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National-scale Assessment of Current and Future Flood Risk in England and Wales

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Abstract. In recent years, through the availability of remotely sensed data and other national datasets, it has become possible to conduct national-scale flood risk assessment in the England and Wales. The results of this type of risk analysis can be used to inform policy-making and prioritisation of resources for flood management. It can form the starting point for more detailed strategic and local-scale flood risk assessments. The national-scale risk assessment methodology outlined in this paper makes use of information on the location, standard of protection and condition of flood defences in England and Wales, together with datasets of floodplain extent, topography, occupancy and asset values. The flood risk assessment was applied to all of England and Wales in 2002 at which point the expected annual damage from flooding was estimated to be approximately £1 billion. This figure is comparable with records of recent flood damage. The methodology has subsequently been applied to examine the effects of climate and socio-economic change 50 and 80 years in the future. The analysis predicts increasing flood risk unless current flood management policies, practices and investment levels are changed – up to 20-fold increase in real terms economic risk by the 2080s in the scenario with highest economic growth. The increase is attributable primarily to a combination of climate change (in particular sea level rise and increasing precipitation in parts of the UK) and increasing economic vulnerability.

Key words: flood risk, flood defence reliability, climate change, socio-economic scenarios

1. Introduction

Over 5% of the UK population live in the 12,200 km^2 that is at risk from flooding by rivers and the sea (HR Wallingford, 2000). These people and their property are protected by 34,000 km of flood defences. Traditionally, this important and safety-critical infrastructure system has been managed locally. It is now become increasingly apparent that flood risk can be managed more effectively by adopting strategic approaches applied at catchment, regional and national scales. These strategic approaches provide the opportunity to coordinate management of flood defence infrastructure with other

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measures, such as techniques to reduce runoff, control the urbanisation of floodplains and organisation of flood warning and evacuation. Strategic catchment-scale flood risk management coincides with the catchment-scale approach adopted in the EU Water Framework Directive.

Broad-scale flood risk analysis is a prerequisite for strategic flood risk management. A risk-based approach to decision-making requires that the risks and costs of all decision options, including the *status quo*, are evaluated in quantified terms. Such an approach also has the potential to put flood management decisions on the same footing as risk-based decision-making in relation to other natural and man-made hazards that policy-makers are bound to address. However, it is important to recognise the contrasting nature of different risks (Royal Society, 1992) and the varying sources of uncertainty in the quantified risk analyses that are conducted in different fields, so considerable caution should be exercised in comparing risk estimates. Nonetheless, regional and national-scale risk analysis does potentially provide decision-makers with powerful tools to develop targeted and potentially synergistic mitigation strategies.

National-scale risk assessment is by no means straightforward, because of the need to assemble national datasets and then carry out and verify very large numbers of calculations. Increasingly, however, national-scale datasets are becoming available. Aerial and satellite remote sensing technologies are providing new topographic and land use data. Commercial organisations are generating and marketing increasingly sophisticated datasets of the location and nature of people and properties. In 2002 the Environment Agency, the organization responsible for operation of flood defences in England and Wales, introduced a National Flood and Coastal Defence Database (NFCDD), which for the first time provides in a digital database an inventory of flood defence structures and their overall condition. Together, these new datasets now enable flood risk assessment that incorporates probabilistic analysis of flood defence structures and systems. Once the necessary datasets are held in a Geographical Information System (GIS) they can then be manipulated in order to explore the impact of future flood management policy and scenarios of climate change.

In the following section of this paper, an overview of the national-scale flood risk assessment methodology for flood risk analysis is provided. Section 3 summarises application of the methodology to all of England and Wales. In Section 4, the same methodology is used to predictions of flood risk under scenarios of climate and socio-economic change.

2. Overview of the Methodology

Flood risk is conventionally defined as the product of the probability of flooding and the consequential damage, summed over all possible flood events. It is often quoted in terms of an expected annual damage, which is

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sometimes referred to as the "annual average damage". For a national assessment of flood risk, expected annual damage must be aggregated over all floodplains in the country. An overview of the methodology by which this can be achieved is given in Figure 1 and described in outline below. Further details can be found in Hall *et al.* (2003).

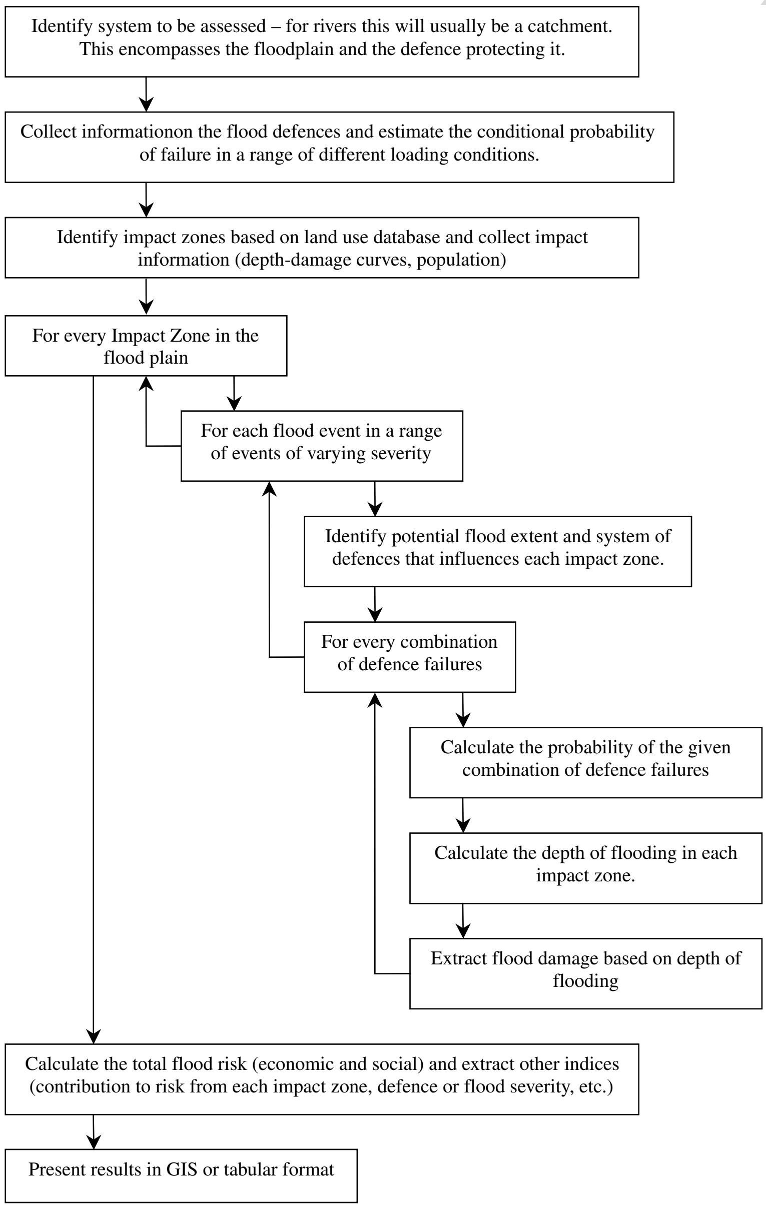

Figure 1. Overview of the national flood risk assessment methodology.

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The most significant constraint on a national-scale flood risk assessment methodology is the availability of data. The methodology presented here has been developed to make use of the following national GIS datasets and no other site-specific information:

1. *Indicative Floodplain Maps (IFMs)* are the only nationally available information on the potential extent of flood inundation. The IFMs are outlines of the area that could potentially be flooded in the absence of defences in a 1:100-year return period flood for fluvial floodplains and a 1:200-year return period flood for coastal floodplains.
2. *1:50,000 maps with 5 m contours*. The methodology has been developed in the absence of a national topographic dataset of reasonable accuracy. Topographic information at 5-m* contour accuracy has only been used to classify floodplain types as it is not sufficiently accurate to estimate flood depths.
3. *National map of the centreline of all watercourses*.
4. *National Flood and Coastal Defence Database* provides a national dataset of defence location, type and condition.
5. *National database of locations of residential, business and public buildings*.
6. *Land use maps and agricultural land classification*.

The 34,000 km of flood defences in England and Wales protect areas most at risk from severe flood damage. An essential aspect of flood risk analysis is therefore to assess the reliability of the flood defence infrastructure. These infrastructures must be dealt with as systems if the flood risk is to be accurately estimated. In the absence of more detailed information on flood extent, in the current methodology the Indicative Floodplain is adopted as the maximum extent of flooding and is further sub-divided into Impact Zones, not greater than 1 km × 1 km. Each flood Impact Zone is associated with a system of flood defences which, if one or more of them were to fail, would result in some inundation of that zone.

Reliability analysis of flood defences potentially requires a huge quantity of data, which are not available for all of the flood defences in England and Wales. An approximate reliability method has therefore been developed that makes use of the so-called Standard of Protection (SOP), which is an assessment of the return period at which the defence will significantly be overtopped. Flood defence failure is addressed by estimating the probability of failure of each defence section in a given load (relative to SOP) for a range of load conditions. Generic versions of these probability distributions of defence failure, given load, have been established for a range of defence types for two failure mechanisms: overtopping and breaching.

Having estimated the probability of failure of individual sections of defence, the probabilities of failure of combinations of defences in a system are calculated. To do so, it is assumed that the probability of hydraulic loading of

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individual defences in a given flood defence system is fully dependent. The probabilities of failure of each of the defences in the system, conditional upon a given load, are assumed to be independent. For each failure combination an approximate flood outline, which covers some proportion of the IFM, is generated using approximate volumetric methods. These methods estimate discharge through or over the defence and inundation characteristics of the floodplain, based on an assessment of floodplain type.

In the absence of water level and topographic data, estimation of flood depth has been based on statistical data. These data were assembled from 70 real and simulated floods for a range of floodplain types and floods of differing return periods. These data were used to estimate flood depth at points between a failed defence and the floodplain boundary, in events of a given severity. Flood depth estimates from a range of floods were used to construct an estimate of the probability distribution of the depth of flooding for each Impact Zone (Figure 1).

The numbers of domestic and commercial properties and area of agricultural land in each Impact Zone were extracted from nationally available databases. These data were combined with relationships between flood depth and economic damage that have been developed from empirical analysis of past flooding events (Penning-Rowsell *et al.*, 2003a). For a given Impact Zone the expected annual damage R is given by

$$R = \int_0^{y_{\max}} p(y)D(y)\,dy$$

where $y_{\max}$ is the greatest flood depth from all flooding cases, $p(y)$ is the probability density function for flood depth and $D(y)$ is the damage in the Impact Zone in a flood of depth y m. The total expected annual damage for a catchment or nationally is obtained by summing the expected annual damages for each Impact Zone within the required area.

The population at risk was estimated from the number of inhabitants within an Impact Zone using 2001 census data. The Social Flood Vulnerability Indices (SFVI) (Tapsell *et al.*, 2002) were used to identify communities vulnerable to the impacts of flooding. Social vulnerability is ranked from ''very low'' to ''very high'' and is based on a weighting of the number of lone parents, the popula tion over 75 years old, the long term sick, non-homeowners, unemployed, non-car owners and overcrowding, obtained from census returns. The risk of social impact is obtained as a product of probability of flooding to a given depth and the SFVI, providing a comparative measure for use in policy analysis.

3. Methods for Scenarios-based Future Flood Risk Assessment

There is increasing concern about the potential impacts of climate change on flood risk. Of equal, if not greater, potentially significance, are the impacts

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that socio-economic changes will have on vulnerability to flooding. Flood management decisions, such as the introduction of new land use planning policies or the construction of major new flood defence infrastructure can take decades to implement. For example studies are now under way to plan the upgrading of the Thames Barrier, even though it will continue to provide the required standard of flood protection until 2030. There is therefore a need to develop long term scenarios of flood risk in order to assist the development of robust long-term flood risk management policies.

A scenarios-based approach explicitly acknowledges that the distant future is uncertain and that several plausible trajectories of societal change can be sketched out. Scenarios are not intended to predict the future. Rather they are tools for thinking about the future, recognising that the future is shaped by human choice and action, and is unlikely to be like the past. Scenarios development involves rational analysis and subjective judgement (DTI, 2003).

Flood defence is an interesting application of the scenarios-based approach because it involves integrated use of two different types of scenario:

- Climate change projections are based on *emissions scenarios*, used to establish the global emission of greenhouse gases to the atmosphere.
- *Socio-economic scenarios* provide the context in which flood management policy and practice will be enacted and relate to the extent to which society may be impacted upon by flooding.

The UK Climate Impacts Programme scenarios for the UK published in 2002 (usually referred to as UKCIP02) (Hulme *et al.*, 2002) have been used. These scenarios are based on four emissions scenarios: Low emissions, Medium-low emissions, Medium-high emissions and High emissions corresponding to the Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios (usually referred to as SRES) scenarios B1, B2, A2 and A1F1, respectively (IPCC, 2000). The UKCIP02 scenarios predict that annual average precipitation across the UK may decrease slightly, by between 0 and 15% by the 2080s depending on scenario. The seasonal distribution of precipitation will change, with winters becoming wetter and summers becoming drier, the biggest relative changes being in the South and East. Under the High Emissions scenario winter precipitation in the South and East may increase by up to 30% by the 2080s. By the 2080s the daily precipitation intensities that are experienced once every 2 years on average may become up to 20% heavier. By the 2080s and depending on scenario relative sea level may be between 2 cm below and 58 cm above the current level in western Scotland and between 26 and 86 cm above the current level in South East England. For some coastal locations a water level that at present has a 2% annual probability of occurrence may have an annual occurrence probability of 33% by the 2080s for Medium-High emissions. The climate change scenarios included within UKCIP02 do not include

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allowance for model error and do not therefore represent the maximum potential range of climate change effects.

The Foresight Futures socio-economic scenarios (SPRU *et al.*, 1999; UKCIP, 2001; DTI, 2003) are intended to suggest possible long term futures, exploring alternative directions in which social, economic and technological changes may evolve over coming decades. The scenarios are represented on a two-dimensional grid (Figure 2). On the vertical dimension is the system of governance, ranging from autonomy where power remains at the national level, to interdependence where power increasingly moves to other institutions. On the horizontal dimension are social values, ranging from individualistic values to community oriented values. The four Foresight Futures that occupy this grid are summarised in Tables I and II.

There is no direct correspondence between the UKCIP02 scenarios and the Foresight Futures 2020, not least because the Foresight Futures are specifically aimed at the UK whereas the emissions scenarios used in UKCIP02 are *global* greenhouse emissions scenarios. However, an approximate correspondence can be expected, as shown in Table III.

The national-scale flood risk analysis model outlined above was used to analyse long term change by making appropriate changes to the model parameters to reflect the time and scenario under consideration. The four scenarios listed in Table III were analysed for the 2080s and chosen to coincide with the years for which climate scenarios were available (Hulme *et al.*, 2002). The input data required by the risk analysis model do not correspond exactly to the information provided in either in climate change or socio-economic sce-

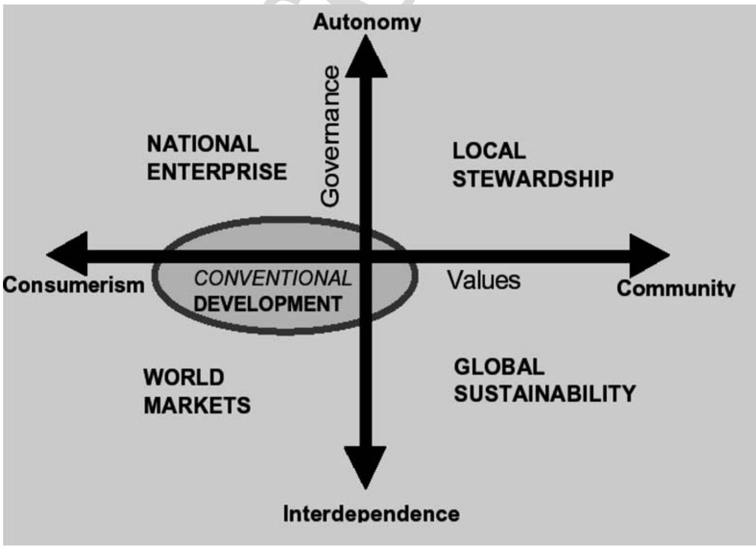

Figure 2. Socio-economic scenarios.

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Table I. Summary of Foresight Futures (DTI, 2003)

	World markets	National enterprise	Global sustainability	Local stewardship
Social values	Internationalist, libertarian	Nationalist, individualist	Internationalist, communitarian	Localist, co-operative
Governance structures	Weak, dispersed, consultative	Weak, national, closed	Strong, co-ordinated, consultative	Strong, local, partici-pative
Role of policy	Minimal, enabling markets	State-centred, market regulation to protect key sectors	Corporatist, political, social and environmental goals	Interventionist, social and environmental
Economic development	High growth, high innovation, capital productivity	Medium-low growth, Low innovation, maintenance economy	Medium-high growth, high innovation, resource productivity	Low growth, low innovation, modular andsustainable
Structural change	Rapid, towards services	More stable economic structure	Fast, towards services	Moderate, towards regional systems
Fast-growing sectors	Health & leisure, media & information, financial services, biotechnology, nanotechnology	Private health and education, domestic and personal services, tourism, retailing, defence	Education and training, large systems engineering, new and renewable energy, information services	Small-scale manufacturing, food and organic farming, local services
Declining sectors	Manufacturing, agriculture	Public services, civil engineering	Fossil fuel energy, traditional manufacturing	Retailing, tourism, financial services
Unemployment	Medium-low	Medium-high	Low	Medium-low (large voluntary sector)
Income	High	Medium-low	Medium-high	Low
Equity	Strong decline	Decline	Improvement	Strong improvement

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Table II. Snap shot statistics for 2050 (UKCIP, 2001)

	Mid 1990s	World markets	National enterprise	Global sustain-ability	Local steward-ship
UK Population (million)	58.5	59	57	57	55
Gross Domestic Product growth per year	+2%	+3%	+1.75%	+2.25%	+1.25%
Gross Domestic Product per capita	£10,500	£61,000	£31,000	£41,000	£24,000
Land use (%)					
Agricultural	75%	60%	70%	70%	75%
Urban	15%	22%	19%	15%	11%
Forest and other	10%	18%	11%	15%	11%

Table III. Correspondence between UKCIP02 scenarios and Foresight Futures

SRES[a]	UKCIP02[b]	Foresight Futures 2020[c]	Commentary
B1	Low emissions	Global Sustainability	Medium-high growth, but low primary energy consumption. High emphasis on international action for environmental goals (e.g. greenhouse gas emissions control). Innovation of new and renewable energy sources.
B2	Medium-low emissions	Local stewardship	Low growth. Low consumption. However, less effective international action. Low innovation.
A2	Medium-high emissions	National enterprise	Medium-low growth, but with no action to limit emissions. Increasing and unregulated emissions from newly industrialised countries.
A1F1	High emissions	World markets	Highest national and global growth. No action to limit emissions. Price of fossil fuels may drive development of alternatives in the long term.

[a] Special Report on Emissions Scenarios (IPCC, 2000).
[b] UK Climate Impacts Programme 2002 scenarios (Hulme *et al.*, 2002).
[c] DTI (2003).

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narios. It was therefore necessary to construct approximate relationships between the variables for which scenarios information was available and the variables required for flood risk analysis. A summary of the relationships adopted in the analysis of risks from river and coastal flooding is provided in Table IV. A quantified estimate was made of the effect in each scenario that a given change, for example urbanisation, would have on the relevant variables in the risk model (Table IV). The cumulative effect of each of the changes in the given scenario was then calculated. Where feasible, regional variation was applied to these adjustments in order to take account of, for example, regional differences in climate or demographic projections. There is no unique mapping between a scenario, which is an inherently vague entity, and a realization of the risk model. In other words, there is not a unique representation of the scenario in the risk model. The quantified analysis presented here is one of many equally plausible representations of the same four scenarios. Whilst no claim is made to the uniqueness of these results, they do illustrate some striking contrasts between different scenarios of change and provide the basis for exploring responses to flood risk that are robust across plausible futures.

Future flood risk is greatly influenced by flood management policy and practice, perhaps more so than it is by changes outside the control of the flood manager, such as climate change or economic growth. However, in the analysis described here current flood defence alignment and form, as well as the levels of investment in maintenance and renewal were kept the same across all scenarios. Clearly flood defence policy will change in the future and will tend to reflect the nature and public expectations of future society *i.e.* flood defence is scenario-dependent. However, the aim of the current study was to inform present-day policy makers and in order to do that, the present day flood defence policy was subjected to particular scrutiny, by analysing its effectiveness in a range of scenarios. Changing scenarios were super-imposed on this fixed flood defence policy (including the current pattern of expenditure and technical approach), in order to assess the capacity of the current policy to cope with long term changes.

3.1. RESULTS FOR THE PRESENT SITUATION

The national-scale risk assessment methodology described above was applied to all of England and Wales in 2002. The results are reported on a 10 km × 10 km grid (though, as described above, the analysis was conducted on the basis of Impact Zones not greater than 1 km × 1 km). Figure 3 shows the proportion of each 10 km × 10 km grid cell that is occupied by floodplain. It indicates the very high proportions of floodplain around the Wash and the Humber estuary on the east coast of England and in several other coastal areas.

Comparison of the extent of the Indicative Floodplain with residential, commercial and land use databases revealed that in England and Wales there

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Table IV. Representation of future scenarios in risk model

Variable used risk model	Explanation	Changes that may be represented with this variable
Standard of Protection (SoP) of flood defences	The return period at which the flood defence (or where none exists the river bank) is expected to overtop.	Climate change[a] Changes in land use management (which may change run-off and hence river flows and water levels) Morphological change (that may also influence the conveyance of the river and hence water levels)
Condition grade of flood defences	An indicator of the robustness of the defences and their likely performance when subjected to storm load.	Morphological changes Maintenance regimes
Location of people and properties in the floodplain	Spatially referenced database of domestic and commercial properties. Census data on occupancy, age etc.	Demographic changes Urbanisation Commercial development
Flood depth-damage relationships	Estimated flood damage (in £ per house or commercial property) for a range of flood depths	Changes in building contents Changes in construction practices
Social flood vulnerability indices[b]	An aggregate measure of population vulnerability to flooding, based on census data	Changes in demographics (e.g. age) Changes in equity
Agricultural land use classification in the floodplain	Agricultural land grade from 1 (prime arable) to 5 (no agricultural use)	Changed agricultural practices Agricultural land being taken out of use
Reduction factors	Measures that will reduce total flood damage, e.g. flood warning and evacuation can be reflected by factoring the estimated annual average damage	Flood warning (including communications technologies) and public response to warning Evacuation Community self-help

[a] For example a scenario in which if climate change is expected to increase water levels by 20% is represented by reducing the SoP of flood defences by an appropriate increment.
[b] Tapsell *et al*. (2002).

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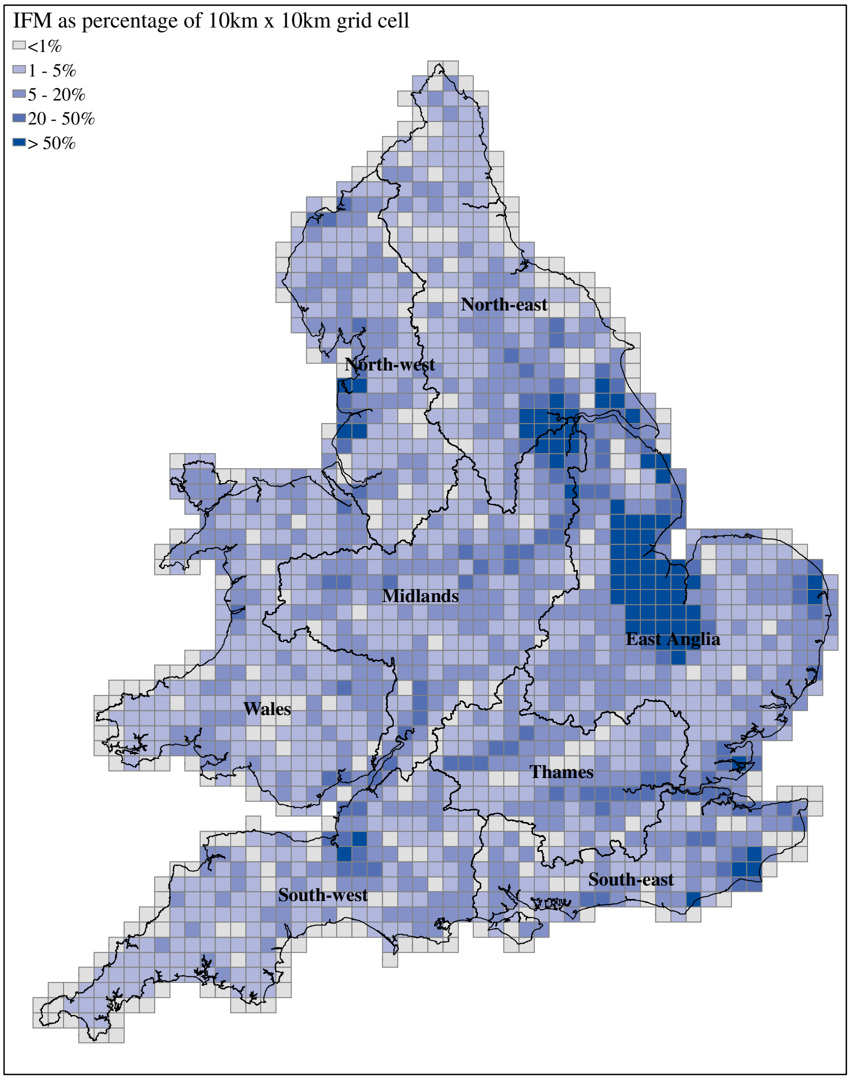

Figure 3. Proportion of land in Indicative Floodplain.

are 1.61 million residential properties and 131,000 commerical properties in the Indicative Floodplain, together with 1.43 million hectares of agricultural land. Comparison on census data with the Indicative Floodplain yields an estimated 4.47 million people resident within the Indicative Floodplain. The total value of residential property at risk is £208 billion.

The national-scale risk analysis yielded an estimated Expected Annual Damage due to flooding of £1.0 billion, with an uncertainty range between £0.6 billion and £2.1 billion. The spatial distribution of economic risk from

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flooding is illustrated in Figure 4. Highest economic risk is located in floodplain areas of high economic value, notably Greater London despite very high standards of flood protection. A number of areas of high coastal flood risk are located along the South, East and North-West coasts of England. The expected annual damage to agriculture is estimated to be £5.9 million, accounting for only about 0.5% of economic damage due to flooding. This loss is very small in economic terms, but can represent considerable impact on the rural economy.

The risk analysis has been compared with recent flood events to assess the dependability and uncertainties in the methodology (HR Wallingford, 2003). The annual average flood damage estimate of roughly £1 billion is of the same order to but somewhat larger than annual losses due to flooding experienced in recent years. For example, floods in Autumn 2002 resulted in economic losses of the order of £750 million (Penning-Rowsell *et al.*, 2003b). Some of the inconsistency is explained by reporting of recent flood events and by assumptions in the model (particularly the exclusion of emergency repair works). Although a single event provides only limited basis for validation of annual average risk estimates, the reasonably good correspondence between model and observations indicates that the model does provide a sound basis for policy appraisal and comparative evaluation of future scenarios.

3.2. RESULTS FOR FUTURE SCENARIOS

The results of the flood risk scenarios analysis are summarised in Table V. No discounting or inflation is applied to economic risks. Risk is estimated at time points in the future using today's prices.

Large increases in the number of people occupying the floodplain in the UK are envisaged in the relatively loosely regulated World Markets and National Enterprise scenarios. Most of this increase is predicted to occur by the 2050s, representing predictions of very rapid growth in the first half of this century which is envisaged to approach a limit associated with a fairly stable population and spatial constraints. Floodplain occupancy is kept stable in the Global Sustainability and Local Stewardship scenarios. However, increasing flood frequency, primarily due to climate change means that even with stable numbers of people in the floodplain, the number of people at risk from flooding more frequently than 1:75 years will increase in all scenarios, assuming that current flood defence systems are continued into the future. Greater climate change by the 2080s, together with the increased floodplain occupancy noted above mean that the World Markets and National Enterprise scenarios will see more than doubling of the number of people at risk from flooding more frequently than 1:75 years.

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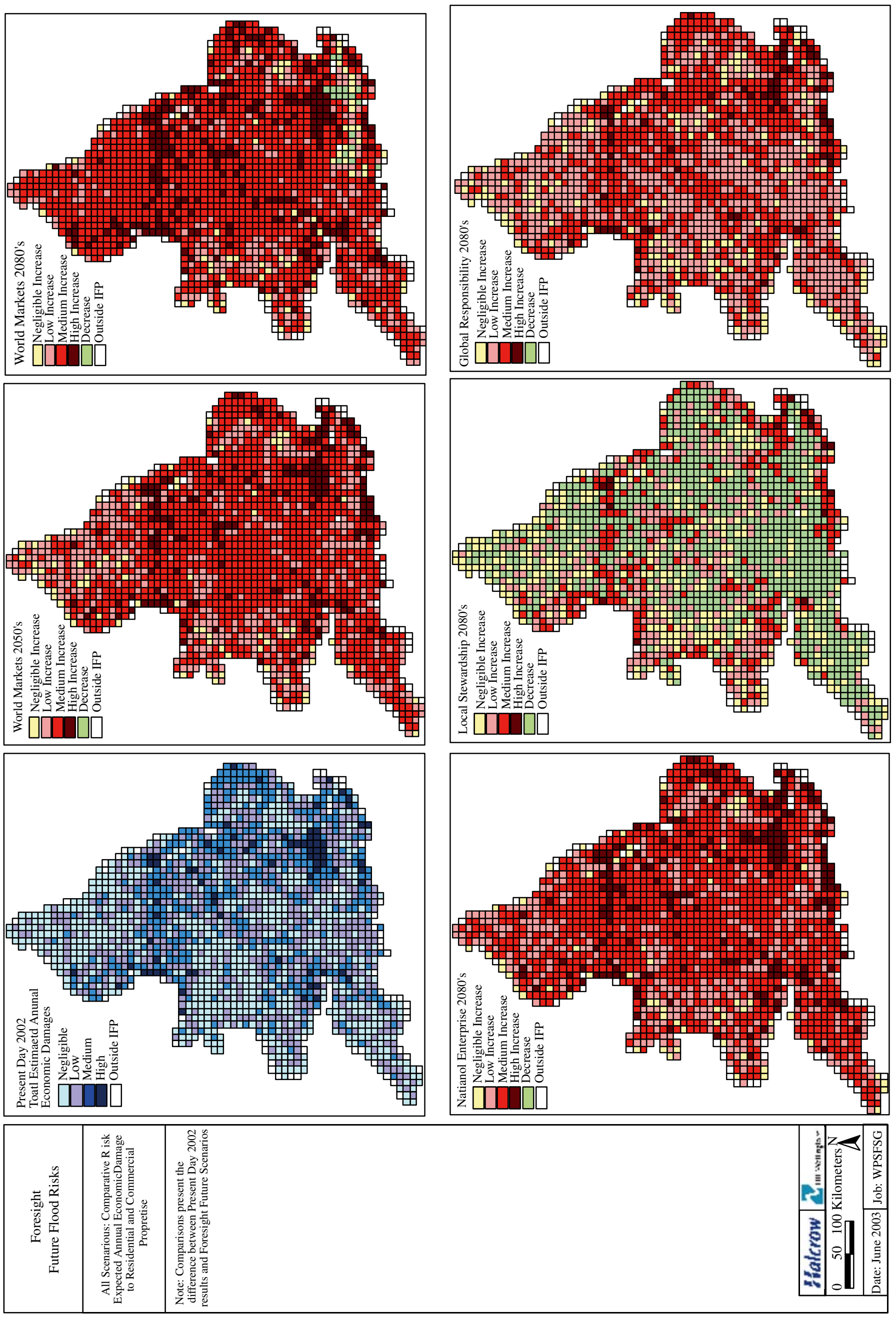

Figure 4. Expected annual economic damage for 2002 and future scenarios.

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Table V. Summary of flood risk scenarios

	2002	World Markets 2050s	World Markets 2080s	National Enterprise 2080s	Local Stewardship 2080s	Global Sustainability 2080s
Number of people within the indicative floodplain (millions)	4.5	6.2	6.9	6.3	4.5	4.6
Number of people exposed to flooding (depth > 0 m) with a frequency > 1:75 years (millions)	1.6	3.3	3.5	3.6	2.3	2.4
Expected annual economic damage (residential and commercial properties) (£ billions)	1.0	14.5	20.5	15.0	1.5	4.9
Annual economic damage relative to Gross Domestic Product per capita	0.10%	0.15%	0.14%	0.31%	0.05%	0.06%
Expected annual economic damage (agricultural production) (£ millions)	5.9	41.6	34.4	41.3	63.5	43.9

In all scenarios other than the low growth, environmentally/socially conscious Local Stewardship scenario, annual economic flood damage is expected to increase considerably over the next century assuming the current flood defence policies are continued in future. A roughly 20-fold increase by the 2080s is predicted in the World Markets scenario, which is attributable to a combination of much increased economic vulnerability (higher floodplain occupancy, increased value of household/industrial contents, increasing infrastructure vulnerability) together with increasing flood frequency.

Change in the ratio of flood risk to per capita GDP provides an indication of how severe or harmful (in economic terms) flooding will be when compared with economic growth over the next century. In the World

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Markets and National Enterprise scenarios flooding is expected to remove a greater proportion of national wealth than it currently does (and thus merit a greater investment to reduce risk). In the Local Stewardship and Global Sustainability scenarios flooding is predicted to remove a lesser proportion of national wealth since these scenarios will tend to be less vulnerable to flood damage and are expected to be subject to somewhat less climate change.

The pattern for flood damage to agriculture is rather different to the pattern from economic damage as a whole. In the globalised World Markets scenario the contribution of agricultural damage to overall economic damage is projected to decrease, with a greater proportion of agricultural products being imported (though the effect of climate change on agriculture globally has not been considered) and low-grade agricultural land being taken out of production. Agricultural damage in the more self-sufficient National Enterprise and Local Stewardship scenarios is expected to be more significant.

Figure 4 shows the distribution of the increase in expected annual economic damage for the World Markets 2050s scenario and all four scenarios for the 2080s, relative to the estimated risk in 2002. Increasing risk is predicted to be concentrated in broadly the same areas as where it is currently highest. Coastal flooding makes an increasing contribution to total flood risk, increasing from 26% in 2002 to 46% in the 2080s. The increasing probability of overtopping the Thames Barrier that protects central London makes a significant contribution to this increase in risk.

Analysis of environmental and socio-economic phenomena over a timescale of 30–100 years in the future involves formidable uncertainties. Model uncertainties in climate projections up to the 2050s exceed the differences between emissions scenarios. There is considerable disagreement about the spatial patterns of climate change down-scaled to the UK. Changes in some climate variables, for example extreme sea levels and short, high intensity rainfall events are particularly difficult to predict. Socio-economic change, which on a global scale leads to changing greenhouse gas emissions trajectories and on the UK scale also determines economic and social vulnerability to flooding, is even more difficult to predict and, it is argued, succumbs only to a scenarios-based approach which seeks to illustrate some of the potential range of variation between different futures. The flood risk scenarios presented here are therefore subject to very considerable uncertainties. They do, nonetheless, provide insights into the sources and impacts of future flood risk and the implications of continuing current flood defence policies into the future.

4. Conclusions

A national-scale flood risk assessment methodology, which includes the effect of flood defence systems, has been applied to all of England and Wales,

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making use of nationally available datasets. The analysis estimates expected annual damage due to flooding of roughly £1 billion, a figure that is slightly higher than, but comparable to economic damage due to flooding in England and Wales in recent years. The largest contribution to this risk is in the Greater London area, despite the very high standard of protection from flooding.

Socio-economic and climate scenarios have been used in combination in order to generate self-consistent projections of potential future variation in flood risk, assuming stable flood defence policy. In all scenarios the frequency of flooding is projected to increase, more so on the coast than on rivers. The increase is greatest in high-emission scenarios. The risk of flooding is strongly modified by societal vulnerability and the scenarios analysis demonstrates how widely that vulnerability may vary according to the trajectory of socio-economic change. The risk that actually prevails in the future will be further modified by flood management activity, which will itself be a reflection of society's values and expectations.

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