An update of the Foresight Future Flooding 2004 qualitative risk analysis
An independent review by Sir Michael Pitt

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June 2008

The Pitt Review

This report was written by:

E. P. Evans, J. D. Simm, C. R. Thorne, N. W. Arnell, R. M. Ashley, T. M. Hess, S. N. Lane, J. Morris, R. J. Nicholls, E. C. Penning-Rowsell, N. S. Reynard, A. J. Saul, S. M. Tapsell, A. R. Watkinson, H. S. Wheater.

A full list of those who contributed to the update is given after the References.

The report should be referenced as:

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

The work was carried out as part of the Pitt Review of the lessons learned from the 2007 floods in England and Wales.

Contents

Throughout this report, explanations and definitions relating to the update process have been given in grey boxes.

Summaries of the key ideas and messages are in light blue boxes.

Fuller technical details can be found in the appendices.

Chapter 1: Background

The Pitt Review

The Pitt Review has collected and considered evidence concerning the floods which occured during June and July 2007 in England and Wales, their impacts on people, property and critical infrastructure, and the implications for flood risk management. While a great deal of useful evidence has been obtained from the first-hand accounts of those directly involved, and the specific circumstances of last summer, it is also important that the longer term is considered.

One of the most important pieces of research that has been carried out to examine what might happen to UK flood risk in the future is the *Foresight Future Flooding* (2004). To assist the Pitt Review, a project has been carried out to update this study and this report details its findings.

Given the time available, it was recognised that, while it would be inappropriate to repeat the quantitative analyses performed in 2004, an update based on the qualitative analysis of the drivers of future flood risk and the responses that might be used to manage those risks would enhance the science base of the Pitt Review.

Introduction

The Foresight Future Flooding study (2004) is one of the most important pieces of research that has been carried out to examine what might happen to UK flood risk in the future. This study provided visions of flood risk in the UK over a 30- to 100-year timescale to help inform long-term policy.

The Foresight Future Flooding Project (2004)

The *Foresight Future Flooding* of 2004 produced a challenging vision of future flood risks and options for flood risk management and coastal defence throughout the UK during the remainder of this century. A scenario-based approach was adopted, over a 30- to 100-year timescale, and the project accounted for risks in terms of the social, economic and environmental dimensions of flooding. Particular attention was paid to recognising and accounting for the high levels of uncertainty associated with many of the key drivers and responses. The 2004 Foresight project has been taken up by key stakeholders to inform policy and its delivery throughout the UK, while the Foresight method has elicited interest in Russia and the USA, and has been adopted by the Ministry of Science and Technology and the Ministry of Water Resources in China.[1]

> The Foresight 2004 project considered different scenarios to look at what might happen to flood risk and its management a long way in the futuwre.
>
> It employed two forms of analysis – a quantitative, probabilistic, computer analysis using very large Geographical Information System (GIS) databases based on the Risk Assessment for System Planning (RASP) system developed by the Environment Agency, and a qualitative analysis. The latter uses a structured method to draw out evidence-based expert knowledge to estimate approximately how big an impact the various drivers and responses might have on flood risk under different future scenarios, and then ranks them in order of impact on flood risk.

This update has retained the principles and approaches applied in the original study. It focuses on those drivers and responses for which updating is merited by events, research and developments that have occurred since 2004, and for which an update can add value to the insights and understanding provided in the existing Foresight reports.

[1] www.nottingham.ac.uk/~lgzwww/foresightchina/index.htm

Chapter 2: Project aims and phases

Project aims and objectives

Aim of the report

The main aim of this update report is to reassess the drivers and responses to flood risk examined in the Foresight 2004 report and identify any new drivers or responses that may have become significant. This update considers evidence and research that has become available since 2004, including evidence gathered in relation to the summer 2007 floods.

The main aim of the report was supported by a number of specific objectives.

- Revisit the Foresight scenarios for climate change (including relative sea-level change) and socio-economic development.
- Conduct a high-level, evidence-based, qualitative analysis that looks from 30 years ahead to the end of the century.
- Take into account new or better data and insights that have emerged since 2004, including making full use of the findings of the Pitt Review interim report.
- Consider the economic, social and environmental risks associated with river, coastal, surface water, groundwater and coincident flooding (flooding from more than one source).

Like the 2004 study, this update is sufficiently general in its approach to be valid for the whole of the UK, though it focuses where appropriate on England for consistency with the Pitt Review.

Definition of drivers and responses

Drivers are phenomena that may change the state of the flooding system, such as climate change, urbanisation or changing agricultural practices. **Responses** are changes to the flooding system that are implemented to reduce flood risk, such as flood defences.

The distinction between drivers and responses is not always clearly defined; some drivers are under the control of flood managers and can act as responses to rising flood risk. Conversely, responses can themselves become drivers in certain circumstances – for example, the use of engineered flood defences to reduce flood risk in one town may affect flood risk downstream and will therefore be a driver of flood risk in another town.

Project phases

The project had three phases as follows.

Scenario updating and driver selection

The project has revisited the scenarios and drivers used by Foresight in 2004 in order to update the scenarios, identify whether any additional drivers have emerged since 2004 and select those drivers for which scientific advances, new/better data, or especially issues encountered in summer 2007, might have significantly changed the assessment of (a) their contributions to future flood risks and (b) their risk ranking relative to other risks in the tables that were produced in 2004.

Driver analysis

Owing to the changes that we found in the climate change scenarios, the considerable amount of research that has been carried out in the intervening period, and the way that these ripple through the analysis, we have re-analysed all the drivers to assess the evidence for any significant changes compared with those reported in the 2004 Foresight project. This includes assessment of the risks associated with river, coastal, surface water, groundwater and coincident flooding events in the context of the summer 2007 floods, the 'near miss' storm surge of November 2007, and other developments since 2004. An important advance over the 2004 study is that we have combined the fluvial/coastal and the 'intra-urban' drivers, that were dealt with separately in 2004, into a single list and set of ranking tables. The main reason for this is the need for flood risk to be managed with in a holistic way in order to tackle all flood risk effectively, especially coincident flooding.

Response analysis

Further qualitative analysis has also been carried out to assess the extent to which new knowledge and events since 2004 have changed the potential for management and reduction of future flood risks in the 2050s and 2080s through appropriate responses. The 2004 Foresight project concluded that a portfolio of responses, including both structural (e.g. flood defences) and non-structural (e.g. improved forecasting) measures, offered the most sustainable approach to future flood risk management in terms of cost efficiency, social equity and environmental impacts. As with the drivers, fluvial/coastal and 'intra-urban' responses have been combined into a single set of ranking tables.

The outcomes of the analyses are explained in revised driver and response ranking tables (traffic light tables) in the main body of this report, supported by updates to the 2004 driver and response descriptions, which can be found in the appendices.

Chapter 3: The analytical framework

> **'Intra-urban' flooding**
>
> The flooding system includes the physical and human systems that influence or are influenced by flooding. The 2004 report used the term 'intra-urban' to describe flooding arising from events within urban areas, in contrast to river and coastal flooding where water enters urban areas from outside. This type of flooding broadly equates to the term 'surface water flooding' used in the Pitt Review report.

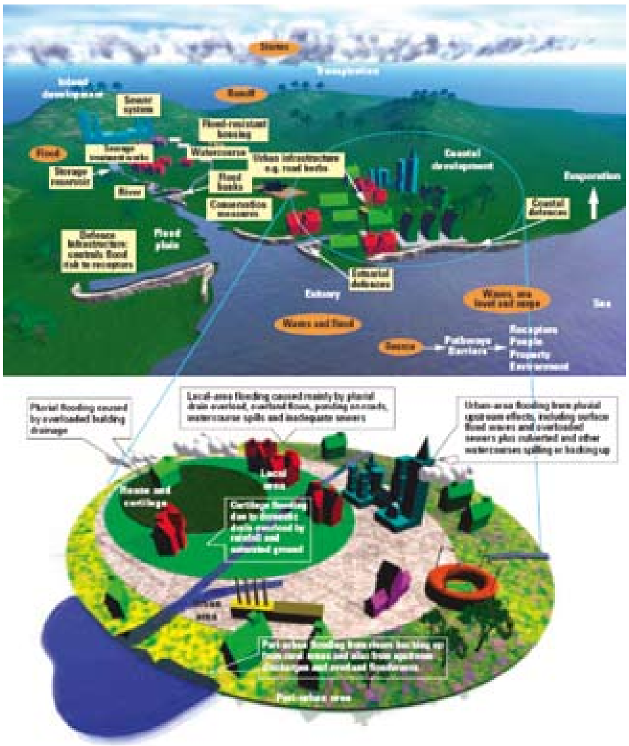

Figure 1: The flooding system. Upper image: the fluvial/coastal flooding system. Lower image: the intra-urban flooding system (from Evans et al., 2004)

In 2004, we used the terms 'drivers' and 'responses' for things that change the flooding system and hence flood risk. They are illustrated in Figures 2 and 3.

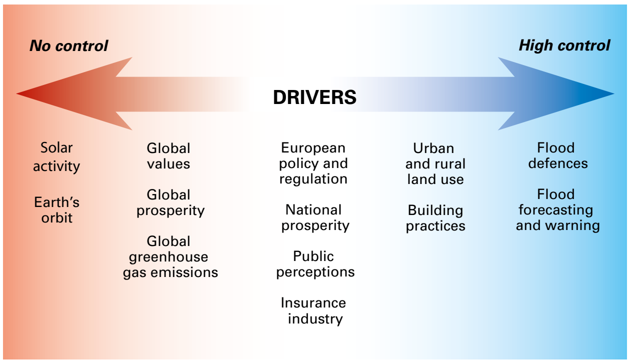

Figure 2: Drivers and responses, showing the degree of control for different drivers: drivers towards the right can be used as responses to flood risk (from Evans et al., 2004)

We used a Source–Pathway–Receptor (SPR) framework in analysing the drivers and responses (Figure 3).

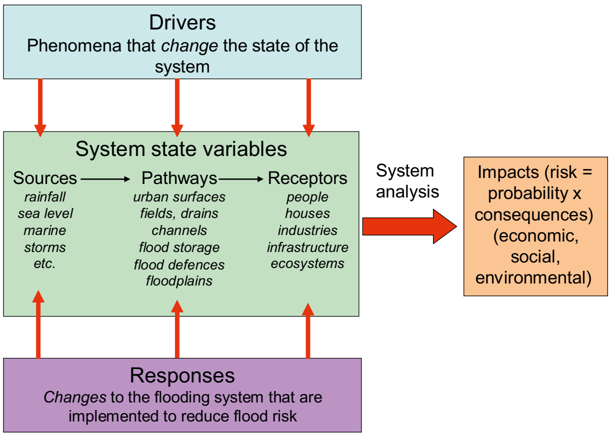

Figure 3: The relationship between drivers, responses, the flooding system and flood risk

In 2004, we used climate and socio-economic scenarios to assess possible UK flood risk between 2030 and 2100. We combined them into pairs (Figure 4) to give us sets of parameters for climate, economics etc. in the future to use in our analyses.

Figure 4: Combined climate change and socio-economic futures used in the Foresight 2004 analysis

The climate change scenarios were based on the report of the UK Climate Impacts Programme, UKCIP02 (Hulme et al., 2002), and the socio-economic scenarios were taken from the Social Policy Research Unit's (SPRU's) 'futures' work (SPRU, 1999), which was based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES).

Framework for analysis

The analyses used the well-established Source–Pathway–Receptor (SPR) model of the flooding system. In this context:

- **Sources** are weather events, or sequences of events, that may result in flooding (e.g. intense rainfall and storm surges).
- **Pathways** are mechanisms that convey floodwaters that originate as weather events to where they may impact on receptors (e.g. flows in and out of river channels and urban overland flows).
- **Receptors** are the people, businesses and the built and natural environments that are affected by flooding.

This is a logical framework around which to build our analysis, and the climate change and socio-economic scenarios, to help us to look at what might happen a long way into the future.

Chapter 4: Updated scenarios

Climate change scenarios

In this chapter we derive potential changes in the 'native parameters' of climate change, such as precipitation and sea-level rise. How these impact on future flood risk is considered in Chapter 5.

Precipitation and temperature

Since the 2004 Foresight study there have been significant developments in the climate change field. Knowledge gained from recent extreme events (not least the summer 2007 floods) leads to the conclusion that there is a clear need to re-visit the original scenarios of change in precipitation and temperature for the UK for this update.

It was previously acknowledged that the scenarios within Foresight 2004 did not represent the entire range of potential changes in the future, especially for rainfall. The work being undertaken for the forthcoming UKCIP08 scenarios supports this assertion, as do the scenarios available as part of the IPCC fourth assessment report (AR4).

The Hadley Centre has run a 17-member ensemble of its Regional Climate Model (RCM), designed to capture both RCM uncertainty as well as a degree of Global Climate Model (GCM) uncertainty. These results show the limited nature of the climate change 'space' represented by the UKCIP02 scenarios. Moreover, data from large international projects such as PRUDENCE (Christensen, 2005) and ENSEMBLES (Hewitt and Griggs, 2004) serve to illustrate the large uncertainty in rainfall scenarios (Rowell, 2005 and 2006), particularly for potential changes in extreme events of both long and short duration.

As part of the IPCC AR4 process, a global coupled climate model experiment was conducted resulting in a multi-model dataset for up to 23 climate models, including projections to 2100 under three scenarios – IPCC SRES (Nakicenovic and Swart, 2000; Meehl et al., 2007). Figure 5 shows the relative percentage changes in winter and summer precipitation. Blue areas indicate increases by the final decade of this century relative to the 1980–99 period. The stippled effect shows those parts of the globe where 90 per cent of the GCMs used in the multi-model analysis agree with the direction (sign) of the seasonal change. For the UK, this provides confidence that winters will become wetter and summers will become drier with Rowell (2005), for example, suggesting changes of between 0 per cent and 30 per cent (but up to 60 per cent for one particular GCM) for the winter and decreases in summer precipitation between 0 per cent and 40 per cent.

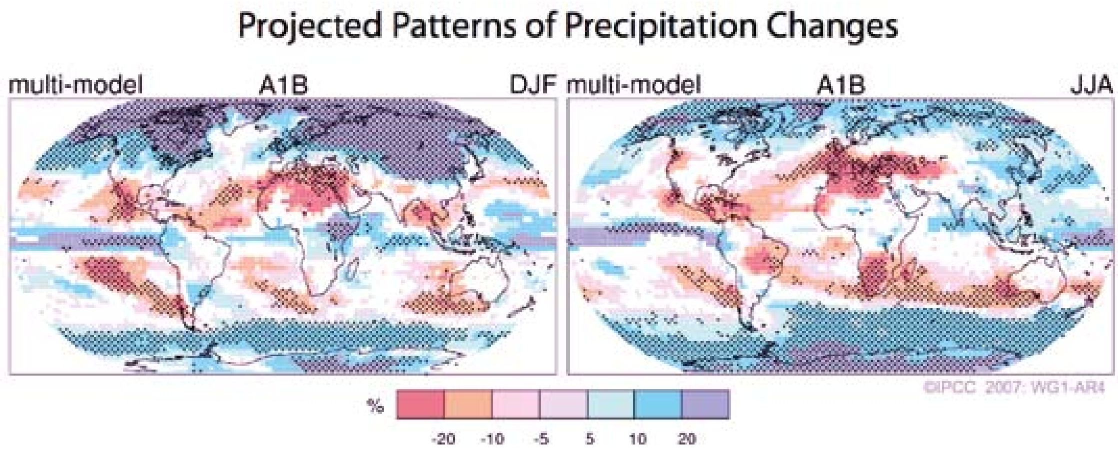

Figure 5: Relative percentage changes in precipitation for the period 2090–99, relative to 1980–99. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right) (IPCC, 2007)

For the UK, Figure 6 shows the spread of the IPCC AR4 scenario changes, by the 2080s, for rainfall and temperature during (a) the winter and (b) the summer. Each dot represents one GCM result under any of the three emissions scenarios for any UK land cell. The smaller boxes represent an approximation of the (2080s) scenario 'space' used for Foresight 2004, with the larger boxes showing the new scenario 'space' for this update.

Taking this new evidence into account, revised 'native parameters' for these drivers are listed in Tables 1 to 3 overleaf, for the 2050s and 2080s. The Foresight 2004 values are shown in brackets where available.

a) Changes in winter precipitation and temperature	b) Changes in summer precipitation and temperature

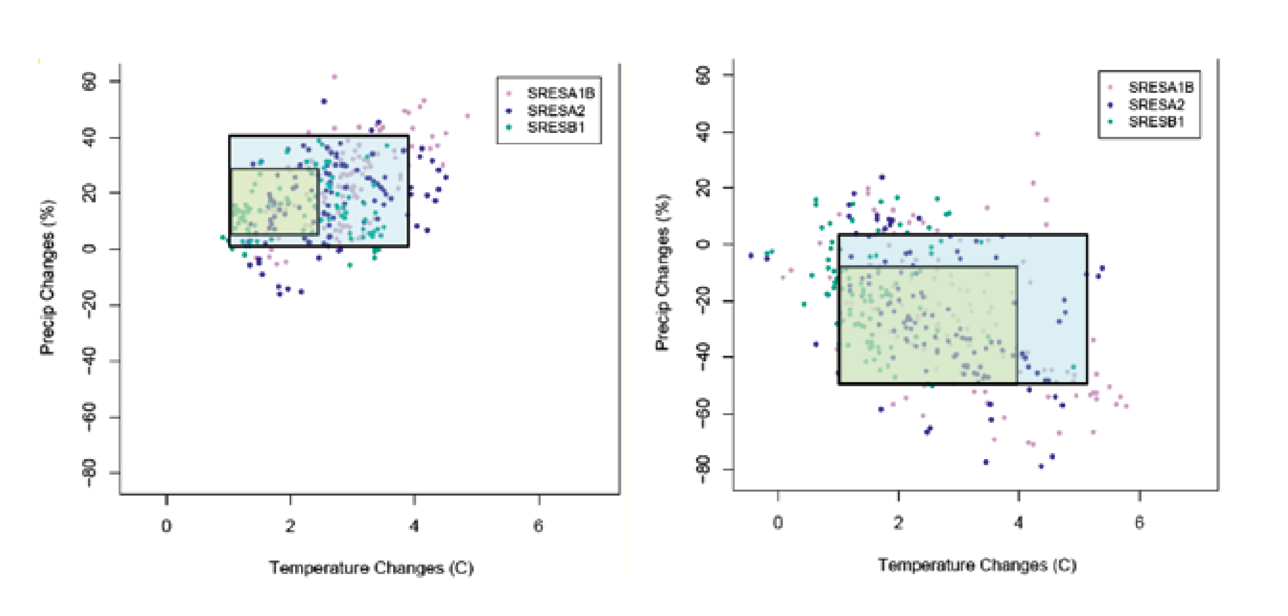

Figure 6: (a) Winter and (b) summer changes in precipitation and temperature for the UK

Table 1 – Change (in ºC) in annual, summer (June–August) and winter (December–February) temperature for the 2050s and 2080s under the four climate scenarios

Scenario	**2050s**			**2080s**		
	Annual	Summer	Winter	Annual	Summer	Winter
World Markets	2.5 (2)	3 (2.5)	2 (1.5)	4.5 (3)	5 (4)	4 (2.5)
National Enterprise	2 (1.6)	2.2 (1.8)	1.5 (1.0)	3 (2.5)	3.5 (3)	3 (2)
Local Stewardship	1.3 (1.1)	1.5 (1.2)	1 (0.5)	2 (1.5)	2.5 (2)	2 (1.5)
Global Sustainability	0.7 (0.5)	0.7 (0.5)	0.5 (0.5)	1 (1)	1 (1)	1 (1)

Table 2: Percentage change in annual, summer (June–August) and winter (December–February) precipitation for the 2050s under the four climate scenarios

Scenario	Annual	**Summer**			**Winter**		
		Total	Inter-annual variability	Intensity	Total	Inter-annual variability	Intensity
World Markets	5 (-5)	-30 (-30)	30	30	25 (15)	5	20 (12)
National Enterprise	0 (-8)	-20 (-20)	20	20	16 (10)	0	10 (6)
Local Stewardship	-5 (-10)	-10 (-10)	10	10	8 (5)	-5	0 (0)
Global Sustainability	-10 (-12)	0 (0)	0	0	0 (0)	-10	-5 (-5)

Table 3: As for Table 2, but for the 2080s

Scenario	Annual total	**Summer**			**Winter**		
		Total	Inter-annual variability	Intensity	Total	Inter-annual variability	Intensity
World Markets	10 (-8)	-60 (-50)	50	60	40 (25)	10	35 (20)
National Enterprise	0 (-12)	-40 (-35)	35	40	30 (19)	0	20 (5)
Local Stewardship	-10 (-15)	-20 (-20)	20	25	20 (12)	-10	5 (0)
Global Sustainability	-20 (-20)	0 (-5)	5	10	10 (5)	-20	-10 (-10)

From Figure 6 we see that the changes to seasonal precipitation are positive (increasing) for the winter and negative (decreasing) for the summer. Temperature changes are positive in all seasons. The magnitude of the changes in both precipitation and temperature for the High (2080s) scenario have been determined by the outer limit of the larger boxes shown in Figure 6.

Update of climate change scenario – Precipitation and temperature

As a result of new research, the potential increases in both total rainfall volumes and intensity are considerably bigger in all cases than the values from UKCIP02 used in 2004. For instance, under the worst case scenario, total winter precipitation increases by 40 per cent as compared with the 25 per cent estimated in 2004. The potential temperature changes have also increased under all of the scenarios, which will affect the nature of the weather events experienced in the future. This indicates higher future increases in flood risk compared with the 2004 estimates.

Two other indices for precipitation have also been defined: the change in the inter-annual variability of the seasonal totals, and the change in the intensity of extreme events. In Foresight 2004, changes in these variables were not quantified. For summer, these typically represent changes in the intensity of short duration extremes, whereas for winter they would be changes in the maximum intensity of precipitation within larger-scale, longer duration, frontal-type events. The changes in rainfall intensity in Tables 1 to 3 apply equally in the intra-urban context, whereas in Foresight 2004 there were certain inconsistencies between the fluvial and intra-urban figures used.

Further evidence to support changes in both the inter-annual variability and intensity of rainfall may be found in Meehl et al. (2007), who suggest increases in summer season variability, but decreases in the winter. Precipitation intensity increases in both seasons, although more during the summer. Palmer and Räisänen (2002) suggest an increase in the number of very wet winters over most of Europe, due to an increase in intense precipitation through the intensification of mid-latitude storms. Equally, for the summer, Christensen and Christensen (2004) suggest increases in the intensity of summer, short-duration rainfall across Europe. Work undertaken for UK Water Industry Research (as quoted in the Foresight 2004 analysis) suggests maximum increases in summer intensities of 60 per cent, while Frei et al. (2006) suggest increases in five-year recurrence interval five-day rainfall totals during the winter of up to 50 per cent for the UK, and increases in the one-day totals during the summer of up to 25 per cent.

The World Markets scenario for the summer suggests a 60 per cent decrease in the seasonal total by the 2080s, but large increases in both the variability of summer totals and the intensity of summer rainstorms. Despite, therefore, decreasing average summer rainfall, there will still be a chance of experiencing a wet summer like that of 2007 (because of the large increase in the variability of summer totals) punctuated with short-duration extreme and intense events (increasing in intensity by up to 60 per cent), as was observed during 2007.

Frequency of 2007 summer floods

The sequence of events giving rise to the summer flooding in 2007 was very rare. Such an episode, even under the new Foresight future scenarios, would still be regarded as unusual. Whether it becomes more likely in the future depends on the interplay between changes in total rainfall, variability of summer rainfall, and rainfall intensity.

The scenarios presented are for a national assessment. Within these changes, there will be local or regional variations in climate changes that are not captured within this qualitative, national update of the Foresight project. This is not to say, however, that the impact of these scenarios on flood risk in the UK will not also exhibit high spatial variability. Catchment response to any given change in climate is highly complex, and depends on a multitude of system-specific interactions such as catchment geology, geomorphology and land use.

Climate change impacts on the coast

Climate change impacts coastal flood risk directly, through sea-level rise, and indirectly through changes in waves and surges resulting from the whole set of climate parameters. The last two phenomena are reviewed under the Waves and Surges driver updates.

Mean relative sea-level rise is the sum of global mean sea-level rise, regional sea-level rise due to change within individual ocean basins and positive or negative local sea-level change due to land uplift or subsidence.

The changes in understanding since 2004 mainly concern global mean sea-level rise. This is composed of three main elements:

- thermal expansion;
- melting of small land-based glaciers; and
- breakdown of the large ice sheets (Greenland and West Antarctica, especially the West Antarctic Ice Shelf – where our knowledge is weakest).

Several relevant documents have been produced since Foresight 2004, such as those published by Defra (2006) and UKCIP (2007), but the most important changes have been the new sea-level rise scenarios published by IPCC AR4 (Meehl et al., 2007) and the discussion that has followed.

Recent satellite-based observations of global mean sea level have exceeded the upper boundary of the scenarios published in the IPCC Third Assessment (TAR) and AR4 reports (Rahmstorf et al., 2007), raising concern that sea level is rising more rapidly in response to global warming than the current climate models can explain. There has also been discussion of the possibility of quite extreme rises in global mean sea level due to breakdown of the large ice sheets (e.g. Hansen, 2007), including geological analogues of present conditions which suggest that a rise of 2 m/century is possible (Rohling et al., 2007). Hence, the possibility of a global mean sea-level rise exceeding 1 m in the 21st century is now considered plausible, though unlikely. In effect, we are now more concerned about the low-probability, high-consequence tail of the distribution of global mean sea-level rise, reviving fears that were paramount concerning sea-level rise 20 years ago. The potential consequences of such a large sea-level rise have been illustrated for London by Dawson et al. (2005), and other coastal cities and communities would face similar challenges.

We are also confident that there will be at least some global mean sea-level rise under all scenarios (continuing trends observed during the 20th century) and, hence, there will be an impact on flood risk even at the lower end of the range of possible sea-level rise within all scenarios.

A comparison of the scenarios in the IPCC TAR and AR4 reports is given in Table 4. While the mean scenarios' values are similar, the range has been narrowed in AR4. However, the IPCC report states that these numbers should not be taken as an upper boundary on global sea level, and a greater rise, exceeding 1 m, is possible. Upper ranges were not calculated for Foresight 2004. For the purpose of estimating the potential changes in the report, the IPCC AR4 scenarios, which include an unlikely, but still possible, additional rise of up to 100 cm due to ice sheet breakdown (see High + column), are used.

Table 4: A comparison of the global mean scenarios from the IPCC TAR and AR4 from 1990 to the 2080s (Table 10.7 in Meehl et al., 2007)

	Global mean sea-level rise scenarios (cm)							
	Third Assessment			Fourth Assessment				
UKCIP02 (SRES) scenario	Low	Mean	High	Low	Mean	High	Ice sheet breakdown	High +
Low Emissions (B1)	9	29	48	17	29	41	50	91
Medium–Low Emissions (B2)	11	33	54	18	32	46	66	112
Medium–High emissions (A2)	13	36	59	19	36	52	84	136
High Emissions (A1FI)	16	43	69	22	42	62	100	162

Update of climate change scenario – Impacts on the coast

Compared with Foresight 2004, the mean estimates of sea-level rise relative to the land have not changed. But much larger rises are seen now as a small but real possibility. While the mean estimate of sea-level rise is around 30–40 cm, it might, with ice sheet melting, be 1–1.6 m. As with the changes in predicted rainfall, this will lead to increased flood risk.

Socio-economic scenarios

In the 2004 Foresight Future Flooding project, four scenarios were used as the basis of what the UK national socio-economic situation in 2080 might be.

In addition to the two axes that represent variation in governance and values, the Foresight scenarios also capture potential variation in demography and settlement patterns, the composition and rate of economic growth, and the rate and direction of technological change. These were fed in to both our qualitative and quantitative analyses. The scenario storylines are internally consistent and draw on an analysis of current socio-economic trends, while introducing elements of novelty and change.

In the Foresight 2008 update, we have considered whether these scenarios should be updated. Our conclusion is that they should not.

This does not mean that we do not recognise that the world is changing, and has changed since 2004. For example, we appreciate that China and India have developed rapidly in the last four years, and that global food prices have risen steeply, as have the prices of other commodities. The population of the UK is rising and its structure is changing demographically to one with larger numbers of single people, affecting the housing stock and, especially where new development is in a floodplain, exposure to flood risk. Authoritative studies by the Organisation for Economic Cooperation and Development (OECD) suggest that climate change is increasing the vulnerability of rapidly growing coastal infrastructure such as ports and harbours. All these changes are affecting the global economy, including the UK economy.

But incorporating these changes in updated scenarios is not the task we should be considering here. These scenarios are not time-specific predictions, but future 'storylines' that are time-independent. Whether the world is moving in the direction of one scenario or another is not the point: the point is to construct and use coherent and internally consistent storylines that tell us what the future might look like; they are not projections against which we need to monitor change and thereby seek to alter the scenarios.

It should be noted in relation to our conclusion in this respect that the AR4 of the IPCC, published in 2007, did not use or define new socio-economic scenarios (Fisher et al., 2007), and assessments continue to be based on the SRES scenarios. It was noted in the AR4 that current population scenarios tended to be lower than those produced at the time of the SRES, and medium-term regional economic projections for some developing country regions were lower than assumed in the SRES, but that "otherwise, economic growth perspectives have not changed much". This means it is not possible – even if it were desirable – to say with any confidence towards which of the four scenarios UK society is now moving.

The only rationale for changing these SPRU-derived scenarios would be if government had selected different ones for its own 'futures' work, or if revised scenarios were being used in other assessments. We can find no evidence that either is the case.

There is, however, a special point relating to agriculture. In comparison with earlier Foresight scenarios, the 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, wider than originally envisaged in the 2004 Foresight report with extremes rather more like a Mediterranean climate than a Maritime-Northwest European one. This will clearly have consequences for the agricultural sector in terms of crops grown, cultivation patterns and the need for irrigation.

Update of socio-economic scenario

While there has been some socio-economic evolution in the UK since 2004, there have not been any fundamental changes in the Intergovernmental Panel on Climate Change (IPCC) socio-economic scenarios, which underpin our work. Since we focus on a period 30–100 years ahead, we will not comment on current approaches, legislation or institutions, or change our assessments except in so far as they cast light on the future operation or impacts of drivers and responses.

The evolution of the British climate towards a more mediterranean one will have general economic consequences, especially for the agricultural sector, but are not included in the socio-economic update.

Chapter 5: Update of the 2004 drivers analysis

Revision of the SPR framework for drivers

Separate tables were used in the 2004 Foresight analysis for the fluvial/coastal flooding system and the ‘intra-urban’ system. The 2004 drivers tables are reproduced in Tables 5 and 6.

> An important advance in this update over the 2004 study is that we have combined the fluvial/coastal and ‘intra-urban’ drivers into a single list and set of ranking tables, thus enabling direct comparisons between these groups of drivers of future increases in flood risk. This has been done in part in acknowledgement of the trend in UK flood risk management policy towards more integrated management of fluvial/coastal and intra-urban systems, advanced in England under *Making Space for Water*, and forcefully supported in the recommendations made by the Pitt Review.

Table 5: Fluvial/coastal drivers (from Evans et al., 2004)

Driver group	Driver	SPR classification	Explanation
Climate Change	Precipitation	Source	Changes in all aspects of precipitation (amount, intensity, duration, location, seasonality and clustering).
	Temperature	Source	Influence of temperature on soil moisture and hence runoff.
Catchment Runoff	Urbanisation	Pathway	Changes in the catchment that increase the area of impermeable surfaces and extent of storm water drainage systems to increase surface runoff.
	Rural land management	Pathway	Effects of land management practices on agricultural and other ‘managed’ rural land, including conservation and recreational areas and wetlands that affect runoff generation.
	Agricultural impacts	Receptor	Impact of flooding and associated high water tables on farm and forestry land and associated managed habitats.
Fluvial Systems and Processes	Environmental regulation	Pathway	Future legislation intended to increase biodiversity and habitat protection may influence policy on flood management, with implications for river and floodplain morphology, vegetation, conveyance, and flood storage.
	River morphology and sediment supply	Pathway	Changes in river channel morphology (size and shape) and sediment supply that alter attributes of the river channel and floodplain to influence flood conveyance, routing and storage.
	River vegetation and conveyance	Pathway	Vegetation and micro-morphology influence velocity distributions and turbulence levels in flows significantly. Hence, changes may affect flood conveyance.
Coastal Processes	Waves	Source	Offshore waves are generated by winds and increase in height with storminess and fetch length. Increases in wave height and changes in wave direction due to climate change may affect transmission of wave energy to the shoreline. Impacts will be influenced by increases in near shore depth caused by changes in next two drivers.
	Surges	Source	Increases in surge levels are expected due to climate change induced increases in storminess. Stronger surges mean that higher extreme water levels with more energy reach the shoreline, increasing the risks of breaching or overtopping of coastal defences.
	Relative sea level rise	Source	Rising relative sea level is due to climate change-induced melting of ice caps and thermal expansion in conjunction with land subsidence or uplift. Rising RSL, makes coastal flooding more frequent, and allows more energy to reach the shoreline. Long term effects include morphological change as the coastline adjusts.
	Coastal morphology and sediment supply	Pathway	Changes in the near-shore sea-bed, shoreline and adjacent coastal land, coastal inlets and estuaries will in the short term affect the wave and surge energies that affect the shoreline. In the long term, the coastline adjusts to changes in coastal processes.
Human Behaviour	Stakeholder behaviour	Pathway	Stakeholders may influence flood risk in many ways, ranging from pre-flood preparedness to self-help after and event. Corporate and government stakeholders influence availability of insurance, agricultural practices, food production, and pursuance of ecological (or other) aims. Future changes in stakeholder behaviour will be strongly linked to societal values and goals.
	Public attitudes and expectations	Receptor	Determines preferences for styles of risk management. Most obviously, ‘public attitudes and expectations’ will act upon flood risk indirectly, through other drivers, particularly, though not exclusively, those associated with stakeholder behaviour.
Socio-economics	Buildings and contents	Receptor	The damage to buildings and their contents, including damage to production and household durables, as well as raw materials, intermediate goods and consumer goods.
	Urban impacts	Receptor	The type and layout of buildings and resulting densities of development, building form and nature of land use, all affect the magnitude of flood losses per unit area.
	Infrastructure impacts	Receptor	The networks of services that enable the economy to transform raw materials into goods, intermediate goods and final consumption. Flooding these networks can have consequences beyond the area directly affected by flooding.
	Social impacts	Receptor	Includes the risk to life, the ‘intangible’ impacts of flooding, the vulnerability of different groups and impacts of flood on community cohesion.
	Science, engineering and technology	Receptor	S.E & T collectively determine the ration of the output of the economy to the required inputs of the natural endowment, labour and capital they enable us to do more with less. They are determined primarily by worldview and influence flood risk via the buildings and contents, urban impacts and infrastructure drivers

Table 6: Intra-urban drivers (from Evans et al., 2004)

Driver group	Driver	SPR classification	Explanation
Climate Change	Precipitation	Source	Changes in short duration precipitation – amount, intensity, duration, location, seasonality and clustering
Runoff	Urbanisation	Pathway	A change in land management with green field and previous surfaces covered by less-pervious materials (buildings and infrastructure) and associated new conveyance systems.
	Management of Part-Urban Rural Land	Pathway	Changes in the management of land adjacent to the urban area that influence runoff into the urban area, for example, muddy floods.
Urban Conveyance Systems and Processes	Environmental Management and Regulation	Pathway	The management of the green areas within the urban landscape, including flora and fauna.
	Urban Watercourse Conveyance, Blockage and Sedimentation	Pathway	Processes associated with above-ground overland surface flow in natural watercourses and man-made systems, including performance, maintenance and operation.
	Sewer Conveyance, Blockage and Sedimentation	Pathway	As above, but associated with processes that occur in below-ground drainage systems.
	Impact of External Flooding on Intra-urban Drainage Systems	Pathway	Loss of conveyance and serviceability in below-ground drainage systems due to flooding from external sources.
	Intra-Urban Asset Deterioration	Pathway	Changes in the performance, condition and serviceability of urban drainage assets (ageing, performance wear-and-tear and rehabilitation management).
Human Behaviour	Stakeholder Behaviour	Pathway	Mechanisms to ensure that all stakeholder's interests are accommodated.
	Public Attitudes and Expectations	Receptor	Taking due regard of the interests of the public, their views, beliefs, attitudes and values.
Socio-economics	Buildings and Contents	Receptor	Accounting for the cost of flood damage to households.
	Urban Impacts	Receptor	The potential to classify the risk of flooding in urban areas.
	Infrastructure Impacts	Receptor	The impact on the performance, serviceability and economics of the drainage infrastructure due to a flood event.
	Social Impacts	Receptor	The value to society of a flood even, primarily intangible, excluded by economic assessment.
	Science and Technology	Receptor	Application and design of the outputs of scientific and technological research.

As compared with the 2004 tables, the drivers have been rearranged in an order better aligned with the SPR framework. One new driver set has been added – Groundwater Systems and Processes. One driver set has been removed – Public Attitudes and Expectations – and moved to the Responses section. This is because it acts on responses through public reactions to changing flood risk and the responses implemented to manage flood risk, rather than being a direct driver of flood risk itself. The combined table of drivers is shown in Table 7.

Table 7: Combined list of fluvial/coastal and intra-urban drivers

Driver group	Driver	SPR classification
Climate Change	Precipitation	S
	Temperature	S
	Relative Sea-Level Rise	S
	Waves	S
	Surges	S
Catchment Runoff	Urbanisation	P
	Rural Land Management	P
Groundwater Systems and Processes	Groundwater Flooding	P
Fluvial Systems and Processes	Environmental Regulation	P
	River Morphology and Sediment Supply	P
	River Vegetation and Conveyance	P
Urban Systems and Processes	Urbanisation and Intra-urban Runoff	P
	Sewer Conveyance, Blockage and Sedimentation	P
	Impact of External Flooding on Intra-urban Drainage Systems	P
	Intra-urban Asset Deterioration	P
Coastal Processes	Coastal Morphology and Sediment Supply	P
Human Behaviour	Stakeholder Behaviour	P
Socio-economics (now includes rural and intra-urban receptors and all types of flooding: river, coastal, pluvial and coincident)	Buildings and Contents	R
	Urban Impacts	R
	Infrastructure Impacts	R
	Agricultural Impacts	R
	Social Impacts	R
	Science and Technology	R

Results and discussion of the updated drivers analysis

Combining the flood risk multiplier scores and rankings of fluvial/coastal, intra-urban and groundwater flood risk drivers allows direct comparison between **all** drivers, but raises the question of how to weight the drivers in the combined list to obtain risk multipliers and rankings that are consistent on a national basis. This is necessary because the risk multipliers obtained in the first instance are 'local' scores, representing the changes in risk to which a person or asset sitting within a fluvial floodplain, coastal floodplain or urban area would be subjected. These must be weighted according to their proportion of the overall flood risk of receptors in the nation as a whole in order to convert them to multipliers of national flood risk.

The 2004 report therefore showed two sets of fluvial/coastal flood risk multiplier tables. The first listed multipliers of local risk. In the second table, the multipliers were weighted according to the estimated Economic Average Damages (EAD) in fluvial and coastal floodplains, obtained from runs of the quantitative analysis, to convert them to national flood risk multipliers. For example, the increase in probability of flooding under a certain scenario owing to changes in precipitation might be threefold, but it only impacts on the fluvial floodplain; the EAD from fluvial flooding is about 55 per cent of the total national EAD, so the effective national flood risk multiplier due to this driver would be $1 + (3 – 1) \times 0.55 = 2.1$. The reason for the apparently convoluted expression is that the 'no change' value of risk multiplier is 1 (not zero). Hence it is the difference from 1 that has to be adjusted, and added to the 'no change' value of 1 to obtain the national multiplier. These weighted flood risk multipliers were then used in creating the national driver ranking table.

There are also estimated EAD figures for intra-urban flood damages in the 2004 reports but there was, and is still, no equivalent of the Environment Agency RASP system used for the fluvial/coastal quantitative risk analysis for intra-urban flood risk, so these were estimated by a different and much more approximate method. In this review, it was decided to adopt the simple assumption that the intra-urban people and assets at risk correspond to all those in the combined coastal and fluvial systems and that the weighting required to convert intra-urban driver scores from local to national flood risk should be unity. In contrast, significant downscaling has been applied to the multipliers for groundwater flooding, based on the limited spatial extent of areas prone to this type of flooding and reports of the damage from groundwater flooding relative to other types of flooding provided by insurance companies.

> We define flood risk as probability multiplied by consequence. Using this simple definition, we can estimate the flood risk multipliers via either the increase in probability, stemming, for example, from increased precipitation making floods more frequent, or the growth in the value of buildings and contents increasing the consequences when they are flooded.
>
> *(continued)*

Our flood risk multipliers are assessed relative to a 'baseline assumption' according to which flood risk management funding, approaches and technologies are held constant in real terms at today's values as the future unfolds and the scenarios diverge.

This is not to say that the Government would keep flood risk management approaches at a constant, but it is a convenient device to establish an easy-to-understand comparison point that is independent of the choice of scenario. Thus, the driver assessments in effect answer the question, "what would happen in the future if we just kept on as we are at the moment with flood risk management – the 'business as usual' case?"

We decided to keep 2004 as our reference date in order to preserve comparability with our earlier calculations and findings. Bearing in mind the long timescale of our vision as set against the four years that have elapsed since the original Foresight flooding work, the benefits of comparability outweigh the neglect of changes in the interim period.

In the event, all the drivers have been reviewed in light of the changes in the scenarios, new or better data and science, and the events of summer 2007.

Driver flood risk multipliers and rankings

Updated tables of local and national flood risk multiplier scores and rankings for the 2050s and the 2080s are presented in this section. Key messages follow each pair of tables.

The updated flood risk multipliers are shown in Tables 8 and 9, with the 2004 figures shown in brackets for comparison and drivers with significant changes in their multipliers highlighted. Orange highlighting indicates an increase compared with the 2004 assessment. Blue indicates a decrease.

We distinguish between local risk and national risk in the risk multiplier tables. This is partly owing to the way we work them out, but showing them separately also adds insight into how people may be at risk in their local areas.

For instance the 2080s local Precipitation multiplier of 8.0 means that the chance of a person living in a river floodplain getting flooded would rise from, say, 1-in-100 in any year to 1-in-12.5. The corresponding Sea-Level Rise multiplier of 20 for a person living in the coastal floodplain means that the chance of experiencing a coastal flood that is currently 1-in-100 would rise to 1-in-5.

Table 8: Summary results for driver impacts on local flood risk: the numbers in the table are multipliers of current flood risk under the four future scenarios with the 2004 values in brackets, where available

Driver group	Driver name	Driver type	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
			2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Climate Change	Precipitation	Source	5.7 *(4)*	8.0 *(5.7)*	4 *(2.8)*	5.7 *(4)*	2.8 *(2.8)*	4 *(4)*	2 *(2)*	2.8 *(2.8)*
	Temperature	Source	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*
	Relative Sea-Level Rise	Source	5 *(5)*	20 *(20)*	4 *(4)*	13 *(13)*	3 *(3)*	10 *(10)*	2.8 *(2.8)*	7 *(7)*
	Surges	Source	5 *(5)*	20 *(20)*	3 *(3)*	9 *(9)*	2 *(2)*	5 *(5)*	1 *(1)*	2 *(2)*
	Waves	Source	3 *(3)*	10 *(10)*	2 *(2)*	5 *(5)*	1 *(1)*	3 *(3)*	1 *(1)*	2 *(2)*
Catchment Runoff	Urbanisation	Pathway	2.8 *(2.8)*	4 *(4)*	2.8 *(2.8)*	4 *(4)*	0.7 *(0.7)*	0.5 *(0.5)*	0.7 *(0.7)*	0.5 *(0.5)*
	Rural Land Management	Pathway	1.4 *(1.4)*	2 *(2)*	1.4 *(1.4)*	2 *(2)*	0.7 *(0.7)*	0.5 *(0.5)*	0.7 *(0.7)*	0.7 *(0.7)*
Groundwater Systems and Processes	Groundwater Flooding	Pathway	0.5	0.3	0.8	0.5	0.9	0.7	1.2	1.5
Fluvial Systems and Processes	Environmental Regulation	Pathway	1 *(1)*	1 *(1)*	0.7 *(1)*	0.7 *(1)*	1.4 *(1.4)*	2.8 *(2.8)*	2.8 *(2)*	4 *(4)*
	River Morphology and Sediment Supply	Pathway	1.4 *(1)*	2.8 *(2)*	1 *(1)*	1.4 *(1)*	2.8 *(2)*	5.7 *(4)*	2.8 *(1.4)*	5.7 *(2.8)*
	River Vegetation and Conveyance	Pathway	1.4 *(1)*	2.0 *(1.4)*	0.7 *(1)*	0.7 *(1.4)*	2 *(1)*	4 *(2)*	4 *(2)*	5.7 *(5.7)*
Urban Systems and Processes	Urbanisation and Intra-urban Runoff	Pathway	1.4 *(1.4)*	2 *(2)*	1.2 *(1.2)*	1.5 *(1.7)*	1.1 *(1.1)*	1.2 *(1.5)*	1 *(1)*	1.2 *(1.4)*
	Sewer Conveyance, Blockage and Sedimentation	Pathway	1.6 *(2)*	2.0 *(3)*	1.2 *(1.6)*	1.8 *(2)*	1 *(1)*	1 *(0.9)*	1 *(1)*	1.1 *(1.1)*
	Impact of External Flooding on Intra-urban Drainage Systems	Pathway	1.4 *(1.4)*	1.8 *(1.8)*	1.1 *(1.2)*	1.3 *(1.4)*	1.6 *(1.6)*	2 *(2)*	1 *(1)*	0.9 *(1)*
	Intra-urban Asset Deterioration	Pathway	2.5 *(1.4)*	4 *(4)*	1.8 *(1.8)*	2.5 *(2.5)*	1 *(1)*	1 *(1)*	1.1 *(1.1)*	1.2 *(1.2)*
Coastal Processes	Coastal Morphology and Sediment Supply	Pathway	5 *(5)*	10 *(10)*	4 *(4)*	7 *(7)*	3 *(3)*	4 *(4)*	2 *(2)*	2 *(2)*
Human Behaviour	Stakeholder Behaviour	Pathway	2 *(2)*	2.8 *(2.8)*	0.5 *(0.5)*	0.33 *(0.33)*	0.25 *(0.25)*	0.2 *(0.2)*	0.25 *(0.25)*	0.2 *(0.2)*
Socio-economics	Buildings and Contents	Receptor	5.7 *(6)*	16.1 *(17)*	2.1 *(2.2)*	3.0 *(3.1)*	3.0 *(3.0)*	4.8 *(4.8)*	2.5 *(2.5)*	4.4 *(4.8)*
	Urban Impacts	Receptor	5.0 *(5.0)*	19.8 *(19.8)*	1.8 *(1.8)*	3.6 *(3.6)*	3.0 *(3.0)*	4.8 *(4.8)*	2.2 *(2.2)*	3.9 *(3.9)*
	Infrastructure Impacts	Receptor	7.1 *(7.1)*	24.0 *(24.0)*	2.4 *(2.2)*	3.2 *(3.6)*	4.0 *(3.0)*	7.5 *(4.8)*	3.1 *(2.5)*	5.6 *(3.9)*
	Agricultural Impacts	Receptor	1.0 *(0.7)*	1.0 *(0.7)*	1.6 *(1.2)*	2.1 *(1.7)*	1.2 *(1)*	1.1 *(0.85)*	1.4 *(0.7)*	1.2 *(0.5)*
	Social Impacts	Receptor	6.0 *(6.0)*	19.8 *(19.8)*	2.2 *(2.2)*	3.6 *(3.6)*	3.0 *(3.0)*	6.1 *(6.1)*	2.2 *(2.2)*	3.2 *(3.2)*
	Science and Technology	Receptor	Known to be important but not quantified							

In the national risk multiplier tables the local risks have been weighted according to the importance to the national economy of the risk associated with them. Thus, because the fluvial floodplain is only about 60 per cent of the national floodplain, the increase in national risk by the 2080s owing to the Precipitation driver would only be 4.9 compared with the figure of 8.0 for the corresponding local risk. Receptor drivers such as Buildings and Contents have been similarly weighted according to their national economic importance.

Readers should be aware that the multipliers cannot be summed or multiplied in any simple way to give increase in total national flood risk from all causes. This was done in 2004 using the quantitative model.

Table 9: Summary results for driver impacts on national flood risk: the numbers in the table are multipliers of current flood risk under the four future scenarios, with the 2004 values in brackets, where available

Driver group	Driver name	Driver Type	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
			2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Climate Change	Precipitation	Source	4.1 *(3)*	4.9 *(3.6)*	3.0 *(2.2)*	3.6 *(2.7)*	2.2 *(2.2)*	2.7 *(2.7)*	1.7 *(1.7)*	2.0 *(2.0)*
	Temperature	Source	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*
	Relative Sea-Level Rise	Source	2.4 *(2.4)*	9.6 *(9.6)*	2 *(2)*	6.4 *(6.4)*	1.7 *(1.7)*	5.1 *(5.1)*	1.6 *(1.6)*	3.7 *(3.7)*
	Surges	Source	2.4 *(2.4)*	9.6 *(9.6)*	1.7 *(1.7)*	4.6 *(4.6)*	1.3 *(1.3)*	2.8 *(2.8)*	1 *(1)*	1.5 *(1.5)*
	Waves	Source	1.7 *(1.7)*	5.1 *(5.1)*	1.3 *(1.3)*	2.8 *(2.8)*	1 *(1)*	1.9 *(1.9)*	1 *(1)*	1.5 *(1.5)*
Catchment Runoff	Urbanisation	Pathway	2.2 *(2.2)*	2.7 *(2.7)*	2.2 *(2.2)*	2.7 *(2.7)*	0.8 *(0.8)*	0.7 *(0.7)*	0.8 *(0.8)*	0.7 *(0.7)*
	Rural Land Management	Pathway	1.3 *(1.3)*	1.6 *(1.6)*	1.3 *(1.3)*	1.6 *(1.6)*	0.8 *(0.8)*	0.7 *(0.7)*	0.8 *(0.8)*	0.8 *(0.8)*
Groundwater Systems and Processes	Groundwater Flooding	Pathway	1	1	1	1	1	1	1	1
Fluvial Systems and Processes	Environmental Regulation	Pathway	1 *(1)*	1 *(1)*	0.8 *(1)*	0.8 *(1)*	1.4 *(1.4)*	2.8 *(2.8)*	2.2 *(2)*	4 *(4)*
	River Morphology and Sediment Supply	Pathway	1.3 *(1)*	2 *(1.6)*	1 *(1)*	1.2 *(1)*	2.2 *(1.7)*	3.6 *(2.7)*	2.2 *(1.3)*	3.6 *(2.0)*
	River Vegetation and Conveyance	Pathway	1.3 *(1)*	1.6 *(1.2)*	0.8 *(1)*	0.8 *(1.2)*	1.7 *(1)*	2.7 *(1.6)*	3.0 *(1.7)*	3.6 *(3.6)*
Urban Systems and Processes	Urbanisation and Intra-urban Runoff	Pathway	1.4 *(1.4)*	2 *(2)*	1.2 *(1.2)*	1.5 *(1.7)*	1.1 *(1.1)*	1.2 *(1.5)*	1 *(1)*	1.2 *(1.4)*
	Sewer Conveyance, Blockage and Sedimentation	Pathway	1.6 *(2)*	2.0 *(3)*	1.2 *(1.6)*	1.8 *(2)*	1 *(1)*	1 *(0.9)*	1 *(1)*	1.1 *(1.1)*
	Impact of External Flooding on Intra-urban Drainage Systems	Pathway	1.4 *(1.4)*	1.8 *(1.8)*	1.1 *(1.2)*	1.3 *(1.4)*	1.6 *(1.6)*	2 *(2)*	1 *(1)*	0.9 *(1)*
	Intra-urban Asset Deterioration	Pathway	2.5 *(1.4)*	4 *(4)*	1.8 *(1.8)*	2.5 *(2.5)*	1 *(1)*	1 *(1)*	1.1 *(1.1)*	1.2 *(1.2)*
Coastal Processes	Coastal Morphology and Sediment Supply	Pathway	2.4 *(2.4)*	5.1 *(5.1)*	2.0 *(2.0)*	3.7 *(3.7)*	1.7 *(1.7)*	2.4 *(2.4)*	1.3 *(1.3)*	1.5 *(1.5)*
Human Behaviour	Stakeholder Behaviour	Pathway	2 *(2)*	2.8 *(2.8)*	0.5 *(0.5)*	0.3 *(0.3)*	0.3 *(0.3)*	0.2 *(0.2)*	0.3 *(0.3)*	0.2 *(0.2)*
Socio-economics	Buildings and Contents	Receptor	3.8 *(4.0)*	6.1 *(6.4)*	3.1 *(3.2)*	4.3 *(4.5)*	0.9 *(0.9)*	0.7 *(0.7)*	1.5 *(1.5)*	1.8 *(1.9)*
	Urban Impacts	Receptor	1.6 *(1.6)*	2.0 *(2.0)*	1.4 *(1.4)*	1.6 *(1.6)*	1 *(1)*	1 *(1)*	1.1 *(1.1)*	1.1 *(1.1)*
	Infrastructure Impacts	Receptor	4.7 *(4.7)*	9.0 *(9.0)*	3.5 *(3.2)*	4.6 *(5.2)*	1.2 *(0.9)*	1.1 *(0.7)*	1.7 *(1.5)*	1.8 *(1.5)*
	Agricultural Impacts	Receptor	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*	1 *(1)*
	Social Impacts	Receptor	6.0 *(6.0)*	19.8 *(19.8)*	2.2 *(2.2)*	3.6 *(3.6)*	3.0 *(3.0)*	6.1 *(6.1)*	2.2 *(2.2)*	3.2 *(3.2)*
	Science and Technology	Receptor	Known to be important but not quantified							

Causes of flooding

The key messages from updating the flood risk drivers are:

- Rainfall is a major driver of flood risk and the risks at both the local and national level have increased compared with the 2004 analysis.
- Coastal Climate Change drivers provide the strongest drivers of risk among physical processes. Communities living behind good coastal defences currently protecting them against a flood with a chance of occurrence of 1 in 100 each year would 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. Although this driver has not been changed through this update, there is an increasing appreciation of the possibility of even greater increases in these drivers than was recognised in 2004.
- Risk from groundwater flooding decreases under the hotter, drier, high emissions climate change scenarios, but increases it under the least extreme scenario. However, the evidence from insurance claims suggests that groundwater flooding has a considerably lower economic impact compared with the wider-scale drivers of fluvial, coastal and intra-urban flood risk. This driver has therefore been assessed as having a neutral affect.
- The risk from rivers has mostly increased as a result of better science and understanding of driver impacts on flood risk.
- The effectiveness of the sewerage system is still one of the most important drivers of risk although other risks have now overtaken it in some scenarios as a result of new research and better data.
- Social and economic choices remain among the most important drivers.
- The impacts of infrastructure loss, as in the 2004 analysis, is the biggest driver of economic risk and increases slightly under most scenarios.
- Our assessment of Agricultural Impacts as a local driver, i.e. the impact on agri-industry, has risen due to increased pressure on land and increases in agricultural commodity prices. However, the national increase in risk remains low owing to its small share of Gross National Product (GNP).

Driver rankings for the 2050s and 2080s, graded by national flood risk multiplier, are shown in Tables 10 and 11. High increase drivers, with risk multipliers of more than 2, are highlighted in red. Medium increase drivers, with multipliers between 1.2 and 2, are highlighted in yellow. Low risk drivers, with multipliers between 1.0 and 1.2, are highlighted in green. Multipliers less than 1.0 are highlighted in blue or purple.

Table 10: Updated national ranking of drivers, graded by national flood risk multiplier – 2050s

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
1	Social Impacts	Infrastructure Impacts	Social Impacts	River Vegetation and Conveyance
2	Infrastructure Impacts	Buildings and Contents	Precipitation	Social Impacts
3	Precipitation	Precipitation	River Morphology and Sediment Supply	Environmental Regulation
4	Buildings and Contents	Social Impacts	Relative Sea-Level Rise	River Morphology and Sediment Supply
5	Intra-urban Asset Deterioration	Urbanisation	Coastal Morphology and Sediment Supply	Infrastructure Impacts
6	Surges	Relative Sea-Level Rise	River Vegetation and Conveyance	Precipitation
7	Relative Sea-Level Rise	Coastal Morphology and Sediment Supply	Impact of External Flooding on Intra-urban Drainage Systems	Relative Sea-Level Rise
8	Coastal Morphology and Sediment Supply	Intra-urban Asset Deterioration	Surges	Buildings and Contents
9	Urbanisation	Surges	Environmental Regulation	Coastal Morphology and Sediment Supply
10	Stakeholder Behaviour	Urban Impacts	Infrastructure Impacts	Intra-urban Asset Deterioration
11	Waves	Waves	Intra-urban Runoff	Urban Impacts
12	Sewer Conveyance, Blockage and Sedimentation	Rural Land Management	Agricultural Impacts	Agricultural Impacts
13	Urban Impacts	Intra-urban Runoff	Temperature	Groundwater Flooding
14	Intra-urban Runoff	Sewer Conveyance, Blockage and Sedimentation	Waves	Temperature
15	Impact of External Flooding on Intra-urban Drainage Systems	Impact of External Flooding on Intra-urban Drainage Systems	Sewer Conveyance, Blockage and Sedimentation	Waves
16	Rural Land Management	Agricultural Impacts	Intra-urban Asset Deterioration	Surges
17	River Morphology and Sediment Supply	Temperature	Urban Impacts	Intra-urban Runoff
18	River Vegetation and Conveyance	River Morphology and Sediment Supply	Groundwater Flooding	Sewer Conveyance, Blockage and Sedimentation
19	Temperature	Groundwater Flooding	Buildings and Contents	Impact of External Flooding on Intra-urban Drainage Systems
20	Agricultural Impacts	Environmental Regulation	Urbanisation	Urbanisation
21	Environmental Regulation	River Vegetation and Conveyance	Rural Land Management	Rural Land Management
22	Groundwater Flooding	Stakeholder Behaviour	Stakeholder Behaviour	Stakeholder Behaviour
23	Science and Technology – Known to be important but not quantified			

Key	Driver impact category	Risk multiplier (M) range	Colour code
	High increase	$M \geq 2$	(orange)
	Medium increase	$2 > M \geq 1.2$	(light grey)
	Low impact	$1.2 > M \geq 1$	(green)
	Medium decrease	$1 > M \geq 0.5$	(blue)
	High decrease	$M < 0.5$	(pink)

Table 11: Updated national ranking of drivers, graded by national flood risk multiplier – 2080s

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
1	Social Impacts	Relative Sea-Level Rise	Social Impacts	Relative Sea-Level Rise
2	Surges	Surges	Relative Sea-Level Rise	River Morphology and Sediment Supply
3	Relative Sea-Level Rise	Infrastructure Impacts	River Morphology and Sediment Supply	River Vegetation and Conveyance
4	Infrastructure Impacts	Buildings and Contents	Surges	Social Impacts
5	Buildings and Contents	Coastal Morphology and Sediment Supply	Precipitation	Environmental Regulation
6	Waves	Social Impacts	River Vegetation and Conveyance	Precipitation
7	Coastal Morphology and Sediment Supply	Precipitation	Coastal Morphology and Sediment Supply	Buildings and Contents
8	Precipitation	Waves	Impact of External Flooding on Intra-urban Drainage Systems	Infrastructure Impacts
9	Intra-urban Asset Deterioration	Urbanisation	Environmental Regulation	Waves
10	Stakeholder Behaviour	Intra-urban Asset Deterioration	Waves	Surges
11	Urbanisation	Sewer Conveyance, Blockage and Sedimentation	Intra-urban Runoff	Coastal Morphology and Sediment Supply
12	Intra-urban Runoff	Urban Impacts	Infrastructure Impacts	Intra-urban Runoff
13	Sewer Conveyance, Blockage and Sedimentation	Rural Land Management	Agricultural Impacts	Intra-urban Asset Deterioration
14	Urban Impacts	Intra-urban Runoff	Temperature	Sewer Conveyance, Blockage and Sedimentation
15	River Morphology and Sediment Supply	Impact of External Flooding on Intra-urban Drainage Systems	Sewer Conveyance, Blockage and Sedimentation	Urban Impacts
16	Impact of External Flooding on Intra-urban Drainage Systems	River Morphology and Sediment Supply	Intra-urban Asset Deterioration	Groundwater Flooding
17	Rural Land Management	Agricultural Impacts	Urban Impacts	Agricultural Impacts
18	River Vegetation and Conveyance	Temperature	Groundwater Flooding	Temperature
19	Temperature	Groundwater Flooding	Urbanisation	Impact of External Flooding on Intra-urban Drainage Systems
20	Agricultural Impacts	Environmental Regulation	Rural Land Management	Rural Land Management
21	Environmental Regulation	River Vegetation and Conveyance	Buildings and Contents	Urbanisation
22	Groundwater Flooding	Stakeholder Behaviour	Stakeholder Behaviour	Stakeholder Behaviour
23	Science and Technology – Known to be important but not quantified			

Key	Driver impact category	Risk multiplier (M) range	Colour code
	High increase	M ≥ 2	(orange)
	Medium increase	2 > M ≥ 1.2	(light grey)
	Low impact	1.2 > M ≥ 1	(green)
	Medium decrease	1 > M ≥ 0.5	(blue/purple)
	High decrease	M < 0.5	(pink)

The overall rankings remain largely unchanged, although the inclusion of intra-urban drivers for the first time reveals their relative importance. The main points arising from the rankings are analysed below:

- Socio-economic drivers, including Social Impacts, Infrastructure Impacts, and Buildings and Contents, top the ranking table in the 2050s, but by the 2080s coastal drivers join them at the top of the table, as in 2004.
- By the 2080s coastal drivers join socio-economic drivers at the top of the table. As noted in the updated Scenarios chapter, although the multipliers corresponding to the central estimates of sea-level rise have not been changed, it is now recognised that there is a small but significant risk of much greater increases.
- As in the 2004 report, the Global Sustainability scenario is rather different, with lower climate change and lower growth rates combined with greater environmental consciousness resulting in environmental drivers such as River Vegetation and Conveyance, Environmental Regulation, and River Morphology and Sediment Supply topping the table in the 2050s. By the 2080s, however, Relative Sea-Level Rise tops the Global Sustainability rankings as well.
- As would be expected from the increased multipliers, Precipitation moves up the tables and is always in the top group of drivers. Although not as strong a driver as the coastal Climate Change group drivers, the possibility of having to find the space through our towns and cities to accommodate flood flows ranging in the extreme up to 30–40 per cent greater than today's values presents great challenges not only in engineering terms but also in urban planning terms.
- In the 2050s, intra-urban drivers – Sewer Conveyance, Blockage and Sedimentation, Intra-urban Asset Deterioration, and Urban Impacts – occupy the middle of the combined ranking table, with medium-level risk increases. However, by the 2080s they progress to the high risk increase zone.

Policy issues emerging from driver analysis update

The main policy points arising from the driver rankings are as follows:

- Paying attention to managing the social impacts of flooding should be high on the Government's agenda.
- The importance of protecting vital infrastructure is also very clear.
- The high ranking of coastal drivers draws attention to their importance and the choices between providing high levels of funding to resist rising coastal threats, realigning defences or abandoning large tracts of land to the sea.
- The Global Sustainability scenario, with its lower climate change and lower growth rates combined with greater environmental consciousness, tends to reduce all multipliers, an indication of the importance of global control of climate change, and the impact of wider government policies on flood risk.
- Although Precipitation is not as strong a driver as the coastal Climate Change group drivers, the possibility of having to find the space through our towns and cities to accommodate flood flows up to 40% greater than today's values presents great challenges not only in engineering terms but also, particularly, to urban planning.
- The effectiveness of urban drainage is likely to become a more and more important factor in limiting flood risk in the future.

Driver uncertainty

The 2004 report also included tables for uncertainty. Updated versions are shown in Tables 12 and 13. Key points follow the tables.

Table 12: Uncertainty: Drivers are ranked by national flood risk multiplier and colour-coded by uncertainty band width – 2050s

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
1	Social Impacts	Infrastructure Impacts	Social Impacts	River Vegetation and Conveyance
2	Infrastructure Impacts	Buildings and Contents	Precipitation	Social Impacts
3	Precipitation	Precipitation	River Morphology and Sediment Supply	Environmental Regulation
4	Buildings and Contents	Social Impacts	Relative Sea-Level Rise	River Morphology and Sediment Supply
5	Intra-urban Asset Deterioration	Urbanisation	Coastal Morphology and Sediment Supply	Infrastructure Impacts
6	Surges	Relative Sea-Level Rise	River Vegetation and Conveyance	Precipitation
7	Relative Sea-Level Rise	Coastal Morphology and Sediment Supply	Impact of External Flooding on Intra-urban Drainage Systems	Relative Sea-Level Rise
8	Coastal Morphology and Sediment Supply	Intra-urban Asset Deterioration	Surges	Buildings and Contents
9	Urbanisation	Surges	Environmental Regulation	Coastal Morphology and Sediment Supply
10	Stakeholder Behaviour	Urban Impacts	Infrastructure Impacts	Intra-urban Asset Deterioration
11	Waves	Waves	Intra-urban Runoff	Urban Impacts
12	Sewer Conveyance, Blockage and Sedimentation	Rural Land Management	Agricultural Impacts	Agricultural Impacts
13	Urban Impacts	Intra-urban Runoff	Temperature	Groundwater Flooding
14	Intra-urban Runoff	Sewer Conveyance, Blockage and Sedimentation	Waves	Temperature
15	Impact of External Flooding on Intra-urban Drainage Systems	Impact of External Flooding on Intra-urban Drainage Systems	Sewer Conveyance, Blockage and Sedimentation	Waves
16	Rural Land Management	Agricultural Impacts	Intra-urban Asset Deterioration	Surges
17	River Morphology and Sediment Supply	Temperature	Urban Impacts	Intra-urban Runoff
18	River Vegetation and Conveyance	River Morphology and Sediment Supply	Groundwater Flooding	Sewer Conveyance, Blockage and Sedimentation
19	Temperature	Groundwater Flooding	Buildings and Contents	Impact of External Flooding on Intra-urban Drainage Systems
20	Agricultural Impacts	Environmental Regulation	Urbanisation	Urbanisation
21	Environmental Regulation	River Vegetation and Conveyance	Rural Land Management	Rural Land Management
22	Groundwater Flooding	Stakeholder Behaviour	Stakeholder Behaviour	Stakeholder Behaviour
23	Science and Technology – Known to be important but not quantified			

Key	Uncertainty band category	Uncertainty band width (B) (B = ratio of upper to lower bound estimates of flood-risk impact multiplier)	Colour code
	High	B ≥ 3	(red)
	Medium	3 > B ≥ 1.5	(light grey)
	Low	B < 1.5	(green)

Table 13: Uncertainty: Drivers are ranked by national flood risk multiplier and colour-coded by uncertainty band width – 2080s

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
1	Social Impacts	Relative Sea-Level Rise	Social Impacts	Relative Sea-Level Rise
2	Surges	Surges	Relative Sea-Level Rise	River Morphology and Sediment Supply
3	Relative Sea-Level Rise	Infrastructure Impacts	River Morphology and Sediment Supply	River Vegetation and Conveyance
4	Infrastructure Impacts	Buildings and Contents	Surges	Social Impacts
5	Buildings and Contents	Coastal Morphology and Sediment Supply	Precipitation	Environmental Regulation
6	Waves	Social Impacts	River Vegetation and Conveyance	Precipitation
7	Coastal Morphology and Sediment Supply	Precipitation	Coastal Morphology and Sediment Supply	Buildings and Contents
8	Precipitation	Waves	Impact of External Flooding on Intra-urban Drainage Systems	Infrastructure Impacts
9	Intra-urban Asset Deterioration	Urbanisation	Environmental Regulation	Waves
10	Stakeholder Behaviour	Intra-urban Asset Deterioration	Waves	Surges
11	Urbanisation	Sewer Conveyance, Blockage and Sedimentation	Intra-urban Runoff	Coastal Morphology and Sediment Supply
12	Intra-urban Runoff	Urban Impacts	Infrastructure Impacts	Intra-urban Runoff
13	Sewer Conveyance, Blockage and Sedimentation	Rural Land Management	Agricultural Impacts	Intra-urban Asset Deterioration
14	Urban Impacts	Intra-urban Runoff	Temperature	Sewer Conveyance, Blockage and Sedimentation
15	River Morphology and Sediment Supply	Impact of External Flooding on Intra-urban Drainage Systems	Sewer Conveyance, Blockage and Sedimentation	Urban Impacts
16	Impact of External Flooding on Intra-urban Drainage Systems	River Morphology and Sediment Supply	Intra-urban Asset Deterioration	Groundwater Flooding
17	Rural Land Management	Agricultural Impacts	Urban Impacts	Agricultural Impacts
18	River Vegetation and Conveyance	Temperature	Groundwater Flooding	Temperature
19	Temperature	Groundwater Flooding	Urbanisation	Impact of External Flooding on Intra-urban Drainage Systems
20	Agricultural Impacts	Environmental Regulation	Rural Land Management	Rural Land Management
21	Environmental Regulation	River Vegetation and Conveyance	Buildings and Contents	Urbanisation
22	Groundwater Flooding	Stakeholder Behaviour	Stakeholder Behaviour	Stakeholder Behaviour
23	Science and Technology – Known to be important but not quantified			

Key	Uncertainty band category	Uncertainty band width (B) (B = ratio of upper to lower bound estimates of flood-risk impact multiplier)	Colour code
	High	B ≥ 3	Red
	Medium	3 > B ≥ 1.5	Grey
	Low	B < 1.5	Green

Uncertainty with drivers of flood risk

Uncertainty analysis matters because it alerts the Government to where our ability to predict is most limited. As in the 2004 report, we are uncertain about many of the drivers that potentially have the strongest influence on national flood risk.

Looking ahead to the 2080s, coastal flooding risks are among both the biggest and the most uncertain, and have become even more so as a result of recent IPCC work. As we noted earlier, mean sea level could rise by over 1 m by the 2080s, compared with the 50–70 cm expected in 2004.

This indicates the importance of building adaptability and 'precautionarity' into our flood defences. By identifying the drivers that are both important and uncertain, the analysis also indicates where research can most usefully be focused in order to reduce uncertainty in predicting future flood risk

Chapter 6: Results and discussion of the updated responses analysis

Revision of the SPR framework for responses

As in the case of drivers, we have combined the lists of fluvial/coastal and intra-urban responses used in 2004.

We noted earlier that Public Attitudes and Expectations, included in 2004 among the drivers, was more of a driver of responses than a driver of risk per se. We recognised in 2004 that we do not know how public perception of flood risk will change over the next 100 years. We do know, however, that there is a social amplification of risk – the 'outrage factor' – which occurs after a major flood event. Modern communications increase this effect, ensuring a national change in perceptions of flood risk following an event. This is likely to create expectations that current levels of flood protection will be maintained, and may lead to higher expectations in the long term. The point here is that effective dialogue with the public and other stakeholders is essential to ensure that they understand the risks and choices. In particular, they need to appreciate that choices do need to be made, and that there will be costs whichever path we take.

'Outrage factor'

After major flooding events, there is a social amplification of risk. Experts term this the 'outrage factor'. This leads to higher expectations from the public and stakeholders as to what flood risk management levels should be provided now and in the future. Effective dialogue is required to ensure that the public and stakeholders understand the present risks and the increased risks in the future and the options that are available. This should include an appreciation of the costs involved.

Table 14 lists the combined responses.

Table 14: Combined list of responses

Response theme	Response groups
Managing the Urban Fabric (a) reducing river flood probability downstream by managing runoff from the urban area	Urban Storage
	Urban Infiltration
	Urban Conveyance
Managing the Urban Fabric (b) reducing intra-urban and coincident flood probability within the urban area	Building Development, Operation and Form
	Urban Area Development, Operation and Form
	Source Control and Above-ground Pathways
	Groundwater Control
	Storage Above and Below Ground
	Main Drainage Form, Maintenance and Operation
Managing the Rural Landscape	Rural Infiltration
	Catchment-wide Storage
	Rural Conveyance
Managing Flood Events	Pre-event Measures
	Forecasting and Warning
	Flood Fighting
	Collective Damage Avoidance
	Individual Damage Avoidance
Managing Flood Losses	Land Use Management
	Land Use Planning
	Flood-proofing
	Building Codes
	Insurance, Shared Risk and Compensation
	Health and Social Measures
River Engineering and Maintenance	River Conveyance
	Engineered Flood Storage
	Floodwater Transfer
	River Defences
Coastal Engineering and Management	Coastal Defences
	Realignment of Coastal Defences
	Abandonment of Coastal Defences
	Reduce Coastal Energy
	Coastal Morphological Protection
Public Attitudes and Expectations	Relates to all responses

Results of the updated responses analysis

As with drivers, combining the multipliers and rankings of fluvial/coastal and intra-urban flood risk responses for the first time allows direct comparison between them and aligns better with the trend for integration in UK flood risk management policy.

Weightings based on EADs have again been applied to the local response multipliers (they are actually less than unity as they reduce flood risk) to obtain national flood risk reduction multipliers and rankings. Owing to the way some responses operate across all floodplains, only the national flood risk multipliers and rankings are shown, and because of the way some responses operate over long timescales, we did not look at the 2050s time horizon separately in the 2004 work.

> In examining responses we remove the baseline assumption of 'business-as-usual' flood risk management adopted in assessing drivers, and allow the responses to take effect. The values of their flood risk multipliers are less than 1, as they reduce future risks relative to those expected under the baseline assumption.

As in the case of drivers, all the responses have been reviewed in light of the updated scenarios, new or better data and science, and the events of summer 2007. Full details of the reviews can be found in the response updates in Appendix B.

Response flood risk multipliers and rankings

Updated tables of national flood risk multipliers and rankings for the 2080s are presented in Tables 15, 16 and 17. The multipliers are the reductions in future flood risk relative to those under the baseline flood risk management assumption.

In Table 15 (updated flood risk reduction multipliers), the 2004 figures are shown in brackets for comparison. Responses with significant changes in their multipliers have been highlighted in orange for increases (i.e. less effective) compared with the 2004 assessment. Key messages follow each table.

Table 15: Updated national risk multiplier scores (multipliers on baseline future risk) for individual response groups for the 2080s (original scores from 2004 study in brackets)

Response theme	Response group		World Markets		National Enterprise		Local Stewardship		Global Sustainability	
Managing the Rural Landscape	1	Rural Infiltration	1.00	*(1.00)*	0.90	*(0.90)*	0.90	*(0.90)*	0.90	*(0.90)*
	2	Catchment-wide Storage	1.00	*(1.00)*	0.80	*(0.80)*	0.80	*(0.80)*	0.60	*(0.60)*
	3	Rural Conveyance	1.00	*(1.00)*	0.90	*(0.90)*	0.85	*(0.85)*	0.70	*(0.70)*
Managing Runoff from the Urban Fabric	4	Urban Storage	0.97	*(0.97)*	0.95	*(0.95)*	0.94	*(0.94)*	0.94	*(0.94)*
	5	Urban Infiltration	1.00	*(1.00)*	1.00	*(1.00)*	1.00	*(1.00)*	0.95	*(0.95)*
	6	Urban Conveyance	1.00	*(1.00)*	1.00	*(1.00)*	0.97	*(0.97)*	0.95	*(0.95)*
Managing the Urban Fabric	U1	Building Development, Operation and Form	1.00	*(1.00)*	1.00	*(1.00)*	0.80	*(0.80)*	0.50	*(0.50)*
	U2	Urban Area Development, Operation and Form	0.80	*(0.80)*	1.00	*(1.00)*	0.80	*(0.80)*	0.50	*(0.50)*
	U3	Source Control and Above-ground Pathways	0.80	*(0.80)*	1.00	*(1.00)*	0.70	*(0.70)*	0.50	*(0.50)*
	U4	Groundwater Control	1.00	*(1.00)*	1.00	*(1.00)*	1.00	*(1.00)*	1.00	*(1.00)*
	U5	Storage Above and Below Ground	0.80	*(0.80)*	1.00	*(1.00)*	0.80	*(0.80)*	0.50	*(0.50)*
	U6	Main Drainage Form, Maintenance and Operation	0.90	*(0.90)*	0.70	*(0.70)*	1.00	*(1.00)*	0.80	*(0.80)*
Managing Flood Events	7	Pre-event Measures	0.86	*(0.86)*	0.89	*(0.89)*	0.81	*(0.81)*	0.80	*(0.80)*
	8	Forecasting and Warning	0.81	*(0.81)*	0.88	*(0.88)*	0.81	*(0.81)*	0.76	*(0.76)*
	9	Flood Fighting	0.81	*(0.81)*	0.86	*(0.86)*	0.81	*(0.81)*	0.80	*(0.80)*
	10	Collective Damage Avoidance	0.95	*(0.95)*	0.93	*(0.93)*	0.88	*(0.88)*	0.86	*(0.86)*
	11	Individual Damage Avoidance	0.86	*(0.86)*	0.92	*(0.92)*	0.75	*(0.75)*	0.80	*(0.80)*
Managing Flood Losses	12	Land Use Management	1.00	*(1.00)*	0.96	*(0.96)*	0.72	*(0.60)*	0.73	*(0.61)*
	13	Flood-proofing	0.88	*(0.86)*	0.87	*(0.84)*	0.76	*(0.70)*	0.81	*(0.81)*
	14	Land Use Planning	0.94	*(0.94)*	0.89	*(0.86)*	0.87	*(0.85)*	0.85	*(0.83)*
	15	Building Codes	0.88	*(0.85)*	0.89	*(0.86)*	0.90	*(0.90)*	0.89	*(0.89)*
	16	Insurance, Shared Risk and Compensation	Note: these responses act to reduce flood risk indirectly via response groups 12, 13 and 15 and their impacts are included in the risk reduction multipliers for those groups.							
	17	Health and Social Measures								
River Engineering and Maintenance	18	River Conveyance	0.83	*(0.83)*	0.78	*(0.78)*	0.89	*(0.89)*	0.89	*(0.89)*
	19	Engineered Flood Storage	0.89	*(0.89)*	0.83	*(0.83)*	0.83	*(0.83)*	0.78	*(0.78)*
	20	Floodwater Transfer	0.99	*(0.99)*	0.99	*(0.99)*	1.00	*(1.00)*	0.99	*(0.99)*
	21	River Defences	0.55	*(0.55)*	0.55	*(0.55)*	0.78	*(0.78)*	0.62	*(0.62)*
Coastal Engineering and Management	22	Coastal Defences	0.64	*(0.64)*	0.63	*(0.63)*	1.17	*(1.17)*	0.68	*(0.68)*
	23	Realignment of Coastal Defences	0.71	*(0.71)*	0.68	*(0.68)*	1.30	*(1.30)*	0.71	*(0.71)*
	24	Abandonment of Coastal Defences	Not used in World Markets		0.69	*(0.69)*	1.53	*(1.53)*	Not used in Global Sustainability	
	25	Reduce Coastal Energy	0.71	*(0.71)*	0.67	*(0.67)*	1.37	*(1.37)*	0.72	*(0.72)*
	26	Coastal Morphological Protection	0.71	*(0.71)*	0.68	*(0.68)*	1.36	*(1.36)*	0.74	*(0.74)*

It should be noted that the Abandonment of Coastal Defences response has not been given a multiplier under the World Markets and Global Sustainability scenarios. We describe coastal defence abandonment as a decision not to maintain existing defences, or a desire to maintain them but an inability to do so due to financial or other constraints. The key difference between coastal defence realignment and coastal defence abandonment is that ultimately the latter is an unmanaged process, which under some circumstances could result in increased flooding or erosion, with consequent impacts on existing land uses or infrastructure and risk to life. Under the National Enterprise and Local Stewardship scenarios, the maintenance of coastal defences may be unsustainable because there is limited funding available. In contrast, the Abandonment of Coastal Defences response is not considered to be a realistic response under the World Markets and Global Sustainability scenarios as the (planned) Realignment of Coastal Defences or Coastal Defences responses would always be favoured.

Some responses only work when combined with others. For example, effective flood fighting needs reliable forecasting and warning. Updated combined multipliers for these responses are shown in Table 16.

Table 16: Updated scores (S=multiplier on baseline risk) for combined response groups (original scores from 2004 study in brackets)

Response theme	Associated groups		Combined response group	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Managing the Urban Fabric (a) reducing river flood probability downstream by managing runoff from the urban area	4	Urban Storage	Managing Urban Runoff	0.99 *(0.99)*	0.98 *(0.98)*	0.97 *(0.97)*	0.95 *(0.95)*
	5	Urban Infiltration					
	6	Urban Conveyance					
Managing Flood Events	8	Forecasting and Warning	Real-time Event Management	0.89 *(0.83)*	0.89 *(0.89)*	0.82 *(0.82)*	0.79 *(0.79)*
	9	Flood Fighting					
	10	Collective Damage Avoidance					
Managing Flood Losses	12	Land Use Management	Land Use Planning and Management	0.94 *(0.93)*	0.84 *(0.81)*	0.59 *(0.45)*	0.58 *(0.45)*
	14	Land Use Planning					
	13	Flood-proofing	Flood-proofing Buildings	0.76 *(0.71)*	0.76 *(0.70)*	0.66 *(0.60)*	0.69 *(0.69)*
	15	Building Codes					

We did not see sufficient reason to change the 2004 risk reduction multipliers, with the exception of certain response groups in Managing Flood Losses which were shaded down (i.e. slightly less effective) in the light of research and experience since 2004.

Updated response rankings for the 2080s are shown in Table 17.

Table 17: Updated response rankings for the 2080s

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
1	River Defences	River Defences	Land Use Planning and Management	Building Development, Operation and Form
2	Coastal Defences	Coastal Defences	Flood-proofing Buildings	Urban Area Development, Operation and Form
3	Reduce Coastal Energy	Reduce Coastal Energy	Urban Source Control and Above-ground Pathways	Urban Source Control and Above-ground Pathways
4	Coastal Defence Realignment	Coastal Defence Realignment	Individual Damage Avoidance	Urban Storage Above and Below Ground
5	Morphological Coastal Protection	Morphological Coastal Protection	River Defences	Land Use Planning and Management
6	Flood-proofing Buildings	Coastal Defence Abandonment	Catchment-wide Storage	Catchment-wide Storage
7	Urban Area Development, Operation and Form	Main Drainage Form, Maintenance and Operation	Building Development, Operation and Form	River Defences
8	Urban Source Control and Above-ground Pathways	Flood-proofing Buildings	Urban Area Development, Operation and Form	Coastal Defences
9	Urban Storage Above and Below Ground	River Conveyance	Urban Storage Above and Below Ground	Flood-proofing Buildings
10	River Conveyance	Catchment-wide storage	Pre-event Measures	Rural Conveyance
11	Pre-event Measures	Engineered Flood Storage	Real-time Event Management	Coastal Defence Realignment
12	Individual Damage Avoidance	Land Use Planning and Management	Engineered Flood Storage	Reduce Coastal Energy
13	Engineered Flood Storage	Real-time Event Management	Rural Conveyance	Morphological Coastal Protection
14	Real-time Event Management	Pre-event Measures	Increase Conveyance or Flow Passed Downstream	Engineered Flood Storage
15	Main Drainage Form, Maintenance and Operation	Rural Infiltration	Rural Infiltration	Real-time Event Management
16	Land Use Planning and Management	Rural Conveyance	Managing Urban Runoff	Pre-event Measures
17	Managing Urban Runoff	Individual Damage Avoidance	Floodwater Transfer	Individual Damage Avoidance
18	Floodwater Transfer	Managing Urban Runoff	Urban Groundwater Control	Main Drainage Form, Maintenance and Operation
19	Rural Infiltration	Floodwater Transfer	Main Drainage Form, Maintenance and Operation	River Conveyance
20	Catchment-wide storage	Building Development, Operation and Form	Coastal Defences	Rural Infiltration
21	Rural Conveyance	Urban Area Development, Operation and Form	Coastal Defence Realignment	Managing Urban Runoff
22	Building Development, Operation and Form	Urban Source Control and Above-ground Pathways	Morphological Coastal Protection	Floodwater Transfer
23	Urban Groundwater Control	Urban Groundwater Control	Reduce Coastal Energy	Urban Groundwater Control
24		Urban Storage Above and Below Ground	Coastal Defence Abandonment	

Key	Response impact category	Risk reduction multiplier (S)	Colour code
	Major reduction in flood risk	$S < 0.7$	
	Marked reduction in flood risk	$0.7 \le S < 0.9$	
	Moderate reduction in flood risk	$0.9 \le S < 1.0$	
	Ineffective	$S = 1.0$	
	Liable to increase flood risk	$S > 1.0$	

Responses to flooding

The key messages from updating the responses to flood risk are:

- River and coastal defences remain at or near the top of the rankings of responses, with major reductions in risk under all scenarios.
- Better land use planning and the flood-proofing of buildings still appear among the most important risk reducers.
- 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 responses.

Nothing has emerged to change our view that there is no single response to solve all problems. Our conclusion remains that a portfolio of structural and non-structural responses, implemented in a sustainable way, is needed to manage future flood risk. It is as much a matter of how we implement the responses as what we do.

Response uncertainty

We have also updated the 2004 grading of responses by uncertainty. The result is shown in Table 18, with the uncertainty band colour-coded.

Table 18: Uncertainty: responses ranked by national flood risk multiplier and colour-coded by uncertainty band width – 2080s

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
1	River Defences	River Defences	Land Use Planning and Management	Building Development, Operation and Form
2	Coastal Defences	Coastal Defences	Flood-proofing Buildings	Urban Area Development, Operation and Form
3	Reduce Coastal Energy	Reduce Coastal Energy	Urban Source Control and Above-ground Pathways	Urban Source Control and Above-ground Pathways
4	Coastal Defence Realignment	Coastal Defence Realignment	Individual Damage Avoidance	Urban Storage Above and Below Ground
5	Morphological Coastal Protection	Morphological Coastal Protection	River Defences	Land Use Planning and Management
6	Flood-proofing Buildings	Coastal Defence Abandonment	Catchment-wide Storage	Catchment-wide Storage
7	Urban Area Development, Operation and Form	Main Drainage Form, Maintenance and Operation	Building Development, Operation and Form	River Defences
8	Urban Source Control and Above-ground Pathways	Flood-proofing Buildings	Urban Area Development, Operation and Form	Coastal Defences
9	Urban Storage Above and Below Ground	River Conveyance	Urban Storage Above and Below Ground	Flood-proofing Buildings
10	River Conveyance	Catchment-wide storage	Pre-event Measures	Rural Conveyance
11	Pre-event Measures	Engineered Flood Storage	Real-time Event Management	Coastal Defence Realignment
12	Individual Damage Avoidance	Land Use Planning and Management	Engineered Flood Storage	Reduce Coastal Energy
13	Engineered Flood Storage	Real-time Event Management	Rural Conveyance	Morphological Coastal Protection
14	Real-time Event Management	Pre-event Measures	Increase Conveyance or Flow Passed Downstream	Engineered Flood Storage
15	Main Drainage Form, Maintenance and Operation	Rural Infiltration	Rural Infiltration	Real-time Event Management
16	Land Use Planning and Management	Rural Conveyance	Managing Urban Runoff	Pre-event Measures
17	Managing Urban Runoff	Individual Damage Avoidance	Floodwater Transfer	Individual Damage Avoidance
18	Floodwater Transfer	Managing Urban Runoff	Urban Groundwater Control	Main Drainage Form, Maintenance and Operation
19	Rural Infiltration	Floodwater Transfer	Main Drainage Form, Maintenance and Operation	River Conveyance
20	Catchment-wide storage	Building Development, Operation and Form	Coastal Defences	Rural Infiltration
21	Rural Conveyance	Urban Area Development, Operation and Form	Coastal Defence Realignment	Managing Urban Runoff
22	Building Development, Operation and Form	Urban Source Control and Above-ground Pathways	Morphological Coastal Protection	Floodwater Transfer
23	Urban Groundwater Control	Urban Groundwater Control	Reduce Coastal Energy	Urban Groundwater Control
24		Urban Storage Above and Below Ground	Coastal Defence Abandonment	

Key	Uncertainty band category	Uncertainty band width (B) (B = ratio of upper to lower bound estimates of flood risk impact multiplier)	Colour code
	High	B ≥ 1.5	(orange)
	Medium	1.5 > B ≥ 1.1	(light grey)
	Low	B < 1.1	(green)

There is uncertainty over the effectiveness of Land Use Planning and Management which is lower under the World Markets and National Enterprise (free-market) scenarios than under the Local Stewardship and Global Sustainability (community-orientated) scenarios. This is because it has been assumed that there will be fewer planning controls to encourage locating future development and redevelopment away from high flood risk areas in the free-market worlds as there will be high-economic growth which will enable areas to be protected. Therefore, there is more certainty that Land Use Planning and Management will have a limited effect.

The relatively high uncertainty in the effectiveness of Land Use Planning and Management under the two community-oriented futures can be seen as reflecting the importance of getting the policy context right – if done well, the opportunities are great; if done badly, the potential will not be realised. The Government needs to look at how Land Use Planning and Management responses are implemented and the need for enforcement of policy decisions to ensure that they are effective.

As in 2004, the intra-urban responses grouped under Managing the Urban Fabric have generally been given higher uncertainty gradings than fluvial/coastal responses. The explanation lies in the fact that, in contrast to fluvial/coastal responses, the impacts of intra-urban flood management responses, even for the present day, are not easily quantified with current technology – a weakness flagged in Foresight 2004. Reliable data, modelling tools and techniques, combining the modelling of underground drainage systems and surface flooding, are new or still under development.

When we go on to consider the future, projections of flood risk across the scenarios are even more uncertain, with potential changes in governance and policy, stakeholder behaviour and science and technology adding to the uncertainty and reinforcing our caution in assessing them. The outcome of the update is consistent with Foresight 2004, but the intra-urban uncertainties have been more clearly exposed.

As with Land Use Planning and Management, this is not to say that the intra-urban responses will be ineffective and should not be pursued, but rather emphasises the importance of getting the right policies and developing the data and modelling tools. It is good to note that considerable progress has been made on both fronts under *Making Space for Water*, and that the Pitt Review gives this strong reinforcement.

In contrast, the conventional responses of engineering come out generally with 'Low' or 'Medium' uncertainty. In this case, the uncertainty is partly based on human factors, and partly on the scientific challenges posed by ever-increasing technical and environmental demands.

Policy issues emerging from response analysis update

There are important policy implications arising from the high uncertainties associated with many of the responses, especially in the urban area where different types of flooding, and hence different policy areas, interact. Different responses will be more or less effective under each of the four different future scenarios. This uncertainty about the future means that flexibility of policy is crucial.

Chapter 7: Sustainability

In considering the effectiveness of each response group in reducing flood risk, it is essential to place that consideration in a sustainability framework. This is because the effectiveness of a measure in reducing flood risk cannot be seen in isolation.
It has to be seen in the context of its cost effectiveness and its impact on society and the environment. In the 2004 Foresight reports we drew on the Government's guidance on sustainability to derive a series of metrics that allowed us to address the economic, social and environmental impacts of the various flood response groups and place them within a governance framework based on sound science (www.sustainable-development.gov.uk). The metrics used in 2004 were:

- cost effectiveness: the value for money of implementing the response option;
- social justice: the impact of action on different types of household; and
- environmental quality: the impact on biodiversity, and the area and quality of habitats.

Consideration was also given to the ability of response options to cope with uncertainty relating to scenario differences in socio-economic factors and climate change (robustness), together with uncertainty relating to their ability to cope with extreme events and how they would operate (precaution).

In our original analysis we identified a range of flood response measures that were very attractive in providing a reduction in flood risk across a range of scenarios and also provided wider benefits (e.g. Land Use Planning and Management, Building Codes). We also noted a range of responses, such as Realignment of Coastal Defence, Flood-proofing and Engineered Flood Storage, that, while being effective in flood risk reduction, presented problems in terms of the sustainability criterion of social justice. These responses gave concerns on two counts. In some cases, the reason for concern was about the differential impacts on poorer or more vulnerable sectors of society related to the mechanisms for funding and uptake of the option; in others, it was linked to the impacts of the actions themselves, in particular where changes in land use are required. Our analysis confirms the conclusion that these are attractive responses, but that there is a greater need to take account of the issue of social justice in the implementation of flood policies than has perhaps occurred to date.

In revisiting the flood responses, we have not rescored the various sustainability metrics, only the potential effectiveness of the response options in reducing flood risk. However, only two measures, Land Use Planning and Management and Flood-proofing, have been rescored, with a reduction in the effectiveness of both measures being assessed. These reductions were, however, insufficient to affect the analyses presented in the 2004 Foresight reports.

The results of the analysis are illustrated in Table 19. This shows in dark green in the first three columns the responses that produce reductions in flood risk across at least three scenarios and which have no sustainability penalties associated with cost, the environment or social justice respectively. Mid-green indicates a social justice failure in one scenario, and light green a social justice failure in two scenarios. The fourth column summarises the overall sustainability rating. The darker the green in this column, the less failures of sustainability criteria there were. The responses in the white cells fell below the sustainability threshold described above.

Table 19: Sustainability of flood responses (from Evans et al., 2004)

Table 7.1 **The flood response measures that produce a reduction in flood risk across at least three scenarios and which have no sustainability penalties associated with a) cost, b) the environment or c) Social Justice (dark green). Those responses which pass all three sustainability criteria (d) are labelled dark green in the right hand column. Mid-green = Social Justice failure in one scenario; light green = Social Justice failure in 2 scenarios.**

a) Cost-Effectiveness	b) Environmental Quality	c) Social Justice	d) Overall
Rural Infiltration	Rural Infiltration	Rural Infiltration	Rural Infiltration
Catchment-Wide Storage	Catchment-Wide Storage	Catchment-Wide Storage	Catchment-Wide Storage
Rural Conveyance	Rural Conveyance	Rural Conveyance	Rural Conveyance
Urban Storage	Urban Storage	Urban Storage	Urban Storage
Urban Infiltration	Urban Infiltration	Urban Infiltration	Urban Infiltration
Urban Conveyance	Urban Conveyance	Urban Conveyance	Urban Conveyance
Pre-Event Measures	Pre-Event Measures	Pre-Event Measures	Pre-Event Measures
Forecasting and Warning	Forecasting and Warning	Forecasting and Warning	Forecasting and Warning
Flood Fighting	Flood Fighting	Flood Fighting	Flood Fighting
Collective Damage Avoidance	Collective Damage Avoidance	Collective Damage Avoidance	Collective Damage Avoidance
Individual Damage Avoidance	Individual Damage Avoidance	Individual Damage Avoidance	Individual Damage Avoidance
Land-Use Management	Land-Use Management	Land-Use Management	Land-Use Management
Floodproofing	Floodproofing	Floodproofing	Floodproofing
Land-Use Planning	Land-Use Planning	Land-Use Planning	Land-Use Planning
Building Codes	Building Codes	Building Codes	Building Codes
River Conveyance	River Conveyance	River Conveyance	River Conveyance
Engineered Flood Storage	Engineered Flood Storage	Engineered Flood Storage	Engineered Flood Storage
Floodwater Transfer	Floodwater Transfer	Floodwater Transfer	Floodwater Transfer
River Defences	River Defences	River Defences	River Defences
Coastal Defences	Coastal Defences	Coastal Defences	Coastal Defences
Coastal Defence Realignment	Coastal Defence Realignment	Coastal Defence Realignment	Coastal Defence Realignment
Reduce Coastal Energy	Reduce Coastal Energy	Reduce Coastal Energy	Reduce Coastal Energy
Morphological Coastal Protection	Morphological Coastal Protection	Morphological Coastal Protection	Morphological Coastal Protection
Abandonment	Abandonment	Abandonment	Abandonment

Sustainability analysis

The 2004 Foresight analysis of sustainability showed that there was no single response that would reduce flood risk in a fully sustainable manner, though some of the responses connected with catchment land use and flood event management were shown to be fairly sustainable.

Social justice emerged as a major issue in the sustainability analysis. It was not, however, so much the response that was the issue but rather the way that it was implemented.

From the diversity of issues that were raised in the sustainability analysis relating to cost effectiveness, social justice and the environment, it was also concluded that engineering was an indispensible ingredient in flood risk management and that the way forward was via portfolios of integrated engineering and non-structural responses.

However, engineering options, in particular, can have big impacts in terms of social justice, if not implemented with sensitivity to such issues. Adverse public reactions to recent major coastal realignment proposals highlight the need to solve these issues, if such schemes are to be put into practice.

While our original sustainability analysis, in terms of the robustness of response options in reducing flood risk within a sustainability framework, remains unchanged, the re-evaluation of the response options has shed further light on some of the sustainability issues identified in 2004.

Social justice

The original Foresight report identified the issue of social justice as being critical in terms of the impacts of the various response measures on those comparatively disadvantaged in future generations. However, re-evaluation of the river engineering options, especially in terms of River Defences, has further highlighted the issue of social justice in terms of its relative impact on rural and urban populations. Flood defences along one reach of a river can raise floodwater levels both upstream and downstream, potentially increasing flood risk in those areas. The pressure to increase river defences in urban areas thus has the potential to disadvantage those in rural areas, and rural populations are becoming increasingly vocal on this topic.

The insensitive application of cost-benefit analysis can also create social injustice in a community through the process of dividing it up into flood cells that have their own flood risk and defences, and calculating the cost-benefit ratio separately for each one. This has the potential, for example, to create a situation whereby an area of a town on one side of the river is protected, but an area on the opposite bank is not. Though the recent introduction of broader outcome measures by Defra will help to give a fairer basis of assessment, this point nevertheless merits attention.

Similarly, within the coastal zone, social justice issues have also been highlighted whereby the cost of maintaining or improving defences is seen as a major issue for sparse rural populations in terms of the cost-benefit issue. This has been highlighted in Norfolk, in areas subject to the combined challenge of erosion of beaches and rising sea levels (Nicholls et al., 2007).

Managed realignment

A review of managed realignment as a response option across Europe has highlighted that the cost effectiveness of this measure may be less than originally envisaged (Rupp-Armstrong, 2008) and consequently it may not be as widely adopted as originally envisaged.

Two factors have a bearing here. The first is the increasing cost of managed realignment schemes associated with new defence build and other significant costs incurred during the scheme preparation phase to deliver environmental benefits. The second is the rising value of agricultural land in the UK and the greater awareness of food security as an issue due to climate change and changing world markets (Brown and Funk, 2008; IAASTD, 2008). Even though less than 1% of the damages resulting from flooding occur in the agricultural sector (Evans et al., 2004), a large proportion of the most agriculturally productive land in England and Wales is dependent on flood protection and land drainage. For example, under all the scenarios in our 2004 report, there was high exposure to flood risk in the Fens of East Anglia. Increased importance placed on future food security may require re-evaluation of response options to reduce flood risk and to maintain standards of land drainage in areas of national strategic agricultural importance.

Environmental quality

The increased costs of coastal realignment associated with the requirement to deliver environmental benefits, along with the issue of food security and value of agricultural land, call into question the extent to which managed realignment will be used for flood risk management and to deliver environmental benefits in areas subject to coastal squeeze under some scenarios. Under extremes of sea-level rise, currently assessed as having a low but finite probability, coastal morphological protection approaches are likely to be much less effective, as they will be unable to keep pace with the rapid change. This will also lead to a loss in the extent and biodiversity value of such sites.

Within the fluvial environment, the recent floods have further highlighted the tensions involved in the management of riverine systems and the multi-functional use of British rivers. For example, increasing the River Conveyance response has the potential to reduce local flood risks, but may increase them downstream, while also having adverse morphological, habitat and environmental consequences.

Chapter 8: Conclusions and policy indications

In the 2004 Foresight report we highlighted potentially large rises in future flood risk under the baseline flood management assumption, as demonstrated by the quantitative analysis, varying by factors of about 1.5 to 20 under different scenarios. These are shown in Table 19.

Table 20: Baseline case: future flood risk for England and Wales by the 2080s under the four scenarios (from Evans et al., 2004)

Flood risks expressed as Expected Annual Damage (EAD) and the baseline costs of flood defence for the business as usual option (continuation of current flood-management policies and expenditure into the future) – catchment and coastal					
	Present day	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Baseline case, EAD £ million/year	1,040	20,500	15,100	1,500	4,860
Baseline cost £ million/year	500	500	500	500	500

Flood risks expressed as Expected Annual Damage (EAD) and the baseline costs of flood defence for the business as usual option (continuation of current flood-management policies and expenditure into the future) – intra-urban					
	Present day	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Baseline case, EAD £ million/year	270	7,880	5,060	740	1,870
Baseline cost £ million/year	320	320	320	320	320

The quantitative analysis has not been repeated in the update, but the changes in the driver multipliers suggest that these factors have increased rather than decreased.

The quantitative analysis also showed that portfolios of engineering and non-structural responses could hold flood risk at somewhere near present-day levels with a favourable cost-benefit ratio under all scenarios. The impact of these responses to future flood risk is shown in Table 20.

Table 21: Integrated portfolios of flood management responses: future flood risk for England and Wales by the 2080s under the four scenarios (from Evans et al., 2004)

Integrated portfolios of flood management – catchment and coastal					
	Present day	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Target standards of flood protection, relative to present day	1	2	2	0.75	1
Residual risks with integrated portfolio, EAD (£m/year)		1,760	1,030	930	2,040
Risk reduction, EAD (£m/year)		18,700	14,000	570	2,820
Flood-management capital costs: Englandand Wales, fluvial and coastal (£m/year)		75,600	77,200	22,100	22,400
Additional annual capital costs to achieve risk reduction (£m/year)		1,600	1,600	500	500
Total annual costs (catchment and coastal) as a percentage of GDP (%)	0.05	0.01	0.04	0.04	0.01

Integrated portfolios of flood management – intra-urban					
	Present day	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Residual risks with integrated portfolio, EAD (£m/year)		4,200	2,400	490	720
Risk reduction, EAD (£m/year)		3,680	2,660	250	1,150
Flood-management costs:					
Additional costs to achieve risk reduction (£m/year)		540	260	400	110
Total annual costs (intra-urban) as a percentage of GDP	0.03	0.01	0.01	0.03	0.005

In 2004 we made the following conclusions:

- Integrated flood risk management must lie at the core of our response to changes in the drivers of flooding and coastal erosion.
- Flood management investment would need to rise to an average over the next 50 years of somewhere between £1 billion and £2 billion per annum in real terms for rivers and coasts, and between £400,000 and £800,000 per annum for intra-urban systems to hold flood risk at around its present-day value. It must be emphasised that these costs are very approximate and that research is needed to refine them.
- We have the choice of whether to make the task substantially easier by pursuing mitigation policies that will reduce climate change and flooding through the control of greenhouse-gas emissions (and potentially macro-engineering the climate).
- The mitigation of climate change has, however, little potential to reduce flood risk by the middle of this century, because of time lags within the system. It will become increasingly important as we move towards the end of the current century and other responses reach their limits. But mitigation must start now, if it is to deliver its benefits in time.

Given this aim, the question that arises is how to get there. In 2004, we posed a number of strategic questions that should inform the long-term approach to flood management, which are given below:

- How we use land, balancing the wider economic, social and environmental needs against creating a legacy of flood risk.
- How we manage the balance between state and market forces in decisions on land use.
- Whether to implement non-structural societal responses with longer lead times; or rely increasingly on bigger structural flood defences with potentially adverse economic, social and environmental impacts.
- How much emphasis to place on measures that are reversible and those that are highly adaptive.

We also drew attention to the key role that science and technology can play in the development of long-term policies in flood risk management.

In the context of these questions, the 2008 update has highlighted a number of issues, as follows.

The threat of rising sea levels

As in 2004, coastal flood risk shows large rises under all scenarios, but the latest work on climate change shows a small but plausible risk of much greater sea-level rise. Coupled with some of the difficulties that have arisen in implementing managed realignment and abandonment, the coast is one of the key priority areas for better science, innovative engineering and social policy development. The issue of food security was perhaps underplayed in the Foresight 2004 review, and now has relevance in the debate over coastal realignment and abandonment.

Rising precipitation

Our review of climate change scenarios in relation to precipitation shows a wider range of possibilities than we envisaged in 2004. In policy terms, this means that we may have to cater for bigger increases in river flows than we have envisaged to date. Finding space for storage and conveyance of this extra water again poses challenges for science, engineering and policy development.

Intra-urban flood risk

We estimated in 2004 that the future risk from the intra-urban system might rise by the 2080s to be of the same order as fluvial and coastal flood risk. This is backed up by the High to Medium rankings of the intra-urban drivers in the new combined qualitative analysis. Confused governance has long been recognised as a barrier to flood management in this area, as recognised in *Making Space for Water* and highlighted by the Pitt Review. The summer 2007 floods highlighted the increased risk from intra-urban flooding and a lack of coordination for managing it.

Land use

The Pitt Review reports show vividly that a number of recently constructed housing estates were flooded in 2007; influencing where to build houses, factories and other infrastructure is now recognised as a key tool in managing future flood risks. However, the question is not a simple one, and we drew attention in 2004 to the need to balance flood management against other economic, social and environmental needs, including, notably, the demand for new housing.

For example, it would be controversial if we were to ban redevelopment of brownfield sites that lie in the floodplain, but are behind well-managed flood defences affording a high standard of protection – this applies to much of London, for instance. The need is perhaps for more sharply targeted policy instruments. One alternative might be to define a corridor along all the rivers flowing through urban areas, sufficient to convey a potential 20–40% increase in flood flows in the future, and zone the corridor to avoid any development or redevelopment within it. It would be a realistic planning aim to pull back from the corridor as sites within it come up for redevelopment over the years.

We have included in Appendix B (in the section on Managing Flood Losses) a short survey of international practice in floodplain and coastal zoning. Some of these practices go beyond the current system applied in England. We hope that this brief survey will be useful to policy makers in the further development of our existing policy instruments.

Uncertainty, adaptability and 'precautionarity'

We noted in 2004 that flood risk may not develop as we anticipate, and we have highlighted the high level of uncertainty associated with coastal drivers of flood risk and, in particular, the increased uncertainty associated with sea-level rise. Flood risk managers need to deal with this.

Adaptability can be incorporated into flood defences at the design stage, allowing incremental implementation and improvement with time – for example, constructing defences with a wider base allows subsequent top-up construction to maintain standards of protection as risk is re-evaluated. Having clear knowledge of options that have reserve capacity and that can be brought forward rapidly is vital. It should, however, be noted that this may result in the additional investment referred to above having to be somewhat front-end loaded.

'Precautionarity' is another important principle. With some flood-response options on the one hand, the way is left open for reversing the measures if society or the climate do not change as expected. Stringent building regulations may be relaxed, and we can allow building on the floodplains and remove some flood defences. On the other hand, some decisions are effectively irreversible. In particular, releasing floodplain land for development is very difficult to reverse, once houses or industry are in place.

We therefore identified in 2004 these choices for flood risk managers:

- to favour reversible options;
- to favour responses that have high adaptive capacity and allow incremental enhancements; or
- to face irreversible adverse consequences for flood management.

Investment

The House of Commons Environment Food and Rural Affairs Select Committee report on flooding (House of Commons EFRA Committee, 2008) cites an "oft-quoted" figure of around £1 billion per year of flood risk management investment as coming from the 2004 Foresight reports. However, as shown in Table 20, the 2004 work gave estimates of the funding needed to maintain roughly the current levels of flood risk varying for different scenarios from £1 billion to £2 billion per annum in real terms for rivers and coasts, with an additional £400,000 to £800,000 per annum for intra-urban systems. These figures were obtained from very approximate estimates of the capital sums needed (£20 billion to £70 billion) and simply spread over the next 50 years, the approximate service life of a typical flood defence asset. The method used gave no information as to the timing of the investment. Work is badly needed to refine the figures and so provide government with a more reliable evidence base from which to set the level of annual investment in flood risk management.

Governance

In addressing the issue of climate change and changing flood risk, the 2004 Foresight report emphasised that a portfolio of responses was required to deliver effective flood risk management in a changing world – there is no single response that reduces flood risk substantially and has no sustainability penalties. The report also emphasised that the effectiveness of different response measures would vary under different scenarios, in part because of variations in governance that are implicit within the scenario frameworks. Governance is a critical issue, because the delivery of responses depends on governance mechanisms; adaptive capacity is determined by governance, and the distribution of costs and benefits in society is determined by governance.

The Pitt Review reports confirm our 2004 assessment. It highlights how important the issue of governance is for the delivery of a range of responses and for social justice, in terms of the distribution of the costs and benefits of flood risk management within society. The increased regionalisation of governance frameworks has, since our previous report, further highlighted the role of governance in the delivery of flood risk management, particularly within urban areas.

Rural communities, in particular, could be disadvantaged where flood protection is deemed insufficiently cost-beneficial and where the rural space is used to temporarily store floodwater in order to avoid urban flooding. Rural areas may require special attention, if they are not to become neglected and unrepresented in flood risk management strategies.

While sustainable development, within the context of changing flood risk, depends critically upon the governance framework, it is not within our remit to explore near-term policy responses to the floods of 2007. We did, however, identify in 2004 some of the longer-term governance issues we will face:

- **Our strategies and choices** for governance and responses need to be matched to the scale of future increases in risk.
- **Governance** (both government and non-governmental) needs to support the concept of a portfolio of responses to decreasing flood risk, and allow its integrated implementation.
- **Adaptability** will be important in the portfolio of responses, and its governance arrangements. It is crucial that the responses implemented can in future be adapted to changing societal and climatic drivers.
- **Investment** will be needed for future flood and coastal management, to promote long-term solutions, appropriate standards and equitable outcomes.
- **Market mechanisms and incentives** should be fully used to manage future risks – while recognising the central role of all levels of government.

In 2008, these issues remain central to deriving and delivering appropriate responses to future increases in flood risk.

Main conclusions

This report highlights a number of key issues.

- **The threat of rising sea levels:** coastal flood risk features highly in all scenarios and there is now a small but plausible risk of much greater sea-level rise than was estimated in 2004. Coastal flooding is therefore one of the key priority areas for better science, innovative engineering and social policy development.
- **Rising precipitation:** the update of climate change scenarios has indicated a wider range of possibilities in relation to precipitation than in relation to 2004. This means we may have to cater for bigger increases in river flows than previously envisaged.
- **Intra-urban flood risk:** 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:** influencing where to place new development is now recognised as a key tool in managing flood risk; however, this does need to be balanced against other economic, social and environmental needs, including the demand for new housing.

Main conclusions *(continued)*

- **Uncertainty:** 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.
- **Investment:** 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 badly needed to refine the figures and provide government with a more reliable evidence base from which to set the level of investment for flood risk management.
- **Governance:** 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.

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List of those who contributed to the update

Name	Affiliation
Prof. Colin Thorne (Team Leader)	University of Nottingham
Prof. Nigel Arnell	University of Reading
Prof. Richard Ashley	Sheffield University
Prof. David Balmforth	MWH
Prof. Edward Evans	University of Nottingham
Prof. Jim Hall	University of Newcastle-upon-Tyne
Dr Gemma Harvey	University of Nottingham
Dr Tim Hess	Cranfield University
Prof. Stuart Lane	Durham University
Prof. Joe Morris	Cranfield University
Prof. Robert Nicholls	University of Southampton
Steve Noyes	Met Office
Prof. Edmund Penning-Rowsell	Flood Hazard Research Centre, Middlesex University
Nick Reynard	Centre for Ecology and Hydrology, Wallingford
Prof. Adrian Saul	Sheffield University
Jonathan Simm	University of Nottingham and HR Wallingford
Sue Tapsell	Flood Hazard Research Centre, Middlesex University
Prof. Andrew Watkinson	University of East Anglia
Prof. Howard Wheater	Imperial College London

PIC TO COME

Appendix A: Updated driver descriptions

Climate Change: inland drivers

Nick Reynard and Steve Noyes

Precipitation

Driver definition

Precipitation contributes to flood risk through its hydrological distribution in space and time.

Precipitation is one of the major source drivers for future flood risk. Precipitation can directly cause pluvial flooding through the occurrence of events that are extremely intense or excessively long. Also, the subsequent drainage of precipitation, from its running off hillslopes to creating excessive discharges in streams, rivers and aquifers, causes 'muddy', river and groundwater flooding, respectively. This means that when predicting future flood risks, it is crucial to understand possible changes to all aspects of the precipitation (rain and snowfall) regimes over the next 30–100 years.

The hydrological distribution of precipitation in space and time, is the means by which this driver contributes to flood risk. However, nowhere is flooding a simple, linear response to precipitation. The means by which we understand how precipitation is translated into river flow is through the science of hydrological, rainfall-runoff modelling. It is also via modelling that we try to understand how changes in all aspects of precipitation (amount, intensity, duration, location and clustering) will impact on the flooding system. Obviously, increases in rainfall at all scales will increase the risk of flooding to a greater or lesser extent. However, decreases in average rainfall could also be associated with increased flood risk, if the mean decrease is coupled with increases in the intensity of extreme events or clustering of events, such as what occurred during the summer of 2007. Both these outcomes are feasible within the climate futures projected for the UK.

Catchments differ in their hydrological responses to precipitation. Small, steep catchments with thin soils and sparse vegetation are sensitive to changes in short duration ('flashy') rainfall, whereas larger, rural catchments, or catchments with a large element of groundwater storage, flood in response to precipitation accumulations over longer time periods.

Long-term precipitation (seasonal) also defines the groundwater recharge season. Excessive recharge can bring the water table to ground level, causing first waterlogging and then groundwater flooding. Pluvial flooding may occur where surface runoff by-passes or cannot reach the river channel as direct runoff in response to intense rainfall in itself, or due to rain falling on impermeable surfaces. These types of flooding are especially important in urban areas.

Rainfall

Climate change brought about by human-induced global warming will alter the rainfall regime of the UK. Precisely how the regime will change over the next 100 years remains very uncertain, particularly with regard to the different types of extreme rainfall event, whether of short or long duration, that lead to flooding. The scenarios used in the 2004 Foresight project were based on the United Kingdom Climate Impacts Programme 2002 (UKCIP02) scenarios. Since then, substantial new work has been done, leading to the development of a new scenario 'space' for this update. The evidence for this is presented in the scenarios section of this report (see Chapter 4), which also quantifies the changes in precipitation (and temperature) expected in the UK by the 2050s and the 2080s. The changes in precipitation have been defined for some of the key flood-producing indices, such as seasonal rainfall totals, seasonal variability and the intensity of extreme events, recognising the great uncertainty associated with scenarios of changes in such extremes.

Snowfall

The latest UK climate scenarios suggest significant reductions in snowfall, by up to 90% by the end of the century. For flooding, the important implication of a warmer world and reduced snowfall is that there will be a change to the partitioning of winter precipitation between rain and snow. Future projections suggest that there will be fewer winters, anywhere in the UK, where significant snow lies and accumulates over long periods. This will change the flood regime of those rivers that currently feature peak flows during the spring, snow-melt season.

Assessing the impact of climate change on flooding presents many challenges (Arnell, 1996). These are most often addressed through hydrological modelling, generally using a continuous flow simulation approach. Climatic input data series (principally precipitation, potential evaporation and temperature) are used to generate hydrological series (e.g. river flow or groundwater level).

Because they are designed on the assumption that the underlying processes are stationary in time, purely statistical methods of flood frequency estimation, such as described in the *Flood Estimation Handbook* (Robson and Reed, 1999), are inappropriate for direct use in climate change studies. However, the design flood obtained through such a statistical method may be enlarged by a factor to accommodate a change in the future climate. This method has been adopted for the modelling and decision support framework for catchment flood management plans (HR Wallingford, 2002). To account for possible climate change in 2050, a 20 per cent addition was made to flows derived using the *Flood Estimation Handbook*. This figure was recommended by the Ministry of Agriculture, Fisheries and Food (2001) and is based on the work of Reynard et al. (1999; 2001) on assessing the impact of climate change in selected catchments in the UK using continuous simulation of river flows.

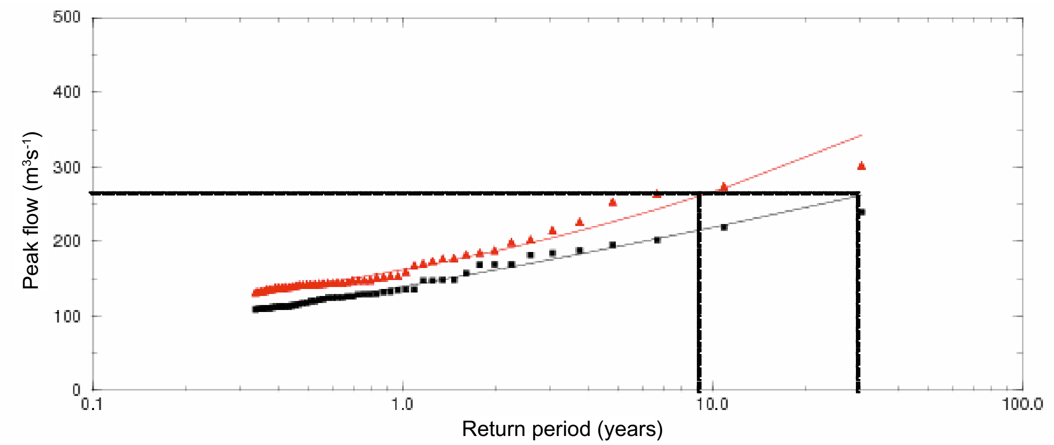
Models specially designed to provide reliable estimates of the current flood regime are available in the literature. The assumption is that the rainfall-runoff processes described by the models (either through conceptual modelling, or physical approaches) will remain the same in the future. The models are run under current climate conditions, i.e. using observed series, or series generated to represent the current climate, and under future conditions, i.e. using future scenarios, or future climatic series assumed to be representative of the future (Reynard et al., 2001; Crooks and Reynard, 2002; Prudhomme et al., 2001; Werritty et al., 2002; Kay et al., 2006).

Figure A1 shows some example flood frequency results for a hydrologically responsive catchment in north-west England. The black points and trend line show the current frequency curve, with the versions indicating possible changes under the 2080s World Markets scenario. In terms of a potential change in flood risk therefore, this is equivalent to the current 30-year flow that might be expected once every nine years – a greater than threefold increase in risk. The scenario used reproduces the changes in the seasonal rainfall totals, and some, but not all, of the change in intensity. The changes in variability could be simply included, so the likely consequence is that the true World Markets 2080s scenario would show larger increases in the probability of the current 30-year flow.

Driver update

Precipitation is clearly the critical source driver for inland flooding. However, precipitation interacts with all other climate drivers to determine the flood regime of a catchment. The same rainfall will have very different flood impacts dependent upon the antecedent catchment conditions, which will be determined by the long-term weather patterns, such as the temperature and wind speed driving the evaporative losses.

Figure A1: Example flood frequency results from a catchment in north-west England. The current flood frequency is shown in black, with the future condition in red



Moreover, non-climate factors such as land use and socio-economic change will also interact with any future rainfall change to alter the flood risk.

There are many ways of classifying sources of uncertainty surrounding changes in the future rainfall regime. Potential changes in rainfall over the next 100 years are more uncertain than other climate variables, including temperature. There are also degrees of uncertainty, depending on what aspect of the rainfall regime is being investigated. There is more confidence in changes in average annual rainfall than in changes in the sub-daily patterns. There is also more confidence in broad-scale regional change than in changes in the rainfall regime at a local level.

The section on scenarios (see Chapter 4) provides a broader discussion of the uncertainty in future projections of precipitation, in the context of the work being done in the UK for the forthcoming United Kingdom Climate Impacts Programme 2008 scenarios, and the data available through the IPCC *Fourth Assessment Report* (AR4) (Meehl et al., 2007).

Conclusion

Given the scenario update information (including changes in variability and intensity of rainfall, the example model results shown in Figure A1 and the inclusion of the intra-urban component of precipitation change) the risk multiplier scores have increased during this updating exercise. As the 'envelope of change' in the scenarios only expanded significantly in the positive direction for temperature and rainfall (see Figure 6 of the scenario text), the risk scores have only been increased for the World Markets and National Enterprise scenarios for this 2008 update.

Temperature

Driver definition

Human activity is increasing the level of greenhouse gases in the atmosphere which will, in turn, create changes in global atmospheric temperatures.

Temperature contributes to flood risk through its operation on the partitioning of precipitation between rainfall and snow, as well as driving evaporative losses. Human-induced climate change is predicted to increase average annual temperatures across the UK by between 1ºC and 4.5ºC. The increases will be generally higher in the south and east of the country, and during the summer and autumn. By the 2080s, temperatures could be between 1ºC and 5ºC higher during the summer compared with the 1961–90 average. As with all climate variables there will be changes to the annual, seasonal, daily and sub-daily temperatures.

An increase in temperature will operate in several indirect ways on future flood risk. In addition to any temperature effects discussed during the description of the Precipitation driver, temperature directly affects the partitioning between precipitation as rain or as snow. In addition, temperature drives evaporation, and hence water availability for runoff and storage as soil moisture and groundwater.

Driver update

Temperature is an important driver in the sense that changes to temperature interact with other climate variables. For example, temperature changes will directly affect rainfall and potential evapotranspiration, which then change future flood probabilities.

The level of uncertainty associated with future projections of temperature is generally lower than that for precipitation. However, like precipitation, uncertainty increases for projections of change in local temperatures and for changes in temperature extremes. A fuller assessment of these uncertainties is given in the climate change scenario section of this report (see Chapter 4), together with a quantified estimate of a range of seasonal change in temperature based on work for the UKCIP08 and IPCC AR4 scenarios (Meehl et al., 2007).

In the 2004 Foresight study, values of unity were assigned to the flood risk multiplier scores for all four future scenarios. This review of the Temperature driver has not revealed any reason to change these scores.

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Climate Change: coastal drivers

Robert Nicholls and Jonathan Simm

Relative Sea-Level Rise

Driver definition

Relative Sea-Level Rise is the local change of sea level relative to the land.

The mean relative sea-level rise is the product of:

- global, mean sea-level rise;
- regional sea-level change due to density and circulation changes within individual ocean basins; and
- local sea-level change due to geological uplift/subsidence and gravitational processes (e.g. glacial-isostatic adjustment).

The changes in understanding since 2004 mainly concern global, mean sea-level rise. This is composed of three main elements:

- thermal expansion;
- melting of small, land-based glaciers; and
- breakdown of the large ice sheets (Greenland and West Antarctica, especially the West Antarctic Ice Shelf where our knowledge is weakest).

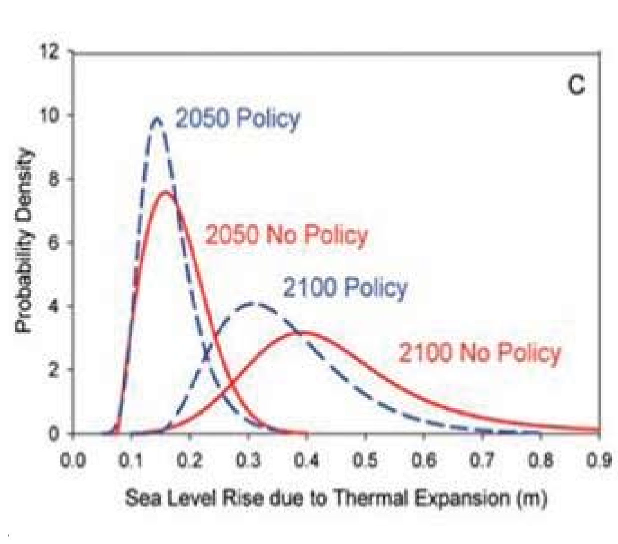
Driver update

While several documents have been produced since the Foresight 2004 study, such as those by Defra (2006) and UKCIP (2007), these are entirely consistent with the Foresight 2004 scenarios. The most important changes come from the new sea-level rise scenarios published by IPCC AR4 (Meehl et al., 2007) and the discussion that they have engendered.

Recently, satellite-based observations of global-mean sea level have been observed to exceed the upper bound of the scenarios published in the IPCC Third and Fourth Assessment Reports (Rahmstorf et al., 2007), raising concern that sea level is rising more rapidly than expected in response to global warming (although variability of ice sheet flows remains uncertain). There has also been significant discussion of quite extreme rises in global, mean sea level that would occur due to breakdown of the large ice sheets (e.g., Hansen, 2007). This includes geological analogues of interglacial, high sea-level rise conditions similar to today, which suggest that a rise of 2 m per century is possible (Rohling et al., 2007). Hence, the possibility of a global, mean sea-level rise exceeding 1 m in the 21st century is now considered an unlikely, but plausible, scenario.

In practice, we are more concerned about the low-probability, high-consequence tail of the distribution of global, mean sea-level rise (e.g. Figure A2), reviving fears that were paramount concerning sea-level rise 20 years ago. The potential consequences of such a large sea-level rise are illustrated for London by Dawson et al. (2005).

Figure A2: Illustrative probability density functions for the thermal expansion component of global, mean sea-level rise showing the positive tail (Webster et al., 2003). The probability density function for ice sheet breakdown is hypothesised to have a similar form



We are also confident that there will be at least some global-mean sea-level rise under all scenarios (continuing trends observed during the 20th century), and hence there will be an impact on flood risk even at the lower end of the range of possible sea level rise, whichever scenario is assumed.

A comparison of the scenarios in the IPCC Third Assessment (TAR) and Fourth Assessment (AR4) reports is given in Table A1. While the mean scenarios are similar, the range has been reduced in the AR4. However, it is stated clearly in the IPCC report that these numbers should not be taken as an upper bound on global sea level, and a greater rise is possible, up to rises exceeding 1 m. Upper ranges were not calculated for Foresight 2004. For the purposes of estimating the potential changes, the 'High+' scenarios are used, which include an additional rise of up to 100 cm due to ice sheet breakdown.

Table A1: A comparison of the global, mean scenarios from the IPCC TAR and the IPCC AR4 from 1990 to the 2080s (Table 10.7 in Meehl et al., 2007). The AR4 scenarios include scaled-up ice sheet discharge, while the 'ice sheet breakdown' term has been added to capture the large, high-end changes that are possible. These will be updated by the publication of the UKCIP08 marine report

UKCIP02 (SRES)	Global, mean sea-level rise scenarios (cm)							
	TAR			AR4				
	Low	Mean	High	Low	Mean	High	Ice sheet break-down	High+
Low emissions (B1)	9	29	48	17	29	41	50	91
Medium-low emissions (B2)	11	33	54	18	32	46	66	112
Medium-high emissions (A2)	13	36	59	19	36	52	84	136
High emissions (A1FI)	16	43	69	22	42	62	100	162

Hence, the scoring of sea-level rise for the mid-estimates remains unchanged from Foresight 2004. Low and high bound scores have been adjusted to recognise that some sea-level rise is inevitable, and there is a small but real possibility that the rise will be large. Given the large potential rise and the high uncertainty, better definition of the upper bound for global, mean sea-level rise is an important science requirement for flood risk assessment and management.

Waves

Driver definition

Increases in the height and direction of coastal waves will transmit more wave energy to the shoreline at some locations and less energy at others, increasing the risks that waves will breach and overtop coastal defences.

The characteristics of offshore waves depend on wind strength, the fetch length and the track of the driving low-pressure pattern. Nearshore waves are influenced by local water depth, offshore wave conditions, and locally generated waves, which themselves depend on wind strength and fetch length.

Driver update

No evidence has emerged to support changes in the judgements made about the mean values of incidence waves in Foresight 2004. However, the larger, high-end sea-level rise scenarios already discussed do support some indirect effects in terms of onshore propagation of waves in depth-limited situations (Townend and Burgess, 2004; Burgess and Townend, 2004). Hence, any relative rise in sea level will increase the loadings on coastal flood defence structures, raising the probability of damage, including breaching.

In the Foresight 2004 work, the basic estimates of changes in risk were made by scaling changes in waves relative to changes in relative sea level. This scaling was based on discussions with Dr Jason Lowe (Hadley Centre) and the relationships apparent in Hadley Centre modelling at that time. This approach was only agreed towards the end of the Foresight 2004 study and was only used to make 'best estimates' of risk and not for the upper and lower bounds, which are also required here. It has therefore been necessary to create new upper and lower bound estimates, even though central estimates have not been changed.

Estimates of the range of changes in wave conditions have generally been produced using the relationships between waves, surges and relative sea-level rise given above. Arguably, all the wave scores could be raised compared to Foresight 2004 due to the importance of depth-limited wave height increasing with sea-level rise. However, given uncertainty about the climate signal, it is questionable if this is really meaningful. Hence, this process is acknowledged but not rescored. In any case, the high estimates of the wave height scores are scaled against the 'High+' scenarios and this takes partial account of depth-limited effects.

Surges

Driver definition

Surges are temporary changes in sea level – positive or negative – that result from meteorological forcing of the ocean surface (Smith and Ward, 1998).

Positive surges in sea level, associated with potential coastal flooding, are most commonly associated with atmospheric depressions. As atmospheric pressure falls there is a local rise in sea level, while strong winds also raise water levels due to wind set-up. The combined effect of a strong wind and low pressure can lead to water levels of over 2 m above normal tidal levels in the southern North Sea. However, in practice the largest positive surges typically coincide with mid-tidal water levels.

Driver update

In addition to mean sea-level rise, more intense and changing storm tracks could further increase extreme water levels and the risk of flooding. For surges, no changes in overall guidance are apparent since 2004, although Lowe and Gregory (2005) have stressed the large uncertainties in published scenarios of future surge climate.

What is even more apparent than in the 2004 Foresight study is that long time series (50 to 60 years) of waves and surges are required to measure systematic changes in these parameters, as opposed to measuring variability of wave and storm climates (e.g. Zhang et al., 2000; WASA Group, 1998; Haigh et al., 2008). Hence, observations made in the latter part of the 20th century about changes in surges, waves and their driving storms may have been over-interpreted to infer systematic changes, whereas they just may represent variability.

Horsburgh and Wilson (2007) have also examined tide-surge interaction and found that the largest surge residuals “will always avoid high water (and low water) for any finite tidal phase shift”. This suggests that existing Defra guidance on combining surge and tides may be rather precautionary in approach. In itself, this might suggest reducing the surge scores, but given the uncertainty already discussed, there is little basis for a systematic rescoring.

As with waves, in the original Foresight 2004 work, the basic estimate of changes in risk were made by scaling changes in surges in relation to changes in relative sea level. This scaling was based on discussions with Dr Jason Lowe (Hadley Centre) and the relationships apparent in Hadley Centre modelling at that time. This approach was agreed towards the end of the Foresight 2004 study and was only used to make ‘best estimates’ of risk scores. It has therefore been necessary to create new upper and lower bound estimates, even where central estimates have not been changed.

These estimates have generally been produced using the same relationships of waves and surges with relative sea-level rise given above. However, the link between relative sea-level rise and surge risks starts to break down at the upper end of the sea-level rise range, where breakdown of ice sheets becomes important. Hence, the high surge effects are scaled against the high sea-level rise scenarios in Table A1 rather than the ‘High+’ scenario.

Conclusion

While few of the mean driver scores were rescored in this update, it has been useful to revisit the drivers. A further, more detailed, update is recommended in the not too distant future. This will be especially important after the publication of the UKCIP08 marine report, which will specifically address the range of coastal climate drivers, including global, mean and regional sea-level rise. In addition, ongoing work by the Tyndall Centre for Climate Change Research, which is due to report in 2009, should improve our understanding of the operation of coastal morphology and sediment supply as a driver.

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Catchment Runoff

Howard Wheater and Joe Morris

Urbanisation

Driver definition

Land use, urban and rural, changes the permeability of the land's surface, which then influences how surface water moves into and through the soil, and how much remains stationary on the surface or flows overland.

The focus here is on the built environment. Urbanisation, an extreme example of changed land use, is characterised by impermeable surfaces and storm-water drainage systems. Urbanisation creates low retention and rapid runoff of water. The result is usually an increase in the volume of storm runoff and a reduction in the time that water takes to reach main watercourses. Thus, urbanisation can lead to a dramatic increase in flood peaks.

Driver update

The issues of catchment-scale impacts are well understood, and there has been no significant development in understanding since 2004 to justify a rescoring of the effects. Urbanisation represents a dramatic change to the land surface. Natural soils and vegetation are replaced by impermeable surfaces, such as roofs, car parks and roads. Instead of rainfall infiltrating into the soil, with the potential for storage and slow drainage to watercourses, a high proportion (typically 70 per cent) will run off quickly as overland flow. Conventional drainage is designed to convey that water rapidly to streams through a piped network of storm drains. The result is a much larger volume of rapid runoff, reaching a stream in a shorter time. The consequence can be a large increase in flood peaks.

Flood seasonality can also change. Natural catchments tend to flood in winter, when soils are more likely to be wet prior to a rainfall event, but winter rainfall characteristically has longer duration and lower intensities than summer rainfall. The effect of antecedent conditions is much less important for urban runoff, so urban areas are likely to flood in response to intense summer storms.

Because these effects are well known, it is common to implement design measures to reduce runoff from urban areas. Historically this has mainly been through construction of storage reservoirs, designed to attenuate runoff through temporary storage and slow release. More recently, there has been growing interest in trying to control runoff at source, for example by directing runoff from impermeable areas to infiltration, using permeable pavements, or retaining water within the piped system. Such approaches are called SUDS – SUstainable Drainage Systems.

Hence, urbanisation can affect the generation of runoff, with potentially large impacts, which nevertheless can largely be mitigated by appropriate design and management. In addition, urbanisation can affect the routing of runoff. There are intense pressures to construct housing and other development in river floodplains. This can increase the flood hazard by removing natural storage from the river floodplain and/or reducing the capacity of the floodplain to transmit out-of-bank flows. In turn, the presence of property and assets in the floodplain increases potential flood damage and hence flood risk.

Conclusion

In summary, the effects of urbanisation can lead to large increases in runoff and flood risk at the local scale, but with effective control and management, these effects can be mitigated. Also, as one moves from local scale to larger catchment scales, these effects tend to decrease as the proportion of urban area becomes less. Hence, the scoring for the effects allocated in 2004 varied from large increases in risk in an unregulated future, to potential reductions in a highly regulated future. Insufficient new evidence has emerged since 2004 to justify changing these scores.

Rural Land Management

Driver definition

Rural land management covers agricultural activities, other land uses associated with economic development in the rural environment, and the management of natural and semi-natural environments.

The driver Rural Land Management considers the effects of land-management practices on runoff from agricultural land in particular. It also covers runoff from conservation and recreational areas, especially wetlands.

Driver update

The effects of rural land management on flood generation remain uncertain. Since 2004, further intensification of agricultural activities has occurred, with evidence of widespread soil degradation, and there have been extensive, mainly anecdotal, reports of increased localised flooding (for example, 'muddy floods'). However, evidence of catchment-scale impacts has proved elusive. This issue is central to the assessment of changing flood risk, and to the development of policy for mitigation of flood risk. Hence a number of relevant research studies are either ongoing, or have recently reported.

A comprehensive review was carried out for Defra within project FD2114 (O'Connell et al., 2004, 2007). This highlighted the:

- complexity of predicting local-scale impacts of rural land use;
- very limited amount of evidence of catchment-scale impacts; and
- inadequacies of available data sources and modelling studies.

The update found substantial evidence that changes in land use and management practices affect runoff generation at the local scale, but the relationship between rural land management practices and flood generation that could be observed at the small-scale field and farm scale (evident, for example, in flash floods and muddy floods), could not be distinguished at the larger catchment scale, especially during extreme precipitation events.

A number of recent studies have confirmed the incidence of soil conditions and land management practices known to be associated with enhanced runoff and flood generation. This is in spite of recent strengthening of compliance requirements for *Good Agricultural and Environmental Condition* and targeted soil management advice for farmers. Clarke et al. (2008) reviewed the impacts of soil compaction in grassland, demonstrating that soil structural damage is still common in most catchments, though varying in time and space. A review of assessments of soil structural conditions in ley and permanent grassland in 10 catchments demonstrated moderate to severe structural degradation in more than 95 per cent of sites examined. Investigation by Howden and Deeks (2007), using an artificial rainfall simulator on soils in the Boscastle catchment, found that the management of land within the same overall land use was of critical importance in determining the percentage runoff, and that this could vary significantly. A reconnaissance survey of three catchments affected by the summer 2007 floods

(Holman et al., 2008) found that 18 per cent of sites showed high soil structural degradation and 27 per cent showed moderate soil structural degradation.

A lack of evidence of the effects of upland land management led to support from the Engineering and Physical Sciences Research Council (EPSRC) Flood Risk Management Research Consortium (FRMRC) for a concerted experimental and modelling study at Pontbren, in mid-Wales (Marshall et al., 2006; Jackson et al., 2006; Wheater et al., 2008). An increase in the numbers and weight of sheep had been reported to be associated with increased surface runoff and 'flashy' stream response. The planting of tree shelter belts has been found to improve soil structure and reduce overland flow. The FRMRC research has completed its first phase and experimental work, supplemented by new modelling techniques, shows a significant link between land use and flood runoff. For example, a 10 per cent reduction in catchment-scale flow peaks was associated with recent localised tree-planting, and widespread planting of narrow tree strips is predicted to reduce flood peaks by a further 20 per cent. Widespread reversion of 'improved' grassland to a more natural condition is also predicted to be significant. However, that phase of FRMRC work only extends up to small catchment-scale (12 km^2) and it has not been possible so far to examine extreme floods. The next phase of FRMRC, as well as projects funded under the Natural Environment Research Council (NERC) FREE programme, addresses these limitations, as well as a wider range of land management situations, including linkage with the United Utilities SCAMP programme, concerned with management of peatlands, and research in the River Parrett in Somerset, concerned with lowland catchment land use and wetland management.

The use of models to explore potential effects has also been reported by JBA Consulting (2007) in Defra-funded research based on the 120 km^2 catchment of the River Skell, a tributary of the Ripon catchment. Within project FD2114, O'Connell et al. (2004) developed a simple methodology to represent hypothetical effects of soil degradation on flood runoff. This was applied by JBA Consulting, using a distributed hydrological model, to the Skell, which had been identified as potentially sensitive to land management impacts. Results indicated that, if soil structural degradation were to occur across the whole catchment, together with additional maintenance of moorland grips, peak flows in the town of Ripon would increase by between 20 per cent for smaller-scale floods and 10 per cent for more extreme floods. A less extreme scenario (soil degradation over 30 per cent of the catchment) led to increased peak flows of 10 per cent for smaller-scale floods and 3 per cent for more extreme events. In contrast, the best case plausible improvement scenario (moorland grip blocking) led to a reduction of flood peak magnitudes in Ripon by up to about 8 per cent when compared to the baseline case.

In the context of catchment-scale effects, Defra project FD2120 (Beven et al., 2008) set out to determine whether land use and management change could explain any observed variation between historical measured precipitation and measured river hydrographs: that is the height, timing and duration of peak river flows. It explored, using time series data, whether there were trends or changes in the precipitation–hydrograph relationship (for example, more rapid runoff from land surfaces, greater 'peakiness' of river flows) that were consistent with historical changes in land use. The modelling could not, however, pick out a clear relationship between variations in land use/management and river flows, for given precipitation events. This primarily reflected the difficulty in identifying change using catchment-scale hydrological data. Even when artificial changes were made to the measured river hydrographs, consistent with land management changes known at the local scale to increase runoff (such as grassland to arable conversion, compacted or bare soils), the models were unable to identify these changes in the river hydrograph.

Project FD2120 concluded that, although it is not possible to confirm from catchment-scale data that there is a strong relationship between land management and river flooding, it is not possible to say there is no relationship. More explicitly, using available measured data (river flow and precipitation) and modelling methods, it is not possible to detect the clear ‘land management signal’ that is observable at the local scale in changes in flows at the catchment scale, given the inherent variability and uncertainty. Progress must therefore rely on simulation methods, recognising the associated uncertainty. The JBA Consulting study is important in providing estimates at the scale of a significant catchment area, although it must be emphasised that the results are based on speculative changes to soil properties. Nevertheless, they are broadly consistent with the results of the Pontbren study, which while also based on hypothetical simulations, are constrained by detailed local data.

Conclusion

We conclude that impacts of land use change remain uncertain, but that important progress towards understanding and quantifying these effects is underway and beginning to deliver significant results. In the context of an update to the Foresight scoring process, however, the new results tend to reinforce previous assumptions, and it is therefore concluded that no significant change is needed to the flood risk multiplier scores for rural land use management as a driver for changing flood risk.

From a policy perspective, while rural land management itself does not appear to be a panacea for alleviating flood risks, it should be considered as part of a programme of flood management measures. Furthermore, and important from a policy perspective, the measures taken to reduce flood generation from agricultural and rural land can deliver multiple benefits, associated with the control of diffuse pollution, soil protection, and enhancement of wildlife and landscapes.

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Groundwater Systems and Processes

Howard Wheater and Stuart Lane

Groundwater Flooding

Driver definition

Groundwater flooding occurs when the water table reaches the elevation of the land surface (waterlogging) or by the emergence of water originating from sub-surface permeable strata.

There are several types of groundwater flooding. The main issue of concern, and hence the focus of this update, is the extensive groundwater flooding that can, under exceptional circumstances, occur in catchments overlying a permeable geology, most notably chalk, which is the major aquifer of southern and eastern England. Such flooding arises from prolonged periods of heavy rainfall. However, groundwater flooding can occur in a wide variety of situations, and from a variety of causes. It can occur in other aquifer types (for example, sandstone and limestone), and floodplain and terrace gravels. The risk from flooding in other aquifers is believed to be localised (Jacobs, 2006b), and flooding from floodplain gravels, while likely to be confused with fluvial flooding, is also likely to be included in floodplain hazard maps.

Other sources of groundwater flooding include cessation of abstractions (as is the case with rising groundwater beneath London), but are not directly relevant to the current assessment. Groundwater flooding can result in inundation of surface or of subsurface infrastructure (for example, basements, tunnels, sewers) and/or damage to foundations (for example, by reduced bearing capacity, changes in loading, uplift pressure, or swelling of soils).

Driver update

Since 2004, groundwater flooding has increasingly been recognised as an important, but neglected, area of flood risk assessment, mainly due to the widespread occurrence of groundwater flooding in the autumn/winter of 2000–01 (Jacobs, 2004, 2006a,b,c; Centre for Ecology and Hydrology (CEH), 2007). Although plans have been made to improve groundwater flood risk management, identification of the occurrence of groundwater flooding has not been systematic, and is believed to be under-reported (Jacobs, 2006c). There are also technical problems in hazard assessment for groundwater flooding – most flood models have been developed for surface water catchments and treat groundwater in a highly simplistic manner; conversely, most groundwater models have been developed for resource management, run on long timescales and have a simple representation of groundwater–surface water interactions. Hence, hazard assessment for UK groundwater flooding is in its infancy and reliable data on the associated risk is not available.

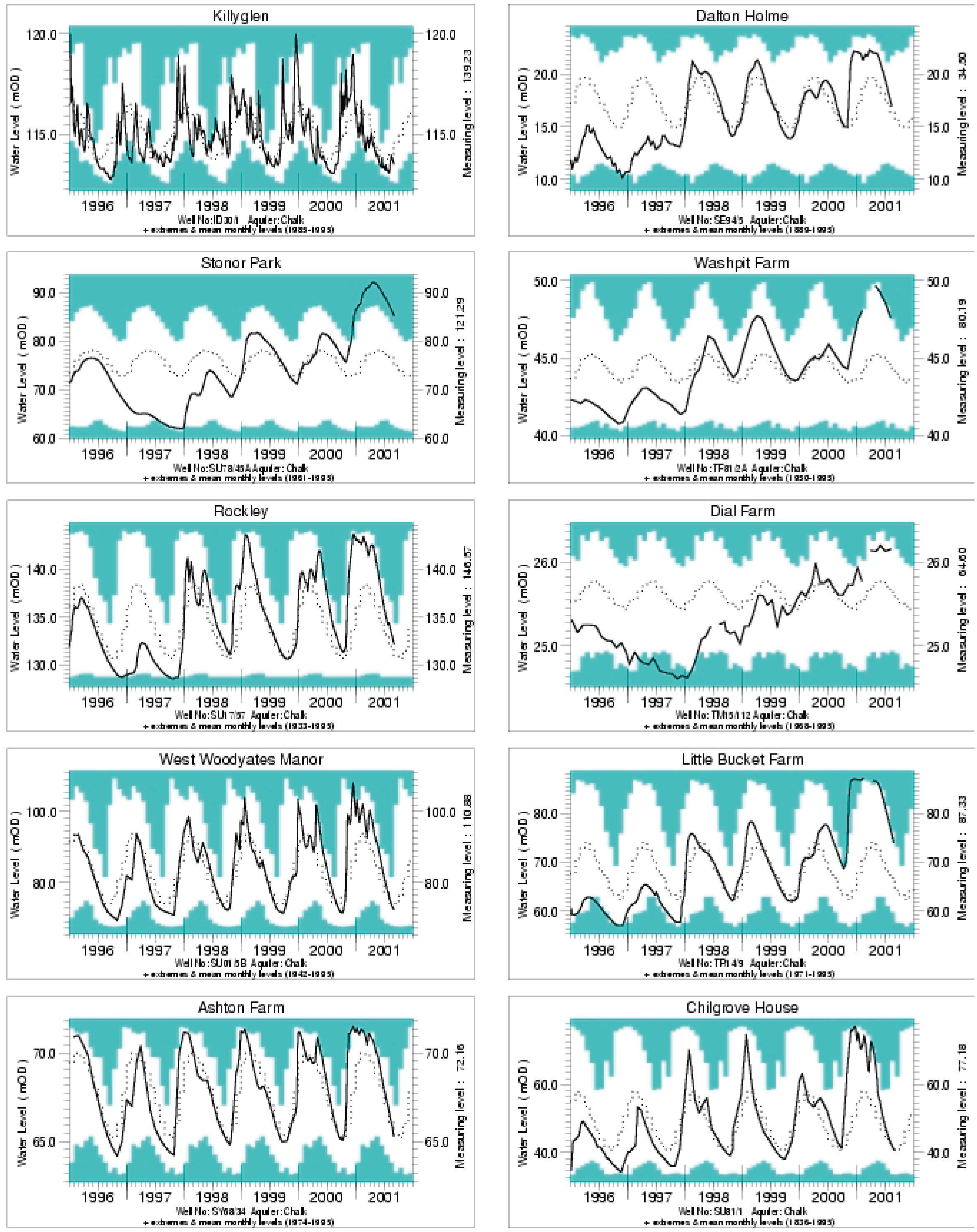
For this update, we consider flooding associated with groundwater-dominated catchments in which unusually high water table conditions can lead to a highly non-linear hydrological response and long-duration flood events. We exclude flooding within river floodplains. Jacobs (2006c) estimates, from national mapping, that 1.6 million properties are at risk from this type of groundwater flooding.

The response of groundwater-dominated catchments has been discussed by Wheater et al. (2006, 2007). One feature is that under normal conditions a relatively small fraction of rainfall (perhaps as low as 2 per cent of the total rainfall) appears in the river as rapid ‘stormflow’ response. Another feature for many is the typical ephemeral behaviour of 'bourne' streams, in which the length of the flowing watercourses expands upslope during the winter and contracts during the summer. Under unusually wet conditions, the stream may expand further than usual, with springs breaking out in locations which may appear new (i.e. not observed within living memory), and normally dry valleys begin to flow. Given the normally very low percentage of storm runoff, these changes in spring sources and saturated areas can have a disproportionate effect on stream flow, potentially exacerbated by more rapid groundwater discharge as water tables rise into areas of enhanced permeability. The water table response in such systems is determined by extremes of very long-duration rainfall (i.e. unusually wet seasons, rather than individual storm events), in contrast to water levels in most river systems. Clearly, the potential risk is greatest when an unusually wet season is followed by one or more extreme events; this was demonstrated in summer 2007.

Figure A3 (opposite) shows examples (from the CEH *Hydrological Yearbook* for 2000). The dotted line is the long-term expected average, the white band the range of water levels and the black line the actual water levels for 1996–2001.

The diagrams are important in emphasising the very great range in groundwater response modes. Some systems (for example, Killyglen) are very sensitive to fluctuations in rainfall, with water levels responding more rapidly. These types of systems are most likely to result in short-term, groundwater flood events. Dalton Holme, in contrast, is associated with long-duration, high groundwater levels: wherever these levels intersect the local topographic level, there will be sustained discharge of water. These types of situations may lead to prolonged flooding problems (for example, long-term road closures, flooded cellars) that are different not only to the very short-term, high-magnitude flood events associated with pluvial flooding in urban areas, but also to the relatively short-term, high-magnitude flood events associated with fluvial flooding from main rivers. Finally, many of the boreholes (for example, Dalton Holme, Dial Farm) show persistence, with progressive rises in groundwater levels over many years.

Figure A3: Water levels from selected boreholes between 1996 and 2001 (black lines), long-term averages (dotted lines) and maximum and minimum values (defined by the white band)



Source: Centre for Ecology and Hydrology, 2001

Given the above, we can summarise the operation of groundwater flooding. It is associated with longer-term fluctuation in water tables in autumn, winter and spring periods when either:

- drawdown rates in the previous summer have been relatively low (due to higher than average effective rainfall in the summer); or
- most importantly, recharge rates have been relatively high.

The nature of the flood risk depends upon the nature of the aquifer system, producing both short-duration and long-duration risks. Floods associated with long-duration flood risk are very different to those associated with either pluvial or main river fluvial flooding.

The main issue in relation to future groundwater flood risk is the potential effects of the climate change sources under different Foresight scenarios. In general terms, increasing temperature should reduce groundwater recharge, especially if this increases water abstraction due to greater crop demands and irrigation. However, changing precipitation patterns may also influence groundwater recharge. Of particular concern will be:

- whether or not climate change increases the inter-annual variability in precipitation totals; and
- the extent to which years in which low levels of summer drawdown coincide with high levels of recharge in the subsequent autumn and winter.

These changes will be compounded by other driver changes and there is a long-term risk that the over-abstraction of groundwater during the 20th century is now being reversed (due primarily to reduced pumping), leading to long-term rises in groundwater levels in some areas. If these trends continue, and there is evidence from a number of deeper groundwater systems that they are, this implies serious potential underground flood risk in relation to infrastructure (for example, foundations, tunnels). Thus, in relation to climate change drivers, both land management and regulatory impacts upon groundwater abstraction may not only increase flood risk, but may do so in ways that are very different to pluvial and fluvial flooding.

Uncertainty

Uncertainties associated with this aspect of the flooding system are high and arise for a number of reasons. First, the exact nature of the changes in climate, and the subtle impacts of increases in recharge due to precipitation changes and decreases due to evapotranspiration changes, could move changing flood risk due to groundwater either side of a better/worse threshold. Of particular concern is whether years similar to 2000–01 and 2007 occur more frequently, not so much in terms of extreme flood events, but more generally in terms of wet summer-autumn-winter periods, which are what leads to sustained recharge.

The second area of uncertainty is associated with the regulatory environment and issues of water abstraction. This is highly sensitive to the Foresight scenario adopted, as this controls the regulatory framework as well as the agricultural system’s demand for water.

The third area of uncertainty relates to geographical variation in the nature of the groundwater system.

Effects of sea-level rise

Although historical groundwater emergence is dominated by inland locations (Morris et al., 2007), there are aquifers where the sea provides a boundary condition for the groundwater flow system, and hence where changes in sea level would be expected to change groundwater levels. However, changes are likely to be complex. The coastal boundary condition will be affected not only by changing sea level, but also by change to the physical coastal/estuarial boundary. This will depend in part on natural geomorphological processes, but also on human interventions, for example, the extent to which defences are maintained or managed retreat allowed. The effect of the coastal boundary condition on groundwater flows and levels will also depend on the balance between groundwater recharge and discharge. Recharge will depend on changes to climate and land use, and discharge will be affected by discharges to lakes and rivers and abstractions for water supply, as well as the changing coastal boundary condition.

A further factor is that for eastern England, extensive areas of lowland agriculture are currently supported by pumped drainage. For example, Arnell (1998) noted that: *"…a large number of low-lying coastal catchments in parts of eastern England rely on pumping to keep flood waters out and water tables low and thus permit agriculture. A rise in sea level will affect water levels within such catchments and hence affect pumping costs."*

We conclude that effects of sea-level rise on groundwater are complex, and depend not only on natural process response to climate change but also strongly on human interventions. However, the effects on groundwater flooding are likely to be localised, and probably relatively small in comparison with other aspects of flood risk. Given the scope and timescale of the present study, it is not considered feasible or justified to provide a more detailed assessment.

Weighting factor for groundwater flood risk

As noted above, groundwater flooding is an issue that has only relatively recently been recognised as of national importance, especially following extensive occurrence in the autumn/winter of 2000–01. There has been no systematic recording of groundwater flooding occurrence, which is considered to have been under-reported, and hence no reliable estimate of associated damage. Due to technical challenges, which are only now being addressed, there is also no reliable estimate of groundwater flood hazard.

Jacobs (2006) estimates that there are 1.6 million properties in England and Wales at risk from extensive groundwater flooding, excluding those areas already included in the 100-year return period (0.01 Annual Exceedence Probability) Indicative Flood Plain. Current research at Middlesex University indicates that the damage associated with inundation from groundwater flooding is greater than for surface flooding, as a result of the long duration of groundwater flooding events. There is also a wide range of potential consequences of groundwater flooding, which may affect subsurface infrastructure, such as basements, tunnels, sewers and foundations.

In this context, assessment of a weighting factor for national flood risk must be speculative. The feasible range of values is estimated to be 0.001–0.10, with a central estimate of 0.01, i.e. 1% of annual fluvial flood damages.

Conclusion

In the context of climate change, issues include not only changes to precipitation and other climate variables, but also sea-level rise. The analysis here has focused on the effect of climate on groundwater flooding. However, sea-level rise can also affect groundwater, and the consequences were also discussed. The issues are complex, and there is almost no published work to support their analysis. It is speculated that the effects will be of limited magnitude and localised spatial extent, and hence in 2004 this source of flooding was not included in the quantitative analysis. However, this is clearly an area where further work is urgently needed.

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Fluvial Systems and Processes

Stuart Lane and Colin Thorne

Environmental Regulation

Driver definition

The Environmental Regulation driver of flood risk includes those elements of habitat and habitat protection that control the ability to manage river channels and habitat in waterways and on floodplains.

Environmental Regulation can affect a river channel's capacity to carry floodwaters, and hence the flood risk. For example, future policies supporting increased biodiversity and habitat protection may restrict flood management policy. The purpose of river management is now shifting from simple utilitarian needs associated with river channel engineering for flood and erosion/sedimentation control towards the addition of a range of goals. Measures which were once optional, such as accommodating ecosystems in flood defence design, are now obligatory.

Driver update

The last four years have witnessed rapid developments in the policies and legislation associated with flooding, continuing a trend that may be traced back for over a decade to the shift from flood defence to flood risk management (Thorne et al., 2007). New approaches and paradigms have emerged at both supranational level (the EU Floods Directive, Directive 2007/60/EC, October 2007) and national level (Defra's *Making Space for Water*). For instance, the EU Floods Directive is explicit (p.2) in stating that: *"With a view to giving rivers more space, they should consider where possible the maintenance and/or restoration of floodplains, as well as measures to prevent and reduce damage to human health, the environment, cultural heritage and economic activity."* It is apparent that the policy changes implicit in these directives and discussion documents signal major shifts in the way in which rivers and watercourses will in future be managed, with implications for rivers, their riparian corridors and their floodplains as pathways and stores for floodwater.

Given these developments, the constraints of the 'baseline assumption' become all the more onerous (and of course all the more untenable) in producing conflicts and tensions between flood management policies, investment levels and technologies that are held constant and futures characterised by stronger and more watchfully invoked environmental regulation. It seems likely that in flood management the emphasis will move away from water conveyance in defended channels and towards reconnecting channels to floodplains in flood-suitable areas. Indeed, this is already happening in some parts of the UK. Many stakeholders, particularly in rural areas, believe that their land and standing crops will increasingly be sacrificed to flooding to achieve environmental goals and relieve flood risks in downstream urban areas. This makes it clear that the promotion of environmental approaches is not without costs in terms of lost farming production and human impacts (perceived as well as real). However, such changes cannot be reflected within the confines of the 'baseline assumption'. What can be assessed is the degree to which Environmental Regulation may confound conventional approaches to flood defence and flood risk management under different future scenarios, depending on the value placed by society on environmental goods and services and the emphasis placed on the conservation function of the nation's rivers.

Also associated with the sequence of serious flood events in England during the last decade has been a series of changes in responsibilities for regulation of fluvial systems. Notably, the designation of what constitutes a 'main river' in relation to the responsibilities of the Environment Agency following from the government response to *Making Space for Water*, in March 2005. Re-designation of some ordinary watercourses as 'main river' appears likely to lead to removal of the distinction altogether, fundamentally changing the regulatory responsibilities of existing organisations, including local authorities, internal drainage boards and the Environment Agency itself. The summer floods of 2007 re-emphasised the confusing nature of regulatory responsibilities for flood management in England.

Although the Water Framework Directive (WFD) had already been signed (in 2000) and was well known to the Foresight team in 2004, we could not know how it would be implemented. Four years on it is clear that the environmental standards set by the Environment Agency's WFD team will be stringent and that the programmes of measures required within forthcoming River Basin Management Plans will generate marked changes in the way British rivers are managed in order to meet at least good ecological status for surface and groundwater bodies. It is also clear that, while derogations can be obtained where environmentally detrimental activities can be proven necessary for the public good, WFD is restricting, and will continue to restrict, the type of management activities (for example, dredging, embanking, hard bank protection) that can be employed in applying structural measures for flood defence.

Implications for driver rescoring

A problem in assessing the impacts of the Environmental Regulation driver on future flood risks is that these impacts vary markedly depending on the catchment context. For instance, the need to restore lost wetland habitats is now embedded into a programme of restoring the functional roles of floodplains in rural areas in ways that not only achieve environmental aims but also reduce downstream flood risk. Indeed, this type of multi-functional approach to water and land management was foreseen in the original consultation of *Making Space for Water* (autumn, 2004), the subsequent government response (March, 2005) and a series of subsequent projects that are already underway. However, it is important to note that the process of designating floodplains as spaces for water is not universally beneficial. For example, while local ecosystems and downstream urban communities benefit from river restoration and reconnection of floodplains to channels:

- almost no river floodplains in England are unoccupied and all have farming interests; and
- occupation involves diffusely distributed homes, often in socio-economically deprived rural areas.

Thus, while the Environmental Regulation driver may translate into reductions in future flood risk for the populations of flood-prone urban areas, flood risk may actually increase for the inhabitants of diffuse communities in rural areas. The difficulty arises in capturing this dichotomy and reflecting it in the scores allocated for this driver.

As this driver is associated with governance and legislation, it is highly scenario-dependent. This was realised in 2004. As part of land use planning, opportunities will be sought in the more environmentally aligned scenarios to improve and to develop environmental assets, as well as to identify and protect those environmental assets, that are at risk – placing constraints on the types of flood management that can be adopted. Environmental improvements will be associated with the full set of water resource issues, including recreation and amenity and, as a result, this driver becomes a node in the framework linking multiple water concerns. The way that the node operates in the different Foresight futures depends on the priority given to Environmental Regulation and, consequently, there are bound to be differences between the driver scores for different Foresight scenarios.

Conclusion

In 2004, it was envisaged that both Global Sustainability and Local Stewardship scenarios would place a heavy emphasis on Environmental Regulation and, under the baseline assumption, this would lead to high impacts on flood risk. This review has not produced any reason to change this view and it is concluded that the Global Sustainability and Local Stewardship scores should remain high. Our best estimates for Global Sustainability scores may be increased slightly, in the light of post-2004 experience in implementing the EU Floods and the Water Framework Directives, and on the assumption that European legislation may become increasingly at odds with market forces in a World Markets future. However, in the light of negative public perceptions of the impacts of Environmental Regulation on flood risks to people and their property that have emerged since 2004, we can see a case for some reductions in the scores for National Enterprise and can argue that the upper and lower bound scores for World Markets should be adjusted. In both cases, this is intended to reflect shifts in the regulatory regimes driven by public attitudes and expectations that move flood defence ahead of environmental protection and make Environmental Regulation certainly less restrictive under National Enterprise and possibly less restrictive under World Markets.

River Morphology and Sediment Supply

Driver definition

River Morphology and Sediment Supply includes changes in the shape and routes of river channels and the changes in the flow of sediment that alter the river channel and floodplain and influence the channel's water-carrying capacity and its role in flood defence.

Alluvial (self-formed) river channels are very sensitive to the flow (hydrological) and sediment (geomorphological) regimes, which shape and maintain the channel. If climate or land use change alter the flow and/or sediment regime, the natural response will be for the channel to adjust its geometry and dimensions to accommodate the new range of channel-forming flows. The extent to which this happens depends on the erosion resistance of the bed and banks, including the type of vegetation on the channel banks and the presence of any artificial bed controls or riverbank protection.

Driver update

Research published just prior to the conclusion of the 2004 Foresight project, but which was not fully integrated into the analysis of this driver, has shown that sediment delivery to rivers in the UK has been sensitised to climatic variability as a result of widespread Holocene deforestation (Macklin and Lewin, 2003). The effect of this realisation is that links between this driver and drivers in the Catchment Runoff driver set are probably much stronger than was recognised in 2004. Also, the sensitivity of channels means that climate-related changes in sediment delivery processes should be given greater emphasis in terms of the impact of the River Morphology and Sediment Supply driver on future flood risks, particularly in the headwater and middle reaches of long rivers.

For example, recent research has generated a quantified understanding of the processes responsible for sediment delivery to the drainage network. The results demonstrate that the controlling variable for sediment delivery from hillslopes to rivers is the occurrence of high-intensity, short-duration rainfall events responsible for generating slope wash and slope instability, and that sediment delivery is independent of the level of catchment saturation (Reid et al., 2006). Application of three downscaling methods to climate change predictions for the 2050s and 2080s suggests a significant increase in the number and potential volume of delivery events by the 2050s, regardless of the climate downscaling scenario used, although the predicted extent of increase is method-sensitive (Lane et al., 2008). The implications are that the River Morphology and Sediment Supply driver is likely to be more sensitive to changes in the magnitude and frequency of extreme rainfall events than was recognised in 2004. This is particularly true for the upper and middle courses of rivers, where hillslopes are closely coupled with stream channels. However, headwater and middle course impacts lead to knock-on effects downstream due to elevated sediment supply that may reduce the conveyance capacity of lowland channels with flood defence functions.

Over longer periods, changes in flood probability may occur due to local aggradation and degradation that occur in response to the downstream passage of sediment waves (Coulthard et al., 2005). It can take decades before a fluvial transport finishes responding to a discrete, high-magnitude sediment input (Harvey, 2007). It has also been observed that the coarser fraction of the sediment load in many rivers (river gravels) rarely reaches the sea, indicating that coarse sediment moving in waves must go into long-term storage at an intermediate point between its headwater sources and the sea, with further implications for flood risk in the middle courses of longer rivers.

For example, evidence from Work Package 8 of the Flood Risk Management Research Consortium[1] indicates that reaches improved for flood control, and featuring over-large channels and/or bank stabilisation to protect flood defence assets, are particularly prone to in-channel gravel sedimentation. This is the case because the channel is unable to migrate laterally, transferring coarse sediment from in-channel to floodplain storage. As a result, maintenance is frequently required to sustain the conveyance capacity at the level required to meet the statutory standard of service for flood defence. However, operation of the Environmental Regulation driver is making gravel extraction increasingly difficult in any British river, a trend that on current evidence looks likely to continue. These recent findings highlight the importance of the River Morphology and Sediment Supply driver and suggest that its impact on future flood risks may have been under-estimated in 2004.

[1] www.floodrisk.org.uk

Substantive evidence of the impacts of river bed aggradation on flood probability has been produced by detailed monitoring of a study reach on the River Wharfe (Lane et al., 2007). Field observations of sedimentation over a 16-month period were used in a hydrodynamic model to elucidate the effects of rising bed levels on floodwater levels. The results were then compared to changes in flood probability due to climate change by the 2050s and 2080s. The findings show that 16 months of sedimentation resulted in an increase in the area inundated by the two-year flood that was commensurate with the increase predicted for the 2050s due to climate change. That is, approximately a year and a half of aggradation produced an increase in the flooded area equivalent to nearly half a century of climate change.

It is because of the immediate and negative impacts of in-channel sedimentation on flood probability that channels with a flood defence function in Britain require routine maintenance involving sediment removal. Operations typically include gravel extraction and desilting. In this context, the impacts of sediment removal on the River Morphology and Sediment Supply driver are now better appreciated than they were in 2004. For example, new research has shown that local gravel extraction may trigger morphological responses and channel instability similar to that caused by larger-scale changes in river and catchment sediment delivery processes (Wishart et al., 2008). This finding highlights the need for more research into how the River Morphology and Sediment Supply driver responds to sediment removal, the exent to which sediment management activities can ever be sustainable, and the true costs and system-wide impacts of sediment removal for flood defence where this is deemed essential in terms of the public good.

Finally, there have been two changes to the organisation of drivers in the 2008 review that are relevant to this driver:

- incorporation of ‘muddy floods’ into the Catchment Runoff driver set; and
- inclusion of intra-urban watercourses within this driver set.

Both these changes have implications for the River Morphology and Sediment Supply driver, because they represent situations where sediment delivery can be particularly important. In the case of muddy floods, the quantities of sediment delivered may reduce the conveyance capacity of first-order streams and drainage channels significantly, while also increasing the risk of sediment blockages at gratings, culverts and bridges. The future flood risk impacts of the River Morphology and Sediment Supply driver must now reflect these effects, as they operate in rural areas, small settlements and around the peri-urban fringe. Intra-urban channels are often small and they customarily lack a floodplain or even a riparian corridor. Consequently, they have very little space in which to store sediment either in the long or short term (between transport events). Inclusion of intra-urban watercourses into the domain covered by the River Morphology and Sediment Supply driver introduces a range of streams with small channels that are particularly prone to in-channel sedimentation and for which the summer 2007 floods demonstrate that the consequences of reductions in flood conveyance can be catastrophic to local residents. Adding of the effects of ‘muddy floods’ and incorporating intra-urban watercourses are both steps which are likely to increase the scores for the River Morphology and Sediment Supply driver.

Conclusion

The new knowledge and changes to the scope of the driver described above translate into an increase in the impact it is likely to have on future flood risks. In summary, this stems from a better scientific appreciation of the extent to which: (a) British river catchments are sensitised to climatic variability; and (b) the types of rainfall, runoff and flood events that are particularly effective in delivering sediment to the channel network (and transporting it from headwater sources to sediment storage zones in the middle and lower course) appear likely to occur more frequently under future climate scenarios.

The extent and types of morphological changes triggered by these changes in sediment supply are inextricably bound with the impacts of the Environmental Regulation driver, which is presumed to constrain the removal of sediment in response to adverse morphological change except where this can be justified as being the only possible management activity and is undeniably essential to the public good. It should be noted that most immediate impacts of this driver on future risk are likely to become apparent in the headwater and middle courses of rivers (recent examples being the flooding at Glossop and Todmorden). Adverse impacts further downstream may follow, as elevated sediment loads travel downstream in the form of sediment waves, although there are ongoing debates concerning how finer 'wash load' sediment delivery drives longer-term river morphological changes in the lower course. This topic needs significant further research.

While there is a strong case for increasing the impact scores for this driver in general, there is less of a case for changing its sensitivity to contrasts between the different future scenarios compared to that used in 2004. This is because the increase in the potential for increased sediment delivery and morphological response identified since 2004 is primarily related to climate change, which is already accounted for in the scenarios. In 2004, the order of decreasing sensitivity for this driver was Global Sustainability > Local Stewardship > World Markets > National Enterprise. This reflected the fact that, under World Markets and National Enterprise there is more likely to be a return to active intervention in rivers to manage and to remove sediment, negating the impacts of this driver, something that would be less likely under Global Sustainability and Local Stewardship, where environmental priorities are stronger. Our rescoring reflects this, although we note that the increase in scores under National Enterprise is likely to be lower than those under Global Sustainability and Local Stewardship.

In interpreting the scores, it must be remembered that the 'baseline assumption' (that flood management practices, investment and technologies remain unchanged) still holds. The effect is to remove the option for more environmentally aligned flood risk management to be introduced as part of integrating flood defence goals with wider aims for environmental enhancement. This will bring flood management into conflict with environmental regulation and result in in-channel sedimentation and reduced standards of service in channels with a flood defence function.

River Vegetation and Conveyance

Driver definition

Changes in the vegetation and micro-morphology in a channel and on a floodplain will alter the ability of a river to convey floodwater.

Most river channels in the UK contain vegetation. Similarly, there is local variability in the channel-bed topography due to grain organisation, for example, dunes in sand-bed rivers and pebble clusters in gravel-bed rivers. Changes in these parameters may alter channel conveyance capacity, changing the water level associated with a given flow, and hence changing flood risk.

Driver update

Incorporation of intra-urban and non-main river watercourses into this driver is highly significant to the assessment of its operation and impacts on future flood risks. This is because reductions in conveyance due to vegetative resistance invariably show an inverse dependence on the product of average velocity and hydraulic radius in a watercourse. Hydraulic radius is defined as the ratio of the cross-sectional area to the wetted perimeter and, characteristically, its value is much lower for small watercourses than larger ones. Also, average velocities are lower in small channels than larger ones. Consequently, energy losses due to vegetation are particularly important for smaller watercourses. Bringing intra-urban and small streams into this driver in the 2008 update implies that the impact scores are likely to increase.

Inclusion of intra-urban watercourses also means that conveyance losses associated with what was in 2004 termed 'micro-topography' are also likely to be more important. This is because intra-urban watercourses are likely to receive trash from industrial, domestic and retail sources. Trash lodged in the channel increases the boundary roughness and partially obstructs the flow, as well as introducing the risk of blockage at hydraulic pinch points, such as gratings, trash screens, culverts and bridges.

A better understanding of vegetation effects on energy losses in British rivers is now possible as a result of research led by HR Wallingford on the Conveyance Estimation System or CES.[2] Synthesis of work reported in the CES documents shows that roughness values for vegetation and obstructions (such as debris or trash) in small watercourses and small- and medium-sized main rivers are generally as great, or greater than, those for the bed sediment. It is also clear that roughness increases substantially with vegetation stiffness and density.

The floods of summer 2007 highlighted a long-standing public perception that flooding may occur (or be exacerbated) due to lack of maintenance. A lack of maintenance in general, and the effects of vegetation in retarding in-bank flows in particular, are mentioned by many flood victims as having contributed to local flooding. Conversely, the Environment Agency's view is that: *"…river channels generally convey water within their banks only at low to medium flows. Above these flows the river will spread onto the floodplain, which is a part of the river."* Their view concludes that, on this basis, *"clearing the channel adds only a small proportion to the flow capacity"(Pitt, 2007)*.

[2] www.river-conveyance.net/ces/index.html

These apparently conflicting views can be reconciled when their different contexts are recognised. The Environment Agency's statement applies to natural reaches of main river that are adjusted to their flow and sediment regimes and hydraulically connected to their floodplains. In such cases, the conveyance capacity of the channel corresponds to a flood with a return period between one and three years – which may be considered to be a low to medium flood (although not perhaps a low to medium flow). In natural fluvial systems, larger floods do indeed spread over the floodplain and, depending on the balance between floodplain storage and conveyance, channel clearance may add only marginally to flow capacity. In contrast, the watercourses referred to by the public are generally small (although as noted above, how small still needs to be determined) and could have been improved (for example by dredging, widening, and artificial vegetation clearance) to fulfil flood defence and land drainage functions. Not only are such heavily modified watercourses particularly sensitive to increases in vegetation and/or trash roughness, but they also convey in-bank discharges with much longer return periods than their natural counterparts.

In terms of this re-analysis of the likely impacts of the Vegetation and Conveyance driver on future flood risks, the lesson learned from the floods of summer 2007 is that although the distinction between main rivers with natural morphologies and small streams and drainage channels that have been heavily modified was implicit in the way we scored this driver in 2004, the significance of vegetation to the flood risks associated with small watercourses needs to be re-emphasised. It follows that, with intra-urban and non-main river watercourses now incorporated into the domain of this driver, it is likely that re-analysis will lead to an increase in the scores for this driver.

The importance of the link between this driver and Environmental Regulation was recognised in 2004, but not to the extent that has become apparent since then. In 2004, conventional approaches to the management of river vegetation still focused on its wholesale removal, but since then, a combination of closer attention to maintenance activities by conservation interests (partly related to implementation of the Water Framework Directive), and a drive to reduce operational budgets for maintenance, means that the intensity of maintenance activities has decreased and become more environmentally aligned. Research funded under the Environment Agency/Defra joint programme, and led by HR Wallingford, has brought forward new and innovative guidance on maintenance designed to balance goals for flood defence, land drainage and habitat provision in a sustainable fashion, in terms of value for money, social equity and environmental impact (HR Wallingford, 2008).

Conclusion

The importance of River Vegetation and Conveyance as a driver of future flood risks has grown since 2004 and this trend is likely to continue for the foreseeable future. However, the impacts of this driver on the probability of flooding are complex in both time and space. For example, increased energy losses due to vegetation and a reduction in in-channel conveyance upstream of an urban conurbation may reduce flood risk if it inundates a natural floodplain that is flood-suitable and so increases attenuation of the flood wave as it passes downstream. Conversely, a vegetation-related reduction in the conveyance capacity of an intra-urban channel is likely to significantly increase flood risk.

Evidence from the summer 2007 floods reveals that the complex role of vegetation in affecting flood risk may not be fully appreciated by public and institutional stakeholders, for whom there is a tendency to see maintenance as either a bad or a good thing. However, vegetation and its management cannot be characterised in such simple terms. It must be considered in the context of the functions required of the watercourse (which may include flood control, land drainage, conservation, recreation and habitat enhancement) and the consequences of a flood occurring in the immediate locality. While there is no general policy to sacrifice rural areas in order to protect urban settlements, 'managed flooding' does have a role in reducing downstream flood risk. In this context, allowing channels to recover their natural assemblages of vegetation in flood-suitable areas can be part of integrated flood risk management at the catchment scale.

Implications for rescoring

The update to the description for River Vegetation and Conveyance suggests that it should be rescored, with scores increasing compared to those allocated in 2004. Central to this case are: the new scientific evidence provided by the Conveyance Estimation System; strengthening of the link to the Environmental Regulation driver; and addition to the domain of this driver of small, intra-urban and other non-main river watercourses. In 2004, under the Global Sustainability and Local Stewardship scenarios, the River Vegetation and Conveyance driver was scored highly, reflecting an expected decline in maintenance, and there is no reason to revise these scores in 2008. However, there is a case for increasing the scores assigned under World Markets, as these were set lower and should be increased in light of the evidence provided above. Under National Enterprise, the priority, at least in the medium term, is likely to remain the protection of farmland, property and other assets at risk of flooding. Hence, maintenance is expected to intensify in response to increased discharges related to morphological changes. This was represented by a decline in the scores for this driver in the 2050s. This makes the impacts of the River Vegetation and Conveyance driver scenario-dependent, which is logical given that they are sensitive not only to climate change but also to the river maintenance practices and environmental standards adopted.

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Urban Systems and Processes

Adrian Saul and Richard Ashley

Urbanisation and Intra-urban Runoff

Driver definition

A change in land management with green field and pervious surfaces covered by less pervious materials (buildings and infrastructure) and associated conveyance systems.

The term ‘urbanisation’ is any increase in the extent of new urbanisation of the peri-urban area that drains, via a new drainage system, to the existing drainage system of an intra-urban area. It also includes any increase in the impervious area that drains to the existing drainage system within an existing intra-urban catchment. This can increase the volume of storm runoff, reduce travel times, increase flood peaks, reduce groundwater recharge and reduce low flows.

Driver update

Compared with the original review in 2004, understanding of this driver has increased significantly, with, for example, a Communities and Local Government discussion document highlighting the costs and potential benefits associated with pervious surfaces. Hence, there may be grounds for reducing the potential impacts of this driver under all scenarios.

However, a recent Organisation for Economic Co-operation and Development study suggests that national governments will have less ability to manage infrastructure, even by 2025, as multinationals will be responsible for meeting more of society’s needs. This would impact under World Markets especially and to some extent under National Enterprise. The other factors of significance include the growing awareness of the need to adopt an integrated approach to manage the whole water cycle, including drought planning simultaneously with flood risk management. Hence the better management and use of storm water at source may be more normal, especially under the Global Sustainability and Local Stewardship scenarios and even under National Enterprise.

A single flood risk management agency may also emerge in the future, thereby providing a better means to holistically manage the regulatory and planning process with control over new urbanisation, changes in urban form and, potentially, urban creep. This is less likely for World Markets. Overall, therefore, under National Enterprise, Local Stewardship and Global Sustainability, the original 2080s driver increases have been reduced slightly.

Sewer Conveyance, Blockage and Sedimentation

Driver definition

Processes associated with above-ground, overland surface flow and man-made, below-ground drainage systems; including performance, maintenance and operation.

Sewers are the principal assets for the conveyance of surface-water runoff in the urban areas of the UK. In older urban areas, the sewer systems are mainly combined, with domestic and industrial effluents and rainfall runoff conveyed in the same pipes. Combined sewer overflows (CSOs) are constructed to relieve the system of the excess flows that cannot be accommodated by the downstream sewers or the treatment works, thereby reducing the risk of surcharge and surface flooding in the catchment upstream of the CSO.

Similarly, storage tanks are commonly employed to retain effluents for subsequent treatment. More recently, and particularly on new or fringe developments, separate drainage systems have been constructed. One set of pipes conveys foul effluents directly to the treatment works, while a second set of pipes discharges surface water directly to inland or coastal receiving waters.

Driver update

The 2008 update has highlighted that two emerging factors are likely to promote a change in future flood risk associated with this driver, both related to developments in science and technology. The first relates to the way in which the below-ground drainage systems will be operated and managed, as recent developments in sensor and communications technology will see the introduction of large numbers of cheap and reliable sensors. The operation of these systems will be based on a strategy of monitoring, modelling and proactive control, in near real time. This will produce a significant reduction in flood risk, particularly in respect to properties at risk of flooding more than twice in 10 years.

The second factor relates to new technologies for water saving, recycling and re-use, and the integrated management of surface water with the introduction of Surface Water Management Plans. Here, the use of more sustainable systems will generate a reduction in sanitary flows and the surface water that enters the below-ground drainage system, with a consequent reduction in the frequency of reduced sewer conveyance and/or blockage, particularly in local drains and sewers. This will result in the potential for reduced flood risk. Under the World Markets and National Enterprise scenarios it is judged that there will be a reduction in the future flood risk multiplier scores, but it seems likely that the scores for Local Stewardship and Global Sustainability should remain unchanged from those assigned in 2004.

Impact of External Flooding on Intra-urban Drainage Systems

Driver definition

Loss of conveyance and serviceability in below-ground drainage systems due to flooding from external sources.

External sources can lead to flooding in an urban area for many reasons. A common source of flooding is when the urban area is downstream of the flood path from the surrounding peri-urban area. Precipitation falling in this area may reach the urban area through overland flow routes across fields, in ditches, and along tracks and highways that eventually lead to the urban drainage system. This surface runoff can flood the intra-urban area because: there is no sewer system where the surface runoff enters the intra-urban area; the flow may not be able to enter the sewer system due to insufficient or inadequate gulley (or other) entry points; or the sewer system is hydraulically overloaded. This results in external flooding that subsequently impairs the gravitational performance of the urban drainage system, potentially increasing the volume of the flood flow and exacerbating flooding.

Similarly, overtopping of flood defences, either fluvial or coastal, will often inundate the urban space. Such inundation will impair the performance of the underground drainage system. The relationship between the extent of inundation and impairment of the underground drainage system is not fully understood.

Driver update

The most significant signs of change since 2004 are the moves in England towards a single co-ordinating agency for runoff management. Similar developments are underway in Scotland and Wales, although in different forms. Such an agency is most likely to be able to deliver integrated flood risk management under a National Enterprise future (in which private water companies may be disbanded) and Global Sustainability, but under the National Enterprise scenario there may be insufficient resources for full effectiveness. A single agency is unlikely to be effective under World Markets and less able to co-ordinate at a catchment scale under Local Stewardship. To reflect these arguments, the multiplier of future flood risk for Global Sustainability has been set below unity and that for National Enterprise has been slightly reduced. The scores for World Markets and Local Stewardship are unchanged.

Intra-urban Asset Deterioration

Driver definition

Changes in performance, condition and serviceability of urban drainage assets (ageing, performance, wear and tear, and rehabilitation management).

The performance of assets and asset failure affect flooding of the urban area. Population growth, increased urban development, increased wealth and an apparent growing need to occupy flood-prone areas have increased flood risk within the urban area. Properties at risk of this type of flooding are defined as properties that have suffered or are likely to suffer flooding from public, foul, combined or surface water sewers due to overloading of the sewerage system more frequently than the relevant period, either once or twice in 10 years.

Driver update

There is no new evidence since the 2004 assessment that this problem is being addressed or has even been properly recognised. A single flood risk management agency may improve the targeting of investment to where it is most needed and hence there may be some grounds for greater optimism than was evident in the 2004 assessments under National Enterprise and Global Sustainability. Lack of sufficient resources may, however, impact on effectiveness, especially in a National Enterprise future. For scenarios where the sewerage assets are privately owned, operated and maintained, the ability to invest in asset maintenance will be limited by price constraints, although ongoing extensions of risk-based approaches to resource allocation may help deliver optimal investments. Again, it is likely that the required investment to maintain the status quo will be underestimated and underfunded, particularly under a Local Stewardship future. However, all these factors were appreciated in 2004 and hence, as no new factors or knowledge have emerged since then, there are no grounds to modify the 2004 flood risk multiplier scores for this driver.

Coastal Processes

Robert Nicholls and Jonathan Simm

Coastal Morphology and Sediment Supply

Driver definition

Coastal Morphology and Sediment Supply describes changes in the seabed form, shoreline and adjacent coastal land, coastal inlets and estuaries.

Changes in Coastal Morphology and Sediment Supply involve erosion of the shore and seabed, the movement of eroded material and its subsequent accretion. The ultimate result is the creation, movement and removal of banks and channels within the sea, changes in the level and position of the foreshore, and the landward movement of eroding coastal features such as cliffs and headlands. The consequences of anthropogenic activities – such as dredging, reclamation, setback and coastal protection – are also a part of this driver.

Driver update

The Coastal Morphology and Sediment Supply driver is one of the more difficult issues in the Foresight study. It is difficult to separate this driver from the responses, because they are so strongly coupled – e.g. the desire to protect the coast under World Markets, versus the desire to have a natural coast under Local Sustainability, which are integral with the scenario storylines and interpretation. Two important issues have been emphasised since 2004 for this driver, based on research by the Tyndall Centre for Climate Change Research (Dickson et al., 2007; Dawson et al., 2007):

- beaches are often starved of sediment today due to historic cliff protection; and
- reverting to a more natural coastline gives flood protection benefits.

Since 2004, detailed modelling of the Norfolk coast has emphasised how strongly coupled erosion and flood risk can be, when there is strong long shore connectivity via littoral drift. Under current conditions, most of the cliffs from Weybourne to Happisburgh in Norfolk are protected (about 70% by length) and the down-drift beaches protecting the Norfolk Broads have been significantly starved of beach sediment due to the lack of sediment supply – as argued more qualitatively for many years by Professor Keith Clayton (see also Orford et al., 2007). In some futures, protection of all the cliffs could see almost total disappearance of the down-drift beach in front of the Norfolk Broads (ignoring nourishment and residual effects of the offshore breakwaters at Sea Palling).

Climate change at the coast, combined with the baseline assumption of no change in coastal management, would lead to increases in flood risk in the Norfolk Broads, especially for the most severe scenario considered (1.2 m rise in relative sea level by 2100). If cliff retreat is reactivated along this coast, it is predicted that the beaches grow and provide sufficient protection to the defences behind them, so that flood risk in the neighbouring coastal lowlands decreases significantly. This research suggests that widespread abandonment of cliff defences could have significant benefits in reducing flood risk in neighbouring coastal floodplains where these areas are linked by littoral drift, and that these benefits can now be quantified (which is relevant to the update of Coastal engineering and management in the Responses section of this report).

This suggests that the range of scores in Foresight 2004 is too small and that, under Global Sustainability, this driver might be neutral or even positive, while under World Markets, the effects could be as important as the other climate change drivers. Given the uncertainties, it does not seem appropriate to rescore the mean values at the moment, but the low and high bound values now reflect these new insights. Ongoing work by the Tyndall Centre, which is due to report in 2009, should improve our understanding of the operation of coastal morphology and sediment supply as a driver.

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Human Behaviour

Edmund Penning-Rowsell and Sue Tapsell

Stakeholder Behaviour

Driver definition

The behaviour of individuals and groups and institutions that will influence flood risk.

This driver operates through such activities as pricing of insurance, agricultural practice, food-purchasing preferences, the pursuance of ecological or other aims, and commercial self-interest as in the promotion of flood-related litigations (Evans et al., 2004, p.273). This driver interacts strongly with other drivers, and the many different categories and types of stakeholder mean that they act in many different ways. In the intra-urban context there are very different institutional arrangements as regards catchments and coasts for mitigating flood risk, in that the water companies, local authorities and the Highways Agency all have important roles.

Driver update

Although social science research and its policy-related focus has accelerated since 2004 with Defra's new policy role, relatively few studies have so far examined further the way that stakeholder behaviour influences flood risk. That said, research in the Flood Risk Management Research Consortium has investigated stakeholder influences on a variety of flood mitigation interventions, and confirmed that they are considerable, as has work for Defra on 'Who benefits from flood management policies' (project number FD2606) and on 'Social justice in the context of flood and coastal erosion risk management' (project number FD2605). Other research in Defra's *Making Space for Water* and EU 'Interreg' projects has come to the same conclusion, thus supporting the high scoring of this driver in Foresight 2004.

In the 2004 Foresight rating of this driver, the mean multiple on current levels of flood risk was 2.85, and ratings were consistently above 2.0 across all socio-economic scenarios for both the 2050s and the 2080s. This means that the 2004 Foresight research led to the conclusion that risk could more than double during this century owing to the impact of this driver alone.

The social science and policy research described above justifies this high score, but it does not lead us to believe that stakeholder behaviour will be even more important than this in the future. Perhaps, if anything, stakeholders are getting more vociferous about the risks that they face (influencing Ofwat and the Environment Agency alike with their actions following flood events), but the risks themselves, so far, have not changed to the extent that we can score this driver higher than the doubling of risk indicated in 2004. Thus, we believe there is no case for changing the scoring of this driver.

Public Attitudes and Expectations

Driver definition

Public Attitudes and Expectations will influence the responses to changes in flood risk.

The Public Attitudes and Expectations scenario signifies preferences for risk management and associated factors, rather than personal preferences as to, say, the desirability of living in certain types of location. Public preferences, while originating from the populace, are heavily influenced by the positions and behaviour of other actors, and hence cannot be viewed in isolation. Furthermore, we recognise that 'the public', as such, does not exist in the sense of having a single position.

Driver update

In 2004, the Public Attitudes and Expectations driver was taken to signify preferences for risk management and associated factors. In the current review, the function of Public Attitudes and Expectations in affecting flood risk was reconsidered and, on the basis that it acts primarily to influence flood risk management decisions rather than flood risk itself, it was decided to treat it as one of the responses. Consequently, the update for Public Attitudes and Expectations may be found in Appendix B.

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Socio-economics

Edmund Penning-Rowsell and Sue Tapsell

Buildings and Contents

Driver definition

This driver encapsulates the damage from flooding to domestic and commercial buildings and their contents.

This driver includes damage to household durables as well as raw materials, intermediate goods, and consumption, together with the costs of recovering from floods and the disruption caused to others in consequence of those properties being flooded. The driver is, in effect, a measure of the exposure and vulnerability of property to flooding, and vulnerability is a function of the susceptibility of the assets at risk to flood damage and the ease or otherwise of the restoration of those assets to the status quo ante the flood. In this respect, this driver is one of the most important of the receptor flood risk drivers, and one that determines to a large extent the growth or otherwise of flood risk in the future.

Driver update

The most recent research on flood damage to property was a Defra-funded project at the Flood Hazard Research Centre (FHRC), Middlesex University, that started in 2001 (Penning-Rowsell et al., 2005). Interim results from that project were published in 2003 (Penning-Rowsell et al., 2003) and it was those interim results that the Foresight 2004 project used in all its risk assessment calculations. The 2005 results for residential properties followed the pattern identified in 2003, showing markedly higher damage potential values than in the research done a decade earlier (Penning-Rowsell et al., 1992). However, this was not the case for non-residential properties. Further sampling and analysis between 2003 and 2005 showed that the previous samples were somewhat biased in favour of potential high-damage sites; the 2005 averages were thus lower than those published in 2003, although only marginally.

It might be considered that the 2007 floods showed that recovery following flooding was a more lengthy, time-consuming and expensive operation than had been appreciated. However, as far as published flood damage research and data are concerned, this is not the case. The FHRC's latest manuals (Penning-Rowsell et al., 2003; 2005) fully take on board this factor, which was one of those responsible for the considerable rise in damage values between the 1990s and a decade later.

This updated research leads us to revise downwards very slightly the scores for this driver, especially in those socio-economic scenarios dominated by high economic growth, such as World Markets.

Urban Impacts

Driver definition

This driver is concerned with changes in the way in which urban areas are managed and urbanisation is effected, and how planning and management may change climate- and social-change effects.

This driver takes the form, for example, of "the renewal of existing urban spaces, new urban forms, new densities of development, more green space, encroachment of green belts, etc." (Evans et al., 2004, p.284). Foresight 2004 recognised that this was a slowly changing driver, with only a 1% annual addition to the urban housing stock, and an even slower (0.1%) replacement rate. However, the operation of this driver is inexorable; once urbanisation has taken place, property law and other institutional constraints in the UK mean that it is almost impossible to reverse: clearance of urban areas for open space is virtually unknown.

Driver update

There appear to be no major – or even significant – changes in direction with regard to planning and managing the urban fabric since 2004. The Government's 'Sustainable Communities' initiative pre-dated the Foresight Future Flooding work, as did the beginning of the Thames Gateway development ideas for the area east of London. However, after the 2000 and 2003 floods we have seen the full implementation of Planning Policy Statement 25, seeking to restrain floodplain development, reinforced by (and reinforcing) the *Making Space for Water* policy change with regard to flood and coastal erosion risk management. But we have also seen continued high levels of economic growth, and maintenance of intense pressures on land for urban development, including that in floodplains.

The evidence here is perhaps somewhat contradictory, which we judge to be sufficient reason for leaving the 2004 risk multiplier scores unchanged until more definitive changes are apparent in the policy or practice in the ways in which urban areas are managed.

Infrastructure Impacts

Driver definition

The relationship between flood risks and the array of networks and nodes that deliver physical services – gas, water, electricity, transport, telecoms, and so on.

The effects of floods on these networks and nodes can spread far beyond the affected area, as was amply demonstrated in the summer 2007 floods. The impact of these effects depends on the nature of the network topology, and any surplus capacity available in the network system. This also means that the effects can be very local (e.g. when an electricity supply to a single property is flooded) or can be spatially very extensive, such as when a major switching station or even a substation is affected. Such impacts are difficult to predict and hence to model. They also include the effects of technological developments. However, looking well ahead to the 2050s and 2080s, it is not clear what technologies will be available for supporting our infrastructure. There may be widespread use of local energy 'renewables', and locally based infrastructure of all kinds, thus reducing the need for the kind of complex infrastructure networks on which we depend now. The alternative could be increasing dependence on large geographical network systems, such as that supplying the UK now with Russian natural gas. However, all this was well recognised in the 2004 Foresight report.

Driver update

In the 2004 analysis, this driver was accorded high-risk multiplier scores (especially for the World Markets scenario, where it scored over 7). However, the Local Stewardship scenario showed multipliers of less than 1.0, reflecting the kind of 'local' analysis suggested above. The 2007 floods showed that infrastructure 'outage' was more important than we had hitherto appreciated, as was the disruption of motorway traffic previously not considered at risk. While there seems to have been little systematic research on this topic between 2004 and 2008 on which to base a change to the 2004 risk multipliers, the 2007 floods themselves point to the need for increasing the risk multipliers. Also, inclusion of intra-urban flooding in this driver suggests that the dependence on infrastructure to drive flood risk is unlikely to decrease under any scenario in the future (hence the need to increase those below-unity flood risk multipliers mentioned above) and for most scenarios will get marginally greater. Indeed, research on asset deterioration extent and rates in the last few years indicates that past projections of this as a key driver of increasing flood risk have not been exaggerated.

The 2007 floods also exposed the risk of flood-related dam failure in the UK, with threats to safety of the Ulley dam near Sheffield. However, this was found to be the result of a deficiency in the spillway maintenance regime, rather than a potential failure of the dam structure itself.

What we saw in the 2007 floods was major disruption to water supply over a large area, and some loss of power supplies (and the potential for much more disruption here). Residential property in Oxford was evacuated owing to the loss of power and water, not because the houses were themselves flooded – a new phenomenon. This suggests that, given the evidence and the nature of infrastructure effects on the disruption caused in the summer 2007 floods, the risk multipliers for this driver should be increased. This perhaps does not apply to the World Markets scenario, where the infrastructure effects of floods were well appreciated in 2004 and the multipliers are already very high.

Agricultural Impacts

Driver definition

The driver Agricultural Impacts involves the impact of flooding and associated high water tables on farm and forestry land, and managed habitats.

Our understanding of the operation of agricultural impacts as a receptor driver of flood risk is reasonably well established and has not changed since the 2004 Foresight report. The magnitude of flood damage costs on farm land for a given flood event depend on the type and value of agricultural land use, the aerial extent of flooding, and, critically, on the seasonality and duration of the event.

It was emphasised in the 2004 Foresight report that agriculture as a receptor is affected by both surface flooding and groundwater flooding that can damage existing arable crops and grassland for livestock. Furthermore, flooding and impeded land drainage critically determine the type of land use that is feasible. It was noted in 2004 Foresight that ‘flood risk management’ for agriculture must include the management of groundwater levels to support commercial farming. Indeed, land drainage for agriculture has long been the subject of major investment by land managers, for many years supported by government grants.

For the most part, however, the 2004 analysis concentrated on surface water, mainly fluvial flooding. The remit for this update includes groundwater flooding as a separate driver and, following the 2007 summer flood events, recognises the importance of non-fluvial flooding.

With respect to the assessment of agricultural impacts, a distinction is made under each long-term future scenario regarding the economic value of production per hectare (based broadly on the ‘profitability’ of farming) and the type of land use in floodplain areas, notably whether farmed intensively, extensively or abandoned (for agricultural purposes). Agricultural commodity prices vary under each scenario (lowest under World Markets, highest under Local Stewardship), reflecting the influence of world market conditions (highest under World Markets and Global Sustainability), agricultural productivity (highest under World Markets and National

Enterprise), conditions placed on farming to meet social or environmental objectives (highest under Global Responsibility and Local Stewardship), and policies on national self-sufficiency in food (highest under National Enterprise and Local Stewardship).

Flood damage costs are not simply a matter of agricultural commodity prices. The costs of flood damage under each scenario are based on loss of value added per hectare, including allowances for differences among scenarios in yields, input levels, and commodity output and input prices.
For example, under the World Markets scenario, it is assumed that, relative to the current situation, the relative profitability of farming would fall in real terms. In the absence of public funding of flood defence for agriculture (a feature of the scenario), low-grade land would not be worth farming. For Local Stewardship, lower-intensity farming would require continued and possible extended use of floodplains, although the losses per hectare due to flooding would be less when it occurred.

Driver update

Three factors in particular might warrant an increase in the 2004 flood risk multiplier scores attributable to agricultural impacts. These are:

- greater vulnerability of farming to revised forecasts of climate change;
- greater importance attributed to groundwater and non-fluvial/non-coastal flooding in the general rural landscape; and
- structural changes in the demand for, and supply of, agricultural commodities.

Revised estimates of climate change suggest increased variation in temperatures and rainfall, increasing the chance of warmer, wetter winters and hotter, drier summers, and more extreme events, including high-intensity, short-duration storms. These revisions could imply changes in the type and productivity of farming, with further variable effects on yields, depending on crops types, soil types, water availability and vulnerability to pests and diseases.

The effects on agriculture of these revisions to climate change estimates are uncertain. In some cases, warmer and drier conditions in autumn and spring could reduce the potentially negative effects of wetter winters. Increased summer temperatures could enhance yields, although low availability of water may act as a serious constraint in the absence of irrigation. Increased incidence of extreme events, including summer storms, could seriously damage standing crops. Furthermore, in the longer term, climate change could modify the geographic distribution of farming and land use, moving arable crops further north and west. In view of these uncertainties, it is not proposed to modify the estimates of risks due to revised estimates of climate change.

It is possible that wetter winters and greater incidence of summer storms could have considerable impacts on the general farming landscape, extending well beyond the confines of lowland floodplains that eventually receive floodwaters. Analysis of agricultural impacts in Foresight 2004 focused mainly on fluvial and coastal flooding. It is possible that this underestimates the aerial extent and costs of flood impacts on farmland, under all scenarios. In the case of farmland, the assessment of the impacts of flooding and waterlogging must be extended to non-floodplain and coastal areas, that is to areas on higher ground that are served by field and arterial drainage systems.

The assessment of groundwater flooding presented in this document suggests a reduction in groundwater flooding for three future scenarios, but notes that if wetter winters outweigh drier summers, then groundwater flooding could become more problematic. Agriculture is particularly vulnerable to groundwater flooding, which affects crop yields and timely field operations.

Since 2004, there have been a number of significant changes in factors which affect potential agricultural impacts of flooding in the UK. It is noted that these are immediate and medium-term manifestations of change in the agriculture sector and must be distinguished from the long-term ‘possible futures’ used in Foresight. They are, however, indicative of underlying structural changes that suggest a fundamental increase in the value of agricultural commodities. Many of the changes are associated with adjustments in world market conditions and are thus particularly relevant for the World Markets and Global Sustainability scenarios. They also have some resonance for National Enterprise and Local Stewardship scenarios that seek to promote greater national food security.

There have been significant changes in policy regimes since 2004, notably the decoupling of subsidies from production, a single payment regime tied to compliance with good practice, and the move towards commodity prices that are internationally competitive. In many respects this has moved agriculture towards the Global Sustainability future scenario.

During the period 2006–08, supply shortfalls and strengthening demand in international commodity markets have led to unprecedented increases in world agricultural commodity prices, more than doubling in the case of wheat during 2007. While these very high prices are not expected to prevail (because past experience has shown that high prices encourage a supply-side response), it is predicted that ‘structural changes’ in agricultural markets are likely to result in future prices that are persistently higher than in recent years (OECD-FAO, 2007; FAO, 2006; EU, 2007).

Over the next 10 years or so, the aforementioned sources suggest that real price increases in agricultural commodities of about 30 per cent greater than 2004 levels may be sustained. This, it may be argued, will encourage the further development of yield-enhancing technologies, although some of the extra benefits will be taken-up by the higher costs of inputs, notably mechanisation and fertiliser due to high energy prices (FAO, 2006).

The Food and Agriculture Organization of the United Nations (FAO, 2006) reports that the global population is likely to increase by 50 per cent over the next 50 years and then level off at about 9 billion. This, together with generally improved diets and greater prosperity in populous developing economies, will more than double the demand for agricultural commodities. FAO predicts that 80 per cent of increased demand will be met by intensification of existing farm land and 20 per cent by new land development. Extension of bioenergy crops (ADAS, 2007) could provide opportunities for agricultural growth, but the potential downsides for food security and the environment are noted. It is not expected, however, that conventional food crops will be a major bioenergy source in the long term (OECD, 2006). For example, at the time of writing, the EU is reconsidering its bioenergy policy in the light of impacts on food supply and prices.

Looking forward 50 years, the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD, 2008) concluded that there is an increased prospect of the failure of world agriculture to meet future food and fibre needs, if actions are not taken now to enhance agriculture's production capability. This requires technological development, new investments and institutional reform, especially given limits imposed by available land and water resources, environmental risks and the potential impacts of climate change. Managing water for agriculture, including flood risk management, was identified as a key area. The analysis generally attributes a "high value" to agricultural sustainability.

Regarding the longer term, a study of agricultural futures and implications for the environment (Morris et al., 2005) applied the Foresight-type scenarios to agriculture in England and Wales through to 2050. A modelling approach was used to derive, among other things, estimates of commodity prices, farm incomes and land use for upland and lowland areas. The results were broadly consistent with the assumptions used in the Foresight Flood Risk analysis. Analysis identified a surplus of agricultural land under the World Markets scenario and to a lesser extent under the highly intensive National Enterprise scenario, but shortages under Global Sustainability (mainly attributable to environmental controls and bioenergy production) and Local Stewardship scenarios. Estimates of the relative profitability of farming – an indication of potential losses in the event of floods – were reasonably consistent with those used for Foresight, although pressure on land suggested higher potential flood damage costs for Global Sustainability.

Conclusion

On the basis of a review of new information on projections for the demand for agricultural commodities and analysis of long-term futures, the risk scores for the impact of flooding on agriculture have been increased. This reflects a combination of perceived increased pressure on land as a whole (which will also increase exposure to flooding), increases in agricultural commodity prices, and also the view that the 2004 assessment underestimated the potential impact of groundwater and non-connected flooding.

The greatest increases in flood risk multipliers are for scenarios most affected by world market conditions, namely World Markets and Global Sustainability. The significant increases under Global Sustainability reflect increased pressure on land, partly associated with bioenergy cropping (mainly non-conventional energy crops). National Enterprise promotes intensive farming for self-sufficiency plus export of bulk agricultural commodities; thus, damages are high when flooding occurs. Local Stewardship involves less-intensive agriculture but greater occupancy of flood-prone areas.

Social Impacts

Driver definition

The risks to life and health as well as the intangible impacts of flooding on people and their communities, recognising that some sections of society are more vulnerable than others.

Some of the effects of this driver are highly localised. Risk to life in floods is a function of warning, floodwater velocity and depth, and generally only arises as a threat in small, 'flashy' catchments where the floods come relatively unannounced. Other effects of this driver are more long term; the so-called ‘intangible’ effects of floods are known to last several years after the flood has long gone, and even to have a permanent effect on people’s lives.

Driver update

In 2007 there was loss of life in the flood events, but generally as a result of human behaviours creating hazardous situations rather than flood conditions per se. It cannot be said that the loss of life in the 2007 floods was unexpected, or on a scale that could not have been appreciated at the time; it was not out of line with the floods of 2000. Other effects of this driver are also well known; research since the early 1990s has shown the health effects of floods. While research has continued (RPA/FHRC, 2004; and at the Flood Risk Management Research Consortium), it has not changed our view as to the importance of this driver (it has only changed our understanding of its quantification), and these results were well anticipated and hence well represented in the high-risk multipliers applied to this driver in 2004.

For the above reasons, and because the multipliers used in 2004 are already high, there is no case to change the social impacts multipliers in 2008. We knew in 2004 that this driver was important across all scenarios and all time-slices, and the multipliers allocated in 2004 reflect this knowledge and judgement. The combination of coastal/catchment flooding with intra-urban flooding in this 2008 analysis does not affect these scores, as much of the research on the health effects of flooding (and some on loss of life in floods) already reflects an essentially urban population.

Science and Technology

Driver definition

Science and Technology collectively determine the ratio of output of the economy to required inputs of natural endowment, labour and capital. Flood losses usually increase with technological advance but this trend may reverse in future, as science and technology make buildings, contents and infrastructure more resilient to flooding.

This driver was assessed as important but not quantified in 2004. The driver encapsulates the results of technological advances and the way that these can either drive up vulnerability (e.g. computers ‘written off’ in flooded office basements) or reduce vulnerability (e.g. wireless communication links that are unaffected by floodwaters). Technological advances may assist in the management of floods (e.g. mobile phones allowing communication even when land-lines are ‘down’), and information technology advances generally have allowed far more accurate weather forecasts and flood predictions over the last decade. Thus, the 2007 floods could be traced in ‘real time’, by examining weather radar images of precipitation as it was falling, rather than relying (as in the past) on rain-gauge data and river flow information.

Driver update

The effect of this driver was much debated in 2004 and the conclusion was that it operates through other drivers, such as: Buildings and Contents (for those computers in basements); Infrastructure Impacts (the information technology networks); and Urban Impacts (real-time forecasting of the locations of floods and their impacts). No research since 2004 has shown this conclusion to be false, although even in 2004 we recognised that current trends in science and technology may not continue and there may be major shifts in technology that could render current assumptions to be false.

For the above reasons, there is no case to change the way that this driver was treated in 2004 for this 2008 updating exercise. We recognise that this driver is important and works in many complex ways, but we see no more compelling case for it to be scored and ranked than existed in 2004.

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PIC TO COME

Appendix B: Updated response descriptions

Managing the Urban Fabric: (a) reducing river flood probability downstream by managing runoff from the urban area

Richard Ashley

Response theme definition and overview

The Urban Storage, Urban Infiltration and Urban Conveyance response groups consist of measures to influence urban pathways in the source–pathway–receptor model of the flooding system.

The responses in this theme are concerned with the mitigation of downstream impacts from flows arising in the urban area. The 2004 Foresight project recognised that urban flood management systems combine above-ground channels and non-channelised flow paths with below-ground drains and sewers, all linked to various storage facilities. Key system attributes include:

- storage – the capability to store and subsequently release flow at a controlled rate;
- infiltration – the facility to allow surface water to soak into a permeable ground surface; and
- conveyance – the capacity to discharge flow downstream rapidly or to slow its passage.

At the catchment scale, an increase in flood risk downstream of an urban area is a symptom of a drainage system that has failed to store water or enable its infiltration in the way that a natural land surface would have done. It has, instead, accelerated the rate at which runoff is conveyed into the receiving waters. The responses discussed provide a means of restoring the urbanised area's drainage system to a condition equivalent to that which existed prior to the introduction of the impervious surfaces that are a feature of urbanisation.

The report concluded in 2004 that there was little potential for the responses in this theme to deliver significant reductions in flood risk downstream of existing urban areas. However, it was also concluded that there will be opportunities to reduce the amounts of runoff which enter receiving waters, and the rates at which they enter receiving waters from areas of new urban development.

The response measures in this theme that could deliver downstream flood risk benefits are listed in Table B1.

Response theme update

In England, Defra is pursuing the vision and paradigms set out in *Making Space for Water* and associated planning process changes, but is having difficulties working with the private water service providers. There are also tensions with the Environment Agency, which acts as the action agency for flood risk management and the regulator responsible for environmental protection. Local authorities are also major players, but they generally have limited engineering capacity (except with respect to highways) and face growing demands for their services, coupled with limited funds available for investment.

Although progress has been slower than would have been hoped in 2004, there have been improvements to the ways in which flood risk management is dealt with in most parts of the UK. The most significant development that pertains to England is the adoption of Planning Policy Statement 25 (PPS25), and PPS15. Communities and Local Government's proposals to remove permitted development rights in England, as well as several other initiatives that may be implemented and that could have an influence, are not expected to affect downstream flood risk materially for some decades, especially as few of the changes they may stimulate will affect runoff from existing urban areas.

Table B1: 2004 response measures in urban areas that could reduce flood risks downstream in the catchment

Table of responses and their effectiveness

Response area	Responses	Effectiveness for downstream risk reduction	Relative order of effectiveness*
Urban-area development	Maintain/extend permeable/green areas. Control developments. Manage 'creeping' urbanisation	Potentially could maintain pre-development hydrology or recover some original conditions for existing urban areas	Up to 1
Increase storage	As above, also sewerage storage and RTC operation, daylighting watercourses	Provides temporary storage to arrest large flow peaks etc. Slow subsequent release	Typically 0.7
Integrated water management	Building design, regulations, water utilisation, low impact development	Locally, effective but would need to include facility for discharge during largest storms	Typically 0.1–0.2
Serviceability of assets	For existing systems, maintain and ensure assets do what they are supposed to	Probably not effective for downstream protection (as will convey flows out of urban area)	Probably up to 0.1 at best
Source control/SUDS	Includes some of the above. Also specific infiltration structures	Not likely to be effective for largest events (>100 year storms)	Probably up to 0.1 at best

* Scales: 1.0 represents the pre-urban condition. 0 represents a fully impervious area draining to a downstream catchment.

With reference to the measures listed in Table B1, PPS25 maps clearly onto the first response measure. There are some signs that green roofs (constructed with vegetation to slow runoff) are being used more, but there is conflicting evidence about their contribution to flood risk reduction. Overseas, in New York, blue roofs (constructed with water storage to slow runoff) that retain rainwater are now being introduced. While there are as yet no plans to promote blue roofs in the UK, there is reason to imagine that the technology could be transferred here sooner rather than later, should it prove effective.

There has been no material change in the vision for urban flood storage since 2004, although schemes applying the reverse approach (of storing water upstream in the catchment to lower flood risk in downstream urban areas) have become more widespread since 2004 (e.g. White Cart Water, Glasgow).

Although flagged in *Making Space for Water*, and despite the aspirations of the new water strategy (Defra, 2008a), integrated water management still does not appear to be high on the Government's agenda.

Asset serviceability remains poor in most urban areas, with little sign of adequate funding being forthcoming for sewerage, minor watercourses or even Critical Ordinary Watercourses (COWS) in England. However, the forthcoming revised Sewerage Rehabilitation Manual number 5 (SRM5) (WRc, 2008) may provide a risk-based approach to the management of flood defence and drainage assets that corresponds with best practice in river engineering, and this may in future improve the use of maintenance resources across the UK.

Wider adoption of sustainable urban drainage systems (SUDS) and source control remain strong aspirations and the use of these response measures is written into many guidance documents. However, no new incentives to encourage their use have emerged since 2004, nor are there clear lines of responsibility governing the management of SUDS and source control where these measures have been implemented. Views on their efficacy for flood risk management vary and few opportunities for retrofitting them have been taken up (e.g. SNIFFER, 2006). This is illustrated by Thames Water's plans to construct a large storage tunnel sewer beneath London to manage storm water, rather than using source control. Even where they are included in sewerage adoption documents (e.g. WRc, 2006 and 2007) the uptake of these measures remains problematic, although Defra's current consultation (Defra, 2008b) is proposing to resolve some of the issues and might lead to further progress.

SUDS for new developments look more promising, but even in this case, their effectiveness in reducing runoff to receiving waters during extreme storm events is questionable. Indeed, Balmforth et al. (2006) show that the combination of SUDS with discharge exceedance routes may in fact increase flood risk from the biggest events in rural areas downstream. Otherwise, designing for exceedance is a positive step within the urban area, provided that adequate care is taken to avoid potentially adverse downstream impacts.

Recent research at HR Wallingford has demonstrated conclusively that rainwater harvesting can help to reduce downstream flood risk (Kellagher and Maneiro Franco, 2005) and Dŵr Cymru Welsh Water is pursuing a storm water disconnection programme as part of its plans for flood risk management, although it appears unlikely that Ofwat will provide funds for this in Periodic Review 2009 (PR09) asset investment plans for 2010–15. In addition, Ofwat could do more to encourage strategic research by the water companies to establish future climate change risks in the next Asset Management Plan (AMP) period.

In light of this brief review, it is difficult to find any justification to amend the flood risk reduction scores allocated in 2004.

Managing the Urban Fabric: (b) reducing intra-urban and coincident flood probability within the urban area

Richard Ashley

Response theme definition and update

The response groups in the intra-urban theme that were identified in the 2004 Foresight study are:

- Building Development, Operation and Form;
- Urban Area Development, Operation and Form (including sacrificial areas);
- Source Control and Above-ground Pathways;
- Groundwater Control;
- Storage Above and Below Ground; and
- Main Drainage Form, Maintenance and Operation.

Table B2 lists the response groups together with their description, the measures included within them, information on their scale of operation and summary updates based on new knowledge and insights gained since 2004. Some of the response measures in these groups may also be used to reduce flood risk in the catchment downstream, and for these groups and measures the commentary in the update section of the previous response theme also pertains here.

Considering the new information that has emerged since 2004, a case could be made for limited rescoring of some response groups, but any modifications would be fairly minor and to some extent arbitrary. In any case, it is unlikely that such changes would change the ranking of the responses significantly, with one possible exception. The exception is the response group Urban Area Development, Operation and Form (including sacrificial areas) considered in the context of new developments and properties, where recent initiatives and in-progress ideas may in the longer term (2080s) result in higher flood risk benefits than were anticipated in 2004. This is largely due to the increased potential for better planning control under the Global Sustainability future scenario. However, further evidence would be needed that this response group could actually convert the potential for greater reductions in future flood risks into delivered outcomes before its score could be increased with any confidence.

Table B2: Response group descriptions and updates

Response group	Description	Response measures	Scale of response	Summary updates
1. Building Development, Operation and Form	Form of roof, building and curtilage drainage. Includes non-main sewer systems. May include siphonic systems.	Design of building drainage (including green roofs, ponding and explicit storage on roofs etc.). Managing urbanisation at the building and local levels (specifically in terms of building development and form). Flood-proofing individual buildings/ parts of buildings with exceedance pathways adjacent, including local flood protection (free-standing temporary barriers, removable/ demountable systems etc.). Rainwater harvesting and local stormwater use, including disconnection of downpipes, which prevents runoff from roofs entering the sewer system. Changing building regulations and local area drainage standards. Road gully inlet control.	At the building level to control local risk to the building envelope. The curtilage of the building (overlaps with 3 below).	Most likely development may be direct use of rainwater, though this is only to be expected in new developments and will be adopted only very gradually. However, it may be common by the 2080s. New buildings will not create new problems under any scenario except perhaps World Markets.

Table B2: Response group descriptions and updates *(continued)*

Response group	Description	Response measures	Scale of response	Summary updates
2. Urban Area Development, Operation and Form (including sacrificial areas)	Changes in urban form – building density, layout and other aspects of development such as green space.	Promoting green spaces. Local flood barriers (transferring water). Controlling new development. Building regulations for flood risk areas to require flood mitigation strategies (e.g. Communities and Local Government, 2007). Abandoning properties most at risk. Sacrificial local storage areas. Local and community protection of 'islands' within urban landscapes (temporary).	Street scale up to city scale (overlaps with 3 below).	Should be implemented in new developments (see above). There is no sign of exceedance pathways, and government targets for house building may compromise these response measures. This response group may be abandoned under World Markets.

Table B2: Response group descriptions and updates *(continued)*

Response group	Description	Response measures	Scale of response	Summary updates
3. Source Control and Above-ground Pathways	Source control is the management of storm water as close to the point of origin as possible. Above-ground pathways include roads, paths and green spaces as well as water-courses.	Design of roads and gully pots. Source control and local sustainable water system management using a variety of techniques. Water reuse and recycling. Reopening of culverted watercourses (daylighting). Controlling pathways of runoff. Pumping off site. Multiple drainage systems. Aesthetic use of water in the urban area. Detention ponds. Permeable land cover.	Curtilages of properties and larger developed areas, up to regional scale (overlaps with 1 and 2 above).	See 2 above.

Table B2: Response group descriptions and updates *(continued)*

Response group	Description	Response measures	Scale of response	Summary updates
4. Groundwater Control	Control of groundwater levels.	Controlling groundwater levels, e.g. by pumping. Maintaining sewerage capacity by reducing infiltration from groundwater. Permeable land cover maintenance. At local levels, tanking of basements and/or installation of non-return valves.	Unlikely to be effective if implemented purely at a local scale – regional scale needed. Local level measures (applies to tanking of basement only).	See review and update of Groundwater Flooding driver and relevant commentary in Managing Flood Losses response theme.
5. Storage Above and Below Ground.	Ponds, tanks etc.	Detention ponds. Mini-storage. Storage along/ adjacent to flood system. Local ponding in flood retention areas. Underground storage. Temporary flood storage (e.g. in parkland).	Ponds and wetlands may come under response group 3. Tanks, where below ground, are part of minor drainage systems (overlap with 6).	There seems now to be an acceptance that above-ground options are likely to be the only viable responses in existing urban areas.

Table B2: Response group descriptions and updates *(continued)*

Response group	Description	Response measures	Scale of response	Summary updates
6. Main Drainage Form, Maintenance and Operation	Ways in which main drainage systems are managed, and alternatives.	System form: • sewer separation; • managing wrong connections; • limiting inflows by constricting inlets or surface disconnections; • limiting groundwater infiltration into sewers by rehabilitation; • localised non-return valves; • pump stations. System operation: • real time control; • pumping. System maintenance: • planned; • integrated.	Urban areas. In the UK the main sewer networks in these areas convey flows from the local, minor systems (see response group 1 above).	Revision of the sewerage rehabilitation manual (WRc, 2008) and UK Water Industry Research (UKWIR) second-stage reports on 21st-century sewerage may shed new light when they appear.

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Managing the Rural Landscape

Joe Morris, Tim Hess and Stuart Lane

Response theme definitions and overview

In the 2004 Foresight project, this response theme included three response groups, each with a subset of individual measures that may be implemented in response to future increases in flood risk. These are:

(a) Rural Infiltration: changing the partitioning of precipitation between overland (rapid) and subsurface (delayed) runoff. This form of land management can reduce the generation of quick flow and so diminish downstream flood risk. This group of measures essentially involves measures such as arable land management (e.g. cover cropping, tillage practices), livestock management (including reducing stocking rates), field drainage, planting buffer strips, afforestation and woodland planting.

(b) Catchment-wide Storage: increasing the storage of surface runoff within the catchment. The retention of quick flow attenuates the flood peak and can reduce downstream flood risk. Measures include on-farm reservoirs, ponds, bunds and ditches, enhanced wetlands and washlands, and some forms of impoundment.

(c) Rural Conveyance: interventions to alter the speed at which surface runoff enters the drainage and channel networks. Slowing conveyance increases flow attenuation and hence can reduce downstream flood risk. Measures in this group include interrupting hillslope–channel connectivity with buffer strips, planting cover crops to roughen the land surface, altering maintenance practices to allow vegetation recovery, and restoring drainage ditches and first-order streams (non-main rivers) to a more natural alignment and morphology.

Possible overlap with the River Engineering and Maintenance response theme is apparent, notably in relation to response groups (b) and (c). The fundamental difference between the type of flood storage described above and the engineered flood storage measures in the River Engineering and Maintenance theme is that the Catchment-Wide Storage response group involves a wider spectrum of storage measures that are:

- widely distributed across the catchment;
- managed for other reasons as well as flood risk reduction;
- uncontrolled or only weakly controlled by pumps, gates and sluices; and
- made up of multiple elements each of which is individually small in scale.

The fundamental difference between the Rural Conveyance response group and measures aimed at managing channel conveyance in the River Engineering theme is that in this theme management is applied to overland flow and flow in ditches and first-order channels – which are not classed as main rivers by the Environment Agency. The aim is to reduce conveyance capacity in order to slow the water and increase attenuation in areas where it is acceptable or even desirable to increase water levels during a flood event. Often this has the dual purpose of reducing downstream flood probability and enhancing the local environment so as to achieve goals of habitat restoration and increased biodiversity. In the River Engineering and Maintenance theme, measures usually aim to increase in-channel conveyance capacity in a main river to lower the water level associated with a given magnitude of flood event locally, in an area where flood risk is too high.

Rural landscape management measures relate mainly to the Catchment Runoff and Fluvial Systems and Processes driver sets. New evidence available since 2004 that relates to these drivers and the measures in this theme has two characteristics. First, it tends to be inferential, being derived from studies of relatively short-return-period floods coupled with extrapolation by modelling of larger events. Second, it does not yet confirm that land use impacts on flood risk (positive or negative) extend to large catchments (>100 km^2).

For instance, new research by the Flood Risk Management Research Consortium (FRMRC) at Pontbren (detailed below) has demonstrated the links between agricultural intensification or de-intensification in an upland area and runoff rates. By inference, therefore, ‘good’ land management would reduce negative impacts downstream of intensely stocked headwater basins and lead to a reduction in flood probability at the catchment scale, but this has not yet been proved.

Similarly, in terms of river processes, targeted woodland planting has been advocated as a means of reducing downstream delivery of sediment, potentially slowing river bed aggradation and so reducing flood risk in the headwater and middle reaches of longer rivers (Lane et al., 2008). Again, this finding has been inferred from numerical simulation but not, thus far, demonstrated in test cases.

Thus our general interpretation of the new evidence available in the context of using these measures to reduce flood risk nationally must be conservative, and this leads us to conclude that, while the results that have emerged since 2004 are highly encouraging, it would be premature to change the scores assigned in 2004.

Management of infiltration

Some new work in England and Wales has been conducted in upland environments. The FRMRC project, part of the Engineering and Physical Sciences Research Council at Pontbren (Wheater et al., 2008), indicates that farm woodlands, field boundary features and reduction of stocking rates in a small catchment can improve infiltration and reduce runoff and potential flood generation. Tree planting in field and riparian buffer strips has been associated with a 10 per cent reduction in flood peaks and more widespread planting of tree strips is predicted to have the potential to reduce flood peaks by a further 20 per cent. Widespread reversion of 'improved' grassland to a more natural condition is also predicted to be significant. Dresser and Godwin (2004) modelled the effects of improved soil management on flooding in the Parrett catchment. They demonstrated that enhanced soil management, including residue and wheel traffic management, resulted in a 1.5-hour delay in the timing and a 20 per cent reduction in the magnitude of the flood peak. This evidence aside, there has been little new work on responses in the lowland mixed and arable farming landscape, in spite of this being identified as a priority for research (O'Connell et al., 2007).

The review of disconnected flooding in the 2008 driver updates, and especially that associated with 'muddy floods', might warrant a change in scores. For example, there is now demonstrable evidence that land management practices, for a restricted range of combinations of geology and land use, can be linked to flooding outside the floodplain. In particular the generation of muddy floods that inundate properties directly, by runoff from fields, sometimes conveyed along roads (see Lane, 2007). However, the risks associated with muddy floods are of limited significance nationally, as the occurrence of floods of this type is limited to areas of particular land uses and geologies.

Catchment-wide storage

There is emerging evidence that confirms the high potential for rural catchment storage as a group of flood reduction measures, where suitable storage sites can be identified. A major Rural Economy and Land Use Programme (RELU) project[3] has tested the use of small-scale bunds as a means of flood retention, using an innovative catchment modelling methodology that combines data-theoretic approaches with local knowledge of suitable bund placement sites. Measures of this type, constructed at very low cost, were sufficient to store a major flood that occurred in Pickering Beck, North Yorkshire in June 2007. However, the scope for implementation of catchment-wide storage in many catchments in England is limited by the terrain, geology and land availability. This was reflected in the scores awarded to this group of measures in 2004, and the situation has not changed since then. Thus, the new research confirms the scores awarded in 2004, and does not necessitate changing them.

Managing rural conveyance

Since 2004, a range of projects have begun to explore the management of conveyance, and its impacts, in a range of hydrological environments. Some of this research has concentrated on hillslope conveyance, with a particular focus on drains and grips in uplands (e.g. the Sustainable Catchment Management Programme project, United

[3] (www.relu.ac.uk)

Utilities, 2008), although the primary motivation for this was not flood risk reduction but the management of water quality associated with the supply of potable water. There is, as yet, no new evidence of the impacts on flood risk, although new projects are underway.

There has been new work in England and elsewhere in relation to conveyance on floodplains, and its effects on downstream propagation of flooding. This is important given the emphasis placed on reconnecting rivers to their floodplains in *Making Space for Water*, in which a reduction in within-river maintenance in rural catchments is promoted as a means of reducing flood risk. Under this group of measures (as distinct from catchment-wide storage) the focus is on using rural floodplains to manage conveyance rather than simply to store floodwater. Ghavasieh et al. (2006) simulated the effect of "roughened strips" (similar to dense forest) on attenuation and delay of the flood peak. Thomas and Nisbet (2006) simulated the effect of increased floodplain roughness on the 1% annual exceedance probability flood in a catchment in South West England. These studies demonstrate that increased floodplain roughness does result in increased depths and reduced velocities of water on the floodplain, but suggest that the relative effect is greatest for smaller floods, with the impact on the 1% annual exceedance probability flood not being very significant. Consequently, the new evidence supports the case for confirming rather than changing the scores assigned to this response group in 2004.

Social acceptability

Although the new evidence base does not support a change in any of the response scores, it is significant that since 2004 there has been a considerable increase in the general acceptance that rural land management interventions **can** make a difference. Indeed, wider implementation of the measures in this response theme is being actively encouraged by both governmental and non-governmental organisations. Rural land management practices which can reduce potential runoff are now promoted under agricultural compliance requirements and the new (2005) Environmental Stewardship schemes, both at entry and higher levels. Defra's *Making Space for Water* makes explicit reference to the role of rural land management in flood risk management; and opportunities to reduce catchment flood risk by increasing flooding in parts of the catchment are explicitly considered in the Environment Agency's Catchment Flood Management Plans. Measures to control flood generation are also included within Defra's Catchment Sensitive Farming initiative. These initiatives, together with proposed interventions under the EU Water Framework and Floods Directives, suggest that the coming decades will see wide implementation of integrated measures to control flood generation from farmland and reduce diffuse pollution to water bodies.

The interim report of the Pitt Review identifies rural management as a potentially important category of responses to managing flood risk. Indeed, in predominantly rural catchments with embedded urban areas, it is apparent that most stakeholders, including farmers themselves, now recognise a role for changes in rural land management to alleviate flood risk, by reducing the speed with which water enters the river system, reducing the chance of disconnected muddy floods, and dedicated storage to reduce quick flow runoff volumes (e.g. Posthumus et al., 2008; Morris et al., 2008).

However, there is also a growing sense of frustration in some rural communities that cost-benefit considerations currently preclude the protection of rural communities and that strategies to protect more densely populated urban areas through increasing storage and reducing conveyance in upstream rural areas involve increased exposure to flood risk for a few, for the sake of reduced flood risk for the many. This is an issue of social justice that is central to this response theme, perhaps more so than was realised in 2004.

Governance

Lane et al. (2007) flagged the critical issue of governance in relation to flood risk reduction measures based on managing rural catchments. These measures are unique because they are generally diffuse and small-scale. For them to be effective as a component of a flood alleviation scheme, there is a need for a system of governance capable of guaranteeing that the necessary land management measures will be implemented in the areas designated and over the time spans required to deliver the desired flood risk benefits. Measures based on managing rural landscapes will also, to varying degrees, require changes in the behaviour of numerous stakeholders who have no personal responsibility for downstream flooding (e.g. farmers) and who may not have any strong incentive to become involved on the basis of the local outcomes of their actions and their own flood risk.

We can now add to these established issues concerning catchment-wide and diffuse measures: the relatively poor perception on the part of flood victims of the merits of upstream land management measures as compared to local flood defences. While there is now an emerging body of research that demonstrates the acceptance by land managers of their flood risk reduction responsibilities, there is much less evidence, that rural land management measures are an acceptable response to future increases in flood risk in the eyes of the victims of flooding, even where there is a demonstrated downstream flood reduction impact.

Summary

As recognised in the 2004 Foresight report and a recent review by Lane et al. (2007), the efficacy of rural catchment management responses in reducing the flood risks directly associated with long-return-period events at the catchment scale remains unproven. To date, only some of the response measures have been researched thoroughly, but they have been shown to be highly effective at a small scale and with regard to shorter return period events. However, some of the evidence necessarily comes from modelling rather than from field observation. There is stronger evidence that reduced stocking densities and the planting of buffer strips does reduce catchment sediment yields, with marked, indirect flood risk benefits.

Lack of conclusive evidence of the efficacy of changes in land use management stems, in part, from the interaction of conflicting effects and the difficulty of identifying unique hydrological indicators. Lane et al. (2007) point out that the potential contribution to flood risk management depends on many downstream, intervening processes and conditions, with the result that linking cause to effect with respect to the action of any one rural land management intervention is difficult. Uncertainty about the contribution that the response measures in this theme can make to managing down future flood risks is therefore very high.

However, “lack of evidence … does not necessarily equate to lack of effect” (O’Connell et al., 2007). In the light of this, while the research results necessary to confirm the efficacy of the measures in the Managing the Rural Landscape response theme are still awaited, the case for optimism that underpinned the scores allocated in 2004 appears to have strengthened rather than weakened between then and 2008. However, on balance there does not appear to be sufficient justification to change the risk reduction scores at this time.

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Managing Flood Events

Sue Tapsell and Edmund Penning-Rowsell

Pre-event Measures

Response group definition

Pre-event measures are those actions that can be undertaken prior to a flood event to ensure that people and agencies are prepared for flooding, to mitigate negative impacts, and to ensure smooth management of the event.

This response group is crucial to many aspects of managing flood events, and the measures in it are necessary for the successful dissemination of warnings, as well as both collective and individual-scale damage avoidance activities. Measures in this response group included in the 2004 Foresight study are:

- flood preparedness planning;
- communication, education and awareness raising;
- flood risk mapping;
- flood plans; and
- flood risk logbooks.

Response group update

Flood-preparedness planning

It is essential that robust emergency preparedness plans exist for all flood risk areas. The summer 2007 floods highlighted a number of problems or issues that were not considered sufficiently in 2004, including the spatial extent of the area affected by a very large event and the possibility for widespread occurrence of coincident flooding. Since 2004 there has been an increase in emergency planning generally. However, there were suggestions of a lack of preparedness on the part of some authorities during the 2007 summer floods (GfK NOP, 2007) due to the magnitude of the event, while in some areas there were no agreed protocols between responders to initiate an effective response. These floods showed how lack of preparedness to deal with really large events can lead to resources being overstretched, possibly reducing the effectiveness of responses deployed during the event.

The Civil Contingencies Act 2004 now places a legal duty on local authorities to take actions to manage flood events: they are Category 1 responders along with the emergency services, the Environment Agency and the National Health Service. According to the Association of British Insurers (ABI, 2007) there was still too much ‘learning on the job’ by emergency responders in 2007, rather than pre-planned responses moving into action. Confusion was noted over the roles and responsibilities of responding organisations and communications between responders were said to have been poor in places. Also, Category 2 responders were said to be inconsistent in their levels of engagement and unfamiliar with emergency response procedures. In contrast, preparedness for the possible east coast flood in November 2007 was perceived to have been much more effective.

The summer 2007 floods revealed a need to be better prepared with respect to identifying and protecting critical infrastructure, including road, rail, water treatment and energy infrastructure (ABI, 2007). Contingency planning for the loss of services is crucial. In the area around Tewkesbury, 140,000 homes were without running water for up to two weeks when the Mythe water treatment works were flooded, and 42,000 homes were left without power for 24 hours when power to the Castle Meads electricity substation had to be turned off (ABI, 2007). Evidence from the interim report of the Pitt Review (Pitt, 2007) has shown that planning for failures is patchy and inconsistent. For example, Yorkshire Water had no contingency plan in place for the failure of the Bransholme pumping station, which plays a key role in draining Hull.

There was also evidence of weaknesses in the arrangements for the provision of logistical support to emergency responders. Better planning is needed to source essential supplies in a major emergency (Water UK, 2008) and to cater for people in transit (in the July 2007 floods 10,000 motorists were stranded on the M5 motorway). The ABI also states that 15 per cent of fire and ambulance stations were at risk from the storm surge on the east coast on 9 November 2007, which suggests a need for better locating or resilience of emergency response facilities.

Evidence from the summer 2007 floods indicates that many organisations and businesses still do not prepare contingency and business continuity plans. Most of the buildings owned by Hull City Council were also not insured against flooding (ABI, 2007). Information available to enable emergency planning for the loss of emergency services was also reported as insufficient in 2007, particularly in relation to the location of critical sites, the mapping of their vulnerability to flooding, and assessment of the consequences of their loss and of their dependencies on other critical infrastructure assets (Pitt, 2007). This can lead to a weakness in local emergency response and therefore effectiveness.

Communication, education and awareness raising

There is currently a public expectation that flood risk will be better managed and resourced in the future without an accurate public perception of risk. Although public understanding of flooding has improved in recent years, and awareness has generally increased, this improvement is largely related to fluvial flooding and public understanding and awareness of the risks associated with intra-urban flooding are relatively weak. The Government now has a policy of managing flood risk rather than defending against all floods. However, the general public seems unaware of this and still expects flooding to be prevented. One assumption in 2004 was that if people who live in a flood risk area are aware of the risk, they are much more likely to be receptive to flood warnings and more inclined to protect themselves and their property. However, evidence from the summer 2007 floods (Pitt, 2007; GfK NOP, 2007) and the EU FLOODsite project (Steinführer et al., 2007) shows that even though people may be aware of flood risk they do not necessarily take actions to prepare themselves. Therefore the effectiveness of communication, education and awareness-raising measures is highly uncertain for all types of flood events, although increased awareness and good communications are still generally considered to help reduce flood risk.

Flood maps, flood plans and flood risk logbooks

Progress has been made in flood risk mapping and modelling in the UK in recent years, resulting in a steady improvement in datasets, the analyses being applied to them, and the decision support tools derived from these analyses. Further advances are likely, and visualisation and real-time maps are being developed which should aid preparedness planning in the future (Pitt, 2007). New indicative floodplain maps have been produced since 2004 which take into account more recent information on historic floods and modelled flood outlines. The revised maps can improve the accuracy of risk registers and the effectiveness of emergency planning. However, the maps only refer to fluvial and tidal flooding and not to other types, such as surface water flooding and flooding resulting from inadequate drainage or groundwater, which were shown to be significant risks in 2007. Catchments that respond rapidly to rainfall are currently being modelled, which will further help to identify and prepare for future floods. Accurate maps require both applicable models and accurate data, and so future methodological improvements will be closely linked to the availability of improved datasets. However, the limited capacity for broad-scale modelling of flood risk from multiple sources in urban areas remains a shortcoming, as the probability distribution for large-scale floods occurring at multiple locations is not yet fully understood.

There is no evidence of any change in the use of family flood plans since 2004, nor in the use of flood risk logbooks. Home Information Packs (HIPs) have been developed and were introduced in 2007 to bring pertinent information to the attention of those in the process of house buying. However, at the moment HIPs are not required to include flood risk; this seems a missed opportunity, as it would increase awareness and could encourage preparedness for flooding when flood-prone properties change ownership. The interim report of the Pitt Review recommends that flood risk be included in HIPs, and the Government is to review whether to include a mandatory flood search in the pack.

While there are issues concerning lack of preparedness plans and awareness, particularly regarding intra-urban flood risk, there is insufficient evidence for changing scores for this response group.

Forecasting and Warning

Response group definition

Forecasting and warning, along with flood warning dissemination, aim to provide flood warnings in sufficient time for people or organisations to take effective actions to reduce flood risk.

Measures in this response group are:

- improved sensing;
- forecasting and modelling, including updating of model predictions during the event;
- updating of model predictions during the event; and
- warning dissemination.

Response group update

Sensing and forecasting

Developments in sensing and forecasting have been made since 2004. The Met Office severe weather warning forecasting system worked well in the summer 2007 floods. Predictions of the time and space distributions of the exceptional precipitation were the most accurate and detailed for any major flood in UK (Met Office, 2007). Improved weather forecasts should lead to improved flood forecasts. Advances in probabilistic and ensemble forecasting technologies, combined with the operational use of higher-resolution models, will give greater confidence both in the broad patterns of future weather events and in the precise details of their distribution, which are especially relevant for intra-urban and surface flooding, such as that experienced in 2007. A 1.5 km resolution model tested in 2007 provided greater accuracy in precipitation forecasting, and current limitations in computing power that restrict the scope of such models are likely to be resolved in future. Combining ensembles of individual forecasts with high-resolution models to forecast the probability of intense local rainstorms will increase the effectiveness of this measure in the future and will allow for more informed decision making, particularly by emergency responders. Recent research by the FRMRC on communicating uncertainty in flood forecasting (Faulkner et al., 2007; McCarthy et al., 2007) suggests that risk communication in flood incident management can be improved through developing hydro-meteorological and engineering models to be used as tools for communicating risk between scientists and emergency management professionals.

Flood warning dissemination

With the increased threat of coastal flooding due to higher global temperatures and sea-level rise, there is a need for effective systems to be in place (Jenkins et al., 2007). Since 2004 a new multimedia flood warning dissemination system has come online. This not only enables more people to be contacted but also allows people more choice in how they receive warnings, e.g. by email, telephone or SMS text to a mobile telephone. However, uptake of the Floodline Warnings Direct (FWD) system has been low, with only 41% of people in England and Wales for whom the service is available currently signed up (Pitt, 2007). In the summer 2007 floods as many as 27% of FWD calls were not picked up by recipients, even though it is possible to list mobile telephone numbers as well as land-line numbers at the address covered by the service. It is therefore not clear what effect the widening use of mobile telephones in recent years has had. Calls for the FWD service to be changed from an 'opt-in' system to an 'opt-out' one in high-risk areas, in order to increase uptake further, are currently being considered. FWD works well where it is in service, and where people take advantage of it, but the approach works best for the type of flood caused by a slowly rising river (catchment flooding) and it may be inappropriate for other types of flood such as intra-urban flooding, as was apparent in 2007.

Differences in the relative success of various methods used to disseminate warnings were highlighted in 2007. Door knocking was widely welcomed, for both the summer floods and the threat of coastal flooding on the east coast on 9 November. Flood wardens also worked well in 2007 (Pitt, 2007). The successful role of the media in disseminating warnings, e.g. nationally via local radio in 2007 and locally in Carlisle in 2005, has also been highlighted. Previous and more recent research (Tapsell et al., 2004; Twigger-Ross and Fernandez-Bilbao, 2008) has also highlighted that a 'one size fits all' approach does not work and that warnings need to be tailored to local needs. A range of mechanisms and methods are needed to warn people, along with more targeted warnings to reach the more vulnerable groups within communities (Twigger-Ross and Fernandez-Bilbao, 2008).

There is still uncertainty as to how recipients will respond to the receipt of any future warning, with many taking inappropriate actions or no action at all (Parker et al., 2007; Norwich Union, 2008). As far as the cost/benefit analysis of warnings is concerned, recent research shows that warnings may actually result in less financial savings from reduced damage to property contents than previously thought (Parker et al., 2007). However, research for the EU FLOODsite project indicates that the economic benefits of warnings are wider than is currently assessed, and include benefits from damage savings to non-residential properties, and operating flood barriers, temporary defences and other measures (Parker et al., 2008). Concerns over the effectiveness of flood warnings in eliciting effective risk-reducing behaviour, which may have led to a slightly reduced score for this element of the response group, are balanced by recent developments in weather forecasting which may have led to a slight increase in scoring. We therefore decided that the 2004 scores should remain unchanged.

Flood Fighting

Response group definition

Flood fighting involves actions to manage floodwaters and peak flows during flood events to reduce their impacts.

Measures in this response group are:

- water level control structures;
- demountable or temporary flood defences;
- emergency repair of failing defences; and
- emergency diversions.

The 2004 Foresight report did not predict any great changes to the use of these measures in the UK in the foreseeable future. There appears to be little evidence since then to contradict this view, and so we suggest that the scores for these measures therefore remain as for 2004. However, a few important issues were highlighted during the 2007 floods which have implications for the effectiveness of some of these measures. For example, most pumping stations are automated and powered by electric motors controlled by level sensors. During 2007, Yorkshire Water had no plan for failure in place for the Bransholme pumping station, which plays a key role in draining Hull. Although the pumping may help reduce the effects of flooding, reliance on critical infrastructure, and its subsequent failure, may compromise its effectiveness. Also, with regard to future intra-urban flooding, it could be suggested that many of the measures in this group would not be applicable, e.g. water level structures and certain types of temporary defences.

Since the 2007 floods, the Environment Agency has stated that temporary defences do not at present offer a large-scale alternative to permanent defences as they need significant lead time to deploy (Pitt, 2007). Although it successfully protected properties in Upton-on-Severn in June 2007 this was not the case the following month, as disruption to transport infrastructure meant that the workforce, plant and materials could not reach the deployment location in time. This highlights that these measures are only suitable for use in locations where the necessary resources and materials can be sourced or stored locally. However, temporary defences were successfully deployed to protect Walham substation in Gloucester and electricity infrastructure on the east coast during the 9 November 2007 storm surge. The situation at the Ulley reservoir in 2007 also illustrated the importance and effectiveness of the emergency repair of failing structures. In addition, the predicted deterioration of assets under certain scenarios could reduce the effectiveness of some of these measures. Recent environmental legislation in the form of the EU Floods Directive (Directive 2007/60/EC, October 2007) may also lead to increased use of emergency diversion and flood storage on agricultural land, with implications for environmental quality and economic production. Pitt (2007) also called for the increased use of washlands. This could result in possible conflicts under certain scenarios (World Markets and National Enterprise) between the demand for flood defence and environmental, agricultural and economic concerns.

Collective Damage Avoidance

Response group definition

Collective damage avoidance is action through a publicly organised or spontaneous removal of people, pets or livestock from properties and areas at risk from flooding to a safe location.

This measure focuses on evacuation of river and coastal floodplains, and intra-urban areas at risk.

Response group update

Little has changed since 2004 to indicate significant changes in this response group. The 2007 east coast storm surge saw people successfully evacuated from high-risk locations, to reduce risk to life. However, the 2007 summer floods saw people in some areas being evacuated due to loss of essential services (electricity and water) rather than due to the risk of being flooded. This raises the importance of protecting critical infrastructure. The 2007 floods also highlighted the issue of the location of rescue centres for evacuees. Leisure centres that had been identified as evacuation centres in Humberside were themselves flooded by surface water (Pitt, 2007). This calls for re-evaluation of the location of evacuation centres in recognition of the threat of increased intra-urban flooding. However, it is not considered that the updated climate change and socio-economic scenarios will have any significant impact on the scoring of this response group.

Individual Damage Avoidance

Response group definition

Individual damage avoidance involves temporary flood-proofing, or use of removable household products, to seal or delay potential flood routes into buildings.

The measures in this response group also include moving assets at risk to safety; flood-proofing individual homes using plastic, wooden or metal products that are temporarily fitted to the building, such as floodgates on external doors, windows and patio doors, covers on airbricks, and flexible plastic ‘skirting’ systems; use of sandbags; and fitting non-return valves to prevent floodwater from backing up into the home via drain or sewer pipes.

Response group update

There has been some increased understanding of the measures in this response group since 2004. With regard to temporary flood-proofing of properties, although research quoted in the Pitt Review suggests that there is still low take-up of these products, other research suggests that residents would consider such measures (McCarthy et al., 2006). Emerging results from recent research indicate that these types of flood resistance measures only become cost-beneficial at a 1:25 return period, and that resilience measures such as changing internal features (e.g. resilient plastering) only become cost-beneficial at a 1:10 return period (Thurston et al., 2008). These are early findings and Defra is planning a consultation on these measures later in 2008.

The Pitt Review identifies the need for property owners to take more responsibility for protecting their homes and businesses and for improving their resilience to flooding. The ABI also states that the Government should encourage people to invest in resilience measures. *Making Space for Water* also places increased responsibility on the individual to protect their property and possessions, yet most people are unaware of this and still expect to be protected by the relevant authorities. Recent research findings also suggest that relatively few people take effective individual damage avoidance measures on receipt of a flood warning (Steinführer et al., 2007; Norwich Union, 2008). One inappropriate measure widely used by the public is sandbagging. The 2007 floods highlighted the extensive public reliance on this measure and low awareness that sandbags do not provide effective protection from flooding at the scale of the individual home or business. They are better used strategically and collectively, rather than by individual property owners. Further research has also shown that moving household assets to safety may result in lower economic benefits than previously thought (Parker et al., 2007), although the psychological benefits of saving sentimental possessions remain strong. Overall, there is certainly potential for these measures to reduce flood risk, although this is dependent on increased awareness of the measures and the provision of better incentives for their use. Therefore, we suggest that the scores for this response group remain unchanged as there appears to be no significant justification for a change.

Conclusions

The new developments and understanding outlined above have various implications for the effectiveness of the response measures under different future scenarios. In the World Markets and National Enterprise scenarios, with the highest risk of flooding from sea-level rise and increased levels of precipitation and storminess, preparedness planning (particularly for the location and protection of critical infrastructure) and awareness of flood risk will be important factors affecting the effectiveness of these response measures for all types of flood events and, particularly, for large-scale and coincident flooding. However, weak governance structures may serve to decrease their effectiveness nationally.

Increased flood forecasting and warning capabilities (and confidence in these), and better flood risk mapping and awareness, may help to counter the lower effectiveness of preparedness planning and some individual flood damage avoidance measures and may lead to earlier and more effective actions. Future investment in science and engineering technologies, given sufficient availability of funding and political commitment, should further enable the development of improved floodplain models, maps, forecasting and warning technologies, and flood fighting and damage avoidance measures. However, increased intra-urban flooding may reduce the effectiveness of some of these measures, unless actions are taken to tackle this issue.

While some of the new evidence is fairly significant (for example, advances in weather forecasting), these developments were largely accounted for in the 2004 report. Many of the other developments are still tentative and are not considered strong enough to revise the existing scores. Much that will influence the effectiveness of these response measures is still uncertain. Moreover, there is no significant new evidence indicating that changes should be made to environmental impact, cost-effectiveness and social justice scores from 2004. Arguments regarding these aspects were well rehearsed in 2004 and, although these aspects fare better under some scenarios than others, overall they tend to counterbalance each other. Similarly the social, health and economic dimensions of risk are not seen to have changed sufficiently since 2004 to warrant revisions to scoring. The majority of the arguments on the potential applicability of the various measures in this theme that were put forward in 2004 are still thought to be valid in 2008, and for others more extensive evidence is necessary in order to revise flood risk reduction scores.

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Managing Flood Losses

Nigel Arnell

Response theme definition

This response theme includes groups of measures that seek to reduce the losses that occur during a flood by reducing prior exposure to flood; the theme does not include emergency or temporary measures that are implemented immediately before or during an event (these are covered in the Managing Flood Events response theme). Neither does it cover measures to improve building drainage, which are covered in the Managing the Urban Fabric response theme.

The response groups in this theme are listed in Table B3. A special article on international practice on river and coastal floodplain zoning and corriders is at the end of the section.

Land Use Management and Flood-proofing apply to existing development (removing it, or making it more resilient to damage), while Land Use Planning and Building Codes apply to new development (making sure it avoids flood-prone areas and reducing its vulnerability to damage). Insurance and Health and Social Measures cover responses that aid recovery from flooding. Not only do these measures redistribute losses, but they also affect the magnitude of losses by encouraging (or discouraging) implementation of loss reduction measures.

In 2004, the assumed effectiveness of each of these measures in reducing national flood risk was based on (i) assessment of the inherent effectiveness of the measure and (ii) the proportion of future floodplain property that already exists (and is affected by land use management and flood-proofing) to new development (which is affected by land use planning and building codes). It was recognised in 2004 that the effects of Insurance and Health and Social Measures were actually incorporated into the scores for the other groups in this response theme through the incentives they create – either deliberately or inadvertently.

Table B3: Response groups in the Managing Flood Losses theme

Land Use Management	Reduce current exposure to loss through changing existing land use (e.g. through planned relocation).
Flood-proofing	Introduce retro-fitting protection measures to existing properties.
Land Use Planning	Limit increase in exposure through spatial planning to curb new development in flood-prone areas.
Building Codes	Introduce flood-resilient measures into new buildings through building codes and standards.
Insurance Shared Risk, and Compensation	Support financial recovery from loss.
Health and Social Measures	Provide practical support for recovery from loss.

Response theme update

There have been a number of developments since 2004 that alter the view of the measures in this response theme, and their possible future effectiveness. Two of these developments are generic, and affect all the measures; the others relate specifically to particular groups of measures.

The first key generic development is a change in the 'policy' landscape. These 'policy' developments include:

(i) Defra's *Making Space for Water* initiative;

(ii) implementation of *Planning Policy Statement 25: Development and Flood Risk* (PPS25) and the introduction of Environment Agency high-level targets/outcome measures concerning floodplain development;

(iii) introduction of catchment flood management plans; and

(iv) increased interest by the insurance industry in encouraging methods to reduce the expected increase in exposure of people and property to flooding.

These policy developments influence land use and buildings in combination. Taken together, they imply that the response measures are more likely to be implemented and effective in future than was believed in 2004, although the magnitude of improvement in likely effectiveness is currently difficult to assess.

The second generic development is an increasing awareness that much flood exposure is outside the currently identified floodplains: this was a feature of the summer 2007 floods and indeed other post-2004 events. This implies that measures that rely on the identification of flood-prone areas and properties are less likely to be effective at reducing **national** flood losses than was concluded in 2004. Set against this, it can be assumed that future maps of flood-prone areas will identify more and more flood-prone locations outside the floodplains, following both enhanced flood estimation methods and continued experience.

Recently, there has been an increase in the use and understanding of flood-resistant and flood-resilient technologies (relevant to the Flood-proofing and Building Codes response groups). This is exemplified by the replacement of the term 'flood-proofing' with the concepts of 'flood-resilience' and 'flood-resistance' measures. Estimates of the inherent effectiveness of these measures in 2004 were based on very limited scientific and practical information. Since 2004, there has been more research into the use of flood-resistant and flood-resilient technologies for both existing buildings (ABI, 2003; Bowker, 2007; ongoing ENTEC project under *Making Space for Water*) and new buildings (Communities and Local Government, 2007), and more evidence that effective technologies can be developed and implemented. This would suggest an increase in the potential for these measures to reduce flood losses. Survey evidence collected by the insurance industry following the 2007 floods (interim report of the Pitt Review, paragraph 4.13; Norwich Union press release 9/4/2008) implies low rates of uptake of flood-resilience and flood-resistance measures. The interim report of the Pitt Review identified a lack of incentives for installing flood-resilience and flood-resistance measures. Research is currently underway to increase uptake (under *Making Space for Water*) by seeking to understand factors influencing uptake (knowledge, access to resources, ownership, etc) and the role of incentives provided through, for example, the insurance industry.

Research published since 2004 (Pottier et al., 2005), together with a reassessment of previous research, has highlighted the potential benefits of reducing flood losses through the adoption of land use plans (Land Use Planning response group) that identify different flood hazard zones within a floodplain. Such plans can be very effective in keeping vulnerable developments from particularly high-hazard areas.

Finally, there is much evidence (e.g. paragraph 4.5 of the interim report of the Pitt Review) that many of the properties flooded during summer 2007 were in relatively recent developments. These had been built despite the fact that policies to curb floodplain development were, in principle, in place. This suggests that existing floodplain management policies have been at least partially ineffective to date, a conclusion supported by recent changes in planning (PPS25) and Environment Agency policies.

Revised response scores: inherent potential to reduce future flood risks

This section describes justifications for revisions to the inherent effectiveness of Land Use Management, Flood-proofing, Land Use Planning and Building Codes in reducing losses to existing development (Land Use Management and Flood-proofing) and future development (Land Use Planning and Building Codes).

Note that the effectiveness scores represent the potential likely effect of each measure on flood risk, making assumptions about rates of uptake. In practice, uptake of each measure will be strongly determined by the policy measures and incentive structures (market and non-market) in place. Experience since 2004 – particularly in the 2005 Carlisle and summer 2007 floods – has highlighted the barriers to effective implementation of each measure. These barriers include access to information, availability of financial incentives for implementation, and the potential conflict between development and flood risk management goals, and would need to be addressed if response measures in this theme are to produce the expected reductions in flood risk.

Table B4: Land Use Management

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Land Use Management	1.00	0.90	**0.65** (0.5)	**0.65** (0.5)
Uncertainty range	0.8–1.0	0.8–1.0	**0.35–1** (0.25–1)	**0.35–1** (0.25–1)

Revised scores in bold; original scores in parentheses where there is a change

This group of measures involves the planned relocation of exposed property away from flood-prone areas. There is no change to the potential for these measures to alter the existing land use of flood-prone areas under the World Markets and National Enterprise future scenarios, as this potential was concluded to be small anyway. The potential for these measures to lower flood risks under both the Local Stewardship and Global Sustainability scenarios is now believed to be lower than thought previously, due to the increase in exposure to risk outside the identified floodplains. The uncertainty range has been adjusted accordingly. As long as flood-prone areas can be identified, it is assumed that planned relocation is equally effective in reducing losses to fluvial, coastal, pluvial, groundwater and other types of flood.

Tabke B5: Flood-proofing of existing properties

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Flood-proofing	**0.70** (0.63)	**0.70** (0.63)	**0.70** (0.63)	0.75
Uncertainty range	0.5–0.9	0.5–0.9	0.5–0.9	0.5–0.9

Revised scores in bold; original scores in parentheses where there is a change

These measures involve the retro-fitting of flood-resistant and flood-resilient technologies to existing properties. This response group is linked closely with use of the emergency flood-proofing measures (which may be planned or spontaneous) described in the Managing Flood Events response theme.

The 2004 assessment assumed that retro-fitted flood-proofing could halve losses to existing properties in the floodplain, regardless of the type of flooding (although different techniques would be appropriate where exposure is to fluvial, coastal, pluvial, groundwater or other types of disconnected flooding). It was assumed that uptake rates were 75% under the World Markets, National Enterprise and Local Stewardship scenarios (for different reasons: market-driven in World Markets and National Enterprise, and local policy-driven under Local Stewardship). The potential for flood-proofing measures to reduce losses to existing development under these scenarios in this update is assumed to be slightly lower than in the 2004 assessment, because of the expected increase in number of flood-prone properties outside identified floodplains and the likely reduction in uptake. The 2004 assessment assumed a high potential for flood-proofing measures under Global Sustainability, because it was predicted that properties would be refurbished in generally more robust ways during normal periodic renovation under this future scenario. Take-up rates for specific flood-proofing measures were therefore assumed to be lower. This assumption has not been changed, so effectiveness scores under Global Sustainability are unaltered.

Experience with flood-proofing measures during the 2007 floods and subsequently has identified barriers to their implementation – awareness, access to information and financial incentives – but has not in itself resulted in changes in effectiveness scores.

Table B6: Land Use Planning for future development

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Future Land Use Planning	0.90	**0.8** (0.75)	**0.35** (0.25)	**0.35** (0.25)
Uncertainty range	0.6–1	0.5–1	**0.1–0.9** (0–0.75)	**0.1–0.9** (0–0.75)

Revised scores in bold; original scores in parentheses where there is a change

This measure involves the use of spatial planning to curb inappropriate development in flood-prone locations. The potential for land use planning to deliver flood risk reductions under World Markets is unchanged, as it is believed to be relatively ineffective anyway. Its potential under the other three scenarios has been reduced, to account for increasing awareness of exposure outside identified floodplains. However, provided the relevant flood-prone areas can be identified, spatial planning should be equally effective in reducing losses due to fluvial, coastal, pluvial, groundwater and other types of flood.

Experience with the effectiveness of land use planning measures (such as PPS25) has identified barriers to their potential to reduce flood risk, but has not in itself resulted in changes in risk reduction scores. This is because the original scores made assumptions about future effectiveness without specifying exactly the form of the measures or how they would be implemented. For similar reasons, increased awareness of the effectiveness of land use policies that identify different risk zones has not resulted in changes in flood risk reduction scores.

Table B7: Building Codes

	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Building Codes	**0.80** (0.75)	**0.80** (0.75)	0.50	0.50
Uncertainty range	0.25–1	0.25–1	0.25–1	0.25–1

Revised scores in bold; original scores in parentheses where there is a change

This measure involves the use of building codes and practices to reduce the flood vulnerability of new development. The potential for these measures under the World Markets and National Enterprise scenarios should be slightly reduced, to account for exposure outside identified floodplains. The potential under Local Stewardship and Global Sustainability is unchanged, because it can be assumed that improved building controls would be implemented even outside identified floodplains. It is assumed that the effect of building codes on damage to an individual property would be the same, regardless of the type of flooding to which the building is exposed.

Revised response scores: impact on future national flood risk

The impact of each group of measures on reducing future national flood risk depends on the rates of new development and redevelopment within flood-prone areas. In this context, there is no reason to change the projections used in the 2004 Foresight report. Table B8 gives the revised scores showing the effectiveness of each measure in reducing **national** flood risk (a revision to Table 2.8 in volume 2 of the 2004 Foresight report). The scores have been derived by weighting the inherent potential scores according to the relative rates of development and redevelopment.

Table B8: Revised impact scores for national flood risk

	World Markets	National Enterprise	Local Stewardship	Global Responsibility
Land Use Management	1.00	0.96	**0.72** (0.60)	**0.73** (0.61)
Uncertainty range	*0.92–1.0*	*0.91–1.0*	*0.48–1.0*	*0.5–1.0*
Flood-proofing	**0.88** (0.86)	**0.87** (0.84)	**0.76** (0.70)	**0.81**(0.81)
Uncertainty range	*0.81–0.96*	*0.79–0.96*	*0.6–0.92*	*0.61–0.92*
Land Use Planning	0.94	**0.89** (0.86)	**0.87** (0.85)	**0.85** (0.83)
Uncertainty range	*0.76–1.0*	*0.7–1.0*	*0.82–0.98*	*0.80–0.98*
Building Codes	**0.88** (0.85)	**0.89** (0.86)	0.90	0.89
Uncertainty range	*0.70–1.0*	*0.71–1.0*	*0.85–1.0*	*0.83–1.0*

Revised scores in bold; original scores in parentheses where there is a change (new uncertainty scores only)

In practice, the four groups of measures will be operated together and their potential when implemented as part of a integrated portfolio is greater than the sum of their potentials if invoked separately. Table B9 shows the revised table for combined response scores (a revision to Table 2.9 in volume 2 of the 2004 Foresight report).

Table B9: Revised flood risk reduction impact score for national flood risk for combined response measures

	World Markets	National Enterprise	Local Stewardship	Global Responsibility
Land Use Planning and Management	**0.94** (0.93)	**0.84** (0.81)	**0.59** (0.45)	**0.58** (0.45)
Uncertainty range	*0.68–1.0*	*0.63–1.0*	*0.30–0.98*	*0.29–0.98*
Flood-proofing Buildings	**0.76** (0.71)	**0.76** (0.70)	**0.66** (0.60)	**0.69** (0.69)
Uncertainty range	*0.5–0.96*	*0.5–0.96*	*0.45–0.92*	*0.44–0.92*

Revised scores in bold; original scores in parentheses where there is a change

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River and Coastal Flood Plain Zoning and Corridors

Edmund Penning-Rowsell, Robert Nicholls, Sophie Nicholson-Cole and Susanne Rupp-Armstrong

There is a strong tradition of floodplain zoning in many countries (Chatterton et al., 1994; Penning-Rowsell and Tunstall, 1996). This zoning is undertaken for a number of reasons, principal among these being the capability to target planning regulations for specific risk bands to the appropriate areas in the floodplain. Most countries (e.g. France, Germany, Hungary and USA) define a series of risk-based bands or zones, the outermost one of which is often the 1 per cent flood (i.e. that with a 100-year return period). However, some countries go further, defining a zone delimiting an even more extreme event, such as the 0.2 per cent flood (500-year return period), or even mapping the outer edges of the geomorphologically-defined floodplain itself. Methods used to map the zones vary widely. For example, France has developed a system of very precisely modelled floodplains, whereas other countries have been more pragmatic and used a range of data-based approaches including historical events, modelling results, or geological deposits (i.e. the sedimentary 'fill' in valley bottoms and coastal plains).

The uses to which risk maps and hazard zones are put also vary between countries, but each zone is usually associated with different types of permitted development (Penning-Rowsell and Tunstall, 1996). High-hazard zones are often defined as areas where risk to life during flood events is acute and where development is therefore prohibited entirely (e.g. in New South Wales, Australia). Other types of development may be allowed in different zones. In France, residential properties are prohibited in zones where the risk of flooding is greater than 2 per cent, but recreational areas and the like are permitted even in the high-hazard zones. There are a range of incentives to encourage local authorities to accept and conform to nationally defined zones. For example in the USA, national zoning arrangements are linked to the federal flood insurance programme, such that communities can only gain access to this programme if they agree to zoning of their floodplain areas.

Despite the existence of laws and incentives, evidence shows that these zoning arrangements are not always fully successful (Parker, 2001). Boundaries can be disputed, owing to poor data or inadequate modelling. Local political influences can 'shift' the zone boundaries if they threaten to inhibit the development of key industrial sites (Pottier et al., 2005). Development permissions within zones can be subjected to local political pressures (Parker, 2001). Nevertheless, zoning provides a mechanism to allow development in the floodplain while avoiding vulnerable development in high-risk areas, and this appears, on the balance of evidence, to be beneficial.

The Environment Agency now has a complete suite of flood maps, showing the outline of the 100-year event (or similar) and more extreme floods. These maps do not show high-hazard zones, and this is a deficiency. Nor do they delimit the zones where flooding is more frequent, which is regrettable as these areas are where development should be discouraged even more than at the edges of the 1 per cent floodplain. PPS25 lays down guidance as to the types of development that should be permitted in the indicative floodplain zones, together with exception tests that allow variation from the central guidance in particular circumstances (e.g. where a whole community is located in the flood risk zone and would be 'blighted' if all development were prohibited). In terms of flood mapping, the Environment Agency has made great strides in the last decade, but the current situation still falls somewhat short of best practices elsewhere in the world.

While floodplain zoning along inland floodplains would be desirable, the case for zoning coastal floodplains is even stronger. Given the observed rise in relative sea level around Britain's coast, and the near inevitability that this rise will continue for many centuries (see the update to the Relative Sea-Level Rise driver), coastal flood risks will also progressively rise unless corresponding risk reduction strategies are implemented. In coastal and estuarine areas, four main risk reduction response groups were identified in Foresight 2004: Coastal Defences, Reducing Coastal Energy, Realignment/Abandonment of Coastal Defences and Coastal Morphological Protection.

To 'hold the line' in shoreline management terms, the first two response groups could be implemented, but the costs of doing so will increase dramatically with sea-level rise, as shown by Foresight 2004 (Townend and Burgess, 2004; Burgess and Townend, 2004). Furthermore, this approach may be unsustainable due to its poor performance in terms of environmental impacts and social inequalities. Changing societal attitudes to risk and vulnerability (during the 20th century people became increasingly intolerant of flooding) also raises questions about future attitudes to the inevitable residual risk of flooding that is associated that a 'hold the line' response, even if this risk is small.

Realignment of coastal defences and coastal morphological protection offer alternative risk reduction strategies, and might even be useful in areas we will defend, such as along the Thames (Shih and Nicholls, 2007). These strategies involve allowing widespread (although not universal) coastal retreat, and it is important that land use planning maintains, and even creates, space for coastal retreat. For instance, developing extra space along the Thames via managed realignment would increase the storage available in the Thames at high tidal levels, and provide space for raising (and setting back) defences if and where needed.

It would also allow people better access to the tidal river and their local environment, as well as allowing more space for estuarine ecosystems. However, analysis shows that significant benefits will only emerge from a flexible, adaptive strategic approach to realignment that fully exploits the opportunities for retreat raised by the redevelopment and renewal cycle, over a number of decades (Shih and Nicholls, 2007). This conclusion for the Thames appears to be more generally applicable to UK coasts.

At present, coastal governance in the UK does not have the capacity to deliver a strategic, managed realignment approach of this type (Milligan et al., 2008; Nicholson-Cole and O'Riordan, forthcoming; O'Riordan et al., 2008). Even robust policy initiatives such as the updated PPS25 appear to be rather fragmented in their approach and are not fully co-ordinated with other aspects of coastal policy and governance. Evidence shows that new buildings are still allowed in the most seaward locations of settlements and building plots, rather than in the most landward position consistent with an anticipatory retreat strategy. Where coastal retreat options are being developed and initiated in and near built-up areas, outcomes appear piecemeal and ad hoc, tend not to be commonly agreed or inclusive of community interests, and result in the costs or losses being borne by individuals. This is largely because of a lack of co-ordination between present national policy and local options for delivery, and the absence of any compensation or adaptation arrangements (Milligan et al., 2008; Nicholson-Cole and O'Riordan, forthcoming; O'Riordan et al., 2008). Taking the Phase 2 Shoreline Management Plan for Sub-Cell 3b in Norfolk as an example, this situation has been shown to lead to feelings of unfairness and inequity in the minds of people living in locations where significant change is intended (Milligan et al., 2006; O'Riordan et al., 2006). This is a significant problem which is likely to translate into a major barrier to widespread implementation of adaptation and realignment responses in the future (Nicholson-Cole and O'Riordan, forthcoming).

These arguments inevitably lead to questions concerning fair treatment of those directly affected by such zoning, and a small number of studies have sought to scope conceivable alternatives for compensation. Suggestions include national or regional solidarity funds to either acquire land or compensate for values foregone, sourced through flood defence levies or marine aggregate taxation (see, for example, Taussik et al., 2006). There are examples from both Europe and North America of schemes that create and promote space for coastal change. In Spain, the national Ministry of Environment safeguards the Maritime Terrestrial Public Domain (a protection area that extends up to 100 m inland, and its catchment area up to 500 m, inland) and buys up land of high natural capital value where this backs onto the public domain. Danish authorities provide compensation from a national flood fund should damage occur (financed through adding DKK20 (approximately €2.70) per year to every fire insurance policy). In France, the 1995 Barnier Act led to the introduction of a national expropriation fund for properties most at risk from natural hazards (Doody et al., 2004). In the USA, within the auspices of the National Flood Insurance Program, after coastal disasters communities can be bought out, with the land acquired being released for public use.

In conclusion, the creation and maintenance of flood risk zones or corridors for managed realignment of defences and allowed morphological adjustment along rivers and at the coast require a significant change to planning and policy regimes in the UK. This will involve the designation of corridors where retreat might be required, well in advance of any retreat options being put into practice (say, at least 50 to 100 years into the future). Within a corridor zoned for possible retreat, undeveloped land would remain undeveloped (or at least constrained with specific caveats), and all the relocation opportunities within developed areas would be systematically exploited. This would need a long-term and flexible strategy that can evolve as we become more certain about future flood probabilities and the resulting requirements for the creation of additional space for floodwaters along our rivers and coastlines.

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River Engineering and Maintenance

Colin Thorne and Edward Evans

Response theme overview

There has perhaps been an intensification since 2004 of the long-established trend to regard river engineering not as a stand-alone solution to flood risk management problems, but as a vital part of a multi-functional portfolio of structural and non-structural responses to future flood risk.

River Conveyance

Response group definition

River conveyance includes engineering measures to increase the capacity of rivers and floodplains to convey floodwater.

The objective of increasing conveyance is to allow the river to carry more floodwater within its channel than would occur naturally, so reducing frequency of over-bank flooding and the depth of inundation when an out-of-bank flow does occur. This is useful in quickly removing water from a flood-prone area, but it does speed the passage of floodwater through the system; while reducing or eliminating the attenuating effect of floodplain storage, it may increase flood probability or depth of inundation in the reaches downstream.

Four forms of engineering intervention are typically implemented when improving river conveyance for flood defence:

- reducing the hydraulic resistance of existing channels by altering their geometry and removing excess sediment and/or vegetation;
- channelisation or creation of multi-stage channels to increase their discharge capacity;
- forming flood-bypass or diversion channels by opening up old channels or creating new channels on the floodplain; and
- enhancing the conveyance of natural or artificial flow paths on the floodplain by removing inappropriate vegetation and/or natural or man-made obstacles to flow.

In practice, the efficacy of these measures is limited by what is feasible in engineering terms and sustainable in terms of cost-benefit ratio, social justice and environmental impact.

Response group update

In the 2004 analysis, improving river conveyance emerged as one of the most effective responses to managing flood risk independent of the scenario selected for analysis, and nothing has happened to change that view during the last four years. However, debate concerning some of the issues that were emerging in 2004 has progressed and new insights have resulted. Specifically, the strongly expressed views of stakeholders affected by the flood events of summer 2007 have refocused public attention on the commitment displayed by the responsible bodies to performing the channel maintenance necessary to support artificially increased conveyance, and on policies that would target resources for maintenance on urban rather than rural areas.

The driver update for River Morphology and Sediment Supply concluded that flood risks associated with this driver are likely to rise significantly during the remainder of this century under the baseline assumption (business as usual). These changes, combined with increases in flood probability due to climate change, changes in catchment runoff and deterioration of flood defence assets in unstable channels, will place increasing pressure on this response group to eliminate, or at least mitigate, the resulting increases in flood probability.

This response group would seek to control morphological instability and/or elevated rates of sedimentation though capital works to re-section unstable channels and maintenance to remove excess sediment. However, recent experience demonstrates that the scope for these types of solution is increasingly limited by issues concerning the multi-functional use of British rivers and the sustainability of such direct interventions in the fluvial system.

For example, in the Lower Thames Strategy Study, options for capital works for flood defence involving diversion channels in the floodplain in one reach and bed re-profiling to increase in-channel conveyance capacity in another have been heavily challenged on grounds of environmental impact, cost and social equity. While it is possible that innovative approaches that involve the creation of diversion channels with enhanced environmental features and 'patchwork dredging' in place of traditional bed re-profiling may be feasible, it is clear that such works will in future only proceed as part of multi-functional river management that seeks sustainable solutions by balancing the needs of flood defence interests against those of nature and cost-effectiveness (i.e. low maintenance).

Similarly, in the River Kent in Cumbria, maintenance involving gravel extraction to remove bars and sustain the capacity of the flood control channel to convey floods through Kendal is opposed by Natural England on environmental grounds. While the case for maintaining conveyance through Kendal for the public good is unanswerable, it seems likely that local maintenance practices will still have to change to accommodate environmental goals. In other areas, where the case for maintenance is less clear, it seems likely that sediment removal will be less and less of an option in flood defence.

The driver update for Vegetation and Conveyance also concluded that flood risks associated with that driver are likely to rise significantly during the remainder of this century under the baseline condition. This response group would seek to control excessive vegetation through increases in the frequency and/or intensity of vegetation cutting. However, evidence emerging from consideration of the Environmental Regulation driver reveals strong and growing opposition to vegetation removal, on environmental grounds. While there are reasons for optimism that new approaches to maintenance, involving selective clearance and avoiding activities during periods key to promoting habitats and biodiversity, can successfully balance the needs of flood defence and nature, it is apparent that the scope for managing future increases in flood risk using this response may be more limited than was realised in 2004.

It is also clearer now than it was in 2004 that the expenditure of public funds on capital works and, particularly, maintenance activities will continue to come under increasing scrutiny. Capital costs range from tens to hundreds of thousands of pounds per kilometre of channel, while maintaining conveyance in a conventionally improved, engineered channel runs at between 1% and 5% of the capital cost, annually. Funding generally comes from the public purse, and expenditure is subject to meeting stringent economic, social and environmental criteria. Costs are currently not recovered directly from beneficiaries. Given this, it is not surprising that capital works and maintenance related to improving conveyance will increasingly be focused in urban areas where the social, health and economic consequences of flooding are most severe. Conversely, channels may be allowed to 'renaturalise' in rural areas, where environmental benefits may be more easily realised and flood attenuation may benefit downstream communities. This was dealt with in the update for the Managing Rural Conveyance response group.

Given the different economic and social backdrops provided by the future scenarios, it appears more likely than ever that improving channel conveyance would not be economically feasible under the poorer Local Stewardship future scenario and unacceptable under the environmentally aligned Global Sustainability. It would, however, continue to feature prominently under the less environmentally oriented National Enterprise and the more prosperous, but less environmentally aware, World Market future scenario.

Conclusion

Increasing conveyance through capital works followed by periodic maintenance is a proven way of reducing local flood risk, and can be highly cost-effective. However, future uptake may be limited by growing concerns over the potential for triggering adverse morphological and environmental changes, increasing downstream flood risks, and tying future generations to the recurrent capital and maintenance costs associated with such works. These factors make the efficacy of this response to future flood risks strongly scenario dependent. However, most of this was foreseen in the 2004 report and developments since 2004 do not merit a change in the risk reduction multiplier scores for this response.

Engineered Flood Storage

Response group definition

Engineered flood storage increases the capacity of fluvial systems temporarily to store floodwater through a variety of engineered measures, some combined with natural features of the river system and its floodplain.

In this response group the measures include:

- creating a flood-storage reservoir through the construction of a dam or a flood barrier;
- creating washlands on floodplains through the construction of embankments;
- enhancing the natural storage provided by floodplain topography; and
- developing artificial storage sites near the river system, above or below ground level.

The aim is temporarily to retain floodwater locally, reducing the magnitude of the flood peak in a flood-vulnerable reach downstream and, in some cases, acting to desynchronise the arrival of floodwaters from different parts of the catchment or different tributaries in the drainage system. These functions may provide a significant reduction in flood risk, but relying on increasing storage alone seldom provides a cost-effective solution and so this response is usually invoked as part of a broader flood alleviation scheme. Often, engineered storage is used as part of a multi-functional approach to meet other goals for habitat creation or sediment retention, which can reduce the effectiveness of the site if this is measured solely in terms of its flood defence benefits.

The feasibility of this form of response depends on the physical attributes of the project river (particularly catchment terrain and land availability upstream of the area to be protected), existing land use and the co-operation of land owners and planning authorities to 'buy into' the vision of the flood managers and project designers. While the physical geography or geology of many catchments permanently rules out this response in many parts of England, recent trends in land planning regulations, and the subsidies and programmes available for countryside stewardship schemes and land management practices that promote habitat creation and increased biodiversity in rural areas, suggest that opposition from land owners may be less of an issue in the future than it has been in the past, especially under the more environmentally aligned scenarios.

Response group update

It has long been routine practice to explore the possibility for engineered flood storage to contribute to new or upgraded flood alleviation schemes around the UK. The Lincoln Flood Alleviation Scheme built in the 1980s is a successful example, which combined two major, controlled washlands upstream of the city with necessarily limited increases in conveyance and defence-raising within the historic city centre (Wakelin et al., 1987).

The potential for engineered flood storage to contribute significantly to flood defence has been further demonstrated since 2004 by the Harbertonford Flood Alleviation Scheme, which was constructed in 2002 and tested by heavy flood runoff during summer 2007. Parker Dam, on the River Harbourne upstream of the settlement, retains flood flows in excess of the five-year event in a seasonally flooded, washland area. Conveyance in the channel through the settlement has been increased to carry the five-year return period discharge through environmentally sensitive improvements that retain the aesthetic and ecological functions of the stream, while reducing sediment-related maintenance requirements to a minimum. Recent adoption of engineered flood storage in planned schemes in Scotland (e.g. Burn of Mossett and White Cart Water) and application of engineered storage to help control tidal flooding (Alkborough Flats, Lincolnshire) suggest that future uptake of this response may be greater than predicted in 2004.

Conclusions

It is concluded that engineered flood storage will continue to contribute significantly to flood risk management. The creation of seasonally flooded storage areas and washlands certainly has the potential to be more sustainable than simply raising linear flood defences in response to future increases in flood risk, where sites that are physically suitable exist. This is reflected in the scores awarded for flood risk reduction multipliers in 2004, which ranged from 0.78 to 0.89. This range reflects the possibility that stakeholder attitudes could limit uptake of engineered storage options for washland creation under the more consumer-oriented future scenario (World Markets) while community-aligned policies under, for example, Global Sustainability could promote this response by providing the necessary fiscal mechanisms to support ongoing income-generating activities in the storage basins or appropriate compensation for loss of earnings. However, while the evidence base to support these conclusions has grown since 2004, no new information has emerged that would justify changing these scores.

Floodwater Transfer

Floodwater transfer involves engineered measures to convey excess water from one river system to another system that is better able to deal with the floodwater and the associated flood risk.

Typically, the measures invoked involve:

- engineering works to allow pumped or gravity transfer of floodwater via natural or artificial channels to a receiving water system; and
- 'compensatory' works in the recipient system to control the resulting flood risk – these could include increasing conveyance, flood embankments, and the provision of flood storage.

This response operates by conveying excess floodwater from one river system to another, but within the UK this is rarely practical as a means of alleviating flood risk because of physical limitations on the potential for inter-basin transfers and the social, economic and environmental issues raised by moving floodwater around in this way.

Response group update

In 2004 it was noted that the efficacy of this response could decline in the future due to climate-related increases in the frequency and magnitude of flood discharges in source systems, physical deterioration of transfer systems, and as the ability of receiving systems to accept the floodwater with an acceptable level of risk decreases with time. It was concluded that the potential for floodwater transfer in the UK will always be limited by topographical and hydraulic factors, and the sustainability of floodwater transfer was rated as low under all future scenarios. These arguments were reflected in the scores awarded to Floodwater Transfer as a response to future flood risk, which ranged from 1.0 under Local Stewardship to 0.99 for the other three scenarios.

In the interim the concerns identified in 2004 have, if anything, grown. The practical utility of this response is increasingly questionable, especially in relation to the environmental impacts of transferring floodwater between river basins and issues centred on the degree to which such actions can ever be socially equitable. Hence, there is no case for rescoring this response in the current review.

River Defences

Response group definition

River defences are artificial structures, sometimes combined with natural formations, whose main purpose is to confine floodwater to specific areas, preventing it from spreading.

River defences may consist of:

- flood embankments and walls along the river channel, sometimes with associated river-training measures;
- ring dikes around vulnerable areas;
- specialist structures, e.g. demountable defences and floodgates to prevent floodwater from entering specific areas; and
- linear infrastructure such as road and rail embankments designed also to act as flood defences.

River defences work by blocking potential flood pathways to reduce the probability of flooding in the protected area, providing a pre-determined standard of service based on the consequential losses should a flood occur. There is a long history of using river defences to manage flooding in the UK, and experience demonstrates that they are capable of providing flood defence that is efficient, cost-effective and popular with stakeholders living in the protected area. Importantly, insurers recognise the flood risk benefits of river defences and provide affordable insurance to owners of homes and businesses in defended areas of river floodplains.

Response group update

Since 2004 it has become increasingly recognised that river defences are not in themselves a panacea for future increases in flood risk. To continue providing the standard of protection required as climate change increases flood probability, defences may become so high as to destroy the property or amenity values that they seek to defend. Under these circumstances, the engineering becomes increasingly difficult and expensive too and, as defences become higher, the risk to life in the event of asset failure or exceedance increases. Also, the reliability of flood defences will decline through time unless they are properly maintained – which requires an annual input that averages 1 per cent to 5 per cent of the capital cost of constructing them and which may be unsupportable in the economically weaker scenarios. Maintenance costs will further increase if, in future, flooding is more frequent and/or prolonged, or if the physical condition of defences deteriorates due to morphological channel changes (e.g. channel widening or incision) that undermine them.

It has long been known by professionals, and is becoming increasingly known among the public, that flood defences along one reach of a river can raise floodwater levels both upstream and downstream, potentially increasing flood risk in these areas. This raises issues of social equity that can provoke strong opposition to the construction of new defences, or the upgrading of existing structures. For example, in 2007 plans for new defences to protect Attenborough, on the River Trent near Nottingham, were vehemently opposed by the residents of Gunthorpe (a village in the Trent floodplain downstream) on the basis that the loss of flood storage in Attenborough would lead to a marginal, but detrimental, increase in flood levels in the largely rural reach downstream between Stoke Bardolph and Fiskerton – which includes Gunthorpe. Evidence emerging since 2004 points towards stakeholders in areas downstream of new or upgraded defences becoming increasingly vocal and effective in opposing the implementation of this response. This issue is discussed further in the theme dealing with Public Attitudes and Expectations.

The flood events of 2007 also reinforced the fact that linear flood defences that divide rivers from urban areas require provision for effective cross-drainage (by gravity or pumped drainage) to allow local rainfall to enter the river as a ‘receiving water’. While the defences certainly reduce the probability of river flooding in the urban area, if cross-drainage is compromised (due to pump failure or high flood stages in the river that prevent gravity drainage), the effect may be to increase the probability of pluvial, sewer or coincident flooding.

Finally, evidence continues to accrue that the presence of flood defences can encourage development in the protected floodplain based on the incorrect perception that the chance of flooding has been eliminated. This false sense of security may lead to inappropriate development that increases the consequences of flooding to a level that offsets the risk reduction gained through reduction of the probability of flooding. This can result in stakeholder pressure for the standard of service to be raised – the escalator effect.

Recent trends in the use of this response suggest that while river defences will remain a cornerstone of flood risk management in the UK for the remainder of this century and beyond, they will not be used alone but as a major component of an integrated portfolio of flood management measures. The extent of defences will increasingly be limited to urban areas where the social and health consequences of flooding are severe, the benefits justify the high capital and maintenance costs of structural works, and the public good outweighs the negative environmental impacts of isolating the channel from its floodplain. The height of defences will be limited by considerations of cost, aesthetics and environmental impacts, with non-structural measures (improved forecasting and warning, flood fighting, improved preparedness, etc.) used to reduce residual risks in integrated schemes that combine defences with other forms of flood risk management.

Demountable defences have been used as an approach to limit the visual impact of permanent defences. However, these are not low-cost panaceas and require careful procedures to be put in place for their mobilisation at time of flooding. In the summer 2007 floods, the defences at Bewdley worked successfully, but in the July event those at Upton-on-Severn could not be erected at the location they were designed for because access routes from their point of storage were flooded or blocked by traffic. Flood defence professionals are coming to the view that it is preferable for significant parts of demountable defences to be permanent (e.g. columns and footings) in order to facilitate rapid deployment.

Under policies like those emerging from *Making Space for Water* and the EU Water Framework Directive, flood defence measures invoked under the more environmentally aligned future scenarios will take better account of the dynamics of sediment and plant debris in fluvial systems. Indeed, under these future scenarios, options appraisal and selection will increasingly stress environmental outcomes alongside engineering efficacy in multi-criteria analyses of policy and option objectives. Indeed, this is already happening in the catchment flood management plans being developed by the Environment Agency for all catchments in England and Wales, with strategic environmental assessment sitting alongside catchment flood management planning and the most environmentally favourable option being recommended wherever possible.

The Lower Colne scheme to the west of London in the 1980s was a pathfinder in combining storage, increased conveyance, channel realignment and raised defences in an environmentally sensitive way and was one of the first examples of multi-disciplinary working and use of the, then new, regulations and techniques of environmental impact assessment to screen and improve engineering. In the spirit of *Making Space for Water*, more sustainable approaches now appear increasingly likely to be selected and these favour realigning or retiring flood defences to allow river and floodplain restoration in flood-suitable areas, and the integration of river defences with complementary structural and non-structural measures in integrated portfolios of flood risk management responses. It is in this context that the 2004 analysis concluded that river defences can be both effective and sustainable when implemented appropriately and, on this basis, they will remain central to future flood risk management. There is, therefore, no case for altering the high scores awarded in 2004.

Coastal Engineering and Management

Robert Nicholls and Jonathan Simm

Coastal Defences

Response group definition

Coastal defences are structures or features that prevent water from entering a defined area or limit the action of coastal erosion.

Coastal defences include flood embankments or dikes, seawalls, revetments and beaches. In an estuarine context they can also include tidal barriers and demountable flood walls. To fulfil their purpose, defences must be high enough to prevent water from flowing over their crest, and of a shape and design that limits the amount of wave overtopping while minimising the risk of breaching. Secondary flood defences behind a main barrier can also be important.

Coastal defences operate by blocking potential flood pathways to reduce the probability of flooding in the protected area, providing a pre-determined standard of service based for flood defence that is set according to the consequential losses should a flood occur. There is a long history of using coastal defences to manage flooding in the UK, and experience demonstrates that they are capable of providing flood defence that is efficient, cost-effective and popular with stakeholders living in the protected area. Importantly, insurers recognise the flood risk reduction benefits of coastal defences and provide affordable insurance to owners of homes and businesses in defended areas of the floodplain.

Response group update

No radical changes in the design, construction and management of coastal defences have emerged since 2004. There is continued confidence in the use of physical barriers to manage flooding during the next 100 years, although there is increasing concern about the sustainability of defences as an option in sparsely populated and environmentally sensitive areas. This concern is particularly evident along coasts such as North Norfolk, which are subject to the combined challenge of beach erosion and rising sea levels. Studies underway since 2004 on the Thames tidal defences by the Environment Agency's TE2100 team have also emphasised the enormous cost of raising defences to respond to rising sea levels, particularly for the more extreme sea-level scenarios associated with ice sheet melting and long-term climate change (post-2080s). The driver update for Relative Sea-level Rise provides more details on this topic. Tidal barriers towards the seaward end of populated estuaries may also become a more common feature under the more extreme climate change scenarios. Maintenance of exposed coastal defences continues to be a significant issue, with life expectancy of a scheme limited to 30–50 years before major refurbishment or replacement. Adaptability to rising sea levels will dominate future design thinking, alongside building in resilience to failure in the event of the defences being overtopped.

Resolving interactions with coastal morphology and natural defences (see also the Morphological Protection response group) is becoming ever more critical in the light of the studies reported in the driver update for Coastal Morphology and Sediment Supply.

Finally, coastal defences protect significant amounts of critical infrastructure in coastal areas, including roads, railways, power stations and gas processing plants. As relative sea level continues to rise, relocation or realignment of these assets, or provision of increasingly heavy coastal defences, may well become a more cost-effective solution than a policy to 'hold the line' more generally. Nevertheless, coastal defences can be effective and sustainable when implemented appropriately and, on this basis, they will remain central to future flood risk management. There is, therefore, no case for altering the high scores awarded in 2004.

Realignment of Coastal Defences

Response group definition

Realignment of coastal defences entails shifting defence infrastructure landward to provide a wider and more resilient foreshore that can act as a natural buffer zone against flooding or erosion.

Implicit in the definition is the relocation inland, or abandonment, of any vital infrastructure currently protected by defences.

Response group update

The two major new issues that have emerged since the 2004 report are the increasing costs of managed realignment schemes and the rising value of agricultural land.

Evidence has recently been collected by Rupp-Armstrong (2008) on the costs of managed realignment schemes and regulated tidal exchange schemes across Europe and, particularly, in the UK. The evidence suggests that first generation schemes (essentially those before the year 2000) did not involve as many licensing, modelling and consequent mitigation requirements as today's schemes, and thus should not be used as a basis for making cost assumptions for future schemes. According to Rupp-Armstrong's figures, costs for post-2000 schemes in Great Britain have averaged at £11,000 per hectare for schemes without major defence construction, rising to £47,000 per hectare for schemes where major new retreated defences are necessary. These compare with equivalent pre-2000 figures of £6,000 and £7,000 per hectare, respectively.

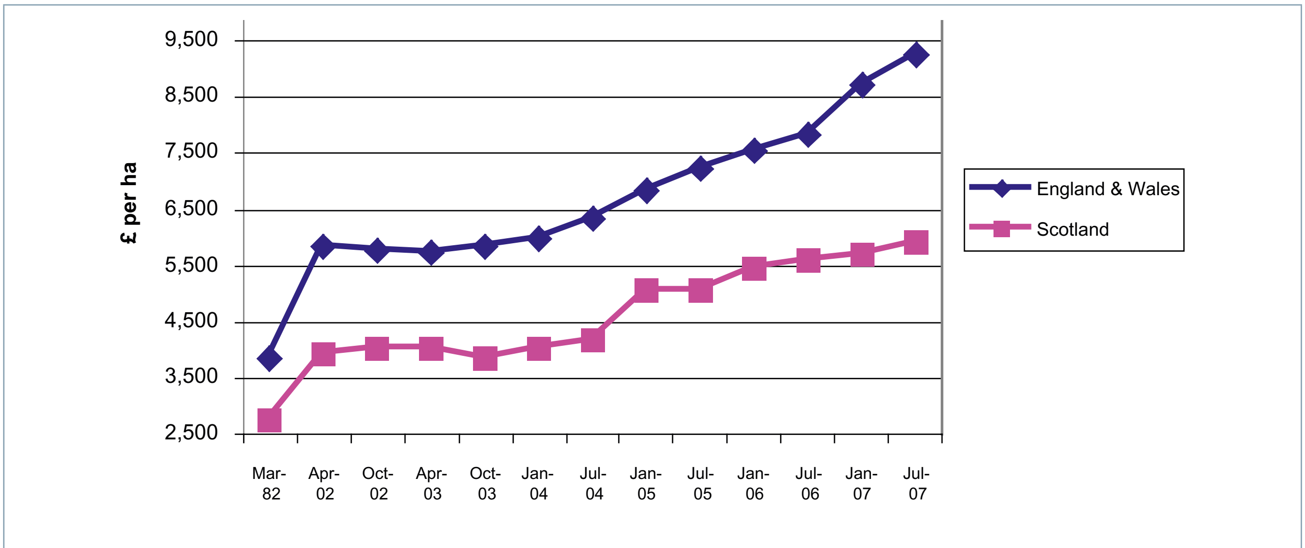
One of the factors driving up costs has been the move towards schemes associated with the provision of compensatory inter-tidal habitat areas in designated English estuaries (i.e. Natura 2000/Special Sites of Scientific Interest/ Ramsar internationally designated sites). Compensatory schemes often require the building of a new coastal defence line. Also, other significant costs are incurred in the scheme preparation phase, including the production of environmental impact assessments to meet the requirements for planning permission and appropriate assessments to meet the requirements of European Directives (Habitats and Birds Directives), as part of which sophisticated hydrodynamic modelling may be required to confirm that the scheme does not negatively affect the estuarine ecosystem.

The other issue that has seen a change since 2004 is the rising value of our agricultural land, from a fairly steady price of just under £6,000 per hectare in 2002–04 to nearly £10,000 per hectare today (Figure B1). Rising agricultural land prices have a direct impact on the cost of managed realignment schemes and this trend is unlikely to be reversed in the immediate future given current expectations of worldwide food shortages and increased biofuel production. Further issues of flood security may emerge in the coming years and these may affect the extent to which managed realignment may be implemented.

Despite these issues with the cost effectiveness of managed realignment, there will be many situations where it will be necessary, and this remains an effective and sustainable solution when implemented appropriately. However, the social and political costs of realignment should be noted, and public resistance to realignment is widely observed. These issues may remain important barriers to implementation and they have become even more evident since 2004.

There is, therefore, no case for altering the flood risk reduction scores awarded in 2004, although the very positive cost-effectiveness score awarded in 2004 for World Markets and Global Sustainability should probably now be reduced. Note that the long-term (post-2080s) commitment to sea-level rise discussed in the Relative Sea-Level Rise driver description suggests that realignment of coastal defences requires long-term strategic planning linked to land use planning.

Figure B1: Value of unequipped dairy land with vacant possession



Source: Valuation Office reports.

Abandonment of Coastal Defences

Response group definition

Abandonment of flood defences is a form of realignment – it involves a conscious management decision not to maintain existing defences. For example, a storm can create a natural breach and financial constraints may mean that existing defences are not maintained or repaired to the desired standard.

The decision to abandon a coastal defence may be taken either as a matter of policy or due to financial or other constraints. The key difference between managed realignment and abandonment of defences is that the latter is an unmanaged process. In Foresight 2004, this response was only thought likely under the National Enterprise and Local Stewardship scenarios, primarily driven by limited funds in these situations.

Response group update

Since 2004, there has been increasing recognition of the heath and safety implications of this approach. The Foresight 2004 report spoke of health and safety mitigation being limited to fencing and signage, but there may be regulatory pressure for unsafe defences to be removed, which will add significantly to the costs of this approach. This might make the approach less than neutral in terms of cost effectiveness. However, there seems to be no case for changing the flood risk reduction scores awarded in 2004.

Reduce Coastal Energy

Response group definition

Reducing coastal energy involves modulators to extract energy from waves and currents so that less energy reaches the shoreline.

This response group includes such measures as:

- foreshore recharge to improve dissipation properties of beaches or inter-tidal flats;
- submerged reefs or 'baffle mats' to attenuate energy;
- offshore breakwaters or fishtail groynes to block or divert energy; and
- energy converters.

The passive structure options listed above have all been implemented within the UK and are established approaches for coastal defence. As noted in the 2004 Foresight report, they are often associated with schemes for morphological protection (see below). Energy extraction techniques, by contrast, have not yet seen active service in combination with coastal defences and therefore their cost effectiveness remains somewhat speculative.

Response group update

No significant further evidence has emerged that would change the overall 2004 appraisal of this approach or its scoring in terms of flood risk reduction.

Coastal Morphological Protection

Response group definition

Coastal and estuarine morphology can be 'engineered' so that natural features are developed, enhanced or recreated to provide increased protection to the shoreline.

The response group varies from low-cost options such as salt marsh, dune or gravel barrier management, or creation of new tidal inlets and associated spits and deltas, to more expensive options involving engineering an embayed shoreline platform by engineering hardpoints or headlands. The approach recognises that coastal systems are dynamic environments. While the standard of protection they offer against flooding may vary in the short term, they function and evolve in a self-regulating manner and consequently possess longer-term sustainability.

Response group update

The update of this response group links to the issues raised in the update to the Coastal Morphology and Sediment Supply driver. There, it was noted that beaches may be starved of sediment due to historical cliff protection, so that reverting to a more natural coastline might provide flood protection benefits to lower-lying coastal areas through renewed sediment supply. Since 2004, morphological modelling of an entire coastal sub-cell has been undertaken, including coupling cliff erosion with beach volume downdrift (Dawson et al., 2007). The results provide increased confidence that this hypothesis is correct, and indicate that the approach might in future be operationalised.

Re-evaluation of the Relative Sea-Level Rise driver (see the Relative Sea-Level Rise driver update) has emphasised the possibility of very rapid sea-level rises (> 1 m/century) as part of the range of probable changes under the different scenarios. Coastal morphological protection would be less effective as a response to future flood risks under these extreme conditions, because sea level would rise too quickly for coastal morphology to keep pace. Hence, rapid sea-level rise could be associated with serious increases in flood risk and significant coastal retreat in many locations. The reason for this is that the supply of sediment required to drive morphological adjustments increases with the rise in sea level. Combining beach nourishment with morphological protection could be a suitable response in this case.

In conclusion, no significant further evidence has emerged that would change the overall 2004 appraisal of this response group or justify changing its scoring in terms of flood risk reduction. However, this response remains an important area for research and development.

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Public Attitudes and Expectations

Response group definition

Public attitudes and expectations will influence the responses to changes in flood risk.

In 2004, the Foresight team took public attitudes and expectations to signify preferences for risk management and associated factors rather than personal preferences as to, say, the desirability of living in certain types of location. The response group operates through public lobbying for, and reactions to, alternative decisions on flood risk management. It is influenced by perceived risk and its tolerability, the cost of intervention and who pays, social equity issues and trust in the system.

Public preferences, while originating from the populace, are heavily influenced by the positions and behaviour of other actors, and hence cannot be viewed in isolation. Furthermore, we recognise that a single 'public' does not exist in the sense of everybody having a single position on flood risk management.

In the intra-urban area, public attitudes may be affected by the relative ignorance of the population concerning the 'forces of nature' responsible for floods and their impacts, which are usually better understood in rural areas. This difference is, in turn, related to the higher relative mobility of urban populations, gauged by the shorter average length of residence in one (urban) location than in the equivalent rural areas.

Response group update

Recent research for Defra, *Who benefits from flood management policies* (FD2606) and *Social justice in the context of flood and coastal erosion risk management* (FD2605), has undertaken in-depth interviews with the public and interested organisations, particularly with respect to issues of inequity. The results show that the public, in general, is not overly concerned about demonstrable social inequities in FCERM provision for different groups (e.g. high standards in estuarine London; low standards in many areas flooded by intra-urban flooding). They are, however, more concerned about procedural inequity (i.e. how decisions are made, especially in the intra-urban vs. rural areas). Outside the research field, we have seen further regulatory influences affecting FCERM (e.g. the EU Floods Directive), and we take this as evidence of further strengthening in public attitudes and higher expectations in terms of flood risk management.

We therefore now have a somewhat better evidence base for assessing this response. What emerges is that the potential for this response to drive reductions in future flood risk through its **independent** influence is quite small; this response operates almost entirely through other responses. Neither does there seem to be a *prima facie* case for envisaging differences in the potential for this response to operate effectively across the different scenarios. However, the large uncertainties concerning the future operation and effectiveness of the Public Attitudes and Expectations response group precluded its scoring as a driver in 2004, and we still lack the knowledge and understanding necessary to score it as a response in 2008.

The Pitt Review
Cabinet Office
22 Whitehall
London SW1A 2WH

Email: ThePittReview@cabinet-office.x.gsi.gov.uk
www.cabinetoffice.gov.uk/thepittreview

Publication: June 2008

The material used in this publication is constituted from 50% post consumer waste and 50% virgin fibre

Ref: 288097/0608

Prepared for Cabinet Office by COI Communications