decisions.

Appendix 2: Project summaries

Ref 1.1	Title: Guidance on qualitative analysis procedures and links to modelling procedures
Objective(s)	Production of a guidance to explain the process of qualitative analysis, how partners are involved in the development of conceptual model(s) and working with experts to agree how these should, if necessary, be implemented in broad-scale or more refined models. It should explain how scenario analysis is used in this process and how extreme and exceptional events should be taken into account as well as more likely scenarios.
Benefits and beneficiaries	Benefits: overall approach to developing solutions is more coherent; resulting modelling is targeted and carried out at an appropriate degree of granularity/complexity. Beneficiaries: Practitioners involved in flood risk analysis and management at a range of spatial scales.
Background and scientific context	Qualitative analysis need not be inferior to quantitative methods and can be a high quality analysis when based on reliable data, which wherever possible is quantitative. Involving all interested parties in this process is vital not just to be seen to be fair and accountable but to ensure that valuable information and opinions are brought into the thinking process. The conclusions can provide a credible evidence base on which to make decisions, even without subsequent quantitative flood systems analysis. The process avoids moving to modelling too quickly or allowing teams to be locked into past assumptions and prevailing thinking. One of the roles of the expert elicitation process is to provide a pre-modelling screening analysis and allow the form of any subsequent modelling to be identified.
Outline work programme	1. Scoping the project 2. Analysis of components and process of qualitative analysis, involving stakeholders and experts 3. Production of draft contents 4. Review of draft contents by stakeholders 5. Production of final guidance
Outputs	Guidance manual
Key linkages	Scenario analysis; broad-scale modelling
Duration	Three months
Indicative effort (FTE days)	10 days

Ref 1.2	Title: Guidance on sustainability analysis
Objective(s)	Production of a guidance which sets out how sustainability analysis should be carried out in the context of flood and coastal erosion risk management. The role and importance of feedback mechanisms should be described and how a range of scenarios can be used to assess intervention measures for their impact on flood risk, social justice, environmental quality, cost-effectiveness and precaution, identifying any examples of unintended consequences. The document should not supplant procedures for Treasury Green Book-based project appraisal and Environmental Impact Assessment, but should set out guiding principles, together with examples of how these might be implemented in practice.
Benefits and beneficiaries	Benefits: overall approach to finding solutions is more coherent; solutions with undesirable feedback mechanisms are avoided. Beneficiaries: Practitioners involved in flood risk analysis and management at a range of spatial scales.
Background and scientific context	There is a danger of well-intended intervention measures or policy instruments having unintended consequences. This was starkly evident when assessing the complex and interconnected nature of the flood system in the Taihu Basin. Sustainability analysis provides an approach to assess these and all other aspects of sustainability, embracing existing appraisal procedures, allowing for feedback mechanisms and examining the impact of intervention measures across a range of scenarios.
Outline work programme	1. Scoping the project 2. Analysis of components and process of qualitative analysis, involving stakeholders and experts 3. Production of draft contents 4. Review of draft contents by stakeholders 5. Production of final guidance
Outputs	Guidance document
Key linkages	Scenario analysis;
Duration	Three months
Indicative effort (FTE days)	10 days

Ref 1.3	*Guidance on efficient modelling procedures*
Objective(s)	Production of a guidance on procedures for efficient modelling of flood risk systems, with a focus on broad-scale modelling for strategic flood and coastal risk management. The manual should provide a set of principles and an overall process flowchart. More detailed guidance should be provided on specific areas including: designing the modelling system to meet project needs (as informed by qualitative analysis), choosing modelling approaches, use of nested models and validation procedures. The overall aim of the guidance should be to improve the efficiency and value of the modelling components of projects.
Benefits and beneficiaries	Benefits: more efficient, fit-for-purpose modelling to better support flood and coastal risk management strategies. Beneficiaries: Practitioners involved in flood risk analysis at a range of spatial scales.
Background and scientific context	Significant sums of money are spent on the modelling components of many strategy projects but in many cases best value is not obtained from the modelling; for example, time overruns in the modelling may mean that the modelling cannot be used to help optimise proposed interventions. Development and use of targeted guidance on efficient modelling procedures would improve the modelling process and benefit flood and coastal risk management.
Outline work programme	1. Scoping the project, including review of perceived failings in sample modelling projects to help target areas where guidance may be most needed 2. Develop guidance material building from existing documentation where appropriate 3. Production of draft contents 4. Review of draft contents by stakeholders 5. Production of final guidance
Outputs	Guidance document
Key linkages	Qualitative analysis
Duration	Three months
Indicative effort (FTE days)	10 days

Ref 1.4	*Title: Scenario development*
Objective(s)	Developing thinking in Defra/Environment Agency on the more systematic use of scenarios in FCERM planning. Develop guidance on producing and using internally consistent scenarios that combine human (social, economic, geographical) and natural (climate, hydraulic) changes and the dependencies between them for use in FCRM policy and strategy development. To understand and realistically represent dependencies and links between social, economic and physical (climate and catchment change) scenarios.
Benefits and beneficiaries	Benefits: Greater analysis and insight into the nature of futures as a context to FCERM policy-making and investment planning. Beneficiaries: Environment Agency and Defra policy-makers.
Background and scientific context	The use of scenarios in Environment Agency forward planning is not at all well developed and in parts is rudimentary (LTIS scenarios are, in effect, just budget target amounts). This situation could be improved with R&D to investigate the different types of scenario used in cognate policy areas, followed by some trialling of a range of scenarios in Environment Agency planning.
Outline work programme	1. Review of the use of scenarios nationally and internationally 2. Consultation with policy-makers on the use of different types of scenario 3. Consultation with other stakeholders 4. Trial of recommended scenarios/methods 5. Conclusions/reporting
Outputs	Research report
Key linkages	To be determined
Duration	Six months
Indicative effort (FTE days)	90 days

Ref 2.1, 2.3, 2.3	*Title: LTIS modelling improvements*
Objective(s)	To improve LTIS modelling in three respects: 1. Improve the speed of analysis, enabling a wider range of scenarios and options to be analysed. 2. Broaden the range of structural and non-structural measures that can be analysed in LTIS. 3. Extend the scope of scenarios (including climate and socio-economic) scenarios that can be analysed and extend the analysis of consequences.
Benefits and beneficiaries	Benefits: More flexible analysis of long-term risks and the benefits of flood risk management, including structural and non-structural measure, to inform long-term investment planning. Beneficiaries: Environment Agency and Defra policy-makers
Background and scientific context	The Environment Agency's Long Term Investment Strategy has been a remarkable achievement in using national-scale risk analysis to provide the evidence for capital investment in flood risk management. It has been assembled as an operational tool and has successfully generated high impact results. In the process of conducting the first generation LTIS analysis a number of important areas for further research and development have been identified. The Taihu work has shown that population change can affect the impacts of flooding, yet this is not considered at all in UK investment and project appraisal methods. This R&D project should also investigate the nature of population change in UK floodplain and other at-risk areas, and develop datasets and modelling techniques to predict the nature of urban and demographic change in the future.
Outline work programme	1. Scope the project though review of LTIS and related initiatives. Prioritisation of development needs. 2. Analyse run-times. Identify and test modifications that will speed up run-times without unduly sacrificing accuracy. 3. Scope range of structural and non-structural options that may be tested. Develop flexible methods to introduce these options. 4. Scope range of required scenarios (including climate and socio-economic). Develop flexible methods to introduce these scenarios. 5. Test and implement new methods for broader analysis of the consequences of flooding, including business interruption and risk to people. 6. Develop prototype new model. 7. Consult with end users. 8. Develop final new model
Outputs	Enhanced model(s)
Key linkages	To be determined
Duration	Two years overall
Indicative effort (FTE days)	150 days (improved speed) + 150 days (broader range of options) + 150 days (scenarios and consequence metrics).

Ref 2.4	*Title: Risk transfer and residual risk analysis*
Objective(s)	Developing methods by which to assess risk transfer as a result of FCERM investment decisions, including social justice and efficiency aspects
Benefits and beneficiaries	Benefits: Greater insight into the redistribution of risk and residual risk with FCERM investment. Beneficiaries: Environment Agency and Defra policy-makers; those working in local and regional flood and coastal risk management.
Background and scientific context	All FCERM interventions redistribute risk. The extent of this redistribution is not well recognised in the UK, yet it is important in policy terms. Approaches and techniques need to be developed to explore this redistribution, which will involve the analysis of residual risk after interventions that change risk profiles. Issues of social justice and equity need to be factored into this analysis, building on projects recently completed in the UK (FD2605: social justice and FCERM; Defra 2008a) and past and current projects on who benefits from FCERM investment (FD 2606; Defra 2008b).
Outline work programme	1. Review of existing literature 2. Scoping of the project 3. Investigation of a selection of Environment Agency PARs and post-project results 4. Consultation with regional FCERM stakeholders 5. Synthesis of results/reporting
Outputs	Research report with an analysis of policy implications
Key linkages	To be determined
Duration	Six months
Indicative effort (FTE days)	90 days

Ref 2.5	*Title: Large-scale flood events: exploring the multiplier effects*
Objective(s)	Developing methods and data by which to determine if there are "step changes" in the impacts from major floods as opposed to those that affect a small number of properties/communities.
Benefits and beneficiaries	Benefits: a better assessment of the full benefits of investment in FCERM. Beneficiaries: Environment Agency and Defra policy-makers; those working in local and regional flood and coastal risk management.
Background and scientific context	Conventional analysis of flood risk involves the quantification of potential flood impacts on a range of individual properties and the links they have within the local economy. But when one analyses the types of large-scale flood events as in the Taihu Basin, it raises the hypothesis that large floods lead to impacts of a different scale, involving a more extensive effect on the regional economy. Behind this hypothesis is the idea that there is a multiplier effect from each individual flood loss into the wider economy. An R&D project could usefully pursue this type of multiplier, examining in more detail this aspect of the 2007 floods in the UK.
Outline work programme	1. Review major flood impacts in the UK (2000; 2007) 2. Review literature on multiplier effects 3. Examine possible "step changes" in impacts in the major UK and European flood events 4. Consult stakeholders and those with experience of major floods (Environment Agency response teams for example) 5. Develop multiplier model of flood impacts 6. Test model (2007 floods; 1997 Polish floods) 7. Consult stakeholders again 8. Refine model and make it user friendly and accessible 9. Consult end users 10. Report
Outputs	Multiplier model and research report
Key linkages	To be determined
Duration	One year
Indicative effort (FTE days)	150 days

Ref 3.1	*Title. Increasing the utility of event analysis in long-term capacity planning*
Objective(s)	Modelling spatial and temporal events with climate and catchment or flood-defence system changes. Demonstration of applicability through case examples relevant to flood incident planning and emergency planning.
Benefits and beneficiaries	Flood incident, emergency and investment planning
Background and scientific context	Needed to increase the utility of event analysis in long-term capacity planning in addition to average annual damages for investment planning. Analysis of changes in spatial patterns and temporal sequences has only been partially applied, sometimes crudely, in existing methods. However, changes in spatial and temporal patterns are important in determining large-scale assessment of risk.
Outline work programme	1. Identify conceptual approach to incorporate climate and flood system changes in event scenarios, drawing on continuous simulation and multivariate extremes methods. 2. Demonstrate application of changes driven by RCM outputs. 3. Demonstrate application of changes in flood management systems, such as defence performance. 4. Reporting. 5. Specification of methodology for application in practice.
Outputs	Technical reporting, demonstration study and methodology proof of concept.
Key linkages	Climate adaptation, impacts studies
Duration	18 months
Indicative effort (FTE days)	200 days

Ref 3.2	*Title. Developing realistic hydrological event scenarios and modifying these to account for environmental change*
Objective(s)	To make methods for realistic spatial and temporal hydrological scenario development accessible and useable in flood risk management practice.
Benefits and beneficiaries	Greater accessibility of technical methods for practitioners. Use for current and future scenarios in emergency planning, strategic planning and options appraisal.
Background and scientific context	Extensive work on continuous simulation (FD2104, FD2105, UKCP09 Weather Generator, FRACAS) and spatial extreme value statistics (SC060088). Whilst methods for producing realistic spatial and temporal hydrological scenarios are evolving at a research level, the use of these scenarios in practice depends on access to tools that can generate data to be used in probabilistic flood modelling methods for risk assessment. These tools should comprise technical methods, implementations in software, supporting data and guidance. The tools do not yet exist, limiting the capability of flood risk management to benefit from the advances in scientific methodology.
Outline work programme	Review of method statements. Production of algorithms, prototype codes and supporting data. Production of guidance.
Outputs	Algorithm statements, code templates, supporting data and guidance suitable for implementation by well-qualified practitioners.
Key linkages	RASP, NaFRA, MDSF2
Duration	Two years
Indicative effort (FTE days)	200 days

We are The Environment Agency. It's our job to look after your environment and make it **a better place** – for you, and for future generations.

Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

The Environment Agency. Out there, making your environment a better place.

Published by:

Environment Agency
Horizon House
Deanery Road
Bristol, BS1 5AH
Tel: 0870 8506506
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk

Would you like to find out more about us, or about your environment?

Then call us on

08708 506 506* (Mon-Fri 8-6)

email

enquiries@environment-agency.gov.uk

or visit our website

www.environment-agency.gov.uk

incident hotline 0800 80 70 60 (24hrs)
floodline 0845 988 1188

* Approximate call costs: 8p plus 6p per minute (standard landline).
Please note charges will vary across telephone providers

Environment first: This publication is printed on recycled paper.