Section 2

Knowing when and where it will flood

This section covers:

- taking an overview of risk; and
- forecasting, modelling and mapping.

Taking an overview of risk

This chapter examines how the risk of flooding is managed, now and in future. It contains sections on:

- climate change impacts; and
- managing risks strategically.

Introduction

3.1 This chapter looks at how our climate is changing and how this affects flood risk management now and in the future. We explore the need for strong central and local government leadership on adapting to climate change and the need for a strategic approach to be taken to flood risk management in light of the increased risk.

3.2 The Review believes that the Environment Agency is best placed to take on a strategic overview role for all sources of flood risk. This chapter looks at the function of Regional Flood Defence Committees (RFDCs) in helping the Environment Agency to fulfil this role and how Catchment Flood Management Plans (CFMPs) will provide one of the essential tools for managing flood risk strategically.

Climate change impacts

3.3 The extent of the linkage between climate change effects and the summer 2007 floods has been a topic of much discussion. Although no single event can be directly attributed to climate change, it can provide an indication of the scale and nature of events in the future.

3.4 The summer 2007 floods occurred due to an unusual weather pattern (see Chapter 1). The location and strength of the Polar Front Jet Stream is subject to natural variation but the warmer sea temperature experienced is consistent with the expected effects of climate change. Warmer temperatures enable more water to be stored in storm clouds, and this will have contributed to the extreme rainfall volumes.

3.5 The Centre for Ecology and Hydrology (CEH) published a paper *The summer 2007 floods in England and Wales – a hydrological appraisal*,[1] after the launch of our interim report. This report looked at the hydrological situation during the summer 2007 floods, placed it in a historical context and evaluated the evidence for long-term increases in the magnitude of major river floods.

3.6 This report concludes that, based on the evidence of rainfall and river levels, statistically the sequence of events during summer 2007 was very unusual. The associated river flooding does not conform to any currently anticipated climate change scenarios which predict drier summers with less frontal rainfall. However, while there is not yet sufficient observational evidence of an increase in the frequency of intense summer storms, these types of storms, which triggered the extreme convective rainfall in 2007, are expected to form part of climate change in the future.

[1] The summer 2007 floods in England and Wales – a hydrological appraisal, T.J. Marsh and J. Hannaford, Centre for Ecology and Hydrology, 2007

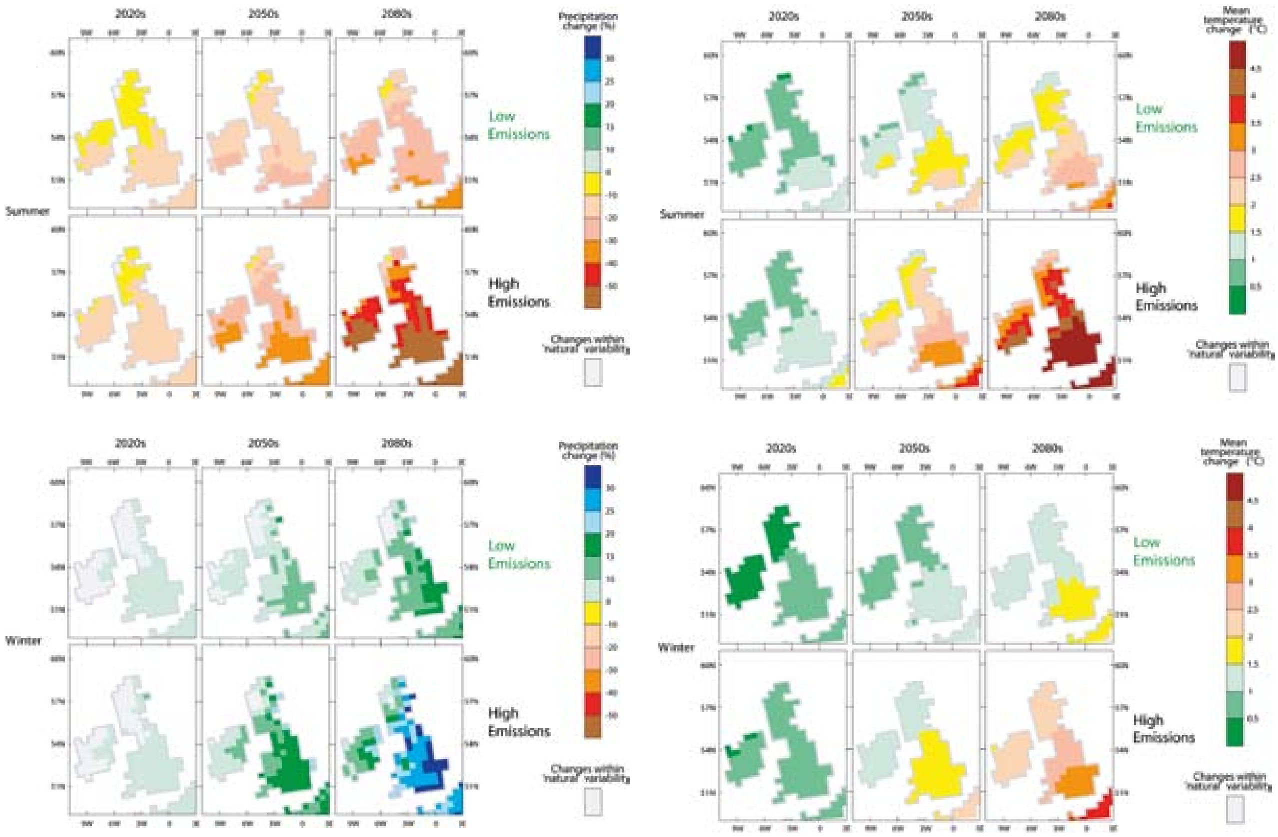
3.7 If we are to meet the long-term challenge that climate change presents, a combination of mitigation (i.e. reducing greenhouse gas emissions) and adaptation (i.e. changing the way we live to deal with the impacts of climate change) will be needed.

3.8 To understand how to adapt to climate change, we need to have an appreciation of what changes might occur, especially in terms of extreme events, and on what timescales. Average global temperatures rose by 0.6°C during the twentieth century, and changes in society in terms of population, technology, the economy, mitigation and adaptation will determine how temperatures will change in the future.

3.9 In 2002, the UK Climate Impacts Programme (UKCIP) produced climate change scenarios for the UK (UKCIP02). Figure 3 shows the predicted temperature and precipitation changes for the UK in summer and winter. The headline results from UKCIP02 were:

- **temperatures will increase** by up to 3°C by the 2050s. There will be greater warming in the summer and autumn, and there will be more summer warming in the South East than the North West of the UK;
- **there will be changes in precipitation,** with winters being up to 25 per cent wetter and summers possibly being up to 40 per cent drier by the 2050s and there will also be significant decreases in snowfall;
- **the global sea level will rise** by up to 36 cm by the 2050s, and there are vertical land movements in the UK (with much of southern Britain sinking and much of northern Britain rising), leading to regional differences in relative sea levels; and
- **the number and intensity of extreme events will increase**, including heatwaves, downpours and storm surges.

Figure 3 – UKCIP02 predictions of temperature and precipitation changes for summer and winter



Foresight update

The *Foresight Future Flooding Study (2004)* provided visions of flood risk in the UK over a 30 to 100 year timescale to help inform long-term policy.

The Review commissioned work to reassess the drivers and responses to flood risk examined in the Foresight 2004 report and identify any new drivers or responses which may have become significant. This update considered evidence and research that had become available since 2004, including evidence gathered in relation to the summer 2007 floods.

There are two main changes to the risks faced from climate change since the assessment in 2004, which are:

- **the potential increases in rainfall volume and intensity, and temperature, are greater than previously assumed.** New analyses indicate the potential for even warmer and wetter winters together with summers that are also warmer but not quite so dry as previously predicted. The potential range of future climates is, therefore, rather more like a Mediterranean climate than a Maritime-Northwest European one. For instance, under the worst case scenario, total winter precipitation increases by 40% as compared with the 25% estimated in 2004. This means we may have to cater for bigger increases in river flows than previously envisaged; and

- **there is a greater risk of extreme sea-level rise.** Coastal flood risk remains one of the biggest risks the UK faces and, although the mean estimates of sea-level rise have not changed since 2004, larger rises of up to 1.6m, due to melting of large ice-sheets in Greenland and West Antarctica, are now a small, but real possibility by 2080. Communities living behind good coastal defences currently protecting them against a flood with a chance of occurrence of 1 in 100 each year could experience a drop in standard of protection by the end of the century to as low as 1 in 5 each year if we were to follow a business-as-usual flood management policy. Coastal flooding is therefore one of the key priority areas for better science, innovative engineering and social policy development.

This report highlights a number of key policy issues which the Review has considered:

- **intra-urban flood risk will increase.** Future risk from intra-urban flooding (or surface water flooding) may rise to be of the same order as fluvial and coastal flood risk. Confused governance is recognised as a barrier to flood risk management in this area, and this will need to be resolved before progress can be made;

- **land use is an important tool in managing flood risk.** Influencing where to place new development is now recognised as a key tool in managing flood risk; however, this needs to be balanced against other economic, social and environmental needs, including the demand for new housing. Finding space through our towns and cities to accommodate flood flows ranging in the extreme up to 40% greater than today's values presents a great challenge to urban planning but the evidence shows that it is among the most important opportunities for flood risk management;

- **uncertainty in a changing climate.** There are high levels of uncertainty associated with a number of drivers and responses to flood risk. Adaptability therefore needs to be incorporated in any decisions taken to manage flood risk, including options for incremental enhancements to be made at minimal cost and having the ability to reverse decisions if necessary. This is especially important in urban areas where different types of flooding, and hence different policy areas, interact.

Foresight update *(continued)*

- **investment will be required to sustain and improve flood risk management.** The 2004 report roughly estimated the costs to maintain current levels of flood risk. However, this did not include timings for investment, as many of the costs will be front-end loaded. Work is urgently needed to refine the figures and provide central government with a more reliable evidence base from which to set the level of investment for flood risk management; and

- **strong governance will be required to implement a range of flood risk management solutions.** There is no single response that will reduce flood risk substantially and that is completely sustainable. Different response measures will vary under different scenarios, and the Government needs to support the concept of a portfolio of responses to decreasing flood risk, which should include structural and non-structural solutions. The Government will also need to take into account social justice implications associated with a planned flood risk management response.

3.10 Research of this kind is continuing to develop; for example, the UKCIP02 scenarios are due to be updated in November 2008 and will employ recent advances in climate science to better quantify some of the uncertainties associated with climate modelling. This version will allow users to interrogate the projections to produce customised probabilistic outputs on projected climate change for the UK. As part of this Review, we commissioned a qualitative update of the *Foresight Future Flooding* report published in 2004[2] (see text box).

3.11 Climate change is already high on the agenda, both nationally and internationally. There has been considerable discussion in central government and the media about mitigating against climate change effects – without tough and timely mitigation measures, the costs of adaptation will increase and it will become more difficult to adapt. However, the Review believes that efforts to reduce emissions need to be combined with adaptation measures to reduce society's vulnerability to climate change. These measures will have to be proactive and we need to understand which of these measures can be taken immediately.

Managing risks strategically

3.12 Dealing with the increased risks that we will face due to climate change, for flooding as well as other extreme natural hazard events, will require a joined-up approach to ensure preparedness for different eventualities. For example, managing the water cycle as a whole makes sense as there might be severe drought problems one year and severe flooding the next. The 2007 floods followed two years of drought and heatwaves which themselves had been preceded by some years of flooding.

Climate change adaptation

3.13 To manage the impact that climate change is already having – as well as the impact that it will have in the future – society will need to start adapting immediately and in a coherent fashion. If it does not, the problem will simply be deferred to the next generation, and the costs will increase. The Government's Stern Review on the economics of climate change[3] concluded that:

> *"if we don't act, the overall costs and risks of climate change will be the equivalent of losing at least 5 per cent of global GDP [Gross Domestic Product] each year".*

According to the *Foresight Future Flooding report (2004)*, the average annual cost of flood damage alone could rise from £1 billion to a worse case of around £27 billion by 2080 – and flooding poses the biggest climate change-related threat to the UK.

3.14 In general terms, adaptive responses to climate change are those that minimise the risk for present and future generations. Any flood risk management solutions need to be able

[2] Foresight Future Flooding report (2004)
[3] Stern Review on the Economics of Climate Change (2006)

to be modified cost-effectively, with minimal extra resources, in the future. That is why the word 'adapting' is more appropriate than 'adaptation' – it suggests that we will need to keep changing to be able to deal with future challenges.

3.15 Flood risk management approaches in the past have tended to promote the use of large-scale physical infrastructure (i.e. flood walls) that has been 'over-designed' to cope with the unknown effects of climate change. However, there is now increasing interest in alternative sustainable adaptation measures, such as including property resilience measures and the use of sustainable drainage systems (SUDS), to enable a flexible approach to adaptation to be taken.

Thames Estuary 2100 – Incremental adaptation

The Thames Barrier was raised for the 100th time last year, 25 years after it first became operational, to protect London from flooding. Since then, the Barrier has already been raised a further nine times which may give an indication as to what is likely to happen in the future. If this is the case, there will need to be consideration as to how increased risk can be dealt with and how the Barrier will need to be adapted.

When the Barrier was built, the fact that sea levels would rise was known and was factored into its design so that it would continue to provide a high standard of protection well into the twenty-first century. What the designers did not know was the degree of impact climate change might have on future sea level rise and flood risk. Although we still cannot definitively predict the future, we can take current estimates and use them to plan and prepare for what might happen. This is the challenge faced by the Environment Agency's Thames Estuary 2100 (TE2100) project – to develop a flood risk management plan for the Thames estuary through to the end of the century.

Thames Estuary 2100 – Incremental adaptation *(continued)*

This plan is scheduled to be presented to the Government by 2010. It will recommend measures to manage future flood risk and when they will need to be implemented, depending on the future scenario for climate change.

In creating the plan, the Environment Agency is taking a new approach that could have wider implications. By modelling the impacts on the estuary of a number of increasingly severe climate change predictions, and how effectively they can be managed through a range of approaches, the Environment Agency is building up a picture of what might need to be done in the future and under what circumstances. The package of solutions it is investigating will be based upon responding to current climate change guidance but will also be assessed for its adaptability to a worst-case scenario if it is found in the future that sea levels are rising at a faster rate than predicted.

By taking this sustainable approach, the Environment Agency can avoid investing in over-engineered flood defence infrastructure which ultimately may not be required, but can identify what needs to be done to keep different flood risk management options open for the future. The plan will ensure that, by keeping pace with the increasing risk, the right solutions can be implemented at the right time.

3.16 Any adaptation measures that are implemented will need to be assessed for their effect, not only on the immediate area but also elsewhere in the locality: for example, a flood wall might prevent one area flooding but may transfer the flood peak further downstream, causing another area to flood. The Review believes that the most effective measures will be those that are adopted widely, are sustainable and complement each other; to ensure this, there needs to be overarching guidance as to how to progress.

3.17 All of the lessons to be learned from the summer 2007 floods – in terms of flood risk management, the protection of critical infrastructure, emergency response and recovery – are forms of adaptation, and involve modifying our environment and behaviour to make us more resilient to the risk of flooding.

Central government leadership

3.18 Adaptation is complicated and in some cases contentious and needs concerted action to work. The Review received a number of submissions which felt that central government should take the lead on adapting to climate change and should coordinate adaptation programmes to ensure a consistent and effective approach. The Government needs to outline the risks, explain how these can be dealt with through a combination of mitigation and adaptation, and set out what individuals can do to help. The Government also needs to demonstrate that progress is being made, and develop and publicise an action plan addressing the long-term requirements. There is widespread support for this approach, with over 80 per cent of people looking to the Government to provide leadership on preparing for climate change.[4]

3.19 Sheffield City Council shares our view that the Government should lead on promoting flexible approaches to adaptation:

> *"Government and the other agencies need to be more committed to developing [adaptation] capacity through establishing personal, business and community learning alliances to begin to help these to adapt existing drainage systems to climate change, especially where the risks cannot be managed by 'hard' systems, such as new sewers."*

3.20 The Government has already made good progress in promoting the importance of climate change adaptation through the following initiatives:

- the Climate Change Bill which will require the Government, on a regular basis, to assess risks to the UK from climate change and publish a programme of how it plans to address these risks. The aim is for the Bill to receive Royal Assent in summer 2008;
- the Adaptation to Climate Change Programme, a cross-Government programme based within Defra to coordinate the Government's work on adaptation in England, bringing together both completed and continuing work by Government and the wider public sector. Phase One of the programme concentrates on developing a statutory framework to support adaptation policy. Phase Two is the National Adaptation Programme which will set out publicly the proposals for meeting adaptation objectives, revised on a rolling five-yearly basis, to ensure that adaptation measures continue to evolve to deal with the future challenges of climate change; and
- the Adaptation Toolkit, a *Making Space for Water* project to help communities adapt to the future impacts of coastal erosion and flooding.

3.21 The Stern Review highlights the fact that, although some adaptation will occur autonomously, other aspects of adaptation, such as major infrastructure and development decisions, will require greater foresight and planning. The Review recognises that this may include the need for Government intervention to lead and coordinate adaptation approaches. The Local Government Association (LGA) believes that:

> *"…it is vital that Government puts in place a robust statutory and regulatory framework together with robust targets and standards that all should adhere to."*

Local authority adaptation

3.22 As we explore in later chapters, the summer 2007 floods showed that local authorities should take an enhanced leadership role in tackling local flood risk (see Chapter 6). This means that local authorities will play a crucial role in adapting to climate change.

3.23 The LGA's Climate Change Commission

[4] YouGov survey for the Association of British Insurers, August 2007 (2012 respondents)

published a report at the end of 2007[5] on how local authorities are facing up to the challenge of adapting to climate change. The report included a survey conducted by the Local Government Analysis and Research group with surprising results:

> *"Only 15 per cent of councils had included adaptation of their own buildings and facilities into their climate change strategy, and only 7 per cent had included adaptation of their housing stock. Some 80 per cent of those surveyed felt that their local authority had not been effective in adapting to climate change."*

3.24 However, there are examples of good practice in a number of regions:

- many local authorities have signed up to the 'Nottingham Declaration on Climate Change' – a statement of commitment to developing mitigation and adaptation measures to counter climate change;
- Leeds City Council has produced its own ambitious climate change strategy. The strategy sets out key recommendations targeting the city's public and private sector organisations including business, developers, education, volunteer groups and health; and
- Oxford County Council has worked with UKCIP to prepare a pilot version of a **L**ocal **CL**imate **I**mpacts **P**rofile (LCLIP) to act as a useful model for other local authorities. Kent County Council has also produced an outline LCLIP examining the impacts of extreme weather events on the county in the last 10 years.

3.25 While central government has a significant role in leading and providing guidance on adaptation to climate change, **the Review would welcome local authorities mirroring this leadership** by identifying adaptation requirements for their own buildings, infrastructure and services. The loss of local services, like schools and roads, during the summer 2007 floods demonstrated how vulnerable they can be if these changes do not happen. Local government should also raise the awareness of adaptation, and encourage and provide guidance to individuals, businesses and the public sector to take the necessary steps to reduce their own vulnerability to climate change in the future.

Barriers and limits to adaptation

3.26 There are limitations to adaptation. It can only reduce the effects of a changing climate, and natural and technical constraints will limit the approaches that can be adopted. There are other barriers to the take-up of adaptation measures; uncertainty about climate change information makes it difficult to plan the level of protection required, there is a lack of incentives to invest in adaptation when the short-term benefits may not be that obvious and there are also financial constraints.

3.27 The Review recognises that adaptation is a difficult and complex subject. Indeed, the discussions we have had about the changes that might be required to manage future flooding shows that organisations already realise they face difficult choices. All of the issues discussed in this section will need to be addressed and the Government should urgently engage with all parts of society to establish the way forward. An ABI survey into public attitudes towards climate change revealed that the public would welcome a national debate on adaptation issues to establish what steps should be taken at national, local, business and individual levels.

3.28 The summer 2007 floods revealed our vulnerability to extreme events which, according to predictions, are highly likely to occur more frequently in the future. The Review believes that adaptation is key in helping society to cope with a changing climate and that central government, in conjunction with local government, needs to take the lead on raising the importance of adaptation.

3.29 The effectiveness of this approach will also depend on the commitment and credibility of the Government – it will need to lead by example by ensuring that it has adapted its own buildings and assets to the increased risks of climate change.

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[5] A climate of change: final report of the LGA Climate Change Commission 2007

RECOMMENDATION 1: Given the predicted increase in the range of future extremes of weather, the Government should give priority to both adaptation and mitigation in its programmes to help society cope with climate change.

Kent County Council – Adapting to climate change

Kent is particularly vulnerable to the impacts of climate change because of its long coastline, south-eastern position, population density and mobility, and its proximity to the continental mainland. County-wide adaptive action is therefore a high priority for Kent County Council's community leadership role and for Kent's local strategic partnership.

Kent County Council is implementing a comprehensive climate change action plan which comprises three main themes:

- carbon management;
- service adaptation; and
- community leadership

Kent's new Local Area Agreement contains, for the first time, a high-level priority to deliver a "low carbon, climate change resilient Kent", supported by a national improvement indicator. This priority reflects the recognition that tackling climate change is an issue for economic development and regeneration in Kent, linking with business opportunities and resilience, and is not just an environmental issue.

Kent County Council – Adapting to climate change *(continued)*

All of Kent County Council's service areas are now required to demonstrate an understanding of how the changing climate affects their business model now and in the future and this has been a mandatory part of business plans since April 2008. The process is supported by tailored workshops with service managers and front-line staff, to introduce climate risk and provide a common methodology for identifying and prioritising vulnerabilities, opportunities and actions.

In applying this approach, Kent County Council have recognised the importance of preparing for both long term climatic changes and extreme weather events, including flooding, which are likely to have the greatest direct impact on council services and the community as a whole. Flood risk from all sources is a key component of their service adaptation framework and is a key issue for planning policy across the county.

Kent County Council realises that adaptation is still a new concept and that the quality and depth of understanding has been variable to date. However, it believes it has a good foundation upon which to build and has identified a number of quick win adaptation actions such as minor adjustments to council policy and processes, definitions of ring-fenced budgets, seasonal patterns in ways of working and demand for services.

Strategic flood risk management

3.30 Clear government leadership needs to be translated into practice. If flood risk management is to form part of our response to the challenge of adaptation, we must make sure that central government is able to offer strategic coordination of delivery.

3.31 In Chapter 1 we describe the uniqueness of the summer 2007 floods. Compared with other floods in recent years, there was a significant proportion of surface water flooding in addition to flooding from rivers. Currently, no organisation is responsible for surface water flooding; this was particularly evident during the summer 2007 floods in places like Hull and parts of Sheffield. There are no warnings for this type of flooding, which can occur very rapidly, and people, including the response organisations, were unprepared. The effects of climate change will increase the risk from all sources of flooding, including surface water flooding, as well as other natural hazards.

3.32 Surface water flooding is also complicated. There are many factors that affect the system's ability to drain water, including saturated ground and high river levels that prevent the system from discharging. The sewerage system is complex. Responsibilities for certain drainage assets remain unclear, a situation that led to frustration among the public during the summer 2007 floods. This complexity and lack of transparency could be improved by having a single organisation with an overarching responsibility for all types of flooding.

> *"Nobody knew what they had to do or where they were going. If it happens again there needs to be somebody else. Some team that are in charge to co-ordinate." (Householder, Rotherham)*

3.33 The *Foresight Future Flooding* report (2004) and the 2008 qualitative update stated that due to climate change, it is likely that:

> *"… future risk from the intra-urban system [flooding in urban areas] might rise by the 2080s to be of the same order as fluvial and coastal flood risk."*

This statement reinforces the need to look at all sources of flooding to assess the risk and take steps to manage that risk.

The Environment Agency's strategic overview role

3.34 The Department for the Environment, Food and Rural Affairs (Defra) 2005 response document *Making Space for Water* stated that, to facilitate a joined-up, risk-based approach to flooding, the Government would need to work towards giving the Environment Agency a strategic overview of all flooding (including surface water and groundwater flooding) and coastal erosion risks. **The Review welcomes the significant progress that has already been made**, with the Environment Agency taking on a coastal strategic overview role on 1 April 2008 which involves looking at coastal erosion in addition to all sea flooding. Work is in progress for the Environment Agency to take on an inland strategic overview role.

3.35 The Environment, Food and Rural Affairs (EFRA) Select Committee's report, published in May 2008, supported the proposal for a strategic overview body and concluded that the Environment Agency is the best-placed organisation to take on that role. It stated that the Environment Agency should continue to devote the majority of its resources to river and coastal flood risk management, as these still pose the highest risk. However, it recognised that surface water flooding was a significant issue during summer 2007 and will continue to be a risk in the future, and that responsibility for managing surface water flooding needs to be determined.

Coastal flood risk – the biggest threat

The *Foresight Future Flooding (2004)* report highlighted the significant risk we face from coastal flooding due to rising sea levels and storm surges. Previous extreme surge events, such as that during the winter of 1953, have led to a considerable loss of life and damage to property. This risk will intensify in the future with climate change bringing increases in mean global sea-level and also the frequency of extreme weather events. The Foresight report estimated that, if current expenditure (as of 2004) on coastal defences were continued, eventually it would not be possible to maintain the same standard of protection and there would be a potential for a twenty-fold increase in local risk to the coastal floodplain.

An Association of British Insurers report on coastal flooding, published in 2006, also emphasised the risks faced from coastal flooding. It estimated that the number of properties at risk of coastal flooding in eastern England, following a rise in sea levels of 0.4m, would rise by 48% from 270,000 to 404,000 and the cost of a single major coastal flooding event would rise to between £7.5 billion and £16 billion. The 2008 update to the Foresight report (see text box) also states that there is a small but feasible possibility of a sea-level rise of 1.6 m by 2080. In November 2007 the UK was reminded of the threat that it faces from coastal flooding when a storm surge came extremely close to breaching defences along the East Coast.

3.36 In our interim report the Review stated that the Environment Agency should have a national overview of all forms of flooding. The majority of people who responded to our consultation have agreed that this is the right way forward to help reduce the confusion over responsibilities and to allow a joined-up approach to be taken. However, there have been some suggestions about how to ensure that the Environment Agency works effectively in this new role; these include resourcing and organisational issues. For example, the LGA has stated that:

> *"… the EA is already under-resourced for the functions it is currently responsible for and the proposal [to give the Environment Agency a strategic overview] would require a step change in its existing capabilities to ensure that it is able to pick up these burdens effectively. It will also need to have robust powers to ensure that local partnerships work and that all agencies play their part."*

3.37 The Environment Agency, in its evidence to the EFRA Select Committee and in its own review into the summer 2007 floods, explains that it sees its role as being one of *"national leadership, coordination and advice to bodies"* and that local authorities would have the main responsibility for surface water planning and management as they have a far greater understanding of the local issues. The Environment Agency envisaged that it would not have any new regulatory role over local authorities but that it would define the tools and methodologies to be used and would also oversee the system by providing quality assurance.

3.38 The Review understands that roles and responsibilities linked with the Environment Agency taking a strategic overview need to be clearly defined and that resourcing will need to be taken into account. Although the Environment Agency has begun to build up its expertise and capabilities with a view to taking on this role, further work will be needed to enable it to carry out the full range of responsibilities effectively. There will need to be close cooperation between the Environment Agency and local authorities, which could be facilitated through Regional Flood Defence Committees (RFDCs). However, we do not believe that it is necessary for the Environment Agency to have any new regulatory role over local authorities.

3.39 A number of people have suggested an alternative approach based on a single, separate flood agency with responsibility for all aspects of flooding, from forecasting and warning through to emergency response, crisis management and post-flood recovery.

Evidence to the Review suggests that this idea has only limited support and the EFRA Select Committee rejected the idea. Many felt that the development of a new organisation would be an unwelcome distraction that would hamper progress in this area at a point when rapid progress is needed. Some were also concerned that an organisation focused purely on flooding, without the links to the water cycle and the environment that the Environment Agency has currently, could be damaging.

3.40 The Review is pleased that the Environment Agency has already started to take on an overview role in relation to all sources of flooding, including work on groundwater flooding (see Chapter 4), mapping surface water flooding hotspots and developing a protocol with water companies on data needs. The urgent requirement for an organisation to have oversight of all sources of flooding, and the proactive steps that the Environment Agency is already taking, leads the Review to believe that the Environment Agency should begin to take on this role immediately. We recognise, however, that an incremental approach to enhancing the Environment Agency's current role to include the different responsibilities will be needed. The first step in this process should be the development of the right tools to understand surface water flood risk. This approach will allow each of the functions to be fleshed out gradually, enabling the Environment Agency to build up its expertise and ensure that each of the different roles can be properly resourced. The exact responsibilities will also need to be covered by legislation (see Chapter 8).

RECOMMENDATION 2: The Environment Agency should progressively take on a national overview of all flood risk, including surface water and groundwater flood risk, with immediate effect.

The role of Regional Flood Defence Committees

3.41 RFDCs support all of the Environment Agency's flood defence functions, particularly the drainage of land and the provision of flood warning systems. The Environment Agency has various statutory powers that operate through the RFDCs, including:

- the maintenance and improvement of sea and tidal defences and of watercourses designated as main rivers;
- the installation and operation of flood warning equipment; and
- advising riparian owners and internal drainage boards.

3.42 RFDCs also provide significant input in their areas to the Environment Agency's flood defence policies, business plan and programme of work, and monitor the Agency's performance against those plans. They determine the local levy on council tax for flood risk management work that does not meet the priority threshold of the Environment Agency's central government grant.

3.43 Each committee has around 20 members, with the chair and other members chosen by the Secretary of State for the Environment, Food and Rural Affairs, two members chosen by the Environment Agency (but who are not Agency staff) and the majority of members chosen by the constituent councils. RFDCs therefore provide a strong link between the Environment Agency and local authorities to ensure that local flood risk management issues are dealt with.

3.44 The RFDCs' role is currently being reviewed in order to strengthen their link with the Environment Agency and to improve processes and clarify responsibilities. The aim is to ensure transparency in the prioritisation and allocation process for flood defences and to improve local input into setting flood risk management priorities and promote ownership.

3.45 The Review strongly advocates local government leadership in relation to local flood risk management. We believe that there is an opportunity for the RFDCs to have a stronger role (through the Environment Agency's strategic overview) to aid local authorities in this task. They should utilise their position between the national and local level to help communication and provide advice.

Catchment Flood Management Plans

3.46 The Environment Agency's strategic overview role should be aided by the production of Catchment Flood Management Funds (CFMPs), which will help deliver an overarching understanding of all flood risks.[6]

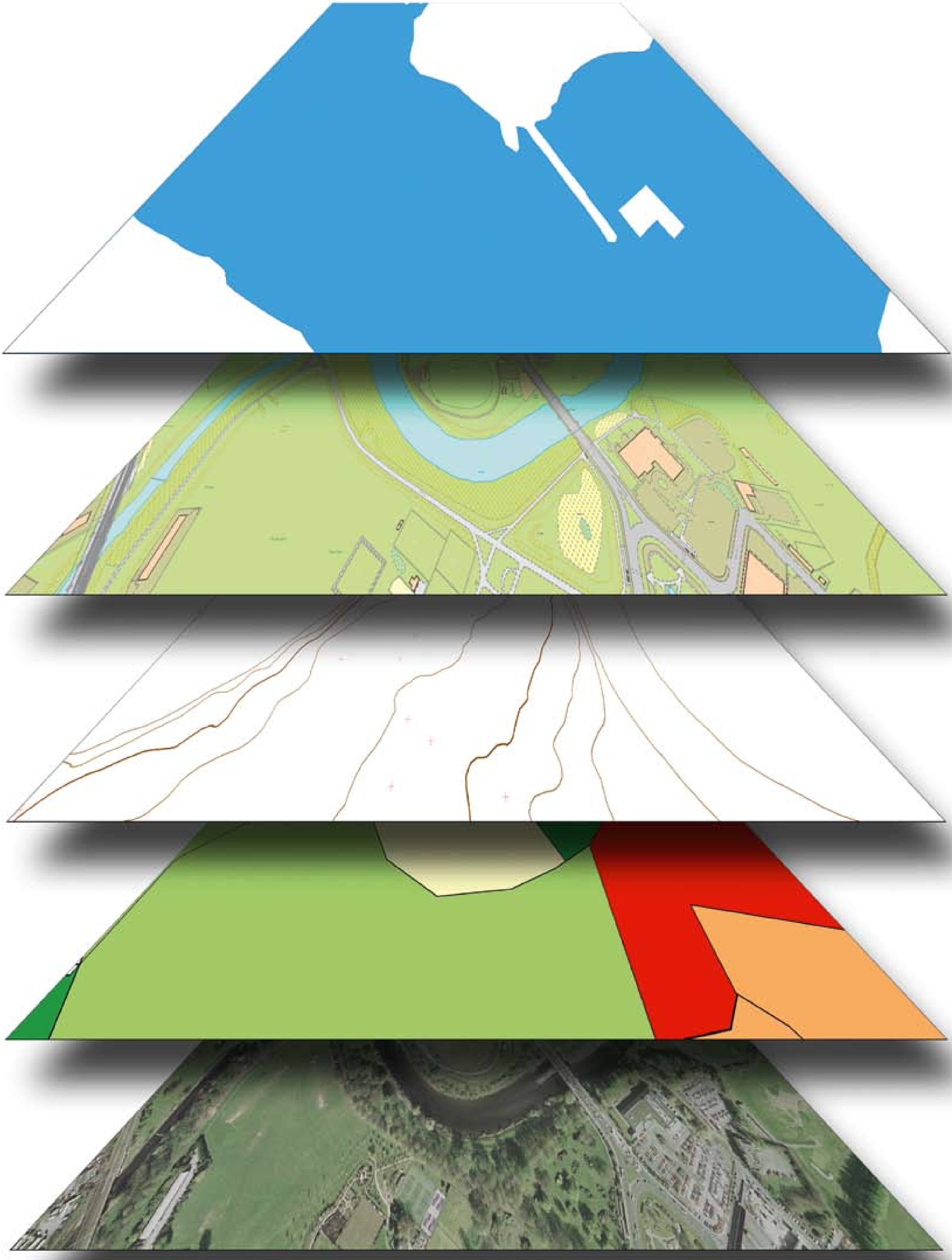
3.47 CFMPs are a planning tool developed by the Environment Agency to investigate and define long-term sustainable policies for flood risk management on a river catchment basis by working in partnership with other key decision-makers. The Review believes that CFMPs will be one of the principal tools to enable the Environment Agency to fulfil its strategic overview role effectively, assuming they properly capture all flood risk. The approach of understanding the risk on a catchment basis is consistant with the EU Floods Directive (see Chapter 8 for more details).

3.48 CFMPs should be based on strategic assessments of current and future flood risk from all sources (including rivers, sewers, coasts and groundwater) within a catchment area in order to understand both the probability and impact of flooding and the effect of existing risk reduction measures. The scale of this risk should then be quantified in economic, social and environmental terms. CFMPs should also help identify opportunities for reducing flood risk on a catchment scale while maintaining, and even enhancing, natural and historic assets and recognising the constraints that may arise.

3.49 There has been some criticism of the draft CFMPs that have been produced so far. The EFRA Select Committee's report in May 2008 stated that they did not effectively address typical 'inland' kinds of flood risk such as surface water flooding, and the Public Accounts Committee (PAC), in its December 2007 report on building and maintaining flood defences, suggested that they should be reviewed to identify the structures that are most at risk. The PAC also raised concerns that the Environment Agency had taken six years to complete its first six CFMPs and that the remaining 60 would not be completed until December 2008.

3.50 The Review recognises these concerns and the fact that CFMPs will be a key vehicle for the Environment Agency in delivering its strategic overview role. We therefore support the recommendation made by the PAC that the remaining plans should be completed by December 2008, as the original deadline for these plans has already been missed. The Review has received assurance from the Environment Agency that all plans will be completed by the end of 2008. There have been concerns from local authorities that they have not been as closely involved with the production of CFMPs for their area as they should have been. The Review therefore urges the Agency to engage with all the main stakeholders as soon as possible to ensure that their vital local knowledge is included.

[6] There are also Shoreline Management Plans, which provide a framework for dealing with coastal flooding and erosion over a large area and may cover a number of communities and sea defences



Forecasting, modelling and mapping

This chapter examines the science and technology behind weather forecasting, flood modelling and mapping. It contains sections on:

- understanding the risks from flooding;
- weather forecasting;
- river, surface water and groundwater flood modelling; and
- integrated approaches to forecasting, modelling and mapping.

Introduction

4.1 The role of science and engineering is crucial in understanding flood risk, and this role will become even more significant as we look to adapt to the increased risk that climate change will bring. The summer 2007 floods demonstrated that the UK has come a long way in terms of weather forecasting and flood prediction, but it also highlighted that there are considerable improvements to be made – especially in terms of surface water flooding and multiple flood events.

4.2 This chapter explains what is meant by flood risk, and looks at the science and technology behind weather forecasting and flood modelling and mapping. It examines how these help to reduce the risk, provides details of the current situation and what enhancements are proposed for the future.

4.3 To ensure that the technological advances in flood forecasting are of value, it is equally important that the issue of communicating meaningful and useful warnings is addressed and improved. We discuss this further in Chapter 21.

Understanding the risks from flooding

4.4 When experts talk about flood risk, they are not simply talking about the likelihood of somewhere being flooded but also the potential impact of the flooding. Understanding where flooding might occur and the potential consequences is vital if flood risk managers, emergency planners and responders are to reduce flood risk and the effects of flooding.

4.5 Flood risk can be calculated by combining the probability of flooding occurring with the consequences of that level of flooding.

The likelihood of flooding occurring is often expressed either in terms of a chance (1 in 100 chance of flooding occurring in any one year) or a probability (1 per cent annual probability of flooding).

4.6 In the past, flood risk has been described by a 'return period' (such as 1 in 100 years), but this can cause confusion when people who have already been flooded believe that they will not be flooded again for a long time. In reality, even when flooding is calculated as a 1 in 100 year event, there is still a 1 per cent chance of flooding the following year.

Recurrence of summer 2007 floods

The probability of the levels of rainfall at specific locations during the summer 2007 floods has been accurately compiled, with a maximum of a 1-in-1000 annual chance being calculated for the level of rainfall at Pershore College (Hereford and Worcestershire). Although we stated in our interim report that the level of flooding that occurred during the summer 2007 had an annual probability of 1-in-150, it is in fact virtually impossible to assign a meaningful probability on the whole sequence of events. This is due to the complexity of combining the chances of all the individual, coincidental events and the sheer scale of the flooding.

The range of durations and geographical spread of the summer 2007 floods made them extremely unusual. But widespread summer flooding will happen again in the future and it is impossible to say precisely when and where. The country must, therefore, be prepared for extreme flooding events, especially due to the increased risk associated with the changing climate.

4.7 The consequences of flooding are the harm that it causes in social terms (for example, loss of life, injury, stress and disruption to daily life), economic terms (for example, damage to property, businesses, roads and infrastructure) and environmental terms (for example, damage to land and wildlife).

4.8 We appreciate that the UK's understanding of the risk of flooding from rivers and coasts is well advanced, the Environment Agency has well-developed maps and models to assess and predict this risk, but information relating to surface water (and groundwater) flood risk is more limited. This was evident from the summer 2007 floods as both the weather forecasts and the warnings during the June floods were less accurate than those for the July floods. This was due to the nature of the weather system that caused the extreme rainfall during June, and the fact that a significant proportion of the flooding was the result of surface water runoff.

Weather forecasting

4.9 Weather prediction forms a crucial part of flood risk management; the ability to predict severe weather, days in advance, provides a first indication of possible coastal, river and surface water flooding events. The Met Office's forecasting ability has improved continuously over the last three decades, with roughly a day's extra lead time for extreme meteor ological events gained every ten years.

4.10 The weather events which caused the summer 2007 flooding were generally well forecast, with the forecasts leading up to the July event being the most accurate and detailed ever provided by the Met Office for any major flooding event in the UK. However, the Review believes that there is still opportunity for improvement; the benefits that need to be realised are as follows:

- **longer lead times.** Evidence suggests that increased lead times for predicting events are directly related to reductions in the damage caused to properties and infrastructure. Improving the science within the models and increasing the quantity and quality of observations used in the models will both help to achieve this;
- **probabilistic forecasting.** The implementation of 'ensemble modelling' (explained below) will enable the most likely and the most extreme scenarios to be identified and shared with emergency responders to facilitate better preparedness; and

[1] The summer 2007 floods in England and Wales – a hydrological appraisal, T.J. Marsh and J Hannagford, Centre for Ecology and Hydrology, 2007

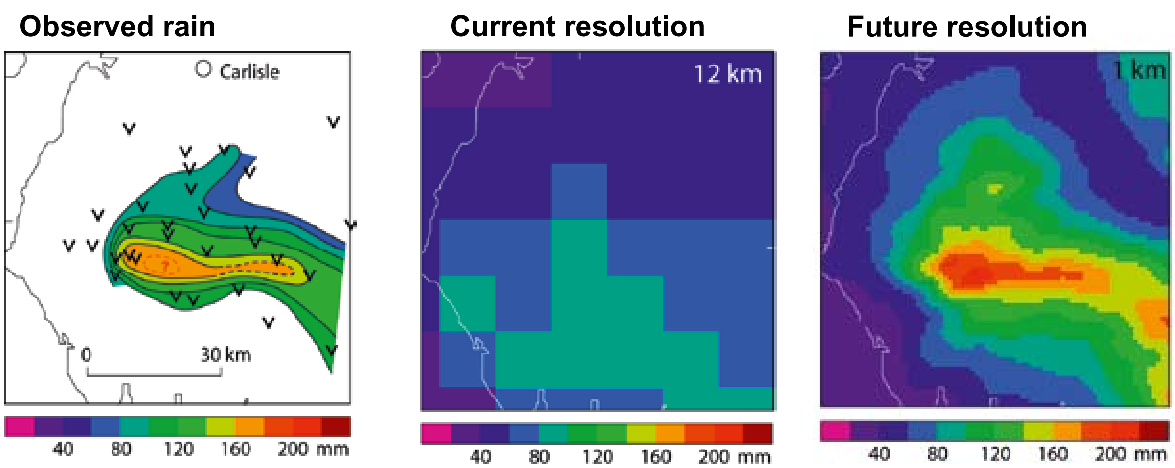
- **more accurate local-scale forecasts.** Enhancements to the resolution of forecasting models (through advances in computing capacity) will allow forecasters to identify where rainfall will be heaviest at a city or town level. This will improve the usefulness and reliability of extreme rainfall forecasts and warnings, which will be essential for providing effective warnings for rapid response catchments and surface water flooding.

4.11 The Met Office uses a suite of computer forecasting models to predict the atmospheric state over a range of areas and timescales. Typically, numerical weather prediction (NWP) models are run once from a given set of initial conditions, which model the observed conditions, to produce a single forecast. Despite vast improvements in these models over the years, large errors can still occur, even over relatively short forecast ranges, due to the chaotic nature of the atmosphere and the fact that the initial conditions will always be subject to a degree of uncertainty. Tiny errors in the state of the initial conditions can be amplified to create large inaccuracies in the predicted weather forecast.

4.12 To combat this problem, an 'ensemble' suite of forecasts can be run. Instead of running a single model with one set of initial conditions, the model is run a number of times starting with slightly different initial conditions to reflect levels of uncertainty. The resulting forecasts are known as an 'ensemble' and can be evaluated to determine the most probable forecast sequence. If the ensemble produces a set of forecasts which are fairly similar then there can be high confidence that the forecast will reflect reality. If it produces a wide range of different weather scenarios then the forecast is less certain. The ensembles can therefore give an indication of the most likely scenario (the scenario which is reproduced most frequently by the forecasts) and the worst-case scenario.

4.13 The resolution of the model determines the accuracy and timeliness of the forecasts, and the specificity of the warnings given. A high-resolution model (1.5 km) was run for a brief period during the summer 2007 floods to test its capabilities and demonstrated the significant improvement this model can achieve. The higher resolution model has also been used retrospectively to assess how accurate it would have been during the 2005 Carlisle floods if it had been available; the enhancement with this model is very apparent in Figure 4.

Figure 4 – Benefits of improved resolution (Carlisle flooding in 2005)



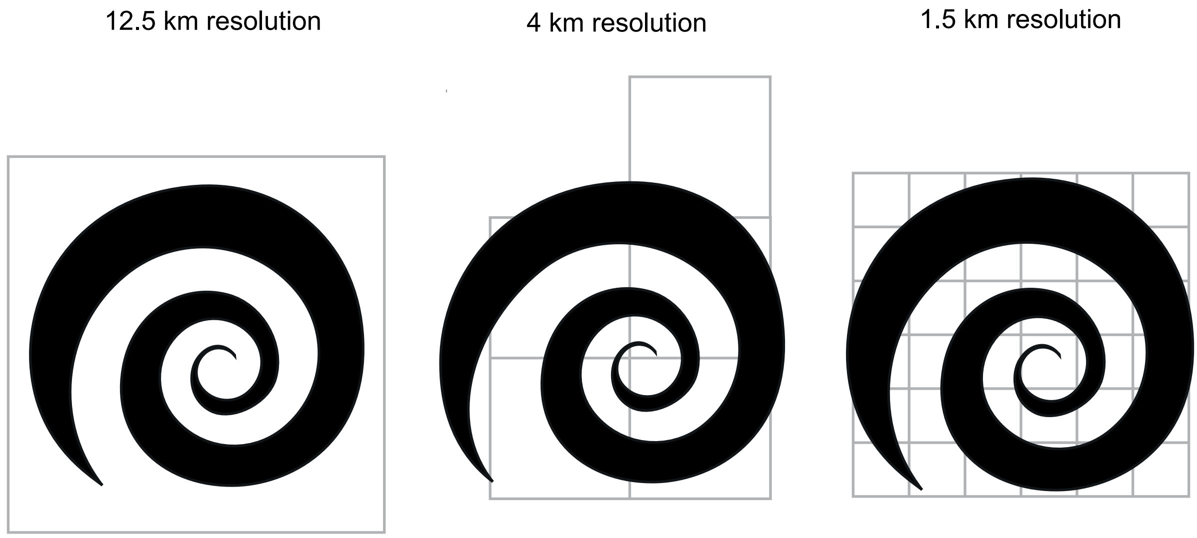
Model resolution

The resolution of a model refers to the grid box size (or area) over which the model calculates an average prediction. It can be compared to the resolution of an image from a digital camera. A digital camera image is broken down into pixels: just as more than one pixel is required to represent a particular object, more than one grid box is required to represent a particular weather feature.

The current computing system performs most of its operations at a 12.5 km resolution (i.e. on a grid box size of 12.5 km x 12.5 km) covering Europe, complemented by a 4km model over the UK.

However, even though the models at a 4 km resolution can produce very good information about general weather conditions, they are inadequate when forecasting convective rainfall because the thunderstorms that cause this type of rain are typically up to 10 km across; this is beyond the limit of the resolving capabilities of the 4 km model. If the model was able to perform at a 1.5 km resolution, a typical thunderstorm would be covered by approximately seven times more grid boxes than the 4 km resolution model, creating a much more accurate representation (i.e. a clearer picture) of the weather feature.

The figure below depicts a typical 10 km diameter thunderstorm against the grid boxes of 12.5, 4 and 1.5 km resolution models. The information within each grid box, or pixel, is averaged by the model. The more grid boxes covering a particular weather feature, the more accurate the representation will be (so, if related back to the camera, the clearer the image will appear).



At 1.5 km resolution, forecasts of extreme rainfall could be made on a city scale, rather than on a regional scale, which would greatly enhance capabilities to provide surface water flooding and rapid response catchment warnings.

4.14 The resolution of the model and ensemble forecasts is limited by the supercomputing capacity available to the Met Office. The current high-performance computing (HPC) capability is, however, reaching the end of its useful life and a new machine is due to be installed in 2009 (with a further upgrade in 2011).

4.15 This will provide the ability to operate the models at a 1.5 km resolution continuously over the entire UK (rather than just for brief periods of time over smaller regions, as is currently the case) to provide an opportunity to produce warnings for surface water flooding with useful lead times. The further enhancement in 2011 will allow a small ensemble of forecasts to be developed, enabling probabilistic forecasts to be produced. This will allow a baseline quantitative risk assessment capability (i.e. with specific probabilities) to be established, and will mean that responders are able to prepare for both the most likely and also the worst-case scenarios.

4.16 All of these improvements will greatly advance the Met Office's capabilities, not only for flood forecasting, but also in terms of benefits to other sectors (including civil contingencies, defence and the provision of climate change advice). To ensure that these enhancements meet the requirements of the end users, the Met Office should engage with Local and Regional Resilience Forums, not only to establish these requirements but to also manage expectations as to what is feasible and at what cost. It is important that the improvements should be driven by user need, rather than simply a desire for improvement. If the system delivers over-specification, it will not be cost-effective.

4.17 In order to realise these benefits for responders, the Met Office should make choices which accelerate the pace of development wherever possible.

RECOMMENDATION 3: The Met Office should continue to improve its forecasting and predicting methods to a level which meets the needs of emergency responders.

4.18 The use of weather radar was mentioned in a number of submissions to the Review, especially from RFDCs and Leeds City Council. RFDCs advocate the use of weather radar (when used in conjunction with detailed topographic information) to identify the areas that are most at risk from surface water flooding, and Leeds City Council is in favour of weather radar being used to help emergency responders ensure that resources are targeted at the most vulnerable areas during an emergency. They have purchased licences to provide live access to the Met Office's rainfall radar data, using a system called 'Enviromet', to officers in land drainage, emergency planning and highway maintenance. This enables them to identify which areas are being worst affected (and which are most likely to flood) and therefore target resources accordingly.

'Enviromet' display – Leeds City Council

4.19 The Met Office believes that weather radar (alongside higher-resolution rainfall forecasting) can form part of the solution to providing a surface water flooding warning system if set in the context of closer working with the Environment Agency and a programme of education that includes the possibility of using a probabilistic approach to warning. This is discussed in more detail in Chapter 21.

Weather radar

The Met Office uses a network of weather radars (13 in the UK) with three ranges of resolution (1 km, 2 km and 5 km) to provide continuous, real-time information on rainfall over almost all of the UK's land areas and inshore waters. Four new network sites are planned for 2008, with one replacing an existing site to make 16 in total, which will improve the coverage over some densely populated areas that are not currently covered by higher-resolution radar.

The advantages of using weather radar are that it can provide detailed and instantaneous rainfall rates over a wide area. It can locate frontal and convective precipitation, and can monitor their movement and development. It can also be used for short-range forecasts through extrapolation and incorporated into weather prediction models.

The disadvantages are that weather radar can be subject to technical and meteorological difficulties (although most of these can be adjusted for), and that it does not show rainfall at the surface. In addition, weather radar can display non-meteorological echoes because of its angle of elevation: too low and it cannot pick up rainfall due to obstacles on the ground, and too high and the estimate of rainfall actually hitting the surface becomes less accurate.

River and coastal flooding modelling

4.20 The Review recognises that considerable progress has been made in modelling and mapping risk from river and coastal flooding in the UK over the last 10 years:

- in 2000, the Environment Agency published indicative flood maps online,
- since 2004, these indicative flood maps have included an extreme flood outline – for floods with a 0.1 per cent chance of occurring,
- the National Flood Risk Assessment (NaFRA) was produced in 2004[2]; and
- the *Foresight Future Flooding* study on current and future flood risk was published in 2004, with a qualitative update produced later in 2008 (see link on Review's website)[3].

4.21 The Environment Agency's indicative flood maps provide an assessment of the flood risk across England and Wales, and give details of the areas that could be affected by flooding from rivers and the sea, the location of flood defences and an indication of the areas that would benefit from them during a major flooding event.

4.22 The maps are divided into flood-risk zones that relate to the areas that would be affected by differing probabilities of flooding events (flood defences are not taken into account, as these can be breached or overtopped). These probabilities are 1 per cent for river flooding, 0.5 per cent for coastal flooding and 0.1 per cent from river or coastal flooding (an extreme event).

4.23 The flood probability zones are used and defined in the Government's planning policy (see Chapter 5 for more information on PPS25) to provide guidance on development on the floodplain. The flood maps provide a good indication of the areas that are at risk of flooding, but they do not provide specific information about the risk to individual properties at the level of detail required. For example, details such as how high a property's floor needs to be above ground level are not available and would be difficult to acquire.

4.24 The indicative flood maps offer a variety of services:

- they are a vital awareness-raising tool for the public, who are able to input their postcode and find out if they are at risk;
- they are essential in helping the Environment Agency to manage flood risk and give an indication of where an automatic warning service should be provided;

[2] www.rasp-project.net/SR659-NationalFloodRiskAssessment_2004.pdf
[3] www.cabinetoffice.gov.uk/thepittreview

- emergency services and local authorities use them to help to develop emergency plans and risk assessments;
- planning authorities incorporate the information from indicative flood maps into their decision-making processes relating to planning applications;
- they help utilities companies to understand their flood risk and hence enable them to make business continuity decisions; and
- the insurance industry uses them to calculate risk (and hence premium rates).

4.25 There is a continuing programme of work to improve the indicative flood maps. As flood models are improved and more detailed information on defences (and the areas that benefit from them) is assimilated, results will be fed into this improvement work.

4.26 The National Flood Risk Assessment (NaFRA) covers the whole of England and Wales, and builds on the indicative flood maps through Risk Assessment for Strategic Planning (RASP). RASP uses a probabilistic approach that takes into account the location, type, condition and performance of flood defences. The three risk categories are:

- **low:** less than 0.5 per cent chance of flooding;
- **medium:** 0.5–1.3 per cent chance of flooding; and
- **high:** more than 1.3 per cent chance of flooding.

4.27 NaFRA results are provided to the Association of British Insurers (ABI) and the financial services industry, enabling them to offer their services to those who live in flood-risk areas. NaFRA enables insurance premiums to take into account the benefits of flood defences: without it, premiums would be higher for those who live in flood plains but are adequately protected.

4.28 NaFRA was first run in 2004 and was re-run in 2006 to improve the data. But there are still uncertainties in the results due to method and data limitations. A project has been initiated to eliminate some of these uncertainties, with the potential for a further re-run later in 2008.

4.29 The Review believes that both the indicative flood maps and the NaFRA map provide an essential range of services across a number of sectors, and significantly help to reduce flood risk by raising the awareness of that risk and enabling people and organisations to prepare themselves. **We welcome the continuous updating of flood maps, and would encourage the Environment Agency to devote further resources to this exercise.**

Limitations of flood mapping

4.30 The Environment Agency monitors rainfall, river levels and sea conditions 24 hours a day. This information is combined with weather and tidal data from the Met Office to provide local area warnings on the possibility and severity of flooding.

4.31 Together with its partner organisations, the Environment Agency has made significant progress in developing and improving its modelling and forecasting capabilities. In general, the Environment Agency's warnings and forecast flood levels during summer 2007 were relatively precise. However, problems did arise:

- certain properties were affected by both surface water flooding and river flooding (known as coincident flooding) and therefore some properties were already flooded by the time the river flooding warning was issued by the Environment Agency;
- the Environment Agency's maps and models use historical data to help understand and predict future flooding. However, the summer 2007 floods were so extreme that relevant data was limited, and river levels in some areas rose far more quickly than during any previous flooding. The rapid response (the speed of the water level rise) of a number of river catchments meant that some warnings could not be given within the two-hour target timescale;

- many rivers flooded at the same time during the summer 2007 floods, causing the water to back up and lead to unexpectedly high and faster-reacting river levels. This is something that had not been considered in much detail before then; and
- some of the telemetry systems failed, either physically (4 per cent of river level gauges and 2 per cent of rainfall gauges) or because they were unable to be read as the event exceeded their operational capabilities (3 per cent of river level gauges and 1 per cent of rainfall gauges), although most of the faults were repaired quickly. There is also evidence to suggest that there is a lack of telemetry coverage in certain areas, especially in smaller tributaries, which exacerbated the problem.

4.32 The Environment Agency has been working to resolve some of the problems with its telemetry system through the installation of new rain and river gauges and the introduction of back-up servers to the flood warning system to ensure that alarms can still be provided on the gauges even in extreme flooding events.

4.33 The Review welcomes the commitment shown by the Environment Agency, through its Flood Risk Science Programme, to develop the tools and techniques that are currently available for predicting and modelling river flooding to cover a wider range of events. In the short term, this could include running data from the summer 2007 floods through the Environment Agency's modelling and mapping systems as part of historical data capture. In the longer term, this will require running different extreme scenarios through the systems, and making sure that the possibility of multiple flood events occurring both simultaneously and within different overlapping time periods is taken into account.

4.34 The Review considers that the biggest risks people face from inland river flooding are due to significant depths and high velocities; 6 inches of fast-flowing water can knock someone off their feet and 2 feet of water is enough to float a car. Although most of the summer 2007 flooding was not of a particularly high velocity (unlike the flooding experienced in Boscastle in 2004), significant depths were reached in some places. As well as posing a specific risk to individuals, in some cases the depth of the flood water hampered rescue efforts, making evacuations dangerous for both the evacuee and emergency responders.

4.35 The Environment Agency has now identified 'rapid response catchments' (i.e. areas with particularly steep and narrow catchments that channel water, causing high velocities) and has committed to engaging with emergency responders to discuss their requirements in this area. The November 2007 EU Floods Directive (mentioned in Chapter 8) requires that flood depths and velocities in high-risk areas are mapped. The Environment Agency will be taking forward this work in preparation for its implementation.

4.36 Although some advances have already been made in this area, and the EU Floods Directive will ensure that flood-risk assessments include multiple events, coincident flooding, depths and velocities, the Review believes that further enhancements to the Environment Agency's modelling and mapping tools should be urgently progressed. This will help to ensure that the rescue capabilities to emergency responders are not hindered unnecessarily and that the risk of loss of life is reduced in future flooding events.

RECOMMENDATION 4: The Environment Agency should further develop its tools and techniques for predicting and modelling river flooding, taking account of extreme and multiple events and depths and velocities of water.

Surface water flooding

4.37 In contrast to river and coastal flooding, capabilities to map and model (and hence provide warnings for) surface water flooding are very limited.

What is surface water flooding?

4.38 In this report, the Review refers to 'surface water flooding' as flooding that occurs due to extreme rainfall and the inability of the water to drain away quickly enough, hence forming pools of water. Pools may also form due to water coming out of drains at other locations. However, the reasons for a lack of drainage capability can be quite varied and are often interlinked. For example, an urban sewerage system (designed to convey surface water runoff into a nearby watercourse) might be unable to discharge water if the watercourse levels are too high, which was the case in certain areas of Sheffield during the summer 2007 floods. This particular type of flooding, where the urban drainage and sewerage system links to the river system, is often referred to as 'coincident flooding' (see *Foresight Future Flooding Qualitative Update 2008*).

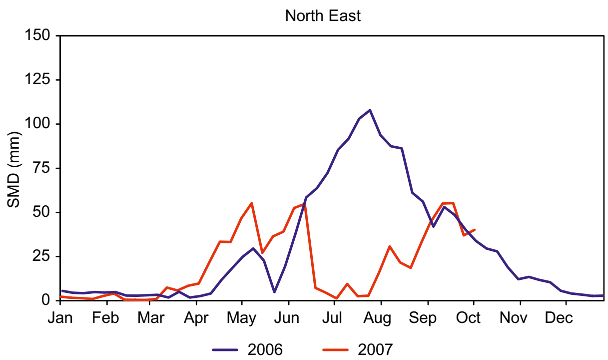
4.39 Many factors affect the likelihood of surface water flooding:

- **intensity of rainfall:** rainwater drains away naturally over long periods of time, but if rain falls in intense bursts, the drainage system may be unable to cope. The probability of this type of intense rainfall occurring in the future is likely to increase due to climate change;
- **the location of the rainfall:** the direction of travel of surface water is directly influenced by the topography of an area. Small changes in the location of rainfall can have a significant impact on where the water ends up;
- **the capacity and condition of the sewerage and drainage system:** this will obviously affect the rate at which rainwater can drain away, but the system is complicated. A number of different people and organisations are responsible for different parts of the system (these roles and responsibilities are described in more detail in Chapter 6), and this is not always transparent. In addition, most of the UK sewerage system was built before the Second World War, and so deterioration is another key issue;
- **the type of surface material:** the permeability of surface material affects the amount of runoff. Urban areas are more susceptible to surface water flooding than rural areas because they are characterised by a significant quantity of built-up (and hence impermeable) areas. Chapter 5 discusses urban creep in more detail;
- **the saturation (or the soil moisture deficit) of the ground:** if the ground is saturated, or in fact too dry, any rain that falls will be converted into runoff (see text box below on soil moisture deficit);
- **river levels:** high river levels will hinder the sewerage system's ability to discharge water; and
- **planning and development:** pressure to increase the amount of housing will reduce the amount of permeable space available and is also likely to reduce the number of open watercourses (many will be converted to culverts – see Chapter 5 for more detail). Sustainable drainage systems can be incorporated into new property developments to help to reduce the surface water runoff and these are considered in Chapter 6.

Soil moisture deficit

Groundwater levels and the saturation level (or soil moisture deficit) of the soil are different phenomena. Groundwater flooding is a complicated process of water being absorbed by sub-surface aquifers and then recharged over a period of time. Soil moisture deficit describes the level of saturation, with the actual figure being how much more water the soil could absorb before being fully saturated, so a soil moisture deficit of zero would mean that the soil is fully saturated.

The Environment Agency currently records soil moisture deficit levels to monitor the water table in the context of drought situations. The Review believes that this monitoring capability should also be used for flood risk management. The saturation level of the ground is especially important for surface water flooding where the amount of run off will depend on the volume of water which can soak into the ground (the converse case of the ground being too dry also affects surface water flooding as the water just bounces off the ground). During the summer 2007 floods, conditions prior to the flooding were such that the ground was already saturated due to heavy rainfall in May and early June and so the soil moisture deficit values were close to zero. This is in stark contrast to the soil moisture levels recorded in summer 2006 (see graph below for the Environment Agency's North East region).



4.40 All of the factors listed above affect and are influenced by a wide cross-section of societal factors. To begin to understand how surface water flooding happens, and hence to be able to develop modelling and mapping techniques, the Review believes that organisations such as the Environment Agency, the Met Office, water companies, local authorities, planning and highways authorities, and riparian owners will all need to work together to pool their expertise and data.

Identifying vulnerable areas

4.41 In response to the recommendation in the Review's interim report that the Environment Agency (supported by other organisations) should urgently identify the areas that are at highest risk from surface water flooding, the Environment Agency has carried out research into developing a surface water flooding alert system for its professional partners. It has improved dialogue with Local Resilience Forums (LRFs), local authorities, water companies and other stakeholders with the aim of sharing existing knowledge of historic surface water flooding.

4.42 To formalise this process, the Environment Agency set up a national project on surface water flooding in April 2008. The main objective of this project is to produce a national set of data to identify areas most naturally vulnerable to this type of flooding by 1 August 2008 and to collect further remaining data on historic surface water flooding by 2010. This should enable local authorities and utility companies to carry out more detailed studies in the highest risk areas and create better plans for dealing with the risk. In collating this data, the Environment Agency will work with its partners to define how the data will be used and what should be included.

Surface Water Flooding maps

Although the summer 2007 floods highlighted the risk of surface water flooding, affecting many areas which had not previously flooded, this risk and the requirement for more data and better modelling tools was identified in the *Foresight Future Flooding report (2004)*.

A number of submissions to the Review have indicated that some organisations have already started to look at how to map the risk from surface water flooding. Examples are:

- Risk Management Solutions (RMS) who provides products and services for the management of insurance catastrophe risks. These tools are widely used by the insurance industry to inform the pricing and management of risk from natural and man-made hazards. RMS has been working over the past couple of years to upgrade their existing UK Inland Flood Model, employing numerical approaches to produce a new, fully probabilistic model covering all sources of inland flood risk. The enhanced model provides information on the flow from major and minor rivers, surface water flow from both rising groundwater and intense rainfall, and drainage overflow in urban areas. The upgrade also incorporates an increased understanding of flood defences by including data from the Environment Agency Flood Defence Database and accounts for the downstream impact of flooding in the event of upstream defence failures.

Surface Water Flooding maps *(continued)*

- Micro Drainage is a drainage engineering software developer whose software is currently used by many of the UK's sewerage consultants and water companies. They have been working with West Berkshire County Council since the summer 2007 floods to produce a 3-D computer flood model for Thatcham as a method of testing the model's capabilities. The model[4] utilised the latest runoff model[5] and data of the July 2007 rainfall to identify the main flood flow paths, depths, velocities and sinks. It also identifies which elements of the drainage system are critical. This model has helped West Berkshire County Council to establish the current level of protection, test proposed mitigation measures, establish appropriate drainage maintenance and structural improvement regimes and inform their emergency procedures and responses.

4.43 The Review commissioned analysis of a number of different approaches to modelling surface water flooding, looking at their effectiveness and providing a basic cost-benefit analysis. The results of this work are set out below.

[4] An ADI computational model
[5] ReFH model

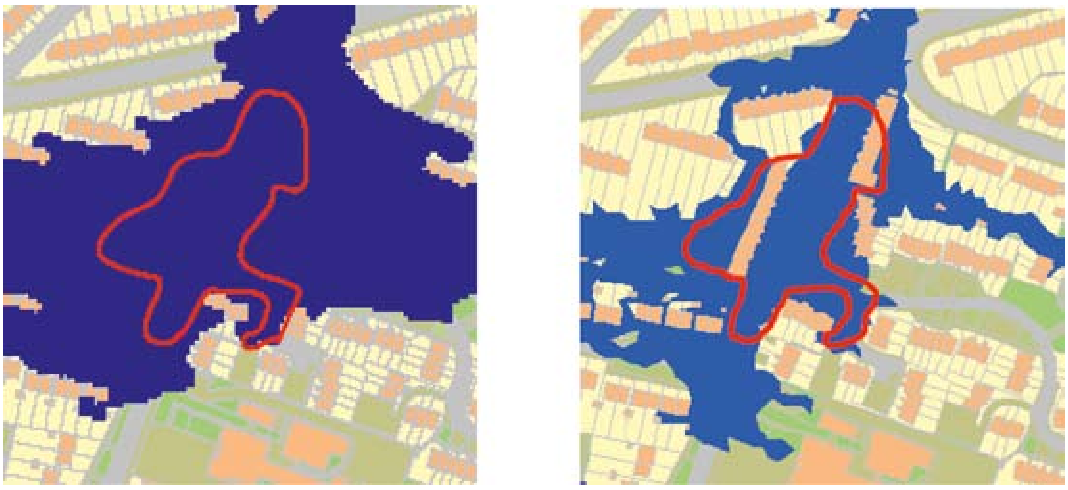
Evaluation of Modelling Approaches to Urban Flood Risk

The purpose of this evaluation was to assess the feasibility of flood risk modelling and mapping in urban areas, and to indicate the different modelling approaches.

The five approaches considered in this assessment were:

- *Topographic index analysis* – This is a basic terrain model with no rainfall input. There is no correlation between the model's outputs and areas of known flooding, and so it would be of little use.
- *2D overland routing of uniform rainfall event* – This model makes no allowance for differences in rainfall, and assumes that every area has a uniform capacity to drain water. It could be used for high level analysis but significantly overestimates the extent of flooding.
- *Decoupled sewer model and 1D overland routing* – This model takes account of the effect of drainage by using a detailed sewerage network model. It is the most accurate method of identifying properties on water company registers but underestimates the spatial extent of flooding.
- *Decoupled sewer model and 2D overland routing* – This model includes 2D surface runoff data and detailed sewerage network data, but does not include assessment of below-ground flooding mechanisms. It produces a much better estimate of the spatial extent of flooding but fails to identify some properties on water company registers.
- *Coupled sewer model and 2D overland routing* – This model combines surface runoff data, detailed sewerage network data and a full 2D model of above-ground flooding. It does not include below-ground flooding mechanisms but this could be added. It gives a very accurate assessment of the spatial extent of flooding but fails to identify some properties on the water company registers.

The figure below shows how different modelling approaches can produce very different results. Each image maps a flooding event with an annual 1-in-30 chance of occurring. The red line indicates the actual extent of flooding at that level.



a) 2D overland routing of uniform rainfall event

b) Decoupled sewer model and 2D overland routing

Evaluation of Modelling Approaches to Urban Flood Risk (continued)

There are some important messages for our assessment of potential progress on mapping surface water flooding.

- tools exist that can reliably and accurately model surface water flooding in urban areas;
- the costs of the different models can vary widely owing to the information and detail required and the cost of accurate modelling can be high if models of sewerage networks have to be built from scratch;
- simplified modelling is possible at relatively low cost but is far less reliable and probably only suitable for high level risk assessments on an area wide basis. Such approaches are not suitable for assessment at the level of detail of individual streets or for producing solutions to flooding; and
- surface water (or urban) flooding can be accurately modelled and mapped but further work is required to understand user needs and the costs associated with meeting those needs. There also needs to be an assessment of what information is currently available and where that information can be obtained.

4.44 The Environment Agency's proposed strategic overview role means that it will be well placed to provide a modelling and warning system to cover surface water flooding. It will need to work with its partners, especially with the Met Office, to develop the tools and techniques required to model surface water flooding.

4.45 It is vital that the Environment Agency also engages with those responsible for different aspects of the drainage and sewerage system – including water companies, local authorities, internal drainage boards, highways authorities, navigation authorities and riparian owners. This will help the Environment Agency to understand how surface water runoff is discharged by the system, what knowledge and data gaps are present and what steps need to be taken to fill them.

RECOMMENDATION 5: The Environment Agency should work with partners to urgently take forward work to develop tools and techniques to model surface water flooding.

Groundwater flooding

4.46 Groundwater flooding is caused by the emergence of water on the surface due to the water table rising. It can result in the flooding of surface or sub-surface infrastructure (for example, basements or sewers) and can cause damage to foundations by reducing their load-bearing capacity. The damage associated with groundwater flooding is believed to be significantly greater than that associated with river and surface water flooding, due to the fact that the water can remain above the surface for long periods of time. It is estimated that around 1.6 million UK properties are currently at risk from flooding associated with groundwater-dominated catchments.

4.47 Although groundwater flooding was not a major contributor to the summer 2007 floods, it did significantly affect certain areas and remained a serious threat in the months following the flooding.

4.48 The Review is aware that, although groundwater flooding has been recognised by flood risk managers as an important element of flood risk, no organisation has responsibility for it and at present it is not well understood. The Environment Agency has established monitoring and warning arrangements for the chalk aquifers in its South-West, Southern and Thames regions (which are most at risk of groundwater flooding), but there are still significant technical problems associated with groundwater flood risk assessment. This is because the models that have been designed for conventional hydrological events have a limited applicability to groundwater.

4.49 The Environment Agency has been investigating ways to develop its groundwater capabilities through the cross-government *Making Space for Water* programme and the Review welcomes this. It has looked at establishing a national database of flooding from all sources, as well as extending its flood risk maps and warning service to cover groundwater flooding. This work has partly been done in preparation for the implementation of the EU Floods Directive, which is discussed in more detail in Chapter 8.

4.50 Following the summer 2007 floods, the Environment Agency commissioned a report from the CEH to assess the groundwater flooding risk for the autumn and winter. It concluded that there was a risk in certain areas, but that this risk would depend on the amount of rainfall received during the autumn. As it transpired, there was no significant rainfall during the autumn and groundwater levels were able to stabilise. However, the report prompted the Environment Agency to undertake a national groundwater level scenario-forecasting exercise in October 2007. A reappraisal exercise took place in February 2008 following the heavy rainfall during January.

4.51 In response to the urgent recommendation made in the Review's interim report, that more frequent and systematic monitoring of groundwater levels should be undertaken, the Environment Agency is continuing to develop its activities. This includes collecting historic groundwater flooding information, extending the monitoring and warning systems and awareness-raising activities.

4.52 The Review welcomes the progress made by the Environment Agency and applauds its commitment to trying to develop its understanding of groundwater flooding. We hope that this work will be facilitated by the Environment Agency's strategic overview role where the responsibility for groundwater flooding can be fully established (see Chapter 3).

Integrated approaches to forecasting, modelling and mapping

4.53 Flood risk needs to be managed in a joined-up way; all sources of flooding need to be considered, as do all parts of the drainage system. Organisations and individuals will need to work together to enhance their understanding of the problems and to develop solutions that will reduce the risk of flooding.

4.54 Programmes, projects and working groups have already been set up to combine the expertise and data that is held within the disparate range of organisations involved and to facilitate closer working. This is particularly pertinent to government organisations, as there should be more of an incentive for them to work together to realise efficiencies and to provide cost savings.

4.55 The summer 2007 floods emphasised the need for organisations to work closer together and many submissions and comments to the Review highlighted the confusion between information received from the Met Office and information received from the Environment Agency.

Sharing information

4.56 The Review believes the sharing of information to be vital to effective flood risk management. Much work has been done by different organisations to collect and record datasets relating to flood forecasting and modelling. These now need to be integrated to fully realise the benefits.

4.57 There are a number of barriers that may hinder this integration, including compatibility and cost. The Review strongly believes that, because the sharing of information is integral to flood risk management, all efforts should be made to overcome these barriers.

4.58 Thus, integration will require information to be produced using consistent software compatible with the technical capabilities of the end user. The Environment Agency must work with partners to examine the range of software available and to provide guidance on how data should be collected and recorded for consistency.

4.59 Many government organisations currently charge for information (albeit often at discounted rates) to recover data acquisition costs. The Review appreciates that this is part of agreed business models, but a recent study for the Department for Business, Enterprise and Regulatory Reform (Newbury *et al.* 2007) indicated that a move towards a near-zero cost access to data for UK Trading Funds (e.g. the Met Office, Ordnance Survey, Hydrographic Office) would lead to considerable net benefits to the economy. **We would welcome further consideration of this approach**.

4.60 As part of efforts to share information more efficiently, the Atlantis Programme was set up in 2004. Its aims are to develop, maintain and promote the use of a definitive national dataset comprising topographical, geological and hydrological data.

4.61 The Atlantis Programme was established by a number of government organisations:

- the British Geological Survey, which maps the geology of the landscape;
- the Centre for Ecology and Hydrology, which has expertise in flood modelling and holds river catchment and depth profiles;
- the Environment Agency, which holds detailed information on the river network and maintains this information;
- the Met Office, which produces weather forecasts and records precipitation measurements;
- the Ordnance Survey, which collects detailed data on contours, surface material type and discrete geographical features; and
- the United Kingdom Hydrographic Office, which charts the world's oceans and provides other navigational and hydrographic information.

4.62 The Review welcomes the Atlantis Programme as a way of improving the ability of organisations to consolidate their data and to provide further detail on the layout of infrastructure and topographical features. This consolidation could provide a platform for more accurate modelling and scenario planning to be developed.

Integrated working

4.63 The Review's interim report highlighted the need for closer working between the different organisations involved in flood risk management. Following the conclusions made in our report, progress has been made towards integrating data, and facilitating the identification and collection of new data to fill existing gaps. For example:

- **Extreme Rainfall Alert.** The Met Office and Environment Agency have launched an Extreme Rainfall Alert (ERA) pilot service on a UK-wide basis for six months. The service has been developed in consultation with the Energy Networks Association and is designed to provide an early indication of extreme rainfall and the implied risk of surface water flooding. The potential value of this pilot will be enhanced with the release of the Environment Agency indicative surface water 'hotspots' which will assist emergency responders in prioritising their response efforts; and
- **Distributed Flood Forecasting.** This is a new method to provide indicative flood forecasts 'everywhere' by running a model on the Environment Agency's existing NFFS platform. This approach uses a chosen grid size (say 1 km), underpinned by a Digital Terrain Model (DTM) and feeds in information from the Environment Agency's telemetry systems and the Met Office's grid-based weather forecasts. This tool does not replace the Environment Agency's River Forecasting models on major rivers, but would work in parallel to accelerate the Environment Agency's programme of improvement works as flow forecasts from small un-gauged catchments would be made available for the Environment Agency to feed into its main river models. By supplementing

current systems, this model will provide a significant additional understanding of real-time flood risk and will be a key building block to further developments.

4.64 The Review places a high priority on the issue of integrated working between the main organisations with responsibilities for and information relating to forecasting, modelling and mapping flood risk. We welcome the progress that has been made in this area through the creation of an Inter-Agency Working Group (see text box below) and an Envronment Agency/Met Office Joint Steering Group.

Inter-Agency Working Group for forecasting and flood warning

The Environment Agency, Met Office, Ordnance Survey and Centre for Ecology and Hydrology decided to establish an Inter-Agency Working Group (IAWG) to provide options and recommendations for the Review on how the key agencies can work together to deliver world-leading flood forecasting and warning services for England and Wales.

The IAWG met over a period of approximately five weeks to discuss and set out a number of proposals:

- **provision of probabilistic flooding alert to professional partners.** Many stakeholders, for example, emergency responders and owners of critical infrastructure, have expressed a requirement for longer lead times for flooding events. Developments in technology could enhance the capability to produce earlier probabilistic forecasts;
- **Distributed Flood Forecasting and resulting alert products.** Work needs to progress on the Distributed Flood Forecasting approach to enable flow forecasting capabilities for locations where there are currently none, the creation of a spatial display of flood risk on a country-wide scale, the capability to forecast for un-gauged and rapid response catchments and longer lead times;
- **provision of a Surface Water Alert Service.** This consists of three approaches:
  1. alert of extreme rainfall – see above;
  2. identification of hotspots and development of a surface water flood map. The Environment Agency has already made progress on this and an indicative map of the hotspots should be available in August 2008; and
  3. development of surface water action plans by responsible authorities. There is currently no agreed remit to plan responses to surface water flooding.
- **education of professional partners.** If new forecasting tools and techniques are to be effective, the professional partners utilising them will need to be educated in their use. This is especially the case with probabilistic forecasting as there will need to be guidance on how to react to such warnings;
- **better presentation of information.** The output from the Atlantis Programme will provide a common reference framework for producing and presenting data. This should facilitate agencies sharing information and delivering a consistent message to the public and other stakeholders;
- **better media management.** The creation of a central media coordination group, which includes press office members from each of the IAWG organisations, to deliver a consistent message as above;
- **better utilisation of information sets.** The Atlantis Programme should be used as a vehicle for improving data interoperability (compatibility) and exchange of information. This will enable high risk areas to be prioritised in terms of maintenance, investment emergency plans and resources; and

Inter-Agency Working Group for forecasting and flood warning (continued)

- **options for closer working between the Environment Agency and the Met Office.** Initial discussions between the Environment Agency and the Met Office about working closer together on forecasting and warning have produced a preliminary range of options:
  - **status quo.** Both the Environment Agency and the Met Office continue with existing work programmes and initiatives and continue to work together under the existing Joint Steering Group arrangement;
  - **accelerated status quo.** As above but with modest additional resources to enable progress to be made more rapidly;
  - **step change in investment.** Significant investment to enable both the Environment Agency and the Met Office to undertake an enhanced programme of projects working together to agreed objectives under the existing structural arrangements; and
  - **joint centre approach.** The creation of a national weather/flood forecasting alert service which builds on, rather than replaces, the services currently provided.

4.65 The Review believes that in order to significantly advance the UK's forecasting and flood warning systems, the Environment Agency and the Met Office should work closer together and pool their expertise to deliver an integrated model for rainfall and subsequent flooding.

4.66 The Environment Agency and the Met Office, in parallel with the IAWG, have been investigating other options for implementation of a joint capacity which are:

- **virtual Environment Agency national centre** – dispersed team delivering National broad-scale river and tidal flood warnings to professional partners;
- **national Environment Agency operations centre** – dedicated team delivering National broad-scale river and tidal flood warnings to professional partners;
- **embedding staff in each other's operations centres** – this would be undertaken at a time of major flooding events. It would require a national Environment Agency operations centre;
- **dispersed Environment Agency/Met Office national operations centre** – national broad-scale river and surface water flood forecasting and alerts service to national partners; and
- **Co-location of national operations centre** – national broad-scale river and surface water flood forecasting and alerts service to national partners.

These options are being developed further, costed and assessed through the Environment Agency/Met Office Joint Steering Group.

4.67 The Review welcomes the work carried out by the Inter-Agency Working Group; this has provided a foundation on which to take forward improvements in forecasting, modelling, mapping and warning systems.

4.68 The summer 2007 floods exposed gaps in our capabilities in relation to forecasting and flood warnings. The Review understands that there are complex issues that need to be resolved but we strongly believe that advances can be made over the next few years. Surface water flooding in particular highlights the need for extreme rainfall prediction and flood modelling to be better integrated.

4.69 The Review strongly believes that in order to maximise advances in forecasting and flood modelling and warning there must be joint working between the Environment Agency and the Met Office. There also has to be a step change in terms of investment to allow joint research to be undertaken and potential capabilities to be realised.

4.70 The Environment Agency and the Met Office should take this opportunity to significantly enhance the UK's flood forecasting abilities and show a willingness to be open to a number of options including a joint centre.

4.71 The Review believes that there should be co-location of appropriate expert staff at a national level from the Environment Agency and the Met Office to integrate the process of weather forecasting and flood modelling and warning. The Review understands that this is a significant change to current arrangements and we do not take the option lightly. The evidence we have received from international examples such as France (SCHAPI) and Sweden (SMHI) (see case study box below) and from submissions to the Review suggest that this approach would maximise the potential enhancements that can be made in the quickest time.

4.72 The Review appreciates that a more in depth assessment of the different joint working options needs to be undertaken to establish the issues and costs involved. We therefore urge the Joint Environment Agency/Met Office Steering Group to take forward the work to consider the different joint working options as quickly as possible.

RECOMMENDATION 6: The Environment Agency and the Met Office should work together, through a joint centre, to improve their technical capability to forecast, model and warn against all sources of flooding.

Close cooperation between hydrological and meteorological services

SCHAPI and Météo-France

The Central Flood Forecasting and Warning Service (SCHAPI) in France was created in 2003 as part of the Ministry of Ecology and Sustainable Development, following severe flooding events, such as the 2001 flood which affected parts of northwest and central France, including Paris itself. The floods highlighted several weaknesses in the previous French flood forecasting and warning system, including the disjointed structure of the forecasting bodies, poor efficiency of flood warnings and a lack of understanding among the general public.

SCHAPI is based in Toulouse, alongside the national meteorological service, Météo-France. Both organisations benefit from the co-location of their office buildings and closer cooperation between meteorological and hydrological experts. This working arrangement has ensured better flood forecasting coordination and technical support and improved flood warnings, including flood vigilance maps. The new relationship between hydrologists and meteorologists has improved anticipation of flood events, through monitoring data from 22 regional flood forecasting centres which extend to 17,000 km of the rivers in France. SCHAPI now aims to provide warnings up to 24 hours ahead of a storm event. The time frame for warning depends on the speeds and flows of the rivers, but can range from up to three days for the River Seine to significantly shorter lead times in river basins that rise much more quickly. There are still limitations, particularly the ability to pinpoint a flood to a street-specific location. In addition, while technologically-advanced river monitoring and radar is used to gather information on possible rainfall events, it is still difficult to accurately forecast flash flood events.

Close contact with Météo-France has modernised the information process of floods, ensuring that SCHAPI can provide flood information to the public and media that is reliable, timely and consistent. One of their key tools is online ‘vigilance maps’[6], which are updated twice a day, and more frequently if necessary during an event. The general public have responded well to the new procedures, and according to SCHAPI’s own statistics[7], three-quarters of the general public felt that they understood the vigilance maps, with around 80 per cent feeling sufficiently informed.

Before 2003, the responsibilities and organisational structures were much more disjointed and, confused than they are presently in England and Wales. The responsibility for flood warnings lay with the Ministry of the Environment from 1979 – 1999 and it suffered from having its staff dispersed across the country with no centralised technical support. The synergy between the meteorological and hydrological agencies remained poor in spite of signed agreements between the Director of Water and Météo-France.

Despite the problems with the French system before the creation of SCHAPI, significant reforms and positive changes have been made in the last 4-5 years. The French have demonstrated that in order to achieve considerable advances in weather forecasting and flood modelling and warning, the meteorological and hydrological agencies need to be located in the same area. At present SCHAPI is located in a new, but separate, building on the Météo-France site, however, they are examining the possibility of physically locating the national weather and forecasting teams within the same building.

[6] Central Flood Forecasting Service (SCHAPI) Flood Vigilance Maps, at www.vigicrues.ecologie.gouv.fr.

[7] Dr Francoise Bénichou and Jean-Michel Tanguy presentation for the World Meteorological Organisation symposium on Multi-Hazard Early Warning Systems for Integrated Disaster Risk Management entitled *Lessons Learnt from France’s Awareness System for Enhanced Emergency Preparedness and Response Authorities*, 2006.

Close cooperation between hydrological and meteorological services *(continued)*

SMHI

The Swedish Meteorological and Hydrological Institute (SMHI) is a government agency which sits under the Ministry of the Environment and uses meteorological, hydrological and oceanographic expertise to provide public services, the private sector and the general public with important decision-making tools relating to the weather, water and climate.

SMHI's services include data collection, weather forecasting, warnings for extreme weather and other hazardous events, providing advice on interpretation of the warnings, inter-agency cooperation and research and development.

This joined-up approach to environmental hazards allows SMHI to provide wide-ranging information; from details of an impending storm, the spread of radioactive dust from a breakdown at a nuclear power plant, through to long-term climate change decisions.

The scope of SMHI is broader than that of SCHAPI and the fact that it is a single organisation, and has been for a number of years, means that it cannot easily be compared to structures in the UK. However, there are many similar lessons that we can learn from this joined-up approach such as joint weather and flood warnings, improved modelling and efficiency savings.