Chapter 4

Quantified flood risks in England and Wales – fluvial and coastal

An important objective of this project is to understand how flood risk will change over the longer term. This has been considered qualitatively in Chapter 2. In this chapter the future risks are quantified for England and Wales.

A cutting-edge flood-risk modelling tool has been used for this analysis, called Risk Assessment for flood and coastal defence for Strategic Planning (RASP), developed by HR Wallingford, in association with the University of Bristol. This has been adapted to analyse risks in the 2050s and 2080s under the various future scenarios outlined in Chapter 1. The potential reduction in risk resulting from a reduction in global emissions is also assessed for the case of a high-growth/low emissions economy.

4.1 Overview of the RASP model

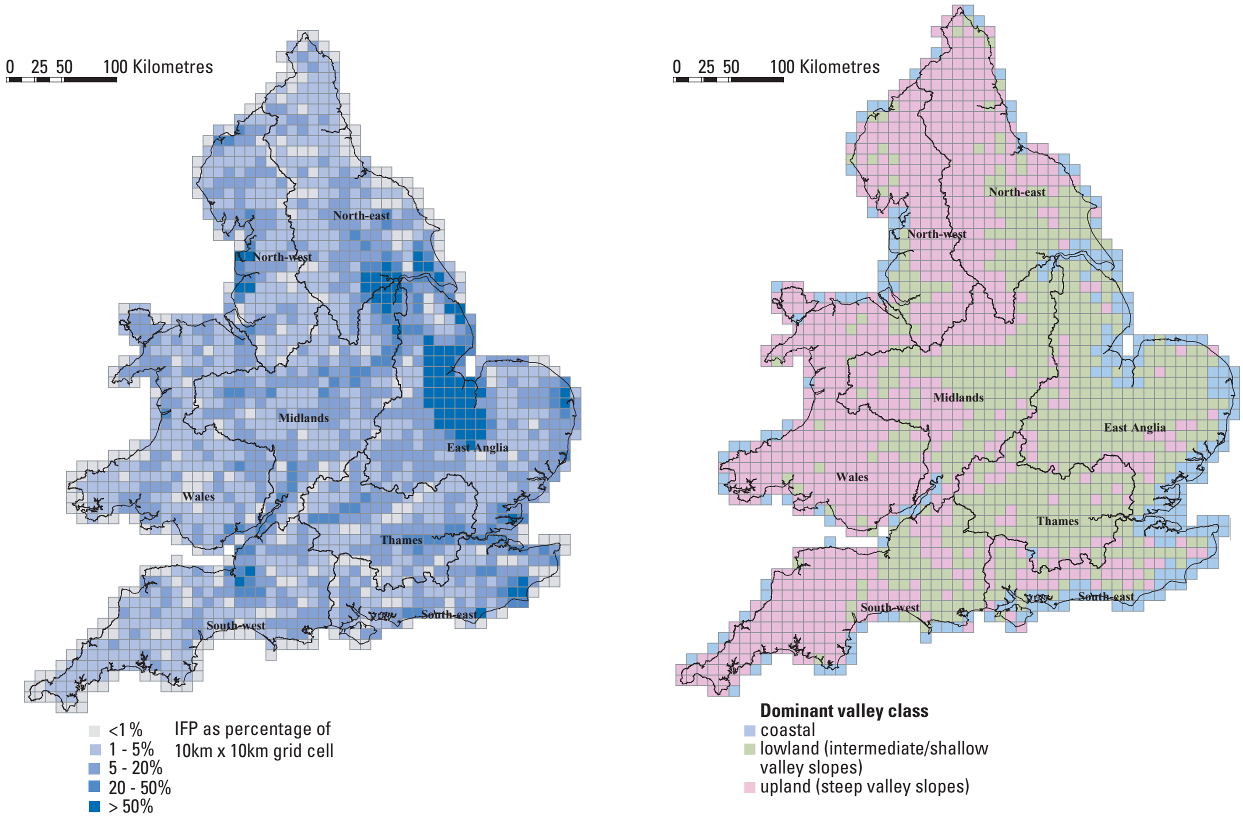
Techniques developed in recent years for Defra and the Environment Agency allow us to analyse the risks from river and coastal flooding in England and Wales on a national scale. These methods inevitably contain considerable uncertainty and are not appropriate for the detailed analysis of local flooding. However, they do provide a broad impression of the scale and distribution of flood risk in England and Wales and therefore provide a powerful tool for policy analysis. These techniques, notably the RASP flood-risk assessment tool (HR Wallingford 2003; Hall *et al*. 2003), have been used to analyse future flood risks from fluvial and coastal flooding in England and Wales. At present however, the RASP model does not include flood impacts from pluvial, storm drainage or groundwater generated inundation.

The RASP tool uses information on the location of river channels, the type of floodplain (see Figure 4.1) and the standard and condition of flood defences. It estimates the probability of flooding to a range of depths on grid squares of up to 1km x 1km. It then combines this depth-probability relation with census data and commercial databases of the location of property and population. Analysis of past flooding then allows us to include information on the relationships between flood depth and economic damage (Penning-Rowsell *et al.* 2003).

The analysis estimated future risk using today's prices, with no discounting or allowances for inflation. In line with the baseline assumption for flood management (used throughout Volume I), investment in flood defences is preserved at current levels across all scenarios in the analysis described. The standard of protection afforded by defences therefore decreases due to the influence of climate change. The results have been aggregated and reported nationally (for England and Wales), regionally and on a 10km x 10km grid. Estimates of the risk to life, health and communities have been obtained by analysing population density and demographics.

It was not possible to use the RASP tool to quantify future risks in Scotland and Northern Ireland due to the unavailability of flood-defence databases in those regions. Other techniques have therefore been used to assess future risks in those parts of the UK – these are reported in Chapter 8.

Figure 4.1 **Distribution of the Indicative Floodplain in England and Wales and classification of floodplain types**



Note: Indicative Floodplain Maps (IFMs) published by the Environment Agency, provide information on the potential extent of the natural floodplain. The so-called Indicative Floodplains (IFPs) therefore represent the area that could potentially be flooded in the absence of defences. For fluvial floodplains they represent a flood with a 1 in 100 chance of occurrence in a given year. In the case of coastal floodplains they relate to a flood with a 1 in 200 chance of occurrence in a given year.

Table 4.1 **Representation of risk drivers in quantified analysis**

Variable used by risk model	Explanation	Drivers 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/coastal bank) is expected to overtop significantly.	Climate change. Changes in land-use management (which may, for example, change run-off and hence river flows and water levels). Morphological change (which may, for example, also influence the conveyance of the river and hence water levels).
Condition grade of flood defences.	An indicator of the structural robustness of the defences and their likely propensity to breach when subjected to flood load.	Morphological changes. Maintenance/improvement 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 household contents. Changes in commercial practice. Changes in construction practices.
Social flood vulnerability indices.	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.
Global reduction factors.	Measures that will reduce total flood damage, e.g. improved flood warning and evacuation, can be reflected by general reduction in the estimated Expected Annual Damages.	Flood warning (including communications technologies) and public response to warning. Evacuation. Community self-help.

4.2 Adapting RASP for the analysis of future scenarios

The RASP analysis model was the basis for this review of long-term change in flood-risk. The RASP model considers a number of parameters, including sources, pathway and receptor terms, in assessing flood risk. These parameters have been varied within the model to reflect the time and the scenario under consideration.

The input data for the risk-assessment model does not correspond exactly to the information provided in the climate change and socioeconomic scenarios. Approximate relationships have therefore been constructed to translate the available information into the variables required for the analysis. Table 4.1 provides a description of the relationships adopted in the analysis of risks from fluvial and coastal flooding.

Thus, for example, in the quantitative analysis, if a scenario of climate change is to be modelled in which water levels increase (affecting the frequency of flooding experienced), the Standard of Protection (SoP) of flood defences is reduced by an appropriate amount. Drivers that affect receptors, such as the value of buildings and contents, are modelled by changing the appropriate depth-damage relationship. Further details of this process are provided in the technical papers that have been produced in association with the main project reports.

From Chapter 1, the four Foresight Futures have been introduced as:

- World Markets/High emissions.
- National Enterprise/Medium High emissions.
- Local Stewardship/Medium Low emissions.
- Global Sustainability/Low emissions.

For each of these scenarios we produced a qualitative assessment of flood risk in the 2080s. In addition, to investigate the evolution of risks over time, the World Markets/High emissions scenario for the 2050s has also been analysed.

It should be noted that the analysis does not take account of:

- How the market might react to an increase in flood risk.
- Consequential damage which would substantially increase costs.

A fifth scenario was also modelled: this enabled us to assess risk reductions that would result for a high growth economy (World Markets) if global emissions were reduced to a low level. This additional scenario is considered at the end of this chapter and will be referred to as 'the fifth scenario' in order to distinguish it from the other four scenarios.

Reliability of the assessment method

The RASP model was previously applied to a National Flood Risk Assessment in 2002 (HR Wallingford 2003). Within the NaFRA 2002 study it was estimated that the annual average economic damage due to flooding is, on average, in the order of £1billion pa. In deciding the overall validity of the RASP HLM, and the NaFRA 2002 results, it is appropriate that the 'believability' of this overall headline figure is critically reviewed.

The fluvial flood events of Autumn 2000 provide some observational evidence of our exposure to flood related economic damage. A detailed review of the economic and financial damages incurred during the Autumn 2000 floods was completed by FHRC (FHRC 2003). The evidence reported in the FHRC report ('The Economic and Financial Damages: Autumn 2000 Floods') suggests economic losses in the order of £750million were incurred. Although the Autumn 2000 floods were driven by widespread extreme precipitation it excluded any significant coastal flooding. Taken as a single event the Autumn 2000 event can be considered severe, however, for many fluvial and coastal areas not effected by the storms the local return period was small. It is also noteworthy that a similar severe fluvial event was experienced in 2002.

At present we do not have sufficiently well documented or extensive datasets over time, to provide a robust statistical estimate of the expected annual damages based on observation alone or to fully validate our models. Therefore to judge the validity of the NaFRA 2002 results on such a short dataset is difficult. Based on the evidence we have (two events in less than five years giving rise to damages approximating the EAD predicted through NaFRA 2002) some comfort can be taken that the results are of the right order. Until a reliable dataset of observed damages is established there will be a need to continue to rely on analysis to provide information on the damages that we may expect from more and less extreme events, or to explore the influence of changed defence or asset distributions. The methodology applied here is by no means a perfect reflection of reality. However, it provides a useful tool to undertake an analysis of flood risk at a national scale and can be considered sufficiently robust to provide insight into trends and spatial patterns. It may also be expected that relative changes between scenarios will be more reliable than the absolute results.

4.3 Results – flood risk under the four scenarios in the 2080s

4.3.1 How the results are presented

The results of the analysis are presented as bar charts and maps.

The data in the bar charts are presented according to the hydrometric regions, which approximate to Environment Agency regions, illustrated in Figure 4.1. The data in the maps are presented for seven parameters:

1. Probability of flooding.
2. Number of people living within the floodplain.
3. Number of people at high risk of flooding.
4. Expected Annual Damage – residential and commercial.
5. Expected Annual Damage – agricultural.
6. Social flood vulnerability (for England only due to a lack of data).
7. Expected Annual Damage – residential and commercial – adjusted by Gross Domestic Product.

The maps are in two distinct types and are colour coded as follows:

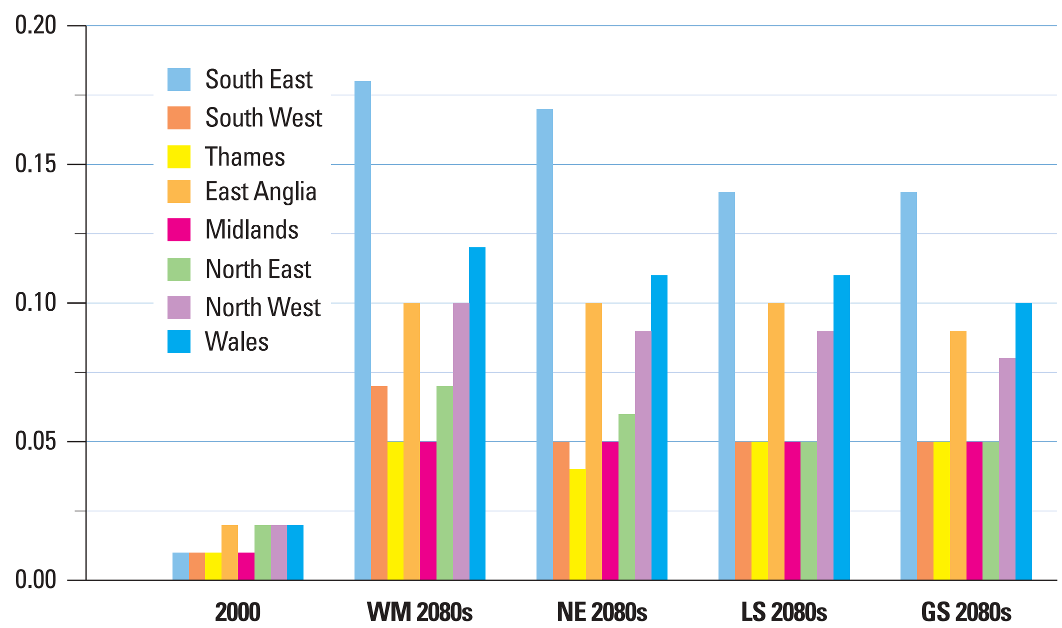
- Maps using primarily shades of blue represent total values of risk. Figure 4.2 provides present-day maps for six of the above parameters. Figure 4.3 provides a similar set for the case of the National Enterprise/Medium High emissions scenario in the 2080s.
- Maps using red and green represent changes 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 a reduced risk.

4.3.2 Regional distribution of risk (presented as bar charts)

Expected annual probability of flooding

For each 10km x 10km grid square the expected annual probability of inundation of the floodplain at that location has been calculated (no account is taken of the depth of inundation in this measure). The method of aggregation ensures that the results are not biased by the size of the Indicative Floodplain within any given grid square. This provides an indication of the combined influence of changes in the source and pathways of risk under the different Foresight scenarios. The results are further aggregated to provide changes in average probability of inundation for each region, as in Chart 4.1. This shows that in every case the probability of flooding is projected to increase – depending on region and scenario, the increase is between 2.5 and 18 times.

Chart 4.1 **All Foresight Futures: expected annual probability of flooding**

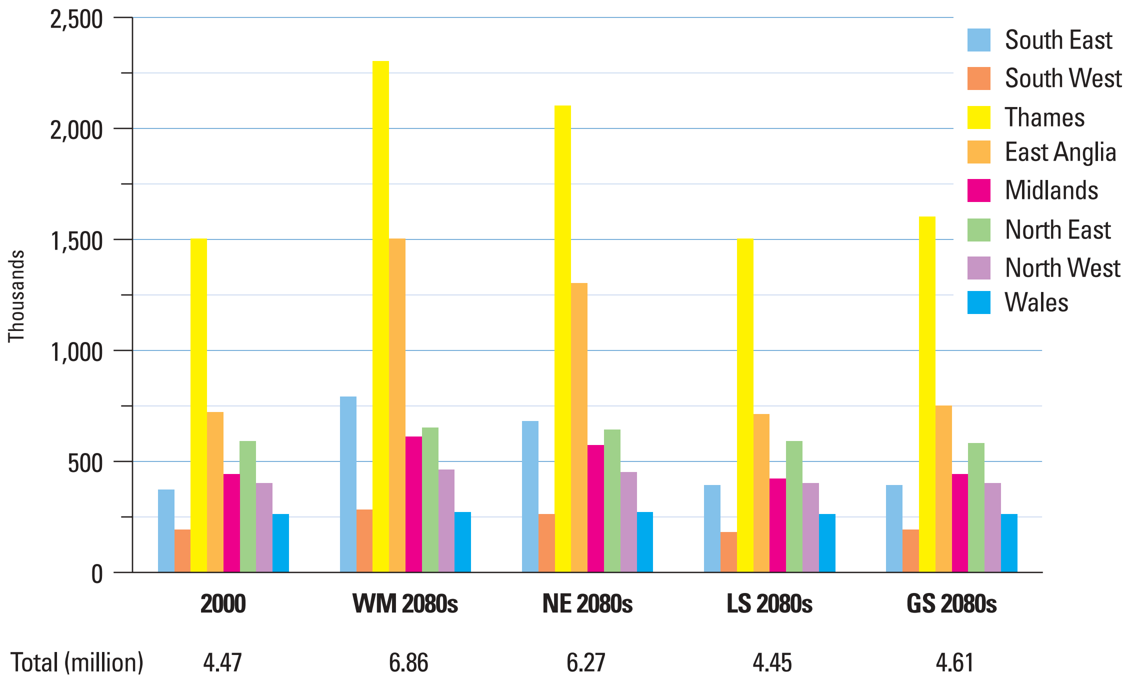


The geographic distribution of these results is shown in more detail in Figure 4.4, accompanied by a commentary.

Number of people within the Indicative Floodplain

For each 10 km x 10 km grid square and for each scenario, the total number of people living within the Indicative Floodplain was estimated by multiplying the scenario-specific household occupancy by the number of residential properties. This provides a useful insight into the significance of the flood risk. The results are shown in Chart 4.2.

Chart 4.2 **All Foresight Futures: number of people living within the Indicative Floodplain**

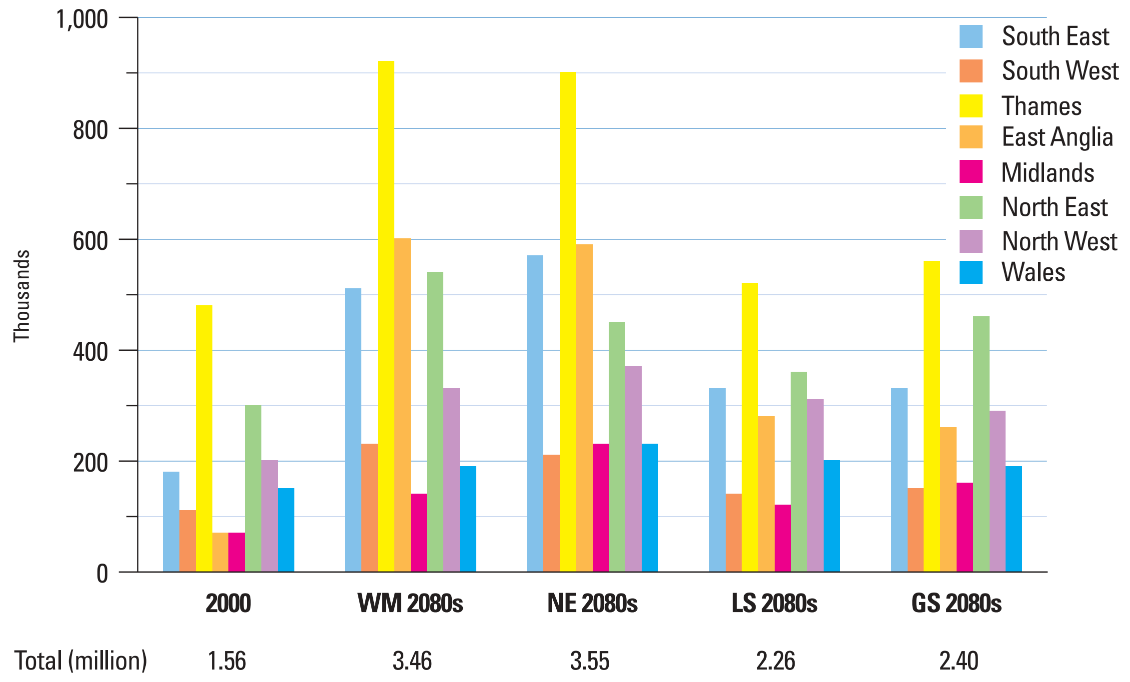


The geographical distribution of these is shown in more detail in Figure 4.5, accompanied by a commentary.

Number of people exposed to 'high' flood risk

This provides a simple count of the total number of people who are exposed to an annual probability of flooding greater than 1 in 75 within each 10km x 10km grid square.

Chart 4.3 **All Foresight Futures: number of people at 'high' risk**



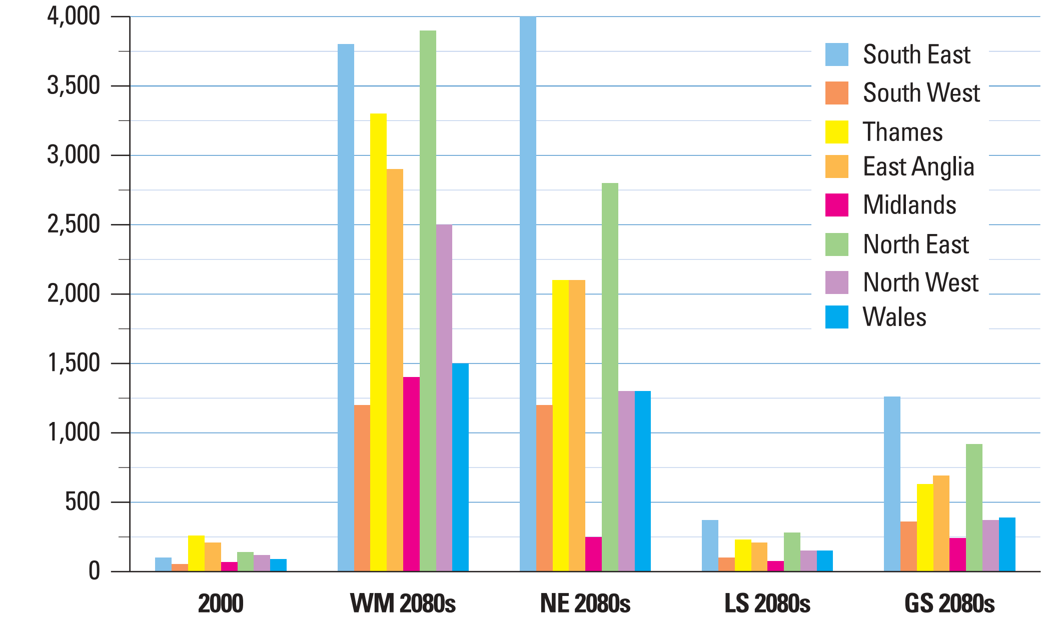
The geographical distribution of people at 'high' risk is shown in more detail in Figure 4.6, accompanied by a commentary.

Expected Annual Damage – residential and commercial properties

The results from the assessment of flood depth against probability have been multiplied by published depth-damage relationships (Penning-Rowsell *et al.* 2003), appropriately adjusted to account for the change associated with each Foresight Future, to provide an estimate of economic risk. Each grid square has then been classified in terms of the total Expected Annual Damage within that square. The results are presented in Chart 4.4, which shows great variation according to region and scenario. However, in virtually every case, the Expected Annual Damage increases.

The results have also been analysed by geographical zone, shown in Charts 4.5a, 4,5b and 4,5c, and in Figure 4.7.

Chart 4.4 **All Foresight Futures: Expected Annual Damage (£ million) – residential and commercial**



Total (£ million)	1,040	20,500	15,050	1,500	4,860

Chart 4.5a **All Foresight Futures: geographical distribution of economic risks (£ million) – upland floodplains**

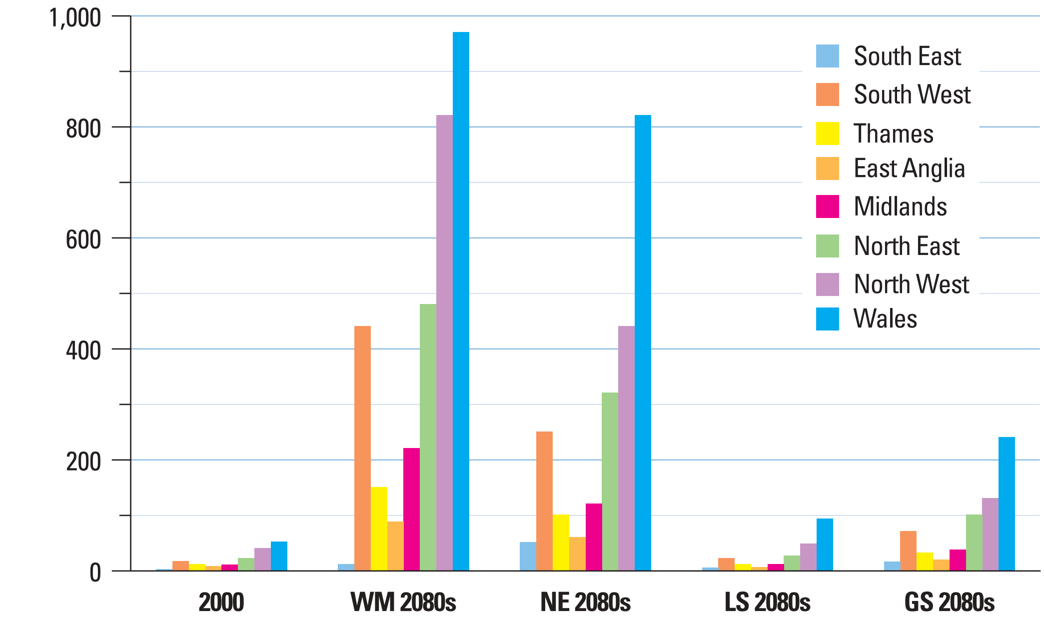


Chart 4.5b **All Foresight Futures: geographical distribution of economic risks (£ million) – lowland floodplains**

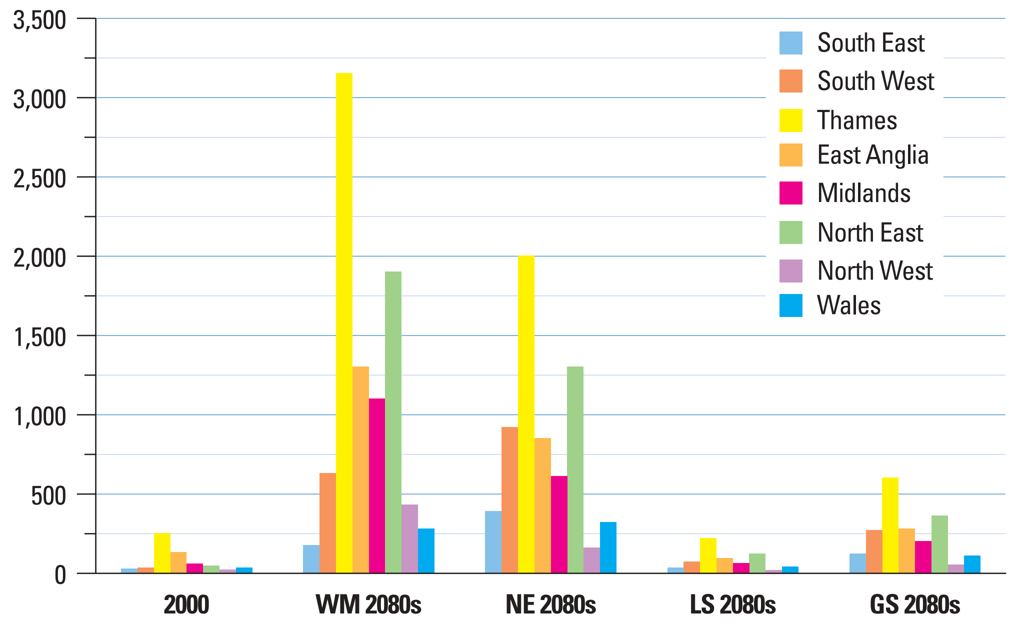
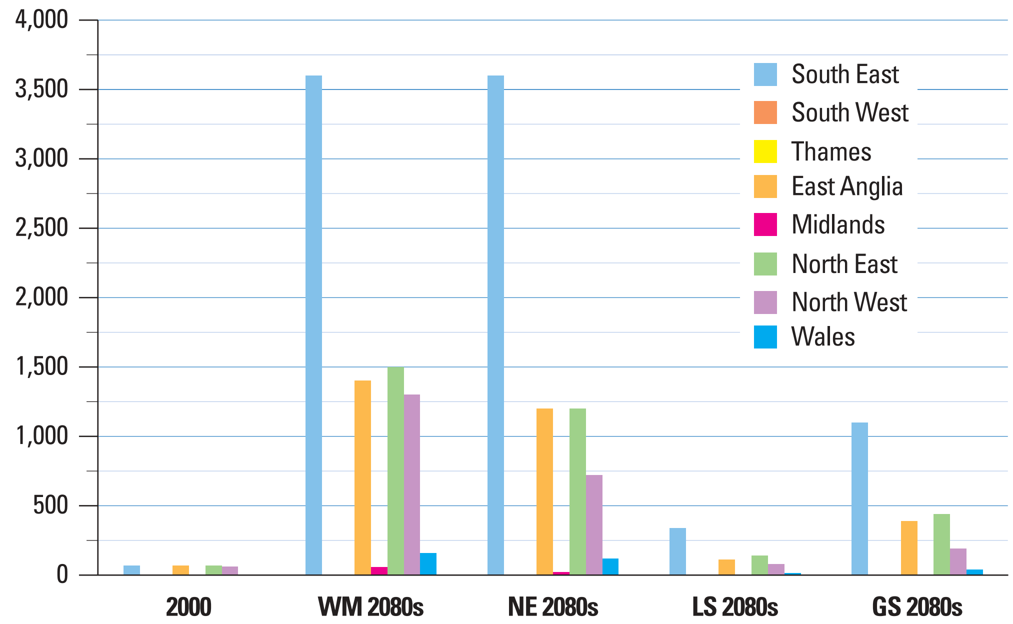


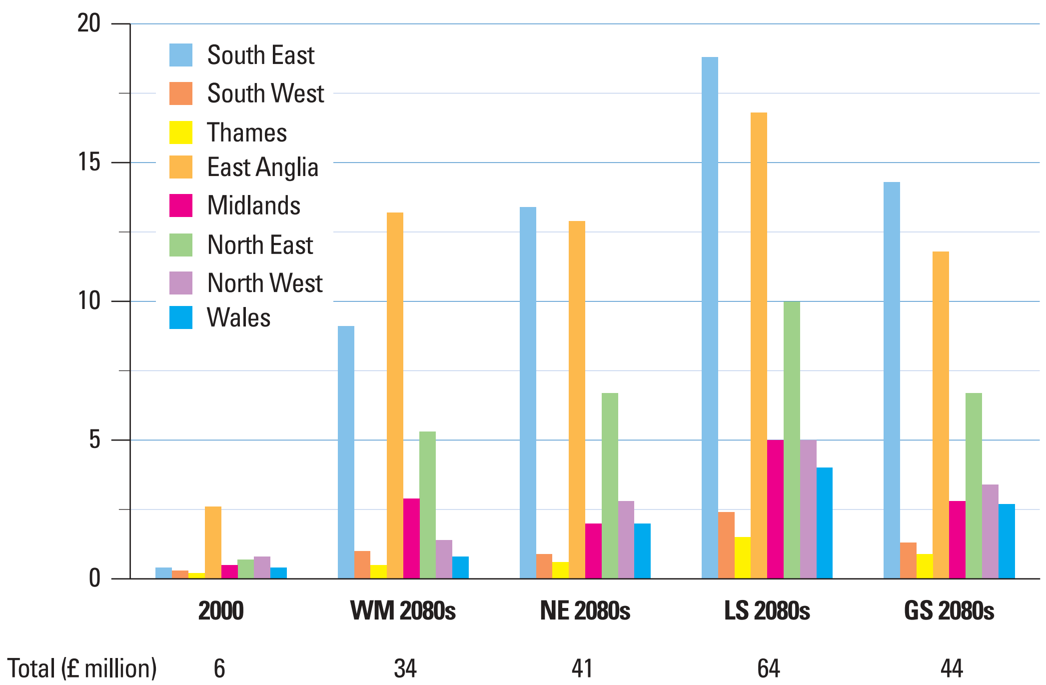
Chart 4.5c **All Foresight Futures: geographical distribution of economic risks (£ million) – coastal floodplains**



Expected Annual Damage – agriculture

Agricultural damage has been based on typical losses associated with the different grades of Agricultural Land Classification. These losses are noted as being incurred during any flood event occurring in summer or an event lasting more than one week in winter. The duration and timing of the inundation event are not, however, represented within the analysis methodology. Therefore, to provide a proxy to the length of time of the inundation, flooding to a depth of 0.5m has been assumed to be sufficiently severe to last one week. To calculate the agricultural losses, the annual probability of inundation to a depth of 0.5m or greater has therefore been multiplied by the potential losses per grade of agricultural land to derive Expected Annual Damage nett of agricultural subsidies. The results are presented in Chart 4.6.

Chart 4.6 **All Foresight Futures: Expected Annual Damage (£ million) – agricultural production**



The geographical spread of these results is shown in more detail in Figure 4.8, accompanied by a commentary.

Social vulnerability to flooding

Table 4.2 below shows the social impacts of flooding, expressed by an index of social flood vulnerability. This is shown for England only – owing to a lack of data for Wales.

Table 4.2 **All Foresight Futures: social flood vulnerability**

Region		Foresight Futures				
	Present day	World Markets 2050s	World Markets 2080s	National Enterprise 2080s	Local Stewardship 2080s	Global Sustainability 2080s
South East	Low	Medium	Medium	Medium	High	Medium
South West	Low	Medium	Medium	Medium	High	Medium
Thames	Medium	Medium	Medium	Medium	High	Medium
East Anglia	Low	Medium	Medium	Medium	High	Medium
Midlands	Medium	Medium	Medium	Medium	Medium	Medium
North East	Medium	Medium	Medium	Medium	High	Medium
North West	Medium	Medium	Medium	Medium	High	Medium
Total	Medium	Medium	Medium	Medium	High	Medium

The geographical spread of these results is shown in more detail in Figure 4.9, accompanied by a commentary.

4.3.3 Geographical distribution of risk (map-based results)

Graphical plots of the distribution of risks, as referred to above, are shown in the following figures. As previously stated, maps in blue relate to total risks. Maps in red relate to the change in risk compared to 2002.

Figure 4.2 **England and Wales in 2002: total risk of flooding – plots of all risk measures**

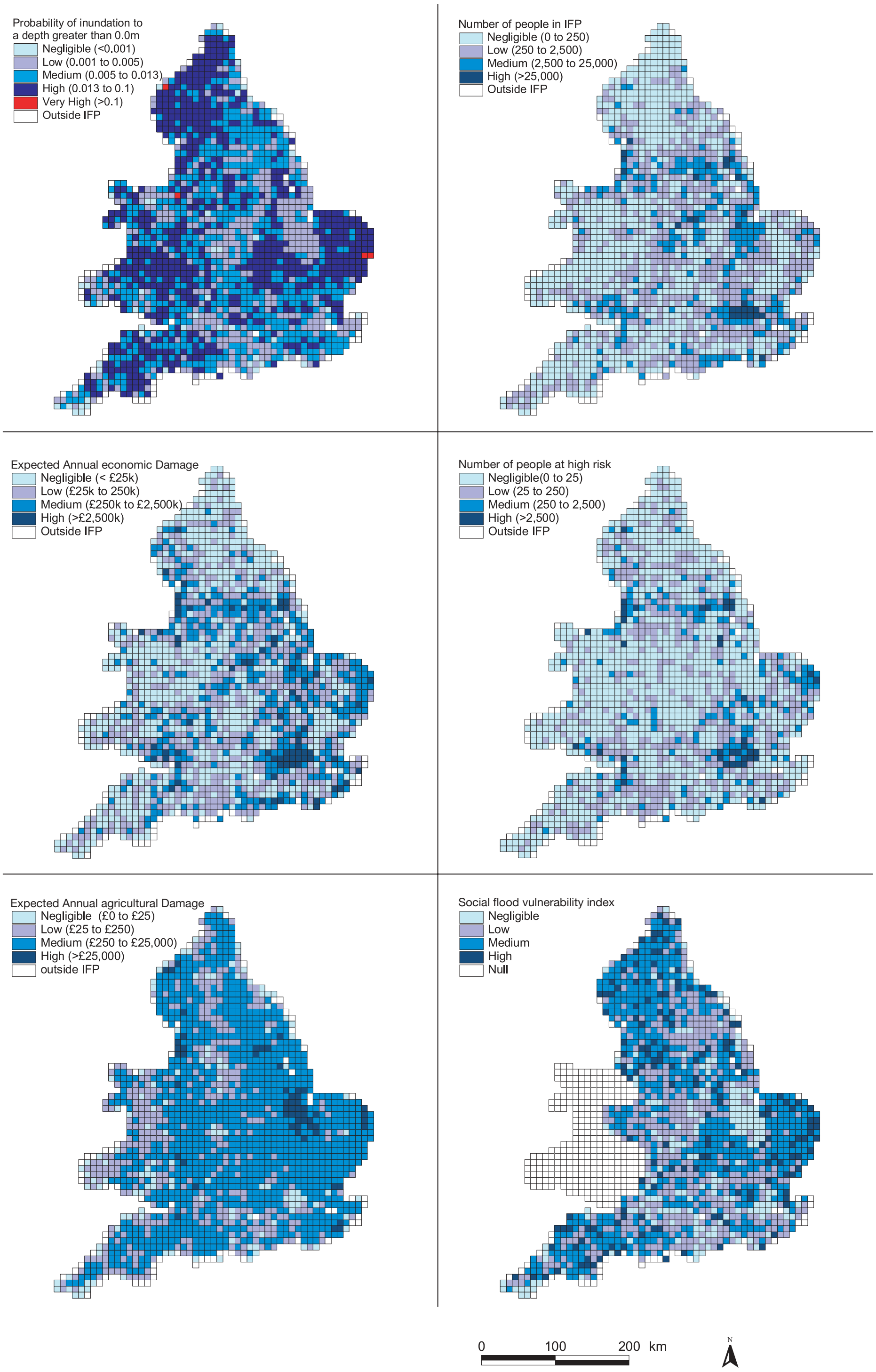


Figure 4.3 **National Enterprise/Medium High emissions in the 2080s: total risk of flooding – plots of all risk measures**

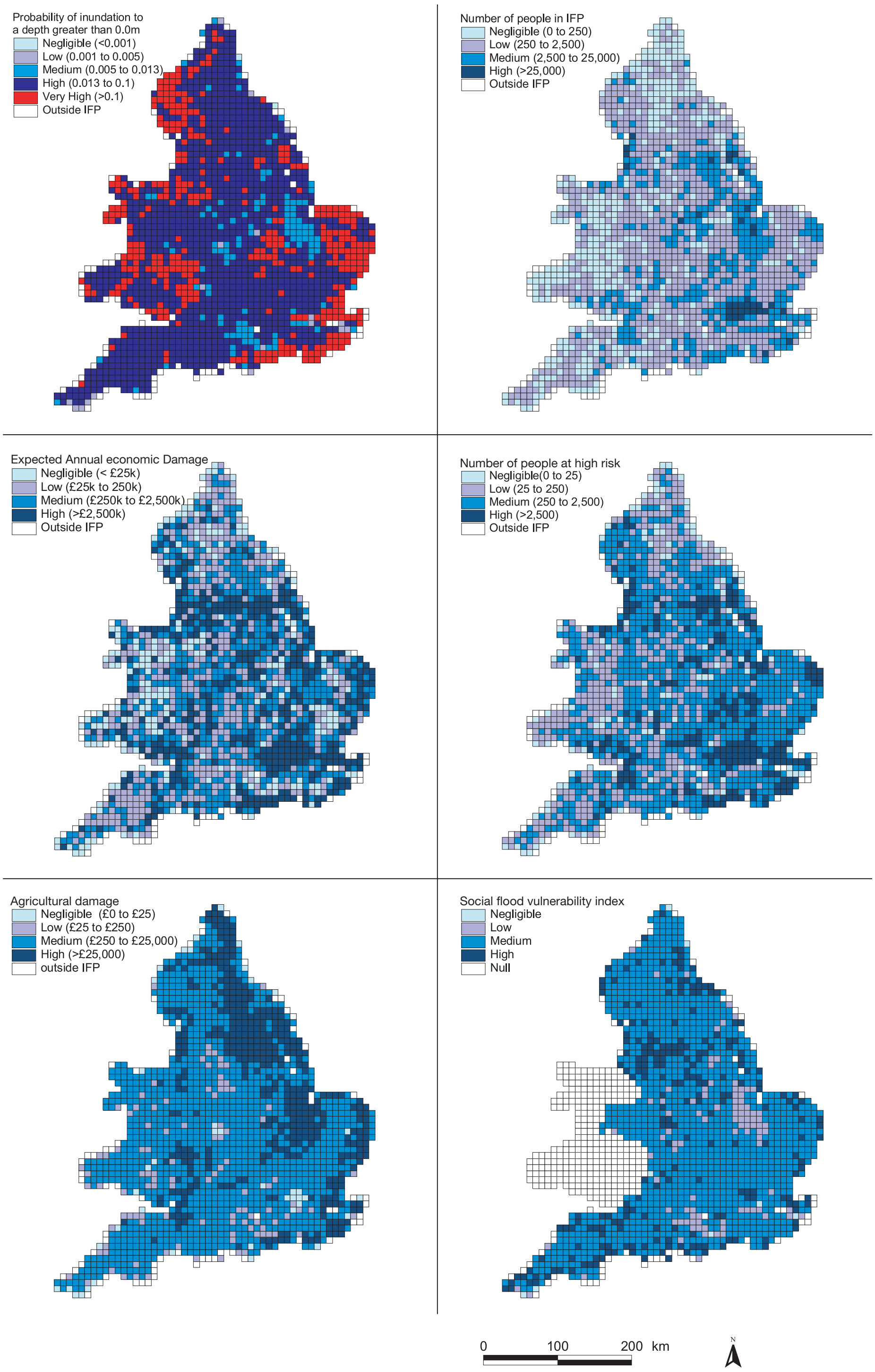


Figure 4.4 **All Foresight Futures: comparative risk – expected annual probability of inundation**

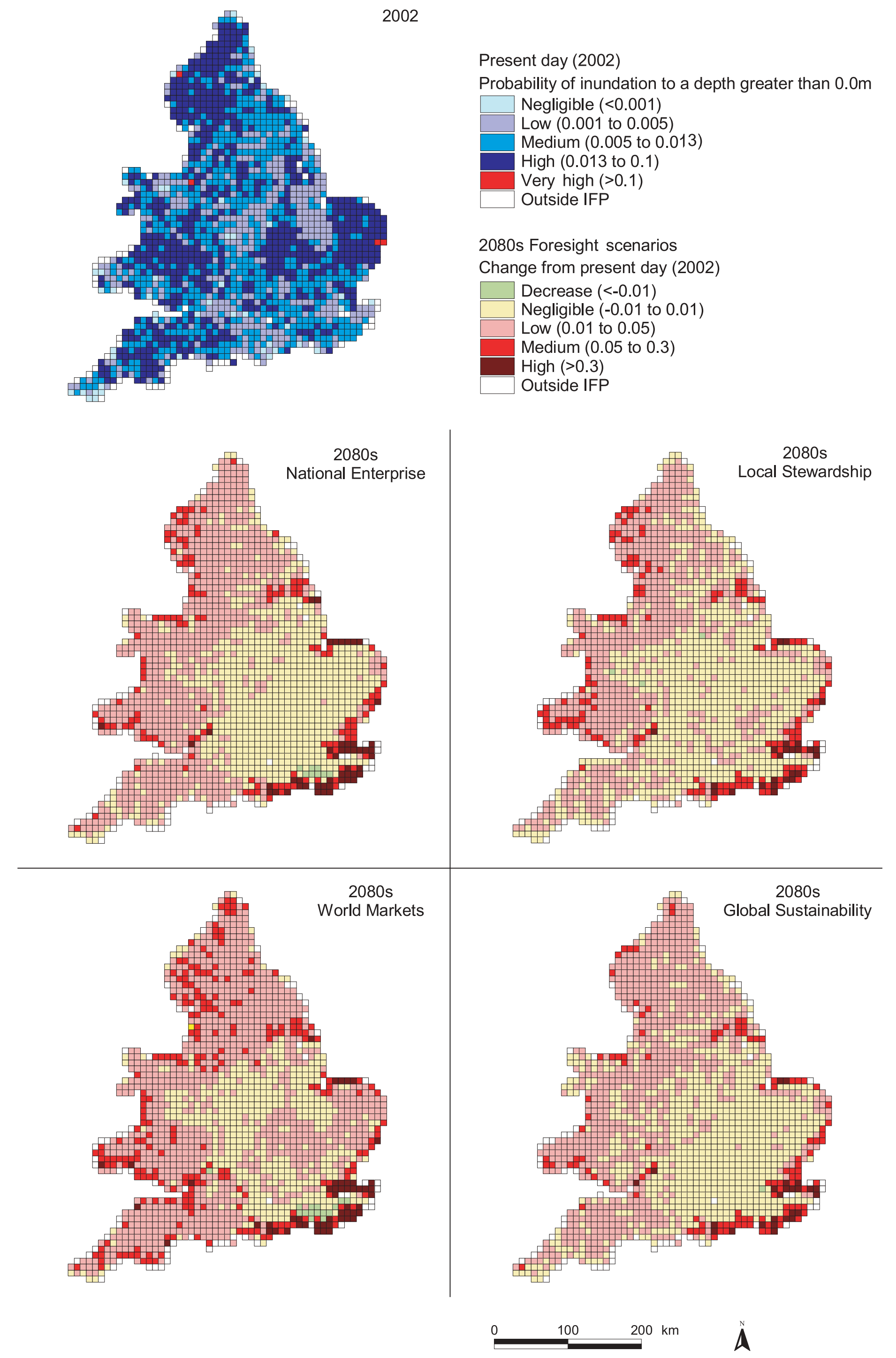


Table 4.3 **Interpretation of Figure 4.4**

Scenario	Interpretation
Present day	Generally the areas exposed to a higher risk of inundation are those in the north of England, East Anglia, mid-Wales and the south west of England. The high defence standards including the south Midlands, the Wash, London and a number of specific coastal locations (for example north Wales) are reflected in the low probability of flooding.
World Markets 2080s	There is a general increase in the probability of flooding. The coastal floodplains of the south east and east coast experience the greatest increase. This dramatic increase reflects the significant impact sea level rise can have on the performance of coastal defences where wave heights are at present depth limited. A small increase in mean sea level can lead to dramatically increased wave impacts and hence significant reductions in the standard of protection defences afford. Other areas such as the coastline of north Norfolk, south Wales and along the outer Humber Estuary also exhibit significant increases in flood frequency. The strong gradient in predicted change in rainfall from northern Scotland to southern England translates to limited changes in central England. The predicted drier climate in the south east leads to a reduced exposure to inundation.
National Enterprise 2080s	There is little difference in the impact of climate change on defence performance between the World Markets and National Enterprise Futures and in many areas similar patterns of increased probability of flood are observed. However, in some regions these relatively small changes appear to lead to significant variation in the probability of inundation. For example, East Anglia appears to experience little change from 2002 and the south west is classed as a low change in the probability of flooding. Although the magnitude of the difference between the probability of flooding in the World Markets 2080s and National Enterprise 2080s is small, in places it is sufficient to cross from one classification threshold to another.
Local Stewardship 2080s	Under the Local Stewardship Future, society's ability to form international agreements and implement effective control is limited. This is reflected in a greater climate change than observed under Global Sustainability although considerably less than experienced under World Markets. The largest variance in flood-inundation probability from present day is observed in Wales and the north west, where the greatest difference in the potential influence of climate change exists.
Global Sustainability 2080s	Under the Global Sustainability Future the changes in inundation probability are less marked, with much of the country experiencing only a relatively small increase in the probability of being flooded. Exceptions to this in the coastal floodplain of the south east and east coast where significant increases are observed. In common with other Futures there is a decrease in the probability of flooding in the inland areas of the south east as a drier climate is predicted.

Figure 4.5 **All Foresight Futures: comparative risk – number of people within the Indicative Floodplain**

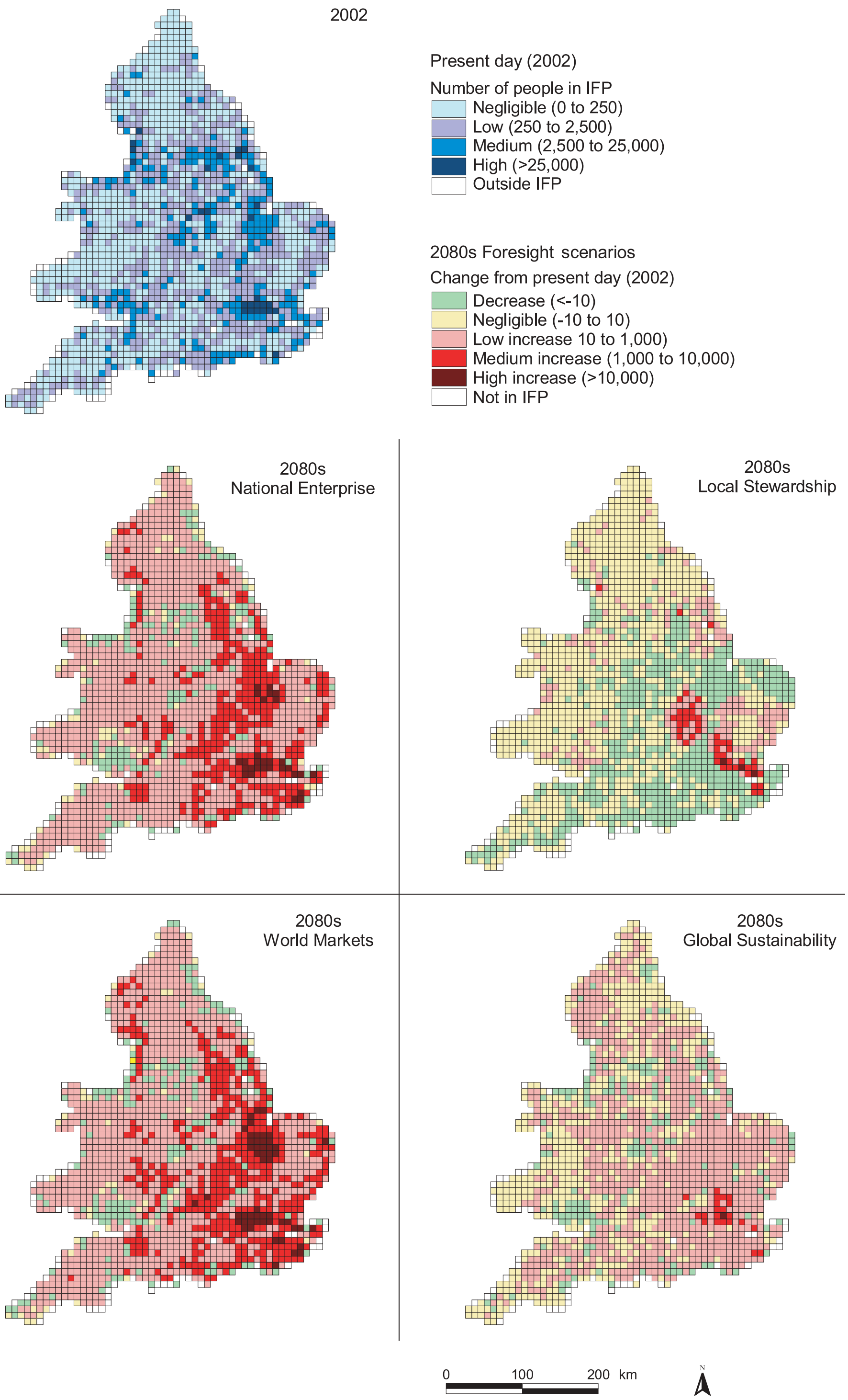


Table 4.4 **Interpretation of Figure 4.5**

Scenario	Interpretation
Present day	The number of people within the Indicative Floodplain is related to the degree of urbanisation and hence reflects a similar pattern. In particular, this relates to Greater London, a corridor stretching from the coast at Lancashire 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 east coast stands out as a significant concentration of people living in the IFP. This reflects the extensive nature of the IFP here (see Figure 4.1).
World Markets 2080s	The Thames valley, east coast and the area between Lancashire and the Humber experience growth in population exposure. Although, the household occupancy reduces under this Future to 1.8 (from 2.34 today), the rate of new build of property, particularly in the south (including significant developments in the London Gateway, Ashford and Milton Keynes), dramatically increases population density.
National Enterprise 2080s	The National Enterprise Future sees similar development to that of the World Markets 2080s. The Thames Valley, east coast and the area between Lancashire and the Humber continue to experience growth in population exposure. The increased housing density in the floodplain is marginally tempered by a reduced average household occupancy, down from 2.34 at the present day to 2.0.
Local Stewardship 2080s	Under the Local Stewardship Future average household occupancy increases and floodplain development is limited, although not stopped. In particular, significant pressures continue to exist on the south east and in particular Greater London (including the Thames Gateway, Ashford, Milton Keynes and some other isolated areas). These 'hot spots' however, counter the general trend of reduced occupancy of the floodplain.
Global Sustainability 2080s	There is a small increase in the number of people living within the floodplain in the south east of England and the Thames Valley.

Figure 4.6 **All Foresight Futures: comparative risk – number of people at 'high' risk**

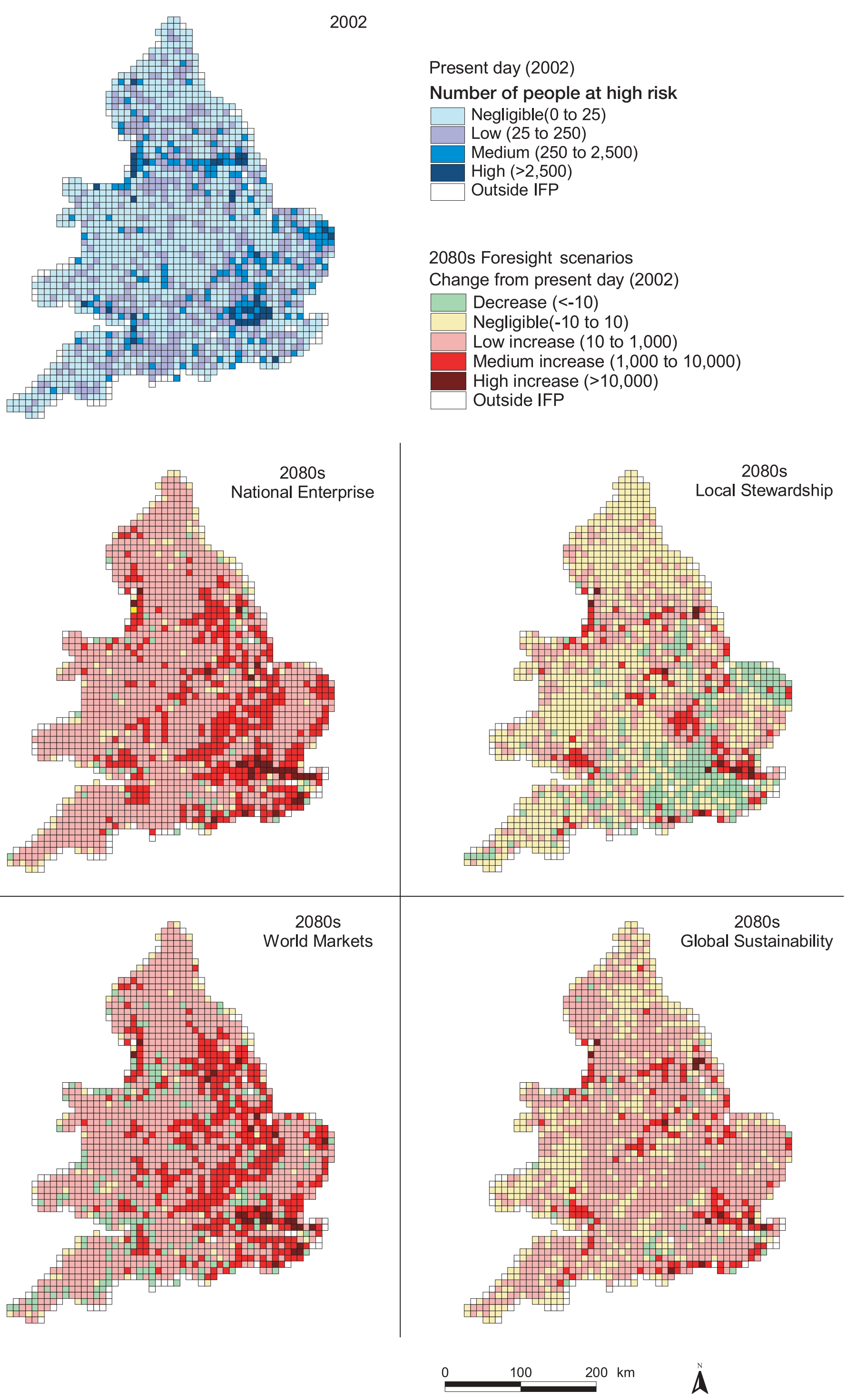


Table 4.5: **Interpretation of Figure 4.6**	
Scenario	**Interpretation**
Present day	Today a number of significant and discrete areas expose significant numbers of people to flood risk. In particular, these include Greater London and the Lancashire-to-Humber corridor containing the major conurbations of Hull and Manchester among others. Elsewhere exposure is significantly less, reflecting the fewer people living in the floodplain.
World Markets 2080s	A few discrete areas continue to dominate the national flood risk. In particular, the area between Lancashire and the Humber, the south Midlands and the Thames Valley represent the most significant areas of focus of flood risk in terms of the potential for loss of life and human impacts.
National Enterprise 2080s	A few discrete areas continue to dominate the national flood risk. In particular, the area between Lancashire and the Humber, the south Midlands and the Thames Valley continue to represent the most significant areas of focus of flood risk in terms of the potential for loss of life and human impacts.
Local Stewardship 2080s	The reduced occupancy of the floodplain allied with a more moderate climate change than observed in the World Markets Future leads to a decrease in the number of people at risk across much of the country. Exceptions to this include the south east coast, and the area between Lancashire and the Humber and the Thames estuary.
Global Sustainability 2080s	Although the number of people in the IFP changes slightly, there are a few areas where the number of people at high risk increases significantly compared to that experienced in 2002 (south coast of Wales, London and throughout the area between Lancashire and the Humber).

Figure 4.7 **All Foresight Futures: comparative risk – Expected Annual Damage – residential and commercial properties**

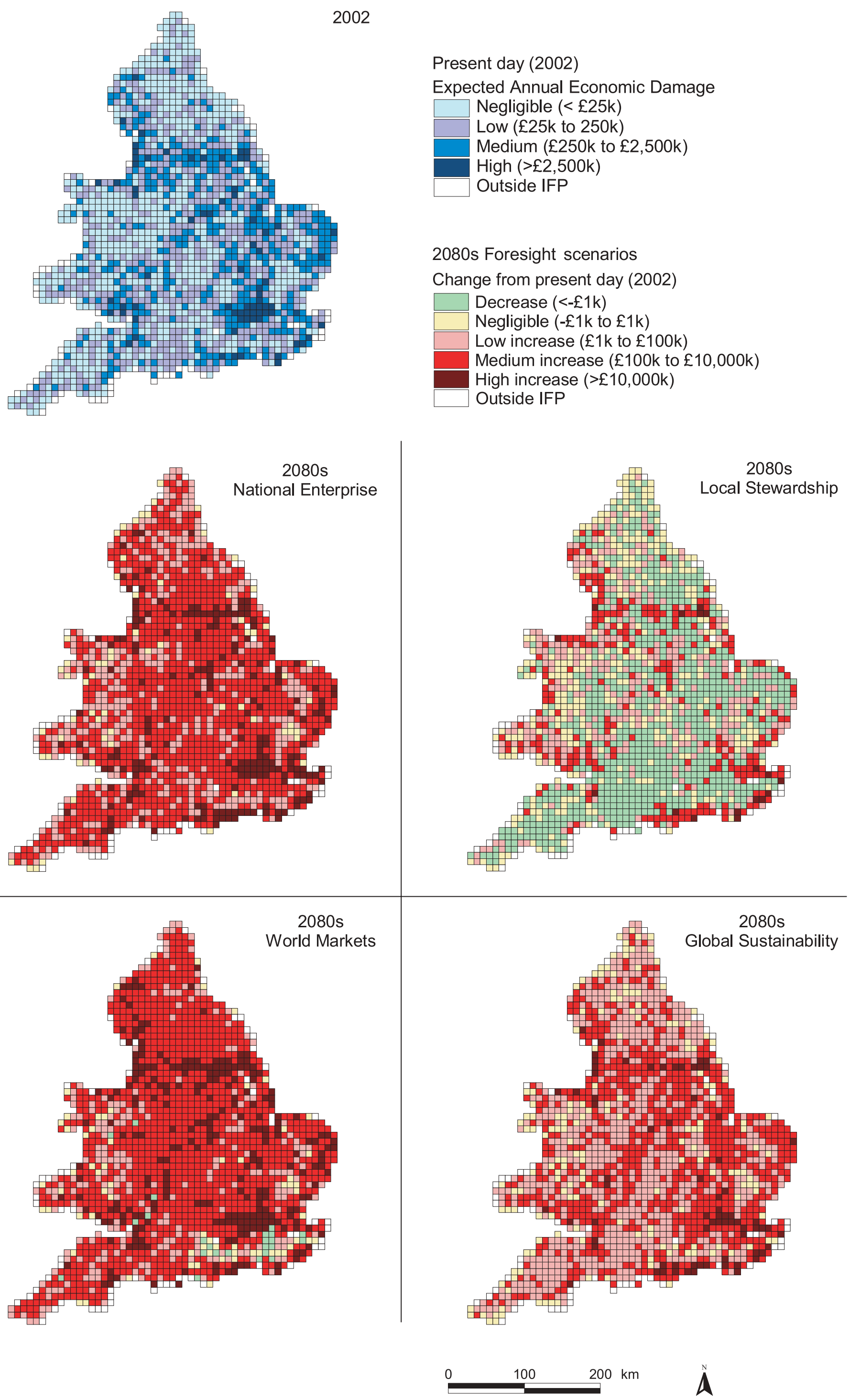


Table 4.6 **Interpretation of Figure 4.7**

Scenario	Interpretation
Present day	As for the people at risk, 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 from the coast at Lancashire across to the Humber.
World Markets 2080s	Significant increases in economic damage are seen throughout the country. This reflects both an increase in the probability of flooding and an increase in the associated consequences as personal material wealth continues to increase. The largest increases are observed where both housing pressure is greatest and the standard of defence is most susceptible to climate change. This critical combination is most clearly seen around the coastal strip of the southeast, East Anglia and south and north Wales. The area between Lancashire and the Humber, and the Thames Valley also sees a significant increase in exposure to economic loss. The drier climate in the south east is reflected in reduced economic damage.
National Enterprise 2080s	A similar pattern is observed to World Markets. The areas that stand out at high risk are coastal areas from the Solent round to the Humber, the Severn estuary, London and the area between Lancashire and the Humber.
Local Stewardship 2080s	There is a general reduction in the Expected Annual Damage across the majority of England, with the coastal areas in Wales being categorised as negligible to low. Some locations still experience large increases in the Expected Annual Damage, particularly the south east coast of England due to the decreasing standard of protection offered by coastal defences, and the area between Lancashire and the Humber.
Global Sustainability 2080s	The majority of areas see a significant change from present day exposure. This reflects the increase in personal wealth and the economic damage incurred in a single flood event. The losses are, however, less than those experienced under the higher emission scenarios of World Markets and National Enterprise.

Figure 4.8 **All Foresight Futures: comparative risk – Expected Annual Damage – agricultural production**

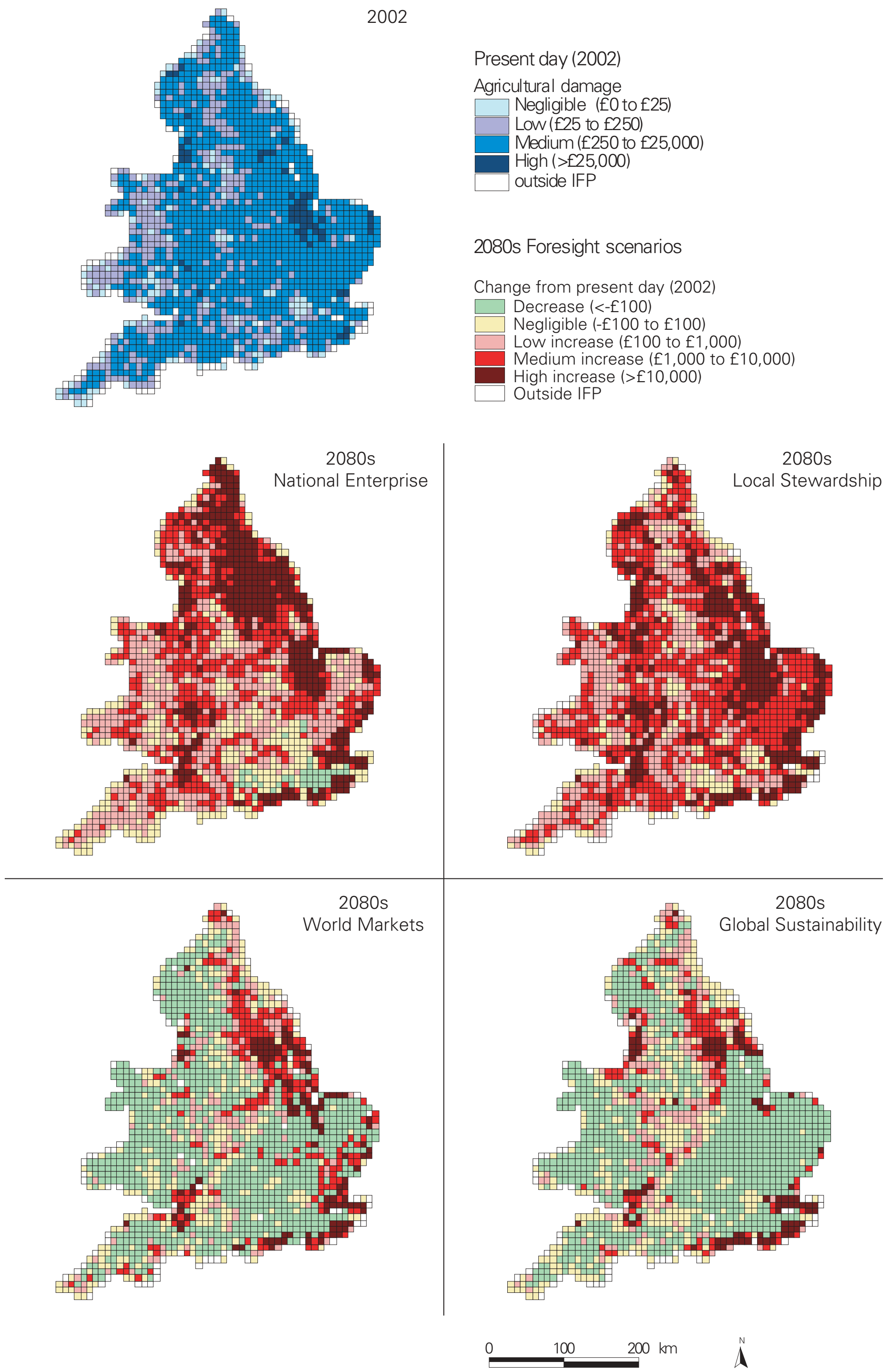


Table 4.7 **Interpretation of Figure 4.8**

Scenario	Interpretation
Present day	Agriculture is relatively evenly exposed to flooding risk. The most striking exception to this is the area in the vicinity of the Wash where significant areas of Grade 1 land lie within the floodplain and, although well protected, significant damage can still be incurred. A number of smaller areas stand out as exhibiting high Expected Annual Damage associated with agriculture, including parts of the south coast and north west. The areas of poorer agricultural land (Dartmoor, west Wales, Pennines etc) are categorised as *low* while the major built up areas (London, Birmingham etc.) clearly exhibit negligible exposure to agricultural damage, reflecting the limited agriculture in these areas.
World Markets 2080s	Under this Future, Grade 4 and 5 land is no longer farmed. For Grades 1 to 3 the flood-related economic damage is also reduced. Although the probability of flooding significantly increases, these economic changes limit the economic impact of flooding. There is a significant decrease in the agricultural damage across most of the country, in particular in Wales and central England, where the land is predominantly Grade 4 or 5. However, where the land is of high agricultural value (Grade 1-3) a significant increase in economic damage is exhibited. When compared to all four other Futures, World Markets exhibits the most widespread reduction in agricultural losses related to flooding. This reflects the changed and significantly more productive agricultural practices associated within a World Markets Future that outweigh the expected increased flood frequency.
National Enterprise 2080s	Under this scenario, all grades of land are farmed and the damage incurred under a flood event increases significantly from those presently experienced. Significant increases in flood damages are seen across the majority of the country, particularly the north east of England, and along the coastline in the vicinity of the Wash, the Severn estuary, the Lancashire coast and the south east coast. There are, however, decreases in the agricultural damage in the inland regions of the south east and East Anglia.
Local Stewardship 2080s	All land grades continue to be farmed and production costs significantly increase. Coupled with a general increase in the probability of flooding in most areas, agricultural losses are seen to increase significantly across the country. In particular, the most significant increases are seen from the Wash to the Humber, along the south east coast and on the Welsh/English border. The resulting pattern identifies this Future as yielding the greatest increase in agriculture-related flood losses.
Global Sustainability 2080s	There is a central band running through England where the cost of damage to agricultural production increases. The increase is particularly high around the Humber and the Wash and along the south east coast of England. In Wales and the south west of England and in East Anglia the costs are reduced.

Figure 4.9 **All Foresight Futures: comparative risk – social flood vulnerability**

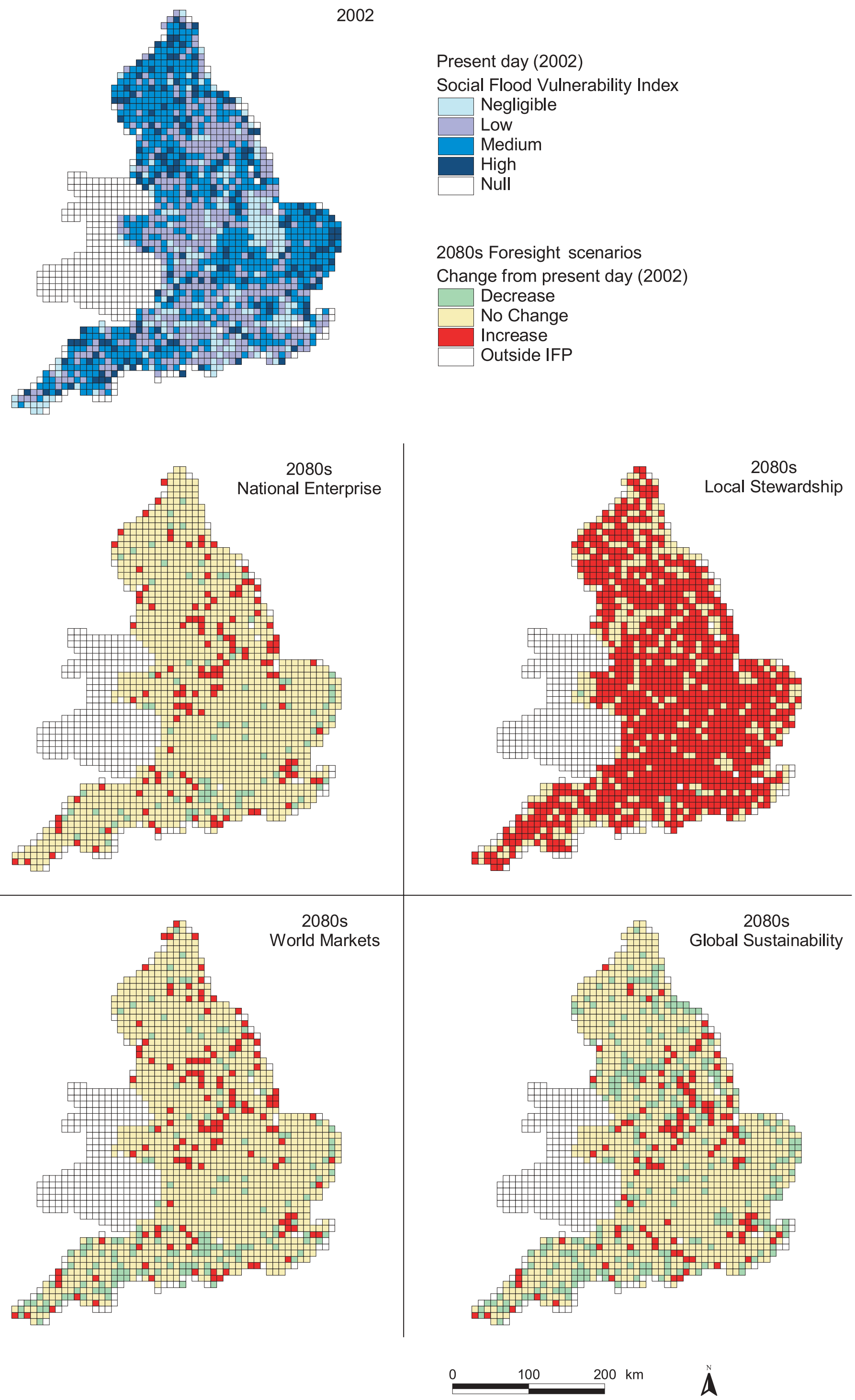


Table 4.8 **Interpretation of Figure 4.9**

Scenario	**Interpretation**
Present day	The Social Flood Vulnerability Index (SFVI) is the most complex of the flood-risk measures to interpret. It involves combining the probability of flooding with the number of people from socially vulnerable classes 4 and 5. The areas that stand out as particularly vulnerable are East Anglia, northern England and part of the Midlands.
World Markets 2080s	The pattern of changing vulnerability is mixed, with similar numbers of areas decreasing to those increasing. A general pattern may be that an urban/rural divide exists, with an increase in vulnerability in urban areas and a decrease in rural areas.
National Enterprise 2080s	Much of the country experiences little change in social flood vulnerability, although there are some locations where changes do occur. The pattern is mixed but with more areas increasing than decreasing. An urban/rural pattern exists with increases generally being located in urban areas and decreases in rural areas.
Local Stewardship 2080s	Society becomes significantly more vulnerable to flooding under this Future scenario. The principal contributor to this change is the belief that those living in the floodplain 'have themselves chosen to live in those areas' and should not be helped. Allied with an ineffectual emergency response and community network, more people find it difficult to recover from floods. To reflect these changes, people within SFVI Class 3 (a medium category) are considered as becoming more vulnerable and are reclassified as SFVI Class 4 (a more vulnerable category). This change is reflected in the dramatic increase in the social vulnerability observed.
Global Sustainability 2080s	Almost the whole of England is in the medium category and little change is experienced between this scenario and the 2002 situation overall. However, more areas decrease in vulnerability than increase.

Figure 4.10 **All Foresight Futures: comparative risk – Expected Annual Damage adjusted by expected gross domestic product**

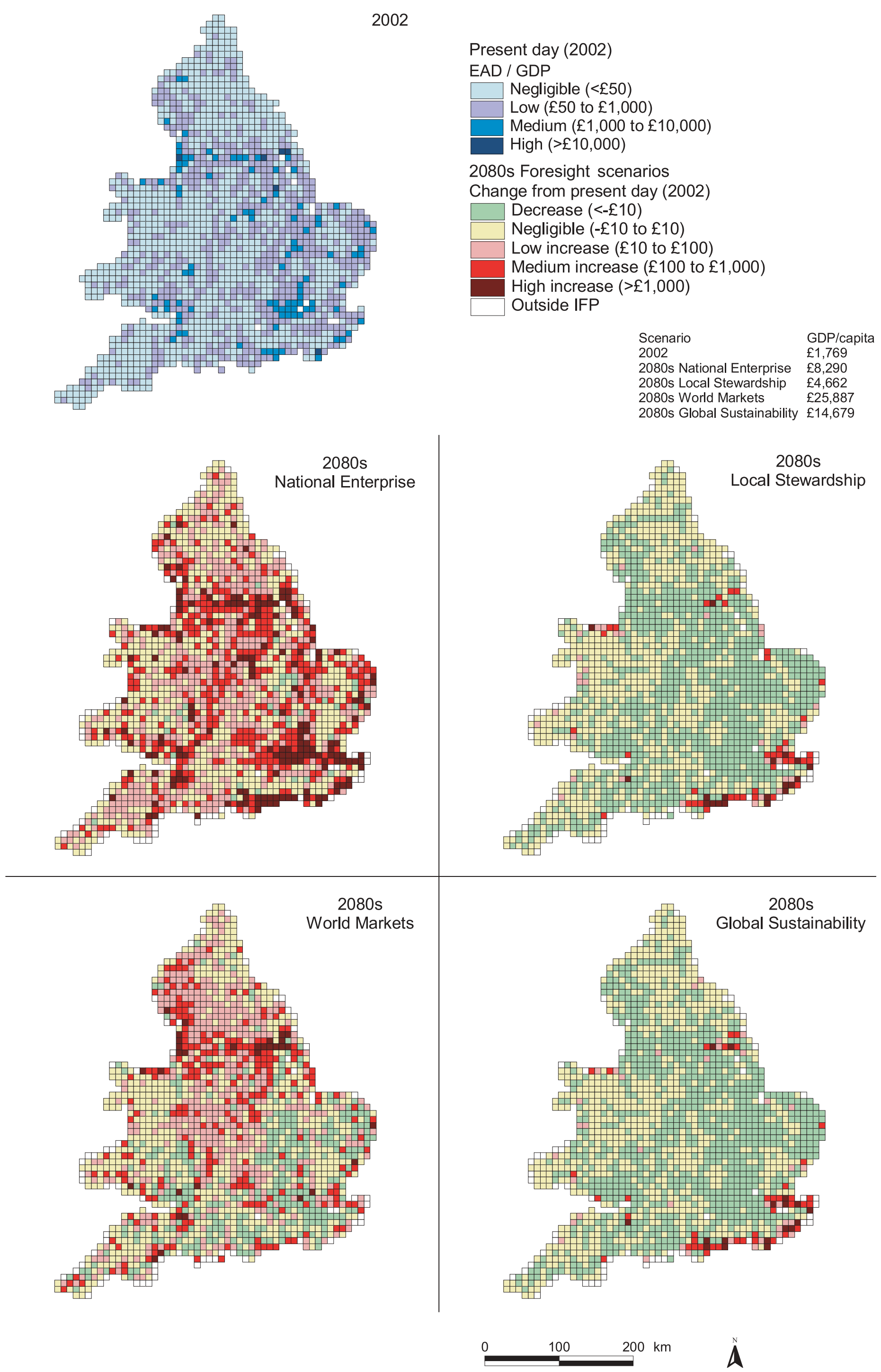


Table 4.9 **Interpretation of Figure 4.10**

Scenario	Interpretation
Present day	To provide an insight to the general economic pain of flooding, the Expected Annual Damage (residential and commercial – see Figure 4.7) have been divided by the Gross Domestic Product.
World Markets 2080s	Under this scenario, by the 2080s the wealth of the nation acts to reduce the overall feeling of economic impact from floods experienced by the population. Although there is an decrease in the adjusted EAD for south east England, East Anglia and parts of Wales, the situation is not so favourable compared to the present day in parts of south west England, the Midlands and northern England. The greatest relative increase in economic damage lies along a corridor stretching from the coast at Lancashire across to the Humber.
National Enterprise 2080s	This scenario represents the greatest increase in relative pain. The most severe relative increase is in the major commercial and residential hearts of London, along the Severn estuary and from the coast at Lancashire across to the Humber. The coastal regions in the south east of England have also experienced a significant increase. Much of England and Wales has experienced a low to medium increase, reflecting greater increase in economic damages compared to GDP under this scenario.
Local Stewardship 2080s	Under this scenario, the EAD adjusted by GDP is very favourable, with a decrease in most areas and negligible change in many others. This is primarily due to a decrease in EAD in most areas under this scenario, coupled with the modest rise in GDP. The only areas that see an increase are the coastal areas in the south east of England, north Wales and the Humber estuary.
Global Sustainability 2080s	The situation under this scenario is very similar to that observed for the Local Stewardship scenario. However, different mechanisms have brought about these changes from the present day. While under this scenario the EAD significantly increases across the country, the GDP also increases. However, the rate of growth in GDP is sufficiently high to compensate for the increase in EAD, resulting in a reduction in the EAD adjusted by GDP in most areas of England and Wales. The exceptions to this trend, where the increase in EAD has surpassed the growth in GDP, are observed in the coastal areas in the south east of England, north Wales and the Humber estuary.

4.4 Time evolution of flood risk

So far, the quantitative analysis of future risks has been performed for the four future scenarios in the 2080s:

- World Markets/High emissions
- National Enterprise/Medium High emissions
- Local Stewardship/Medium Low emissions; and
- Global Sustainability/Low emissions

It is also important to understand how flood risk might change during the period covered in this project. It is beyond the scope of the present project to investigate future flood risks in all of the above future scenarios between 2030 and 2100. A single scenario was therefore selected – World Markets/High emissions and the risks analysed for the 2050s. The results were then compared to those for the same scenario in the 2080s, and to present day risk levels. Whilst this provides limited information, it nevertheless yields useful insights into the time evolution of future risks which can be applied to the other scenarios.

We show in Table 4.10 the number of people at high risk and the Expected Annual Damages (residential and commercial) in 2002 and in the 2050s and 2080s. The corresponding maps are provided in Figure 4.11.

Table 4.10 **Comparison of risks for present day, World Markets 2050s and World Markets 2080s**

World Markets risks due to flooding			
Timeframe	**Present day**	**2050s**	**2080s**
People at high risk in England and Wales	1,600,000	3,300,000	3,500,000
EAD in England and Wales (£ million)	1,000	14,000	21,000

The table and maps show that nearly all the increase in the number of people at high risk is reached by the 2050s. This reflects the significant programme of planned development over the coming 30 years. Thames Gateway, as well as expansion of Ashford and Milton Keynes, for example. A second factor is the increase in the probability of flooding due to the growth of global emissions, which will vary according to scenario (see Figure 4.12).

Figure 4.11 **Maps showing the progressive change in risk for the World Markets/High emissions scenario. Two risk parameters are plotted: number of people at high risk and Expected Annual Damage. Present day total risk is plotted (blue) together with the difference in risks (compared to 2002) for the 2050s and 2080s**

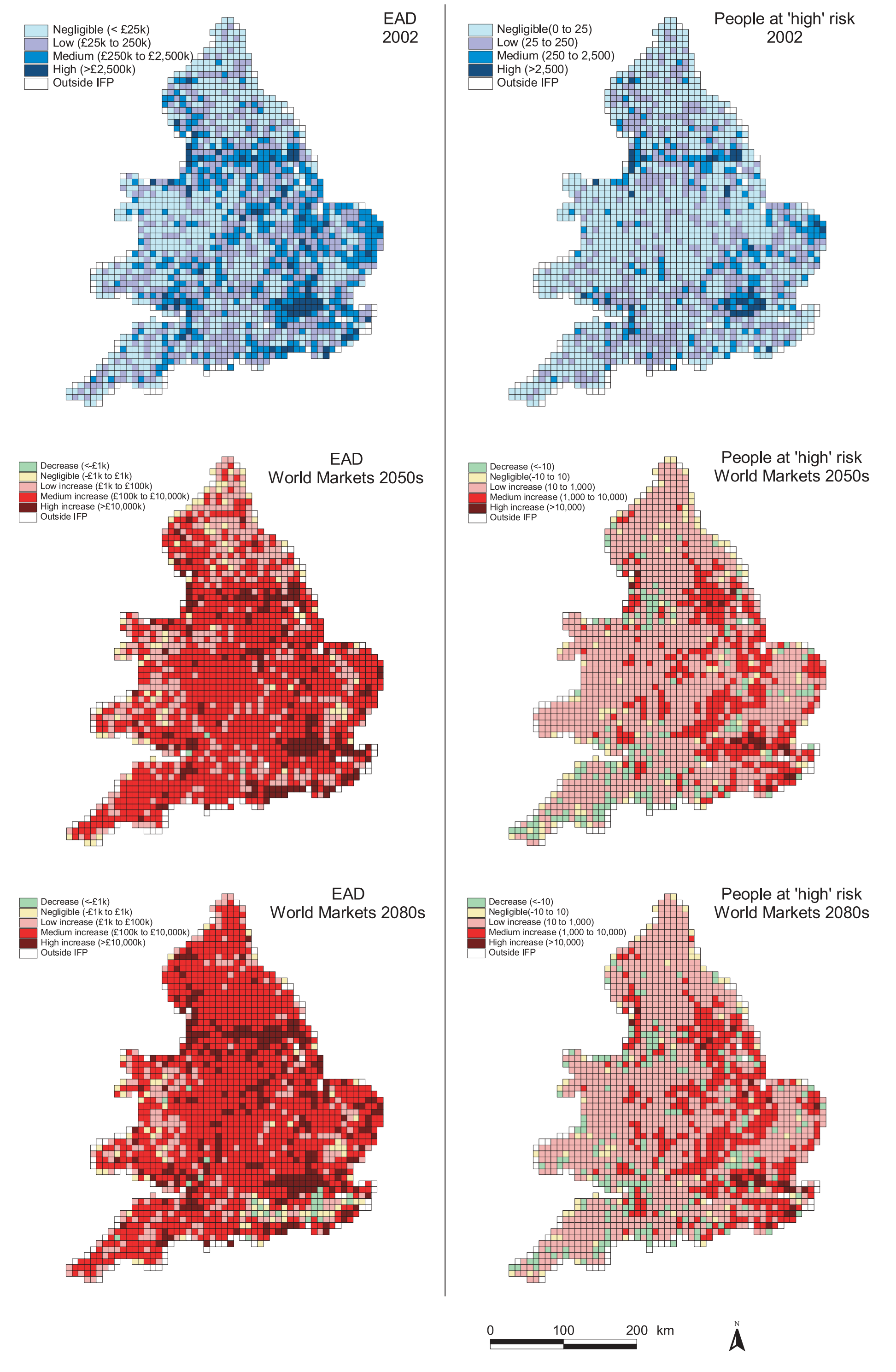


Figure 4.12 **Four scenarios for emissions of carbon dioxide are used in the project: Low emissions, Medium Low emissions, Medium High emissions and High emissions. These come from UKCIP02, the 2002 report of the UK Climate Impacts Programme**

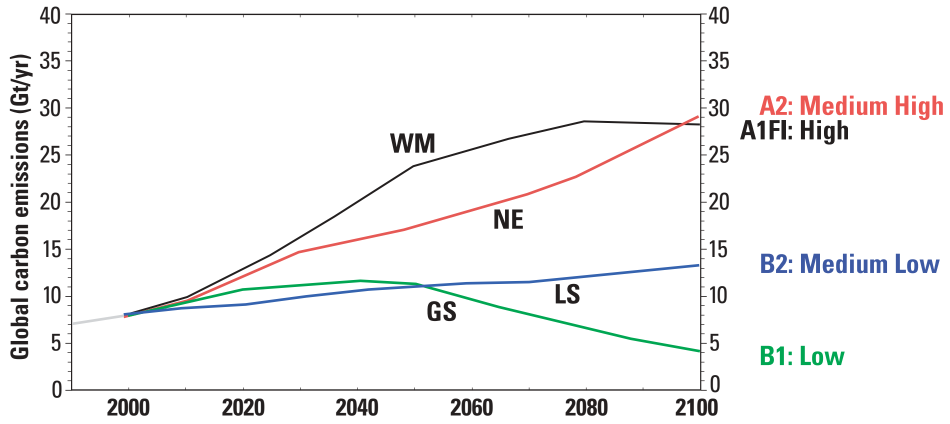


Table 4.10 shows, by contrast, that economic damage, which is a function of the numbers of properties at risk, the probability of them getting flooded, and the damage suffered, grows approximately linearly. This is not unexpected: whereas the first two factors increase at a high initial rate, economic growth has been taken as compound and therefore the value of assets affected increases according to a concave trajectory. Taken together, the factors lead to a near linear growth in economic damage under World Markets.

Notwithstanding the above interpretation, it is considered that much more work is needed to fully analyse the rate of growth of risks and its relationship to the drivers.

4.5 The influence of global emissions on future flood risk

The future flood risks outlined in the previous sections are caused by a combination of climate change (resulting from global emissions) and socioeconomic changes (resulting from national change). In order to separate out the influence of climate change from the influence of socioeconomic drivers on flood risk, a fifth scenario has been evaluated. This has assumed a high growth economy, equivalent to the World Markets socioeconomic future in the 2080s, but now coupled within a low-emissions future climate.

By comparing the results of this fifth scenario with the World Markets/High emissions scenario reported above, the contribution of global emissions to the increased future flooding risks can be assessed.

Figures 4.13 and 4.14 shows the difference between the two World Markets scenarios for:

- Probability of inundation.
- Number of people at high risk.
- Expected Annual Damage – residential and commercial.
- Expected Annual Damage – agricultural.

As can be seen from the figures and the quantification of these changes in Table 4.10, a significant reduction in our exposure to flood risk is achieved when climate change is limited (a reduction in Expected Annual Damage of the order of £5billion – for catchment and coastal flooding, and excluding benefits in reducing intra-urban flood risk). However, under the baseline assumption of the continuation of present-day investment in flood management, the underlying risk continues to increase substantially from the levels observed today.

Table 4.10 **Comparison of Expected Annual Damage under the World Market High and Low emissions scenarios**

Region	Expected Annual Damage – Residential and commercial (£ million)		Expected Annual Damage – Agricultural (£ million)	
	High emissions	Low emissions	High emissions	Low emissions
East Anglia	2,900	1,400	13.2	6.9
Midlands	1,400	900	2.9	1.5
North East	3,900	3,600	5.3	4.3
North West	2,500	1,100	1.4	1.9
South East	3,800	3,500	9.1	8.5
South West	1,100	1,100	1.1	0.7
Thames	3,300	2,300	0.5	0.5
Wales	1,500	1,200	0.8	1.5
Total	**20,400**	**15,100**	**34.3**	**25.8**

Figure 4.13 **Comparison of flood inundation probability and change in number of people at high risk under World Markets High and Low emissions scenarios**

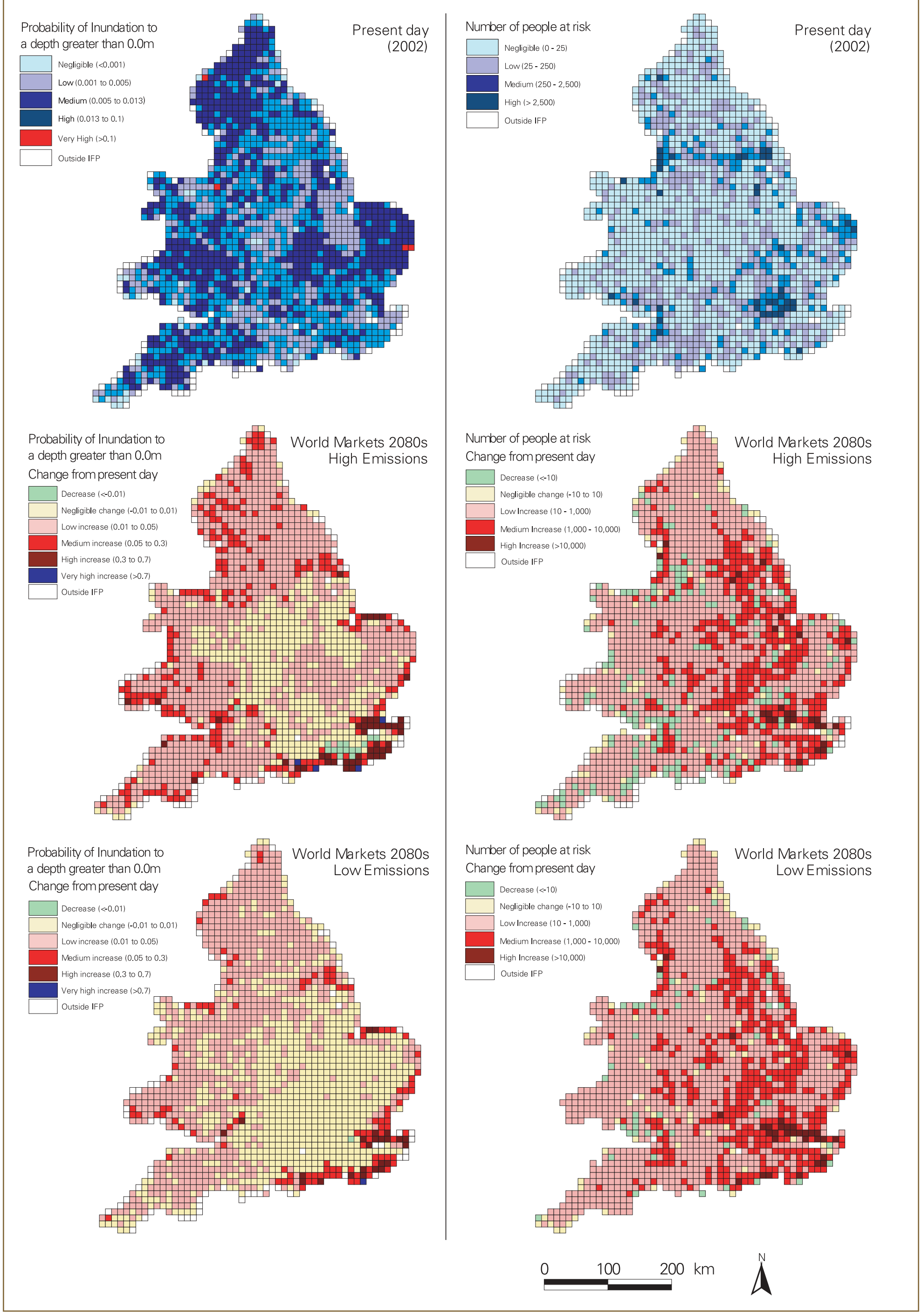
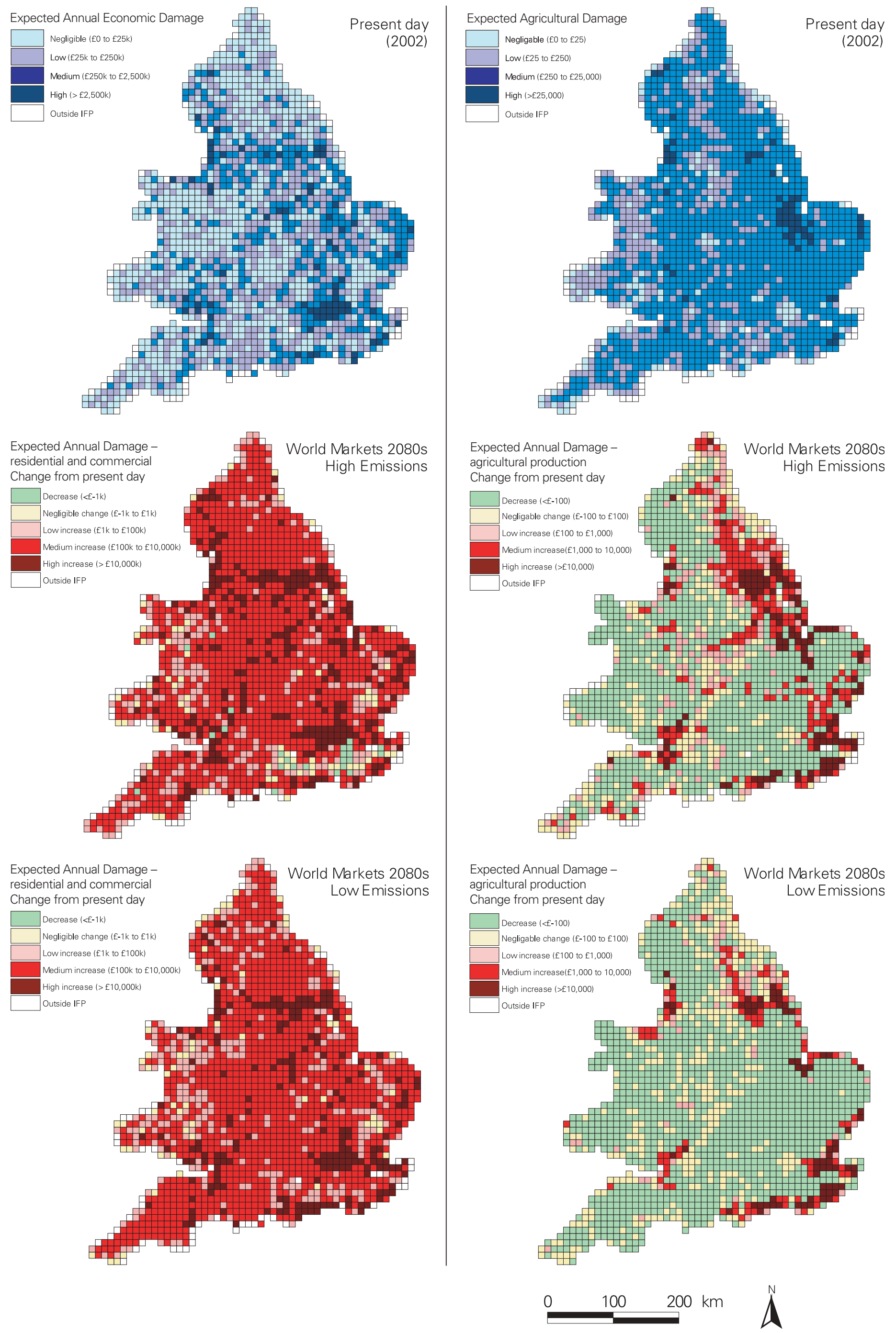


Figure 4.14 **Comparison of Expected Annual Damage under the World Markets High and Low emissions scenario – residential/commercial and agricultural**



Interpretation of Figures 4.13 and 4.14	
Scenario	**Interpretation**
World Markets	Figures 4.13 and 4.14 show a comparison of future risks – high emissions against low emissions assuming a high growth economy. The differences between these scenarios are discussed below.
Probability of inundation	The less dramatic climate change associated with a low-emissions scenario is reflected in a general reduction in the scale of change. This is reflected in reduced inundation in the north, midlands and south west areas. The predicted reduction in precipitation in the south east of England is observed in the significant reduction in flood probability under the high-emission scenario. This is not so pronounced under the low-emission scenario.
Number of people at risk	Given that both scenarios adopt the same socioeconomic climate, the differences between the scenarios directly reflect differences within the distribution of the high inundation probability category within the underlying probability data.
Expected Annual Damage – residential and commercial	Overall, a decrease in the Expected Annual Damage of approximately £5,000m is observed in the low-emissions scenario compared to the high-emissions case (see Table 4.10). As shown in Table 4.10 under high emissions, damage increases by a factor of 21 from the present day. This reduces to a factor of 15 under a low-emissions scenario. In both scenarios coastal floodplains continue to contribute significantly to expected losses.
Expected Annual Damage – agricultural	There is a significant decrease in the distribution of the Expected Annual Damage to agricultural production. Figure 4.14 shows that this is particularly prominent in the north east of England.

4.6 Extreme normal events

The analysis in this report focuses on the broad average characteristics of floods at a national scale and not on extreme flood events. However, in the probability domain, the process of calculating Expected Annual Damage may conceal low-frequency/high-consequence flood events – these are referred to as 'extreme normal events'.

There is a further aspect which is not apparent from the analysis, which is the spatial dimension of risk. Major flood events may involve flooding over a large area, and the consequences (damage, disruption, etc.) may increase disproportionately. The spatial pattern of a 'source' driver such as precipitation may thus affect the consequences of flooding, as well as the probability of a flood occurring. The high-level approach required for a nationwide study, however, precluded detailed consideration of secondary flood-risk impacts due to the spatial distribution of the area at risk.

The above points are illustrated below by three hypothetical examples of future extreme floods. These are provided purely for illustrative purposes and are not intended to be predictions – many of the consequences are based on events which actually occurred in the 2003 floods in central Europe.

One further 'extreme normal event' that demands consideration is flooding caused by the failure of a dam. As it would be inappropriate to use a hypothetical example to illustrate the consequences of such an event, the drivers and risks are described generically in the box below.

Drivers and risks associated with dams in the UK

Context

There are over 2,500 statutory reservoirs in the United Kingdom that hold more than 25,000m^3 of water above the level of the adjoining natural ground. About 1,400 of these have communities downstream that would be at risk of flooding if a dam failure occured.

Drivers

The most important drivers of risk of failure of dams include:

- Climate change: the key influence will be on the generation of more severe storms and the potential for change in the types of storm. It is likely that the storms that influence future reservoir flood design will arise from meso-scale convective complexes. Such storms presently occur on average about once every 14 years but, with climate change, they may occur more frequently. However, there is great uncertainty about this as existing models have difficulty simulating these events. Extreme rainfall upstream of a dam will increase incoming peak discharges. Also, increased storminess could increase wave heights in reservoirs. As a result, climate change is expected to yield some increase in risk in the next 30-100 years.
- Number and value of properties at risk downstream of dams: these are expected to increase – possibly several-fold during the next 30-100 years, putting more people and assets at risk.
- Deterioration of dam structures due to ageing: the average age of dams is now around 100 years, and will therefore double by the end of the century if they are still in use.
- Regulatory frameworks and inspection: these are presently strong and are being strengthened. Strengthening is expected to continue during the remainder of this century.

While the increase in future risk due to climate change and increasing development/property values will be somewhat balanced by factors such as the strengthening of the regulatory framework, it is beyond the scope of the present project to accurately assess how risk levels pertaining to dam failure will evolve over the next 100 years.

Nevertheless, it is hoped that much of the analysis performed in this project will help to inform more detailed studies.

4.6.1 Year 2030: a major coastal flood disaster in an estuary

The event is a worse-than-1953 flood event in an estuary, overtopping and breaching the defences.

The floodwater pours through the breaches at high tide, which cannot be repaired before the next two high tides. The flood affects 2,000,000 properties and 450,000 people spread over 75 km^2 of the tidal floodplain.

Despite the vastly improved warning and contingency plans compared with 1953, not all the population can be evacuated in time. There is a large number of deaths, as in 1953, damage running into many billions of pounds, and economic disruption for the following 12 months. The transportation, power and communications infrastructure is heavily affected, including damage to the power and signalling systems, creating months of dislocation to the major rail network.

A huge sewage treatment plant is submerged, backing up sewage and spreading pollution over a wide area. Irreplaceable heritage assets are lost.

Government is faced with the imminent failure of two insurance companies with insufficient reinsurance cover. The result is a commitment by government, aided by the European Commission, to compensate all flood victims, irrespective of whether they had insurance, as practised in other EU countries. The event has a long-term effect on the availability of flood insurance.

4.6.2 Year 2045: a fluvial flood disaster on a major city located on a river

Much of the city lies behind flood defences along the river that were constructed in the 1950s to cope with floods of an annual probability of 1 in 50-100.

A flood with a probability of 1 in 200 threatens the city. Despite good flood warnings and huge efforts by civil and military agencies the defences are breached adjacent to the city centre.

A wall of water engulfs parts of the city. This occurs in darkness late on a Saturday in January, making emergency response extremely difficult. A weekend event means that there are unusually low levels of cover in the emergency services, while the police are overstretched owing to the crowds in the city and the sheer scale of the event as the flood waters devastate the retail centre. A number of people are swept away and drowned.

Power supply to the city is cut and the city's hospitals are disrupted, hindering treatment of the injured. Sewage treatment plants in the floodplain are inundated and the 11,000 homes in the floodplain are invaded with sewage-contaminated floodwater that remains there, in some cases, for more than a week. Deaths from respiratory illnesses run at ten times the normal winter weekly average.

The industrial area is hardest hit, with 45 industrial plants flooded and severely damaged, leading to closures and threats to employment. A major railway bridge 25 miles downstream is undermined, causing closure of the line for the next 12 months whilst the bridge is rebuilt. Power stations are severely disrupted, leading to regional-scale electricity blackouts at a time of peak winter power demand.

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

Climate change could bring increased storminess in British latitudes, and this would have serious consequences for the urban drainage infrastructure of our cities, much of which remains of Victorian origin.

A major summer thunderstorm event hovers stationary over the city, producing 20 cm of rainfall in one day: a fifth of the city's normal annual average rainfall, similar to that which caused the Lynmouth disaster. The urban drainage system is completely overwhelmed, compounded by a number of sewer collapses caused by the very rapid runoff and high debris concentrations.

Many of the city's older residential areas have large properties with substantial basements. These have been progressively converted between 1990 and 2040 from storage areas and old kitchens into family dwellings, encouraged by the city council's efforts to meet government housing targets. More than 1,000 such properties are flooded. Conditions on the local motorway delay assistance from emergency services. Scores of people are trapped in their basements, and loss of life is considerable among the elderly and the disabled. Fifty percent of the households are still not back in their homes a year later.

Sewage overflows into parts of the city and causes serious ecological damage to the newly designated Coastal Conservation Area. Traffic in the city is halted for 48 hours, exacerbated by the litter of damaged vehicles in the city centre. More than a score of major stores in the new shopping development are devastated, and cannot reopen for three months. Many of the cultural buildings in the city centre are flooded, causing the loss of many of the historical archives stored there. The damage runs into hundreds of millions of pounds.