5.1 Overview of the analysis – approach and methodology **114**

– Achieving standards of flood protection matched to each scenario using an integrated portfolio of responses 114
– Evaluating the risk reduction of the portfolios 114
– Evaluating the costs of implementing the portfolios of responses 117
– Estimating costs associated with defence raising 118

5.2 Results of the risk analysis **119**

– How the results are presented 119
– Number of people living within the Indicative Floodplain 120
– Expected annual probability of flooding 124
– Number of people exposed to ‘high’ flood risk 128
– Expected Annual Damage – residential and commercial properties 132
– Expected Annual Damage – agriculture 136
– Social vulnerability to flooding 140

5.3 Results of the investment analysis **144**

5.4 Sensitivity analysis – the benefits of an integrated approach **144**

– Results of the sensitivity analysis 146

5.5 Conclusions **147**

5.6 Extreme normal flood event scenarios – the ability of portfolios of responses to reduce risks **148**

Chapter 5

Quantifying flood-management responses – catchment and coastal

Chapter 4 introduced four portfolios of flood-risk management measures – one for each future scenario. In this chapter the residual risk following implementation of each portfolio of responses is quantified along with its associated cost.

A sensitivity analysis is then used to assess the benefit, in terms of risk and cost reduction, of implementing an integrated portfolio of responses compared with an approach based more on engineering.

The results of this analysis are used in Chapters 7 and 8 in support of the broader discussion of issues of sustainability and governance.

5.1 Overview of the analysis – approach and methodology

5.1.1 Achieving standards of flood protection matched to each scenario using an integrated portfolio of responses

The reduction in risk achieved by adopting the integrated portfolios of non-structural and structural responses defined in Chapter 4 has been quantified using the RASP methodologies. For each portfolio of responses applied under each of the four future scenarios different target standards of flood protection have been applied as given in Chapter 4, Table 4.4.

Both the choice of responses within each portfolio and the target standards of flood protection reflect the different aspirations under each scenario. For example, under World Markets the level of protection afforded to an urban area is assumed to be higher than present day, whereas protection afforded to a rural area is assumed to reduce. Equally, for example, structural responses are favoured under a World Markets future (such as defence-raising). In contrast, a greater reliance is placed upon non-structural measures in Global Sustainability (such as improved flood warning and evacuation procedures).

The analysis is based on the quantified risk-analysis method described in Volume I and uses the RASP risk modelling tool. Because RASP uses databases of flood defences and assets at risk that presently only cover England and Wales, the analysis is confined to those parts of the country. Nevertheless, the results provide a broad feel for the likely performance of the portfolios across the whole of the UK. The analysis is inevitably approximate and results at particular locations should be treated with caution. The analysis methodology employed has been previously applied to estimate present day risks. The results of the previous analysis are comparable with observations from recent flooding (see Volume I), providing confidence in the results.

5.1.2 Evaluating the risk reduction of the portfolios

Each of the responses used in a given portfolio influence either the probabilities or consequences of flooding (see Tables 4.1 and 4.2), and these in turn are reflected in the RASP input parameters. Table 5.1 illustrates the extent to which the various responses affect the RASP input parameters for each of the four future scenarios.

Table 5.1 **Overview of the translation of the flood risk management responses to parameters used by the RASP modelling tool**

Variable used by the quantified risk analysis	Response modelled	Scale of use in each flood management portfolio			
		WM	NE	LS	GS
Standard of Protection (SoP) of flood defences					
To reflect an increased or decreased protection against flooding from a range of measures.	**Managing the Rural Landscape**				
	Water Retention and Management of Infiltration into the Catchment	–	–	–	+
	Water Retention through Catchment-Storage Schemes	–	++	++	+++
	Managing Conveyance	–	–	–	++
	Managing the Urban Fabric				
	Increase Storage in Urban Areas	+	+	++	++
	Increase Infiltration in Urban Areas	–	–	–	–
	Managing Flood Events				
	Flood Fighting: Actions to Manage Floodwaters and Defences During the Event	++	++	++	++
	Engineering & Other Large Scale Interventions (Fluvial)				
	Increase Conveyance or Flow Passed Downstream	++++	+++	++	+++
	Increase Storage	++	++	+++	+++
	Floodwater Transfer	+	+	–	+
	Physical Barriers	++++	++++	+++	+++
	Realignment	+	+	++	++
	Abandonment	–	++	+++	–
	Engineering & Other Large Scale Interventions (Coastal and Estuarial)				
	Physical Barriers	++++	++++	++++	++++
	Realignment of Flood Defence Infrastructure	+	+	++	+++
	Reduce Energy	++	++	+	+++
	Morphological Protection	+	+	+	++
	Abandonment	–	++	+++	–

Table 5.1 **Overview of the translation of the flood risk management respones to parameters used by the RASP modelling tool** *(continued)*

Variable used by the quantified risk analysis	Response modelled	Scale of use in each flood management portfolio			
		WM	NE	LS	GS
Location of people and property in the floodplain and flood depth-damage relationships					
To reflect a change in the number of people at high risk and likely economic damage to be incurred during a flood event.	**Managing Flood Events**				
	Pre-Event Measures	+	–	–	–
	Real-Time Forecasting and Warning	+	–	–	–
	Collective-Scale Damage-Avoidance Actions	+	+	++	++
	Individual-Scale Damage-Avoidance Actions	++	+	+++	+++
	Managing Flood Losses				
	Reduce Current Exposure to Flood Loss Through Land Use Management	–	–	+	+
	Reduce Current Exposure to Flood Loss Through Floodproofing	++	+	++	++++
	Limit Increase in Exposure to Flood Loss Through Land Use Planning	++	+++	+++	++++
	Limit Increase in Exposure to Flood Loss Through Changing Building Codes and Construction Practices	++	++	+	++++
	Facilitate Economic and Financial Recovery from Flood Loss	n/c	n/c	n/c	n/c
	Lessen the Health, Social and Practical Impacts of Flooding	n/c	n/c	n/c	n/c
	Abandonment	–	++	+++	–
Reduction factors					
Measures that will reduce total flood damage, e.g. flood warning and evacuation, have been reflected by factoring the estimated annual average damage	**Managing Flood Events**				
	Pre-Event Measures	+	+	+	+
	Real-Time Forecasting and Warning	++	++	++	++
	Collective-Scale Damage-Avoidance Actions	–	–	–	–
	Individual-Scale Damage-Avoidance Actions	++	+	+++	+++

**The defences to be realigned or abandoned have been selected nationally as those that have the lowest benefit cost ratio. Realignment then implies a 10% reduction in potential damages within a given flooding system. Abandonment implies a 100% reduction in potential damages within a given flooding system.*
The '+' indicates the relative risk reduction achieved by each separate response when compared to others applied within a given portfolio as follows: – does not feature, + Low, ++ Medium +++ High ++++ Very High, n/c not considered within the quantitative analysis.

5.1.3 Evaluating the costs of implementing the portfolios of responses

Each portfolio uses both structural and non-structural measures to reduce risks. It has not been possible to estimate the 'true' costs of both the structural and non-structural measures proposed within each portfolio. The costing of non-structural measures would be extremely difficult and the results highly uncertain. Therefore, for the purposes of this study, the costs associated with implementing each portfolio of responses has been based on the structural costs alone (i.e. the investment required to implement the engineering component – raising the level of defences and ensuring adequate structural robustness). This provides a useful indicator of the total investment required in engineered defences.

In determining the degree of engineering required under each scenario it was recognised that non-structural measures will reduce the need for structural protection. Therefore, the extent of engineering utilised under each scenario takes account of the benefit in risk reduction afforded by the non-structural measures. However, when reviewing the results presented it is important to note that implementation of the non-structural solutions, although extremely difficult to cost and not included here, could be significant and would not come 'cost free'.

The degree to which structural solutions feature within each scenario reflects three issues:

- The target standards of flood protection under each scenario discussed in Chapter 4.
- The reduction in the standard and condition of defences observed under the baseline assumption for each scenario.
- The emphasis placed on structural flood risk mitigation measures within each scenario.

Given knowledge of these, the investment requirements have been established based on a number of assumptions concerning the cost of modifying the defence infrastructure, namely:

- The defence infrastructure is upgraded on its present alignment.
- Improvements in defence standards are achieved through raising rather than construction of major infrastructure such as barriers, barrages or offline storage.
- Within any flooding system **all** defences are raised to the indicative probability of flooding matched to each scenario.
- The cost of maintaining the defences over time (and in some cases rebuilding due to failure in structural condition) is not considered.
- The costs are assumed to be the one-off capital costs of raising the defence standard and condition to achieve the indicative probability of flooding matched to each scenario.
- The costs are in present-day terms.
- Both inflation and discounting are excluded.

5.1.4 Estimating costs associated with defence raising

Analysis of both the Environment Agency's Unit Cost Database (UCD) and information held by Defra has enabled indicative amounts to be established for the total cost of construction for the key defence types described in the RASP risk-analysis model. These average costs are presented in Table 5.2.

Table 5.2 **Indicative costs of construction per kilometre of defence**

RASP defence type	Comments	Average total cost/kilometre (£)
Earth embankment	Typical cost	550,000
Culverts	Typical cost	2,000,000
Protected embankments and sea walls	Typical cost	2,700,000
Dunes	Management activities of planting/ fencing only, NOT replenishment	53,000
Shingle beaches	Includes the typical costs of associated structures such as groynes, breakwaters etc. where part of scheme	5,100,000

The indicative costs represent the typical total cost of constructing a new flood defence and include design and supervision costs but exclude costs associated with land purchase, compensation or significant environmental mitigation measures.

The methodology for assessing the level of investment in defences is reliant on the Environment Agency's National Flood and Coastal Defence Database. Experience from previous studies indicates that the estimates of costs are likely to contain significant uncertainties and would not be appropriate for detailed local comparisons without significant data improvement. However, the approach is considered appropriate for providing a broad indication of the relative magnitude of the costs associated with improving the defence infrastructure under each scenario.

The scenario approach used here aims to provide a snapshot of possible expenditure. The cost estimates reflect the capital expenditure required to raise current defences to meet a particular target in these futures and exclude maintenance and non-structural costs. In particular, there is no attempt to construct a time series of costs and damages avoided and further work would be needed to perform a cost-benefit analysis or to compare with present-day expenditure levels.

5.2 Results of the risk analysis

5.2.1 How the results are presented

The future change in flood risk is presented for the following measures (these are explained more fully in Volume I, Chapter 4).

1. Number of people living within the floodplain (based on the underlying scenario assumptions).

2. Annual probability of flooding.

3. Number of people at high risk of flooding.

4. Expected Annual Damage – residential and commercial properties.

5. Expected Annual Damage – agricultural.

6. Social flood vulnerability.

The geographical distribution of the risks, and their relative magnitude, are displayed through two distinct types of maps which are colour coded as follows:

- Maps using primarily shades of blue represent total values of risk as estimated in 2002.
- Maps using red and green represent changes in risk compared with the present day. Progressively deeper shades of red indicate progressively increased risk when compared to the 2002 risk assessment results. Green indicates reduced risk.

Two sets of maps are presented for each risk measure: those on a left-hand page (e.g. Figure 5.1a) are reproduced from Volume I and detail the change in risks under the baseline flood-management assumption (i.e. that flood management policies and levels of expenditure on flood defence remain unchanged). Maps on the right-hand page (e.g. Figure 5.1b) present the change in risks when the portfolios of flood management are implemented for each of their respective future scenarios.

5.2.2 Number of people living within the Indicative Flood Plain

The total number of people living within the Indicative Flood Plain (IFP), as estimated under the baseline case (Figure 5.1a), has been modified to take account of the influences of regulation and land-use planning proposed under the flood-management portfolios (Figure 5.1b). It is interesting to note that our ability to reduce occupancy of the floodplain is very limited under all scenarios, with a maximum of a 10% reduction observed in the Global Sustainability and Local Stewardship futures.

Table 5.3 **Explanation of plots of number of people within the Indicative Flood Plain (Figures 5.1a and 5.1b)**

Scenario	Interpreting the effectiveness of an integrated portfolio of responses
Present day	The number of people within the IFP is indicative of the degree of urbanisation and hence reflects a similar pattern (see the blue map). In particular, concentrations occur in Greater London, a corridor stretching from the Lancashire coast across to the Humber, areas along the Severn estuary as well as smaller concentrations along the south-east coast and the Midlands. It is particularly interesting to note that, although sparsely populated, the fenlands stand out as a significant concentration of people living in the IFP. This reflects the extensive nature of the IFP in East Anglia rather the density of urbanisation.
World Markets 2080s	The limited influence of regulation and structured land-use planning has little impact on the number of people living within the IFP with the continued concentration of populations within large urban areas.
National Enterprise 2080s	As under the World Markets, regulation and land-use planning play a limited role within the context of an integrated management response. Hence, limited difference is observed between the baseline and integrated response scenarios.
Local Stewardship 2080s	The improved land-use planning – albeit largely ad hoc – reflects in a 10% decrease in the number of people within the IFP compared to the baseline case.
Global Sustainability 2080s	As with Local Stewardship, a 10% decrease in the number of people within the IFP is observed compared to the baseline case.

Figure 5.1a **Number of people in the Indicative Flood Plain – baseline case**

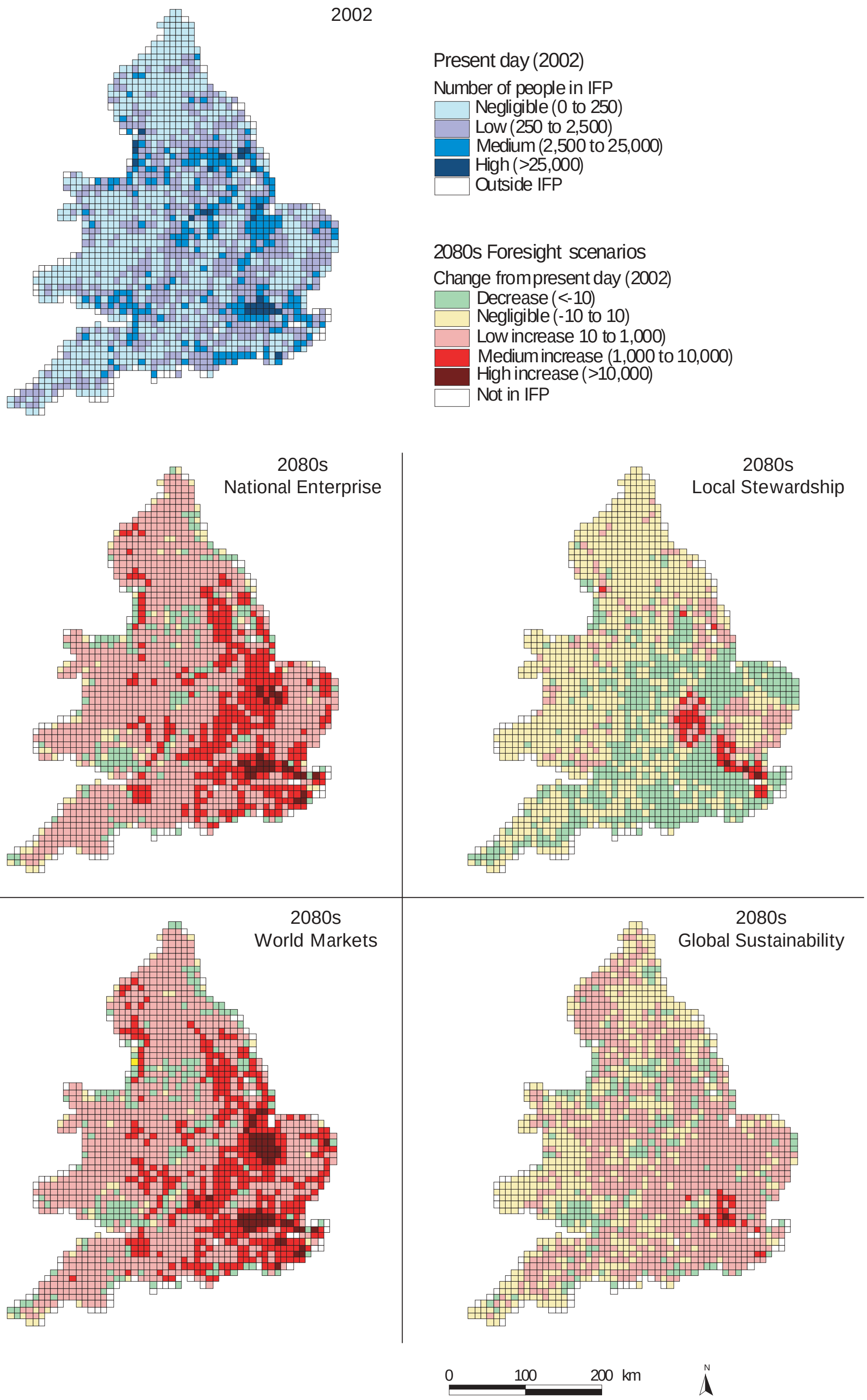
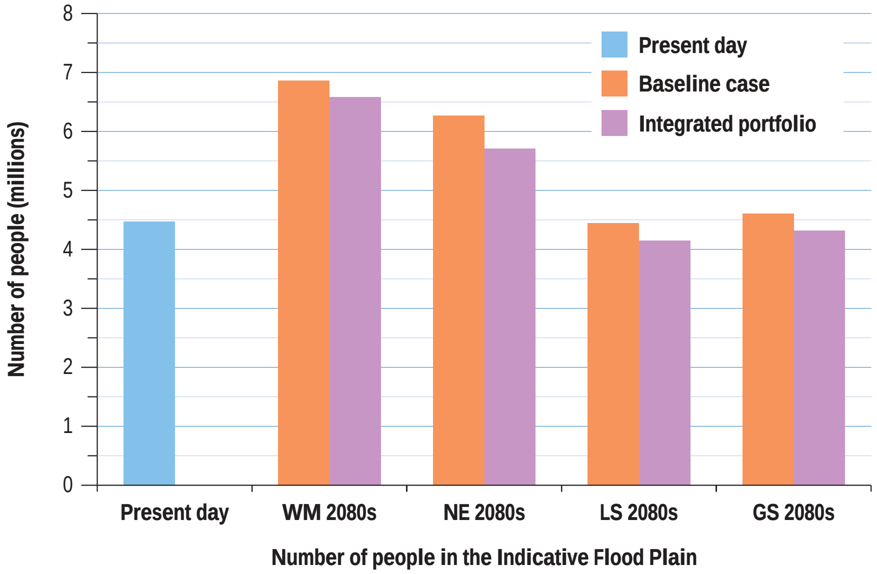
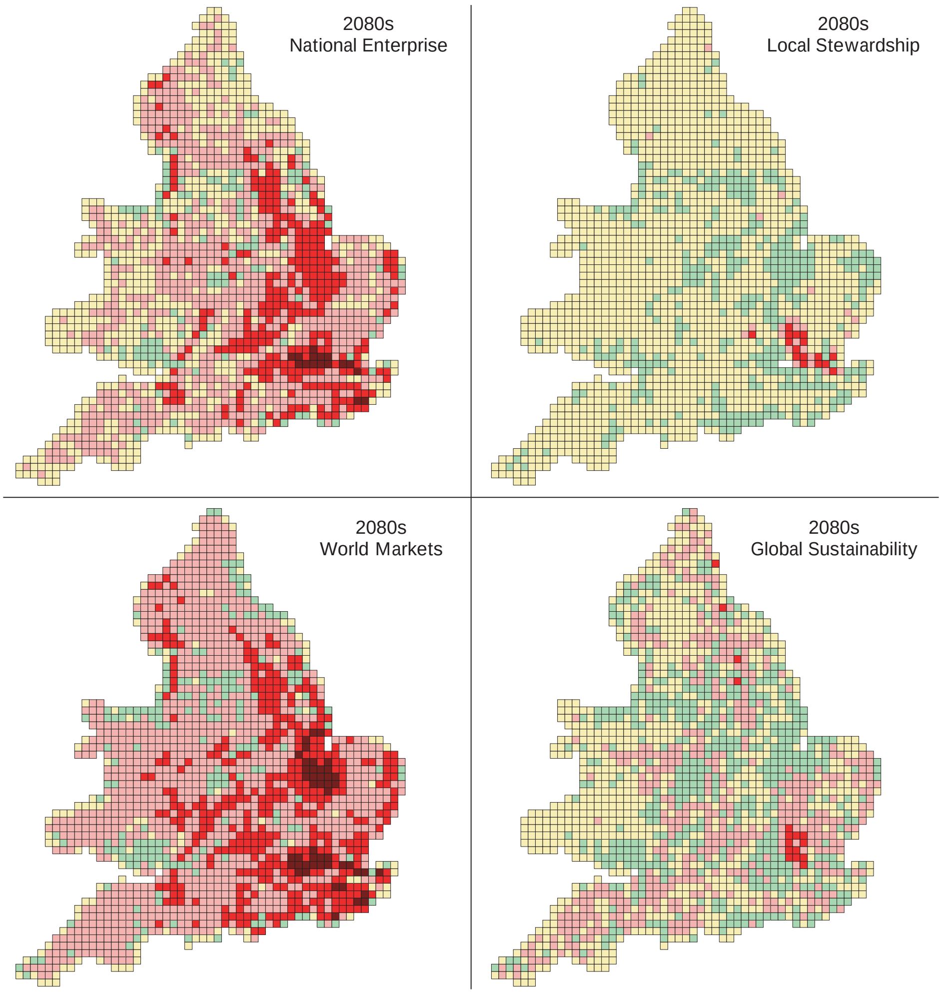


Figure 5.1b **Number of people in the Indicative Flood Plain – response portfolios implemented**





5.2.3 Expected annual probability of flooding

The expected annual probability of inundation estimated under the baseline case (Figure 5.2a) has been modified to take account of the responses affecting the standard of protection afforded by the defences, as outlined in Table 5.1 (Figure 5.2b).

Table 5.4 **Explanation of plots of expected annual probability of flooding**

Scenario	Interpreting the effectiveness of an integrated portfolio of responses
Present day	Generally the areas exposed to a higher risk of inundation are those in the north of England, east coast, mid Wales and the south west of England (see the blue map). The high defence standards including the Wash, south Midlands, London and a number of specific coastal locations (for example north Wales) are reflected in the low probability of flooding.
World Markets 2080s	The significant investment in defence infrastructure proposed under this scenario, and the significant protection afforded to urban areas through the indicative flood probability targets, yields a significant and widespread reduction in the probability of flooding. In particular, areas containing the major conurbations, for example, the Thames and Humber corridors, are afforded significantly improved protection. In contrast, more rural areas, particularly those around the Wash that are currently afforded a high degree protection for agricultural reasons, experience increased flood frequencies when compared to baseline scenario. The investment in coastal defences is successful in combating increased coastal flooding.
National Enterprise 2080s	As under the World Markets scenario, a significant emphasis is placed on reducing flood probability rather than managing flood losses. This emphasis is again reflected in a significant decrease in flood frequencies showing a similar pattern to that observed in the World Markets.
Local Stewardship 2080s	The management of flood risk under this scenario is mixed. All land-use types receive some level of protection and in many rural areas this translates to providing for greater protection from flooding than provided today. Exceptions to this include areas that are presently well protected but are more sparsely populated. Highly urbanised areas continue to receive protection from flooding to similar or marginally improved standards when compared to present day.
Global Sustainability 2080s	The portfolio of flood management associated with this scenario includes a balanced range of measures covering both the prevention of flooding and the management of its impacts. It should be borne in mind that under this scenario the target levels of flood protection are generally present-day values, whereas they have been doubled under World Markets and National Enterprise. This yields a less dramatic impact on flood probabilities than observed under the other scenarios when compared to the baseline assumption. Significant improvements can, however, be observed in the coastal strip and the major conurbations lining the Thames and Humber estuaries.

Figure 5.2a **Expected Annual Probability of Inundation – baseline case**

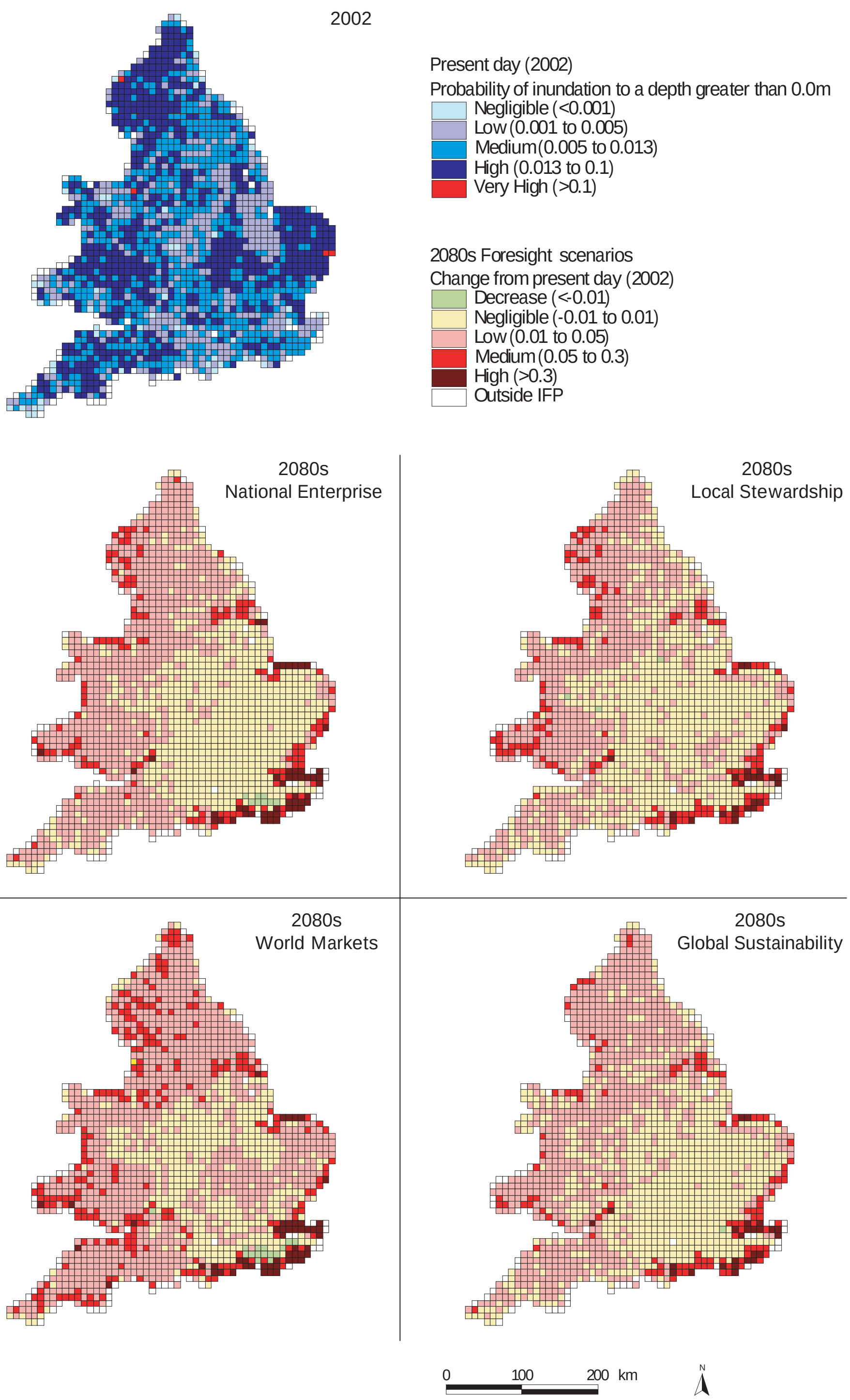
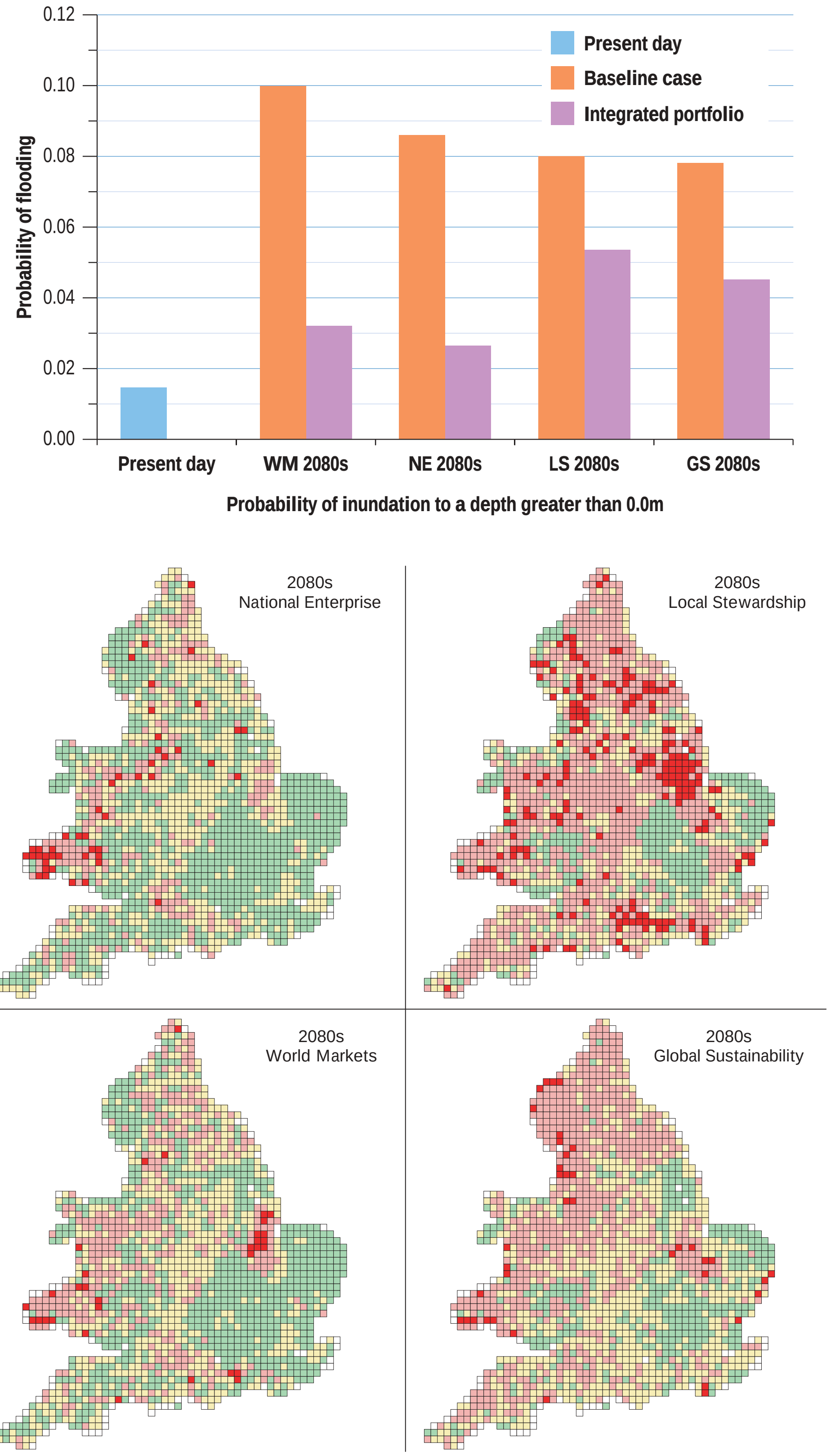


Figure 5.2b **Expected Annual Probability of Inundation – response portfolios implemented**



5.2.4 Number of people exposed to 'high' flood risk

This provides a simple count of the total number of people experiencing a probability of flooding in a given year greater than 1 in 75. The results are reproduced in Figures 5.3a (baseline case), and 5.3b (portfolio of responses modelled).

Table 5.5 **Explanation of plots of number of people exposed to 'high' flood risk (Figures 5.3a and 5.3b)**

Scenario	Interpreting the effectiveness of an integrated portfolio of responses
Present day	Some of the areas at high risk of inundation are rural and contain relatively few people. The pattern is therefore one of a number of significant and discrete areas that expose significant numbers of people to flood risk. In particular, these include the Thames Valley and the Lancashire to Humber corridor (containing the major conurbations of Hull and Manchester, among others).
World Markets 2080s	Reflecting the high level of protection afforded to urban areas, the number of people at high risk significantly reduces by approximately 70% (from 3.5million to 1million) relative to the baseline. The number of people at risk in the extensive floodplains of the East Anglian fens significantly increases compared to the baseline scenario.
National Enterprise 2080s	As under the World Markets scenario, the emphasis placed on reducing flood probability leads to a significant decrease (80%) in the number of people at high risk (from 3.5 million to 800,000). The moderate improvement over World Markets reflects the protection of rural as well as urban areas.
Local Stewardship 2080s	The change in the number of people at high risk reflects the pattern of changing flood probabilities and reduces marginally by approximately 20% (from 2.3 million to 1.5 million – equivalent to present-day levels of exposure).
Global Sustainability 2080s	The protection provided to the major conurbations reduces the number of people at high risk significantly by approximately 60% (from 2.4 million to 1 million). Both major conurbations and more sparsely populated rural areas see an increased level of protection.

Figure 5.3a **Number of people at 'high' risk – baseline case**

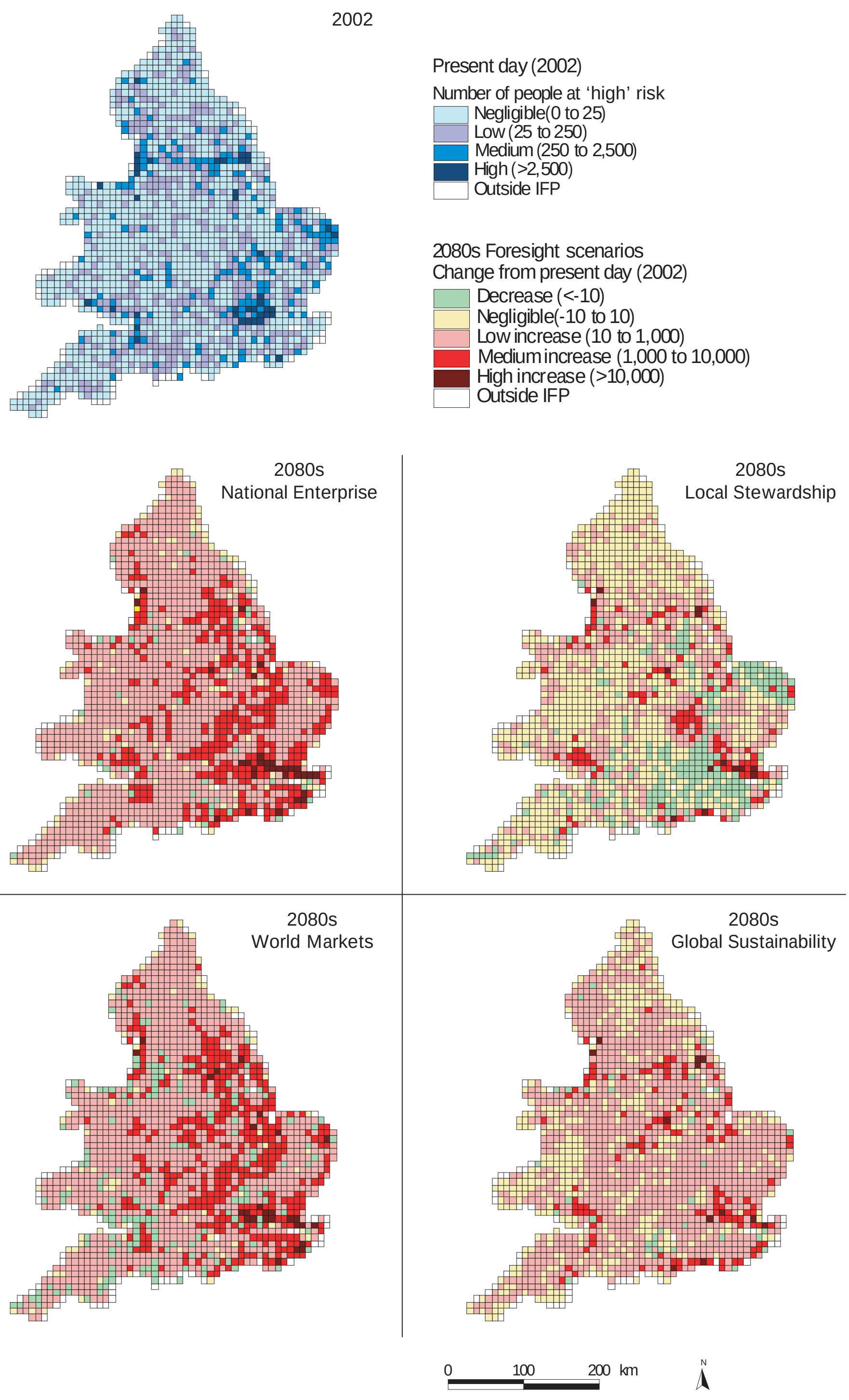
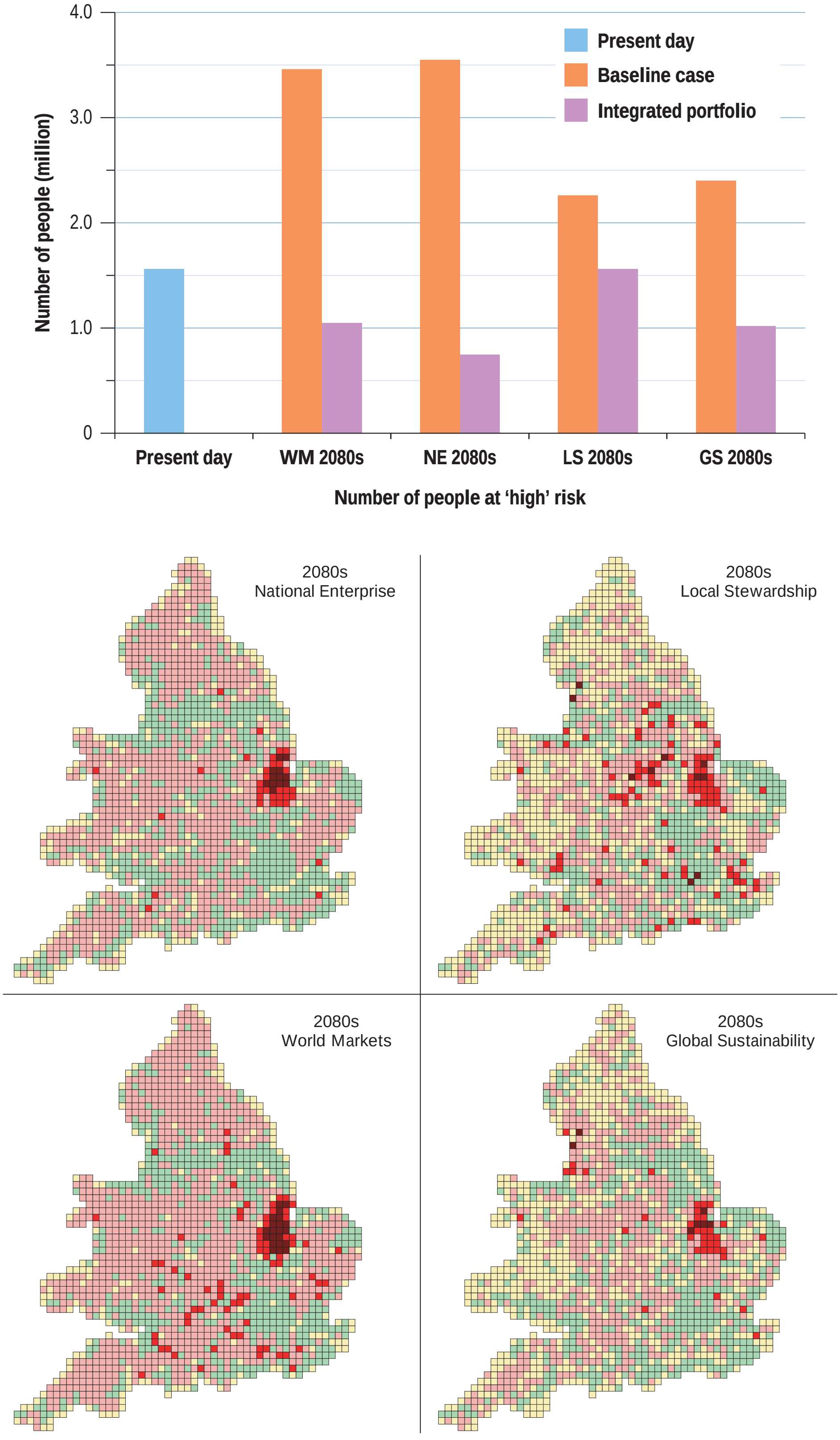


Figure 5.3b **Number of people at 'high' risk – response portfolios implemented**



5.2.5 Expected Annual Damage – residential and commercial properties

The Expected Annual Damage estimated under the baseline case has been modified to take account of the protection against flooding and the management of its impacts proposed under each integrated portfolio of responses (Figure 5.4).

Table 5.6 **Explanation of Expected Annual Damage – residential and commercial properties (Figures 5.4a and 5.4b)**

Scenario	Interpreting the effectiveness of an integrated portfolio of responses
Present day	As in the 'people at high risk' case, the principal contributions to the national exposure to economic damage are driven by a few discrete areas. In particular, these include Greater London, the south-east coast, parts of East Anglia, along the Severn estuary and the corridor of the coast at Lancashire across to the Humber.
World Markets 2080s	The pattern of economic damage provides a striking contrast to the baseline management scenario (exhibiting a reduction of 90% in the Expected Annual Damage from £21billion to £1.8billion). The major urban conurbations stand out as exhibiting a significant reduction in their exposure to flood damage: as exemplified in the Thames, Lancashire to Humber corridor and within the Severn estuary. Outside of the major conurbations the exposure to economic damage is more evenly distributed than observed in the baseline. This leads to a clear divide in the level of exposure between those living within the cities and those in more rural communities. This is particularly apparent in the red spine down the centre of England in Figure 5.4b (World Markets). This reflects a lowering of the standard of protection for some classes of agricultural land under this scenario. The natural tendency for coastal floodplains to be urbanised is reflected in the significant investment in new defences (see Table 5.10) and the corresponding reduction in economic damage observed at the coast.
National Enterprise 2080s	As under the World Markets scenario, implementation of the integrated portfolios of responses significantly reduces Expected Annual Damage (from £15.5billion to £1billion – a level similar to present day). The continued protection of both urban and rural areas is reflected through a dramatic decrease in risk when compared to the baseline assumption in the Thames, Humber and Severn estuaries as well as in a number of less densely populated areas.
Local Stewardship 2080s	Under the baseline management scenario the spatial distribution of expected damage is diverse. This remains the case following implementation of the integrated portfolio of responses. Key changes, however, include the reduction in coastal damage and the increase in damage expected in the areas of the East Anglian fens which are at present well protected – a level of protection that would be reduced under this scenario.
Global Sustainability 2080s	A significant reduction in expected damage is observed in the major conurbations. This high degree of protection is most striking in the Thames, Humber and Severn estuaries. The implementation of measures to manage flood losses and the effectiveness of land-use management also delivers a significant reduction in damage in less urbanised areas outside of the main conurbations when compared to the baseline. As under the other scenarios the Fens experience an increase in risk reflecting the reduced protection afforded to rural areas under this scenario when compared to present-day standards in this area. It should be borne in mind that the present target levels of flood protection have been maintained under this scenario, whereas they have been doubled under World Markets and National Enterprise.

Figure 5.4a **Expected Annual Damage – residential and commercial properties – baseline case**

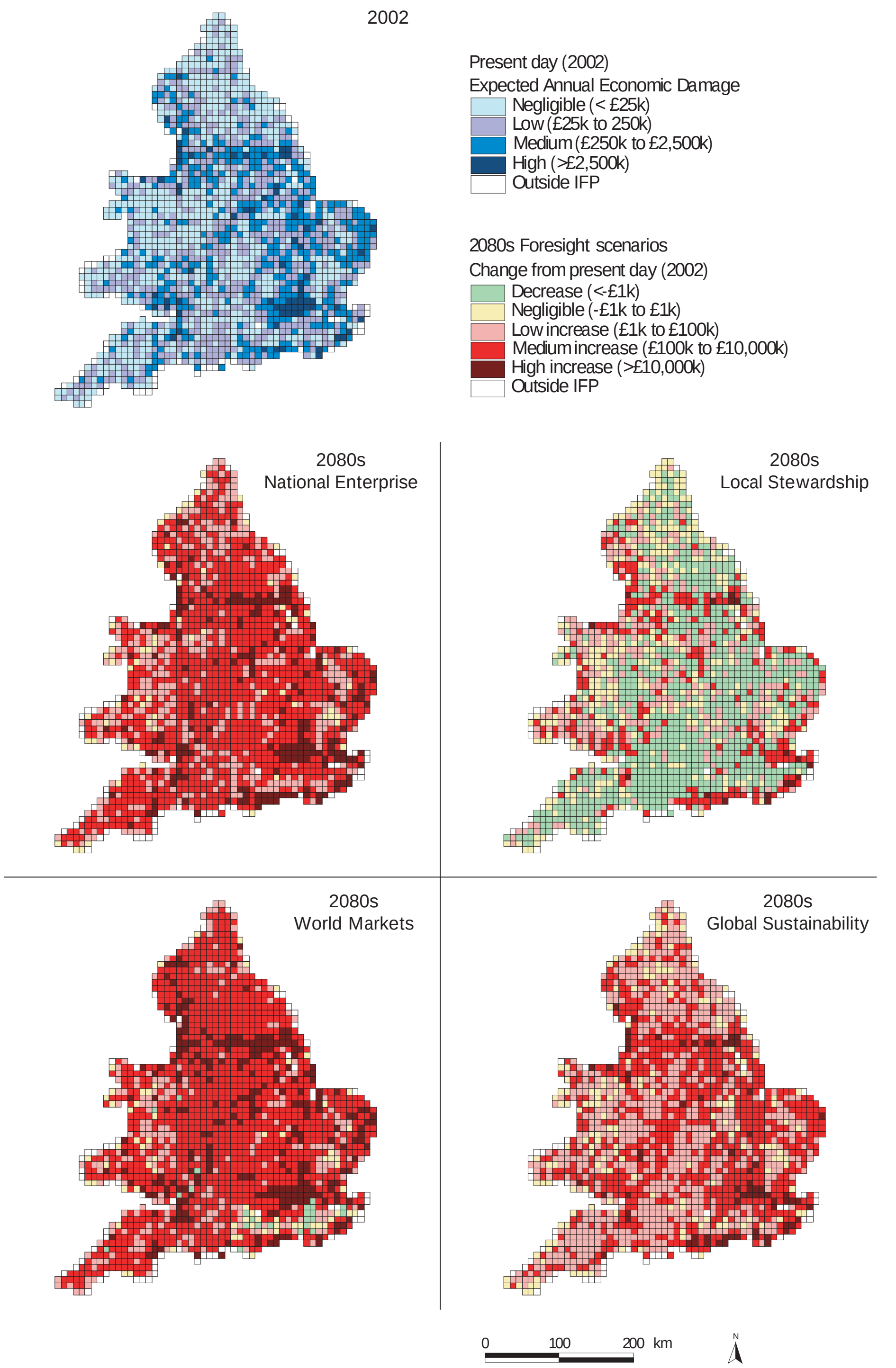
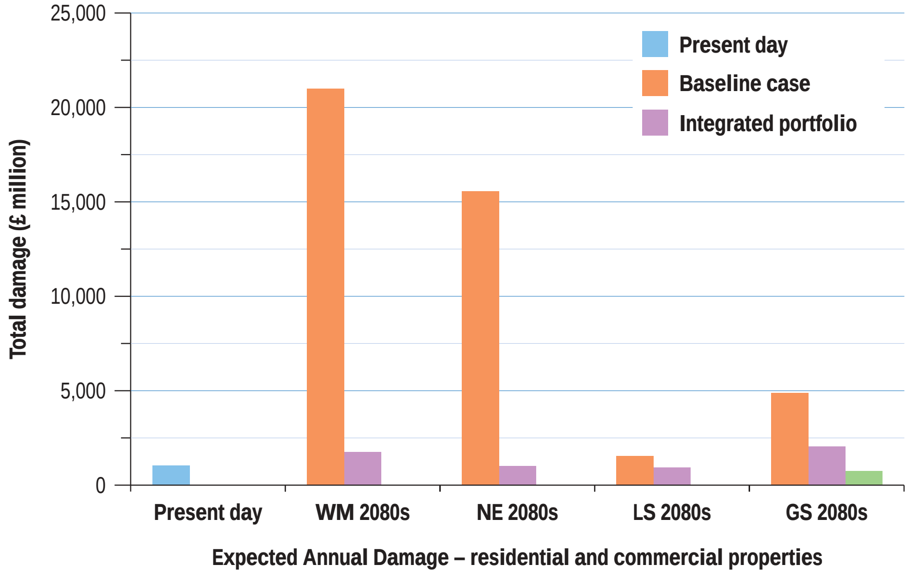
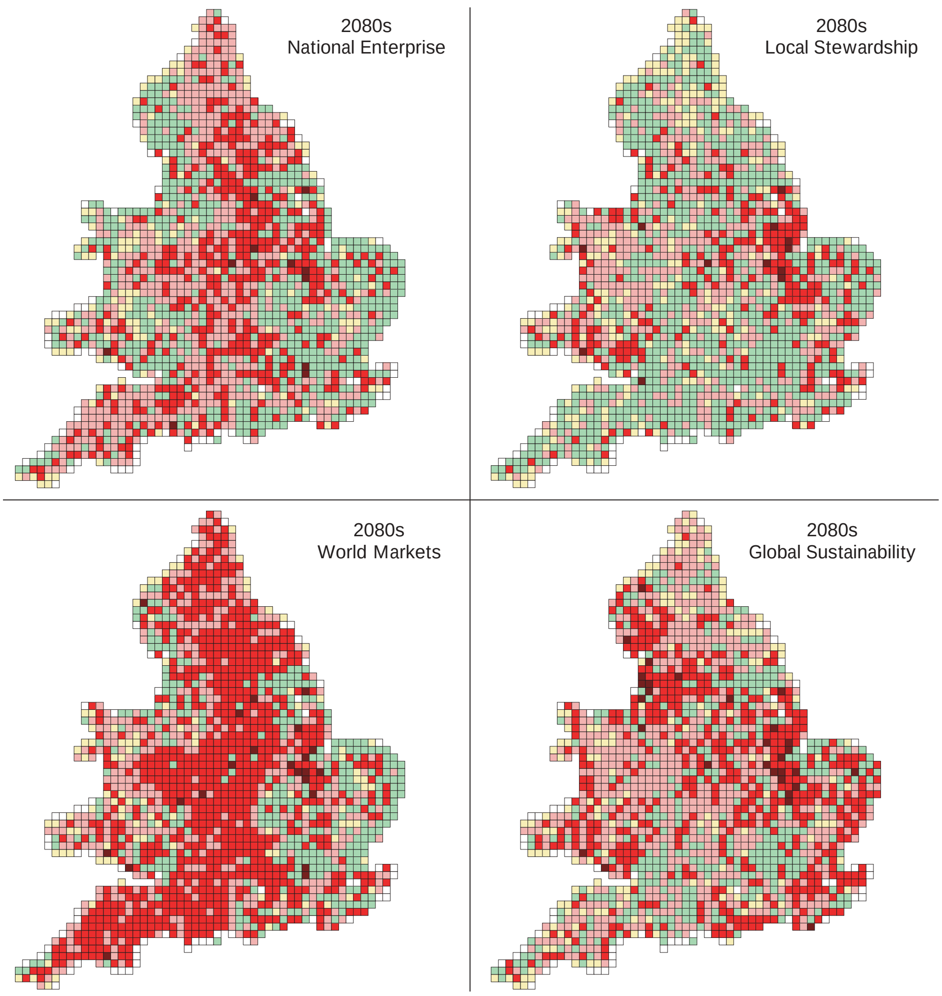


Figure 5.4b **Expected Annual Damage – residential and commercial properties – response portfolios implemented**





5.2.6 Expected Annual Damage – agriculture

The expected annual agricultural damage estimated under the baseline case (Figure 5.5a) has been reassessed to take account of the increased standards of protection resulting from the implementation of the portfolios of responses (Figure 5.5b).

Table 5.7 **Explanation of Expected Annual Damage to agriculture (Figures 5.5a and 5.5b)**	
Scenario	**Interpreting the effectiveness of an integrated portfolio of responses**
Present day	Today, agriculture is relatively evenly exposed to flooding risk across England and Wales (see blue map). The most striking exception to this is in the vicinity of the Wash where significant areas of Grade 1 land lie within the floodplain and, although well protected, significant risk of flooding remains. A number of smaller areas also stand out as exhibiting high agricultural risk including parts of the south coast and north-west. The areas of poorer agricultural land (Dartmoor, west Wales, Pennines etc) are categorised as low risk whilst the major built-up areas (London, Birmingham etc) exhibit negligible exposure to agricultural damages reflecting the limited agriculture in these areas.
World Markets 2080s	The implementation of an integrated portfolio of measures causes agricultural losses to reduce dramatically from an Expected Annual Damage of £35 million (under the baseline assumption) to £12 million. However, this damage reduction is a side-effect of a policy of protecting urban areas rather than part of a policy of protecting domestic agriculture. The most significant reductions occur in the south-west, Midlands and north-east. This reflects the improvement in defence standards for less extensively urbanised areas where high grade agricultural land sits within broader, well protected, urban areas (see, for example, the Humber and Thames estuaries). The key exception to this is in the heartland of the East Anglian fens, where the standards observed today are not maintained into the future.
National Enterprise 2080s	The implementation of a similar portfolio of responses, focused on increased protection against flooding, yields a similar reduction in agricultural damages to that observed under the World Markets scenario. The reduced agricultural damage is a direct result of a policy to protect domestic agricultural production.
Local Stewardship 2080s	Agricultural damage under the baseline assumption increases to £65 million per year by the 2080s. Although the implementation of the portfolio of measures is successful in reducing damage (by approximately 20%) overall their impact has a distinct regional variation. Outside of East Anglia agricultural damage is significantly reduced (by between 50-90%). However, within the highly valuable grade 1 land within the fens a significant reduction in standard is observed and expected damage increases by 50% (up to £33 million pa – over half of the future national exposure).
Global Sustainability 2080s	Implementation of the integrated portfolio of measures has a mixed impact on agricultural damage, as in World Markets urban areas are well protected. This is reflected in a decrease in agricultural damage compared to the baseline assumption in the majority of coastal floodplains and those on the outskirts of urban areas, such as those within the Thames and Humber estuaries. However, the use of non-structural measures to protect property and people within less densely populated areas provides for an increased flood probability and hence associated agricultural damage, notably in the East Anglia fens.

Figure 5.5a **Expected Annual Damage – agricultural productivity – baseline case**

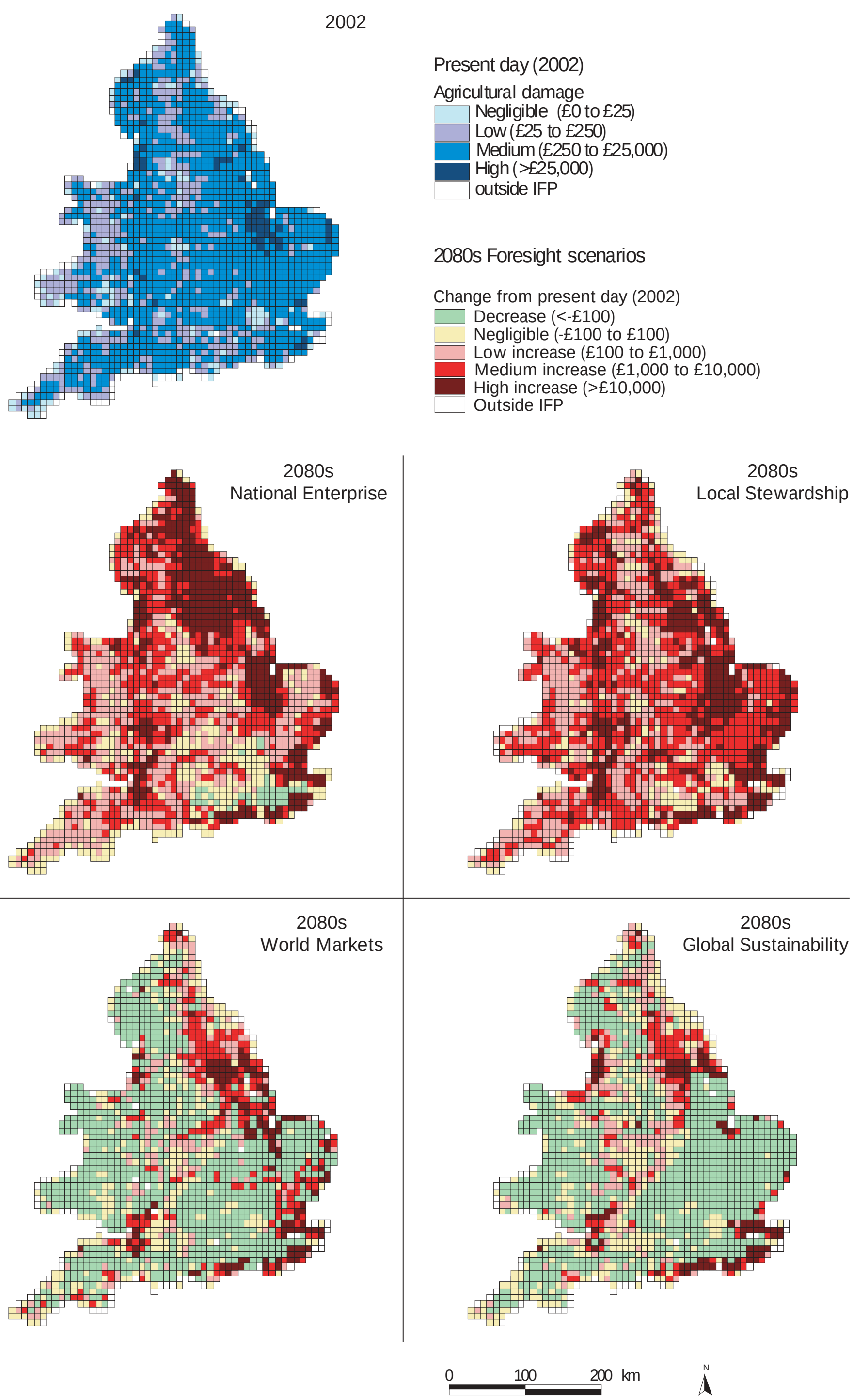
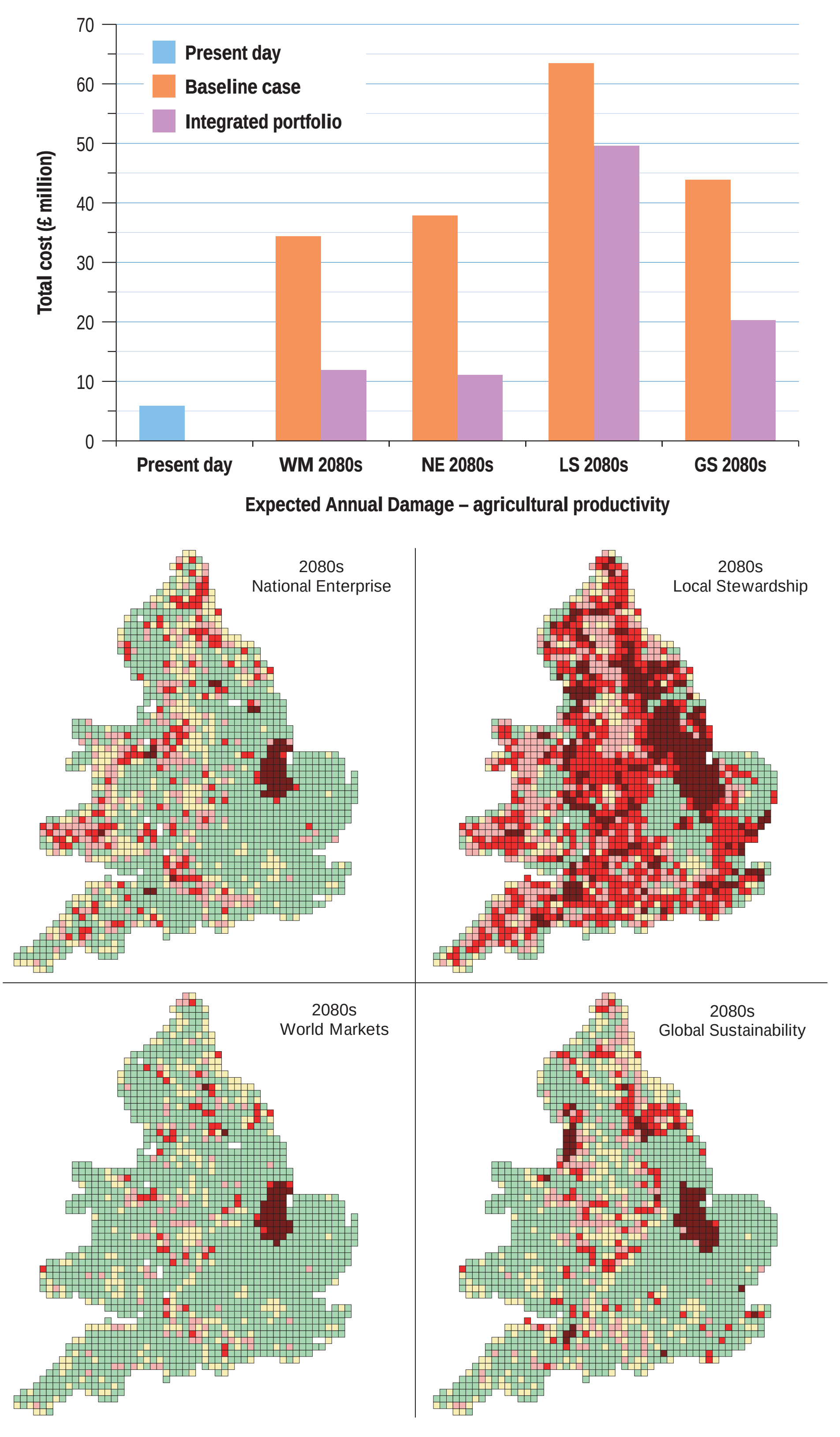


Figure 5.5b **Expected Annual Damage – agricultural productivity – response portfolio implemented**



5.2.7 Social vulnerability to flooding

The social vulnerability to flooding estimated under the baseline case (Figure 5.6a) has been reassessed to evaluate the effect of the integrated portfolios of responses (Figure 5.6b). Social vulnerability is the most difficult risk metric to interpret as it combines both a notion of a community's social vulnerability – in terms of wealth, health and age – with its ability to respond and recover from flooding.

Table 5.8 **Explanation of plots of social vulnerability to flooding (Figures 5.6a and 5.6b)**	
Scenario	**Interpreting the effectiveness of an integrated portfolio of responses**
Present day	The Social Flood Vulnerability Index (SFVI) is the most complex of measures to interpret. It involves combining the probability of flooding with the number of people from socially vulnerable classes of 4 and 5. The areas that stand out today as particularly vulnerable are East Anglia, northern England and parts of the Midlands.
World Markets 2080s	The improved protection against flooding in the main towns and cities is reflected in a decrease in social vulnerability to flooding in the Thames, the Humber and along the coast. The lower standards and protection in fenlands compared to the baseline assumption translates to increase in vulnerability.
National Enterprise 2080s	The similar management responses applied under National Enterprise and in World Markets are reflected in a similar pattern in social vulnerability.
Local Stewardship 2080s	The significant increase in social vulnerability observed under the baseline scenario persists following implementation of the integrated portfolio of responses. The principal contributory factor in this change is the need for self-reliance in people who have chosen to live in floodplains. Allied with an ineffectual emergency response and community network, more people find it difficult to recover from floods. To reflect these changes people within the SFVI Class 3 (a medium vulnerability category) are considered as becoming more vulnerable and are reclassified as SFVI Class 4 (a more vulnerable category).
Global Sustainability 2080s	As with World Markets and National Enterprise the implementation of a portfolio of measures delivers a more defined divide – between the low vulnerability of communities occupying well protected urbanised floodplains and those in the low-lying rural areas. See for example, the dramatic difference between the Thames and the fenlands of East Anglia.

Figure 5.6a **Social vulnerability to flooding – baseline case**

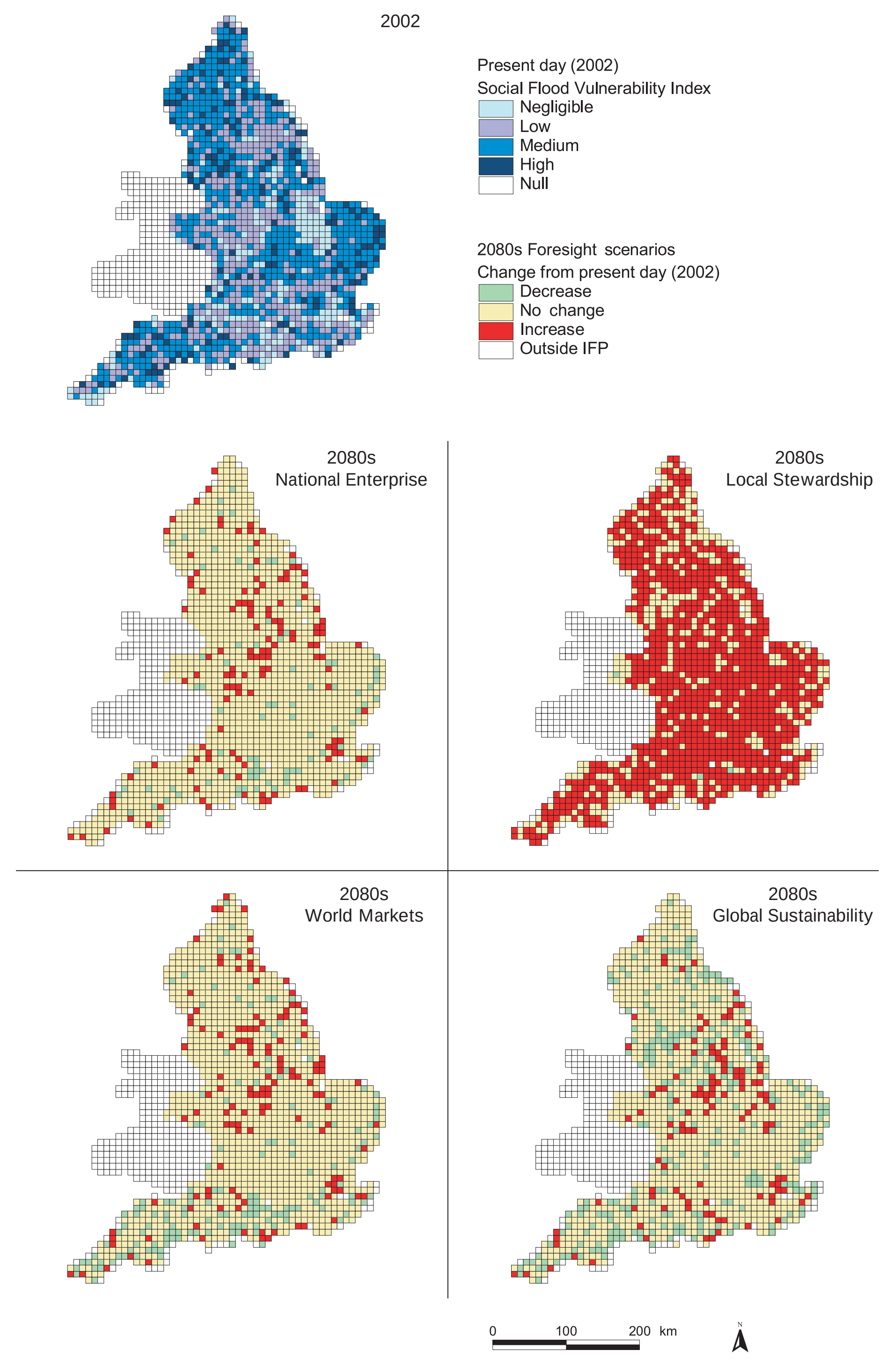
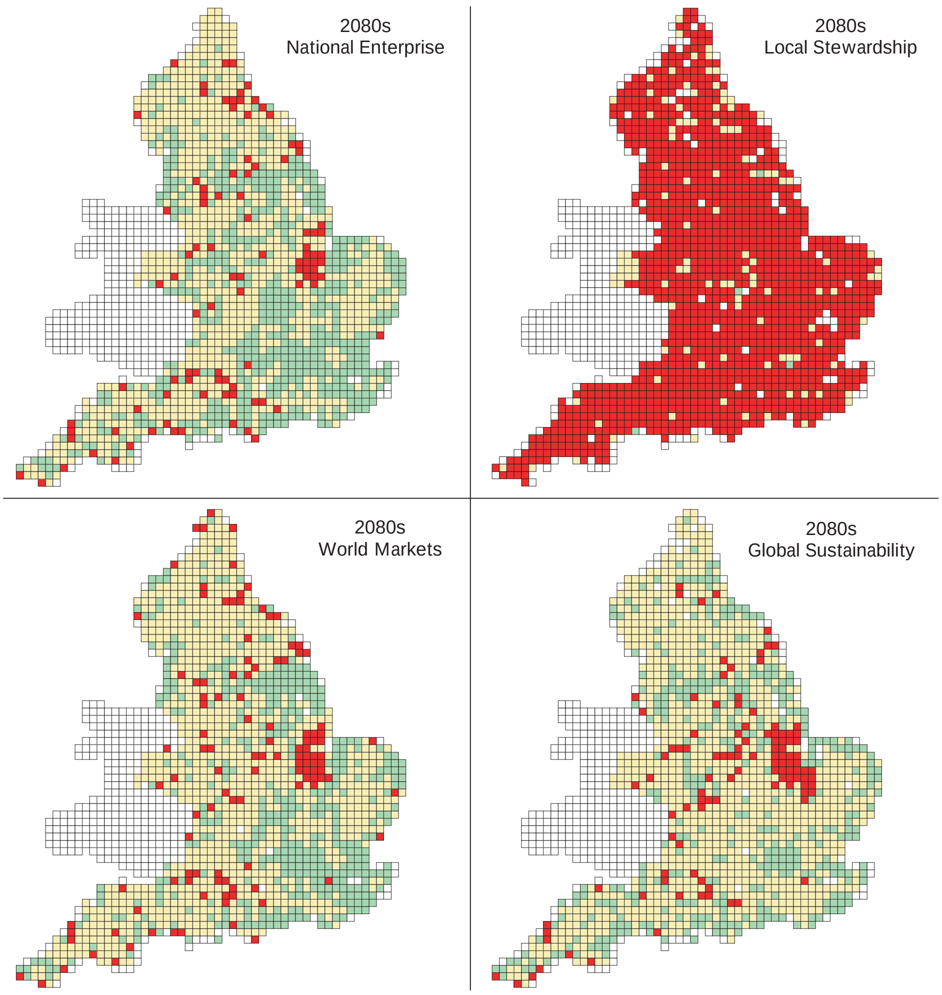


Figure 5.6b **Social vulnerability to flooding – response portfolios implemented**

Region	Present day	WM 2080s		NE 2080s		LS 2080s		GS 2080s	
		baseline	portfolio	baseline	portfolio	baseline	portfolio	baseline	portfolio
East Anglia	Low	Medium	Medium	Medium	Medium	High	Very High	Medium	Medium
Midlands	Medium	Medium	Medium	Medium	Medium	Medium	Very High	Medium	Medium
North East	Medium	Medium	Medium	Medium	Medium	High	Very High	Medium	Medium
North West	Medium	Medium	Medium	Medium	Medium	High	Very High	Medium	Medium
South West	Low	Medium	Medium	Medium	Medium	High	Very High	Medium	Medium
South East	Low	Medium	Medium	Medium	Medium	High	Very High	Medium	Medium
Thames	Medium	Medium	Medium	Medium	Medium	High	Very High	Medium	Medium
Wales	–	–	–	–	–	–	–	–	–
Total	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**High**	**Very High**	**Medium**	**Medium**

Social vulnerability



5.3 Results of the investment analysis

Table 5.9 details the costs of implementing the engineering components of each of the integrated portfolios of responses, divided according to geographical regions.

The results show a striking contrast between the 'protection'-led approaches adopted in World Markets and National Enterprise (requiring nearly £80 billion capital investment in defence-raising) compared to the more 'management'-led approach adopted in Global Sustainability (requiring a significantly more limited investment in defence infrastructure of £20 billion). It must be remembered that under Global Sustainability the present target levels of flood protection are maintained whereas they are doubled under World markets and National Enterprise. Under Local Stewardship, the less ambitious targets for flood protection and the more mixed approach to flood-risk management translates into an investment in defence infrastructure similar to that under Global Sustainability.

While these figures provide a broad feel for the scope of the financial investment needed, it should be remembered that they underestimate the full cost of implementing the various portfolios. For example, the costs of implementing non-structural responses are not included, nor are factors such as the purchase of land to implement defences. Indeed, the cost of the non-structural response is likely to be higher under the Local Stewardship and Global Sustainability scenarios reflecting the greater reliance on such measures. In addition, the costs of environmental mitigation measures are not included.

5.4 Sensitivity analysis – the benefits of an integrated approach

The use of integrated portfolios of responses draws upon a wide range of possible measures. Some of these such as engineering have potentially large direct costs, whereas others such as changes to planning policy less so. Because of the large potential sums involved (see Table 5.9), it was considered desirable to perform a

Table 5.9 **Investment required to raise defences to achieve standards matched to scenarios in the 2080s following implementation of other non-structural solutions**

Region	Residual investment in defence raising (£m)			
	World Markets	National Enterprise	Local Stewardship	Global Sustainability
East Anglia	20,846	19,967	6,587	5,314
Midlands	8,106	8,570	1,263	1,940
North East	6,354	6,577	1,637	1,887
North West	3,922	4,052	1,215	1,189
Southern	13,845	13,588	3,586	4,162
South West	8,943	9,386	2,305	2,490
Thames	6,835	7,259	2,612	3,201
Wales	6,790	7,781	2,908	2,181
Total	**75,641**	**77,180**	**22,115**	**22,365**

sensitivity analysis to assess the effectiveness of an integrated portfolio approach in reducing costs and in managing risk – compared with an approach based more on engineering.

In order to perform the sensitivity analysis, an engineering-based risk-management approach was assessed for the Global Sustainability scenario in the 2080s, and compared with the portfolio approach. This new analysis assumed the simple raising of defences to support present-day standards of flood protection. It took account of demographic and climate change. Similar standards of protection were targeted in the two cases – these are similar to present-day standards.

5.4.1 Results of the sensitivity analysis

Table 5.10 details the investment costs required for the engineering-based approach, broken down according to the type of works required. The key figure here is the total investment cost of £52 billion, compared with £22 billion for the portfolio approach (see Table 5.9). Since the standard of flood protection is similar for the two approaches, the residual risks would be broadly similar. It should be noted in comparing the costs that the integrated portfolio cost of £22 billion does not include any costs for the non-structural responses. Nevertheless this demonstrates the large cost savings that may be possible with an integrated approach – in addition to the wider benefits of sustainability.

Table 5.10 **Investment required to raise defences to achieve present day standards in the 2080s for the Global Sustainability scenario**

Global Sustainability 2080s								
Floodplain type	New Build	Significant Major Works	Major Works	Significant Minor Works	Minor Works	No Works	Total investment (£m)	Length of defence improved (km)
Lowland valley	56%	27%	13%	4%	0%	0%	12,000	49,000
Steep valley	55%	30%	11%	4%	0%	0%	8,000	36,000
Coastal	74%	20%	4%	1%	0%	0%	32,000	17,000
							52,000	102,000

5.5 Conclusions

The analysis demonstrates that future flood risk can be managed under all the future scenarios but at varying cost. In some cases the costs could be very substantial – both economically and in broader terms. The key results are:

- A common level of residual flood risk across all scenarios – in the range of £1 billion to £2 billion per year. This is in contrast to the large variance in flood risk predicted under the baseline assumption (ranging from £20 billion per year for England and Wales in World Markets to £1.5 billion per year in Local Stewardship).
- The target flood frequency is only maintained under Global Sustainability whereas it is doubled under World Markets and National Enterprise. This suggests that there is scope for further risk reduction under Global Sustainability.
- The most striking potential reductions in risk are observed under World Markets – from £20 billion per year (baseline case) to £1.8 billion per year. Combined with an increase in wealth, this represents a considerable reduction in the impact of flooding on the economy. However, this is relatively expensive, comes with a high price to the environment, and the reliance on defence improvements raises issues of sustainability (see Chapter 7).
- Towns and cities typically become better protected in each of the flood-management portfolios. This conclusion is exemplified under World Markets where key urban areas, such as the Thames and the Humber, are well defended leading to a reduction in risk compared to the present-day level.
- Protection for the less densely populated and rural areas declines across all the scenarios when compared to the present day, although protection levels remain higher than typically estimated under the baseline case. In particular, the agricultural heartlands of East Anglian fens, where the present-day defences afford a high degree of protection, experience a significant reduction in standard. In fact, the protection against flooding afforded to this area is higher under the baseline assumption than was achieved under any of the four integrated portfolios. This suggests the present-day standards in this area are higher than those expected in any of the future scenarios considered.

- The results show a marked inability to reduce the number of people living within the floodplain. Only limited reductions are achieved in Global Sustainability and Local Stewardship (approximately 10%) with no change observed under the World Markets and National Enterprise futures. This reflects the inertia within the housing sector and a reluctance to abandon existing housing under all scenarios.
- The costs of implementing the structural component of the response portfolios ranged from around £75 billion (World Markets and National Enterprise) down to £22 billion (Global Sustainability and Local Stewardship). This demonstrates a clear division between the investment in, and hence reliance on, flood defences within World Markets and National Enterprise futures as opposed to the more mixed approaches adopted under the other two scenarios. The variation in investment also reflects the different levels of protection against flooding afforded in each scenario and the scenario-specific demographics.
- The portfolio approach yielded substantial cost savings compared with an engineering-based approach. For example, in the case of Global Sustainability in the 2080s, the cost was £22 billion as opposed to around £52 billion. The former does not include costs of the non-structural responses. Conversely, the latter carries signficant sustainability penalties.

5.6 Extreme normal flood event scenarios – the ability of portfolios of responses to reduce risks

As in Volume I, the quantified risk analysis described above inevitably deals with broad average situations at a national scale and not with local extremes. Also, it conceals low-frequency/high-consequence flood events within the process of calculating annual average damages.

In Volume I three illustrative examples of major extreme floods that could affect Britain were described. All are cases of rare events that would cause substantial damage, economic disruption on a large scale, and have the potential to lead to significant loss of life. We now revisit those cases to assess what would happen if the portfolios of responses were in place. As in Volume I, this analysis, as far as possible, is founded on historical examples and research.

Year 2030: a major coastal flood disaster in a large estuary

The event is worse than the 1953 east coast flood event. It has a probability in any one year of 1 in 5,000, potentially overtopping the defences downstream of a tidal barrier which is protecting a major city. The cause is a record tidal surge – generated by a very substantial and deep depression creating a surge that coincides with a high spring tide and record flood flows in the river and its tributaries.

Under World Markets, the target standard of flood protection has risen to 1:10,000 and no overtopping or breaching occurs. The same applies to Global Sustainability. Thus, in these cases, economic growth has allowed massive expenditure on flood-defence measures to match the increased economic use of the floodplain, thereby avoiding disaster.

Under National Enterprise, the standard of flood protection stays the same as now (1:1,000), and the flood consequences are potentially as serious as described in Volume I. Under Local Stewardship the standard of flood protection has declined to 1:500, so the flooding is potentially worse. But in both cases, the integrated bundle of responses alleviates the situation greatly. For example, considering just the six most effective responses in each case:

National Enterprise:

- Enhanced physical barriers at the coast, reducing the power of the floodwaters.
- Extensive floodproofing of buildings, protecting many people and businesses.
- Some coastal realignment and abandonment, reducing the risk of flood impacts.

- Better floodfighting performance, reducing vulnerability and damage.
- Better warning and response, reducing loss of life significantly.
- Better land-use management, and hence less development in the floodplain, thus reducing the risk.

Local Stewardship:

- Better land-use management, and hence less development in the floodplain, thus reducing the risk.
- Better individual damage-avoidance measures (e.g. raising valuables), thus reducing damage.
- Extensive floodproofing of buildings, protecting many people and businesses.
- Better warning and response, reducing loss of life significantly.
- Enhanced pre-event measures, making the population more aware of the risk and promoting avoidance actions.
- Better floodfighting performance, reducing vulnerability and damage.

The result would still be massive damage, especially under Local Stewardship, and there would be loss of life, but not as much as without these measures. Long-term economic dislocation would continue, and the future of the city as a centre for international business would be threatened.

Year 2045: a fluvial flood disaster in a city on a major inland river

The city is substantially built behind old flood defences along the river, constructed in the 1950s at a design standard to cope with a flood of no more than 1 in 50-100 years. Much of the modern city occupies areas well below the level of the flood defences.

As described in Volume I, a flood with a return period of 150 years threatens the defences and the city. The standards of flood protection now in operation in the area depend on the scenarios tested. Under World Markets the standard of flood protection has risen from 1:50-200 to 1:200 and no overtopping or breaching occurs. The same applies to National Enterprise. Under Global Sustainability the standard of flood protection is only 1:100, so the town suffers flooding as described in Volume I, whereas in Local Stewardship the standard of flood protection *falls* to 1:50, so the flooding occurs with greater severity under a 1:150 year flood than would be the case in other scenarios.

However, the flooding under Global Sustainability and Local Stewardship is modified by the integrated portfolio of responses. Considering just the most highly ranked fluvial flood responses in each case:

Global sustainability:

- Enhanced flood defences (perhaps some local protection in the city).
- Measures to increase conveyance in flood-bearing rivers (although this would have little effect on cities at the downstream ends of rivers).
- Some upstream engineered and other flood storage, although again this would have little effect on such a large river.
- Flood-proofing of property in the city to reduce impacts.
- Better flood-fighting performance, reducing vulnerability and damage.

Local Stewardship:

- Some upstream engineered flood storage, although this would have little effect on such a large river.
- Better land-use management, and hence less development in the floodplain, thus reducing the risk.
- Extensive floodproofing of buildings, protecting many people and businesses.

- Better individual damage avoidance measures (e.g. raising valuables), thus reducing damage.
- Some upstream catchment flood storage, although this would have little effect on such a large river.
- Better warning and response, reducing loss of life significantly.

The result would still be massive damage. This is especially the case under Local Stewardship, where standards of protection would have fallen and the city would experience prolonged disruption. There would be the likelihood of significant loss of life in the flood event.

The response measures inherent in the World Markets and National Enterprise scenarios prevent the disaster because the assumed economic growth has allowed massive expenditure on flood defence measures to increase the average standard of protection well above that enjoyed in 2004.

Year 2075: catastrophe in a major city from a major urban storm flood event

As described in Volume I, climate change is likely to bring increased storminess in British latitudes, and this has serious consequences for the standards of urban drainage in many of our cities, much of which is still of Victorian origin.

The flood is driven by a major summer thunderstorm event hovering stationary over the city for 24 hours in July 2075, producing 20 cm of rainfall (this would be marginally worse than the Lynmouth event of 1952). A fifth of the city's normal annual average rainfall falls. Nothing like this has been seen for more than 200 years; damage is massive and loss of life is likely under nearly all scenarios.

World Markets:

Major cities will be very much richer than they are in 2004, and will have invested heavily in urban infrastructure to protect that wealth. Damage from the flood from this rainstorm event could therefore be less than if it had occurred in 2004, although the increased wealth in the city centre means more assets are at risk; damage is therefore still very significant (and loss of life remains likely).

National Enterprise:

The situation with regard to flood damage and loss of life will be similar, as GDP growth rates will also have been high and the national focus will mean major cities will be favoured in this investment. The water industry remains privatised, and there is some confusion of responsibility as to who does what with regard to urban flooding.

Local Stewardship:

There will have been a move of the population away from large cities, and therefore some de-urbanisation. This has allowed for more greenspaces to be developed in the city, creating storage areas for floodwaters. The result is much less flood damage than under any other scenario, and very little loss of life.

Global Sustainability:

A greater focus will have been given to water recycling, and the integration of the quality and quantity aspects of water management. Investment throughout the water cycles' systems (sewers included) will have been considerable, leading to less damage. Loss of life in the flood would be less, but the population certainly cannot be protected fully from such a severe event.