Chapter 2

Drivers of flood risk – catchment and coastal

This chapter analyses a range of important drivers that affect future flood risk at the catchment scale and also at the coast.

The drivers are first located within the Source-Pathway-Receptor (SPR) model outlined in Chapter 1 and their operation and interaction analysed. They are then scored according to their impact on future flood risk – for the 2050s and the 2080s – for four future scenarios at local and national scales.

Finally, they are ranked according to their importance in affecting national flood risk, and the uncertainty associated with these rankings is analysed.

2.1 Defining the drivers

A driver was defined in Chapter 1 as any phenomenon that may change the state of the flooding system. Some drivers, such as the conveyance of rivers and floodplains, are amenable to our intervention. Many, such as the amount of rainfall or the value of houses and their contents, are effectively beyond our control. This chapter considers drivers that operate at the scale of catchments and their estuarial and coastal equivalents.

We have grouped the drivers into five sets that are functionally related and which exhibit strong interactions (see Table 2.1). More detailed descriptions of the drivers may be found in Appendix A – these descriptions set out the operation and interaction of the drivers, discuss how changes in the drivers might occur for the four socioeconomic scenarios, and consider issues of driver uncertainty. Further information on the drivers is also provided in the technical papers that have been produced by the project.

The choice and classification of the drivers required careful consideration to ensure consistency with the Pressure-State-Impact-Response (PSIR) and SPR models described in Chapter 1, and with the framework of analysis of the entire project. During analysis of driver operation, it emerged that two drivers acted primarily through other drivers. These drivers are grey-toned in Table 2.1.

Two issues of special note also arose during driver investigation. These relate to: the treatment of urban areas within an analysis conducted at the catchment and coastal scale, and special circumstances surrounding drivers relating to flood management, and to public attitudes and science and technology.

Table 2.1 **Drivers of fluvial and coastal flooding (note: drivers that are grey-toned affect flood risk indirectly via other drivers)**

Driver set	Driver	SPR classification	Explanation
Climate change	Precipitation	Source	Changes in all aspects of precipitation (amount, intensity, duration, location, seasonality and clustering).
	Temperature	Source	Influence of temperature on evapotranspiration, soil moisture and hence runoff.
Catchment runoff	Urbanisation	Pathway	Changes in the catchment that increase the area of impermeable surfaces and extent of stormwater drainage systems to increase surface runoff.
	Rural Land Management	Pathway	Effects of land management practices on agricultural and other 'managed' rural land, including conservation and recreational areas and wetlands that affect runoff generation.
	Agricultural Impacts	Receptor	Impact of flooding and associated high water tables on farm and forestry land and associated managed habitats.
Fluvial processes	Environmental Regulation	Pathway	Future legislation intended to increase biodiversity and habitat protection that may influence policy on flood management, with implications for river and floodplain morphology, vegetation, conveyance, and flood storage.
	River Morphology and Sediment Supply	Pathway	Changes in river morphology (channel size and shape, floodplain topography) and sediment supply that alter attributes of the river channel and floodplain to influence flood conveyance, routing and storage.
	River Vegetation and Conveyance	Pathway	Vegetation and micro-morphology influence velocity distributions and turbulence levels in flows significantly. Hence, changes may affect flood conveyance.

Table 2.1 **Drivers of fluvial and coastal flooding (note: drivers that are grey-toned affect flood risk indirectly via other drivers)** *(continued)*

Driver set	Driver	SPR classification	Explanation
Coastal processes	Waves	Source	Offshore waves are generated by winds and increase in height with storminess and fetch length. Increases in wave height and changes in wave direction due to climate change may affect transmission of wave energy to the shoreline. Impacts will be influenced by increases in near-shore depth caused by changes in the next two drivers.
	Relative Sea Level Rise	Source	Rising relative sea level is due to climate change-induced melting of ice caps and thermal expansion in conjunction with land subsidence or uplift. Rising relative sea level makes coastal flooding more frequent, and allows more energy to reach the shoreline. Long-term effects include morphological change as the coastline adjusts.
	Surges	Source	Increases in surge levels are expected due to climate change-induced increases in storminess. Stronger surges mean that higher extreme water levels with more energy reach the shoreline, increasing the risks of breaching or overtopping of coastal defences.
	Coastal Morphology and Sediment Supply	Pathway	Changes in the near-shore seabed, shoreline and adjacent coastal land, coastal inlets and estuaries will, in the short term, affect the wave and surge energies that affect the shoreline. In the long term, the coastline adjusts to changes in coastal processes.
Human behaviour	Stakeholder Behaviour	Pathway	Stakeholders may influence flood risk in many ways, ranging from pre-flood preparedness to self-help after an event. Corporate and government stakeholders influence availability of insurance, agricultural practices, food production, and pursuance of ecological (or other) aims. Future changes in stakeholder behaviour will be strongly linked to societal values and goals.
	Public Attitudes and Expectations	Receptor	Determines preferences for styles of risk management. Most obviously, ‘Public Attitudes and Expectations’ will act on flood risk indirectly, through other drivers, particularly, though not exclusively, those associated with Stakeholder Behaviour.

Table 2.1 **Drivers of fluvial and coastal flooding (note: drivers that are grey-toned affect flood risk indirectly via other drivers)** *(continued)*

Driver set	Driver	SPR classification	Explanation
Socioeconomics	Buildings and Contents	Receptor	The damage to buildings and their contents, including damage to production and household durables, as well as raw materials, intermediate goods and consumer goods.
	Urban Impacts	Receptor	The type and layout of buildings and resulting densities of development, building form and nature of land use, all affect the magnitude of flood losses per unit area.
	Infrastructure Impacts	Receptor	The networks of services that enable the economy to transform raw materials into goods, intermediate goods and final consumption. Flooding these networks can have consequences beyond the area directly affected by flooding.
	Social Impacts	Receptor	Includes the risks to life and health, the 'intangible' impacts of flooding, the vulnerability of different groups and impacts of flooding on community cohesion.
	Science, and Technology	Receptor	Science and Technology collectively determine the ratio of the output of the economy to the required inputs of the natural endowment, labour and capital; they enable us to do more with less. They are determined primarily by worldview and influence flood risk via the Buildings and Contents, Urban Impacts and Infrastructure drivers.

2.1.1 Treatment of the urban area

In our current analysis, the only properties of urban receptor areas considered are their density, spatial extent and assets at risk – including buildings, infrastructure and other assets damaged by flooding. Because the source terms in the SPR model are typically long duration (catchment-wide precipitation events and equivalent marine events), urban areas are assumed to have no internal flooding-pathway mechanisms. Therefore, the last link in the flooding pathway is the overtopping or failure of the peripheral flood defences. Flooding that develops due to rain falling within the urban area is considered in Chapter 3.

2.1.2 Flood management

Assessment of the future flood-risk impacts of drivers in Phase 2 of the project is made under the baseline assumption that current flood-management strategies remain unchanged. For this reason, it would be inappropriate to consider the operation and effect of changes in flood management in the present analysis. Consequently, we exclude from analysis in this phase drivers involving changes to flood management.

Eliminating flood-management drivers in this phase of the project does not mean that we have ignored the potential for changes to flood-defence infrastructure, technology or investment to change flood risk. We return to these in Volume II when possible responses to future flood risks are considered.

2.1.3 Public Attitudes and Expectations

Public Attitudes and Expectations, a part of the Human behaviour driver set, is an unusual driver for two reasons: first it does not affect the probability or consequences of flooding directly; and second, it is tightly coupled to other drivers. As a result, it clearly differs from, for example, precipitation as a *source*, or urban impacts as a *receptor*.

The main reason for this difference is that public attitudes operate primarily through the so-called ‘outrage’ element of flood risk. For example, increased public concern following a large flood can influence future flood risk through the driver Stakeholder Behaviour. However, Public Attitudes and Expectations only becomes effective in altering either the probability or consequence of flooding if stakeholders respond to the demands of the public – for example, through changes in flood defences. Under the baseline flood management assumption, the possibility for changes in flood-management is excluded from this assessment and so Public Attitudes and Expectations would not produce the anticipated reductions in flood risk.

For this reasons we have left this driver in all the driver lists, rankings and the uncertainty analysis in the remainder of this volume, but we have designated it as ‘Known to be important but not quantified'. This should not be taken to imply that this driver is not of great significance, but that it acts primarily through the responses to flood risk rather than itself driving risk up or down.

2.1.4 Science and Technology

As indicated in Table 2.1, Science and Technology is an important driver of flood risk, but it operates indirectly through others (e.g. through the enhanced technologies that result in greater damage potential in Buildings and Contents).

In the driver ranking exercise there were divergent results. Initially this set of factors was ranked lowly, partly on the basis that the character of science and its role in society was partially subsumed in the scenarios (i.e. under Local Stewardship there might well be concerted moves towards an 'intermediate technology' approach). Later work suggested that this driver was much more important, because it affected so many others. But the danger here, methodologically, was that the quantification might double-count these effects.

In the final analysis, therefore, this driver has been left within the driver list, but labelled simply as 'Known to be important but not quantified'. This may mean that we have missed some elements of science and technology that are not counted in other drivers, but we feel that this is the lesser of two evils.

2.2 Describing the drivers

Our approach rested on broad-brush assessments of the national picture together with specific case examples to deepen the assessments of drivers of flood risk and to quantify their impacts under the four Foresight Futures. Our driver descriptions and assessments (summarised in Appendix A) were the result of desk studies backed by expert knowledge, literature searches and contact with individuals, research organisations and agencies in the UK and abroad.

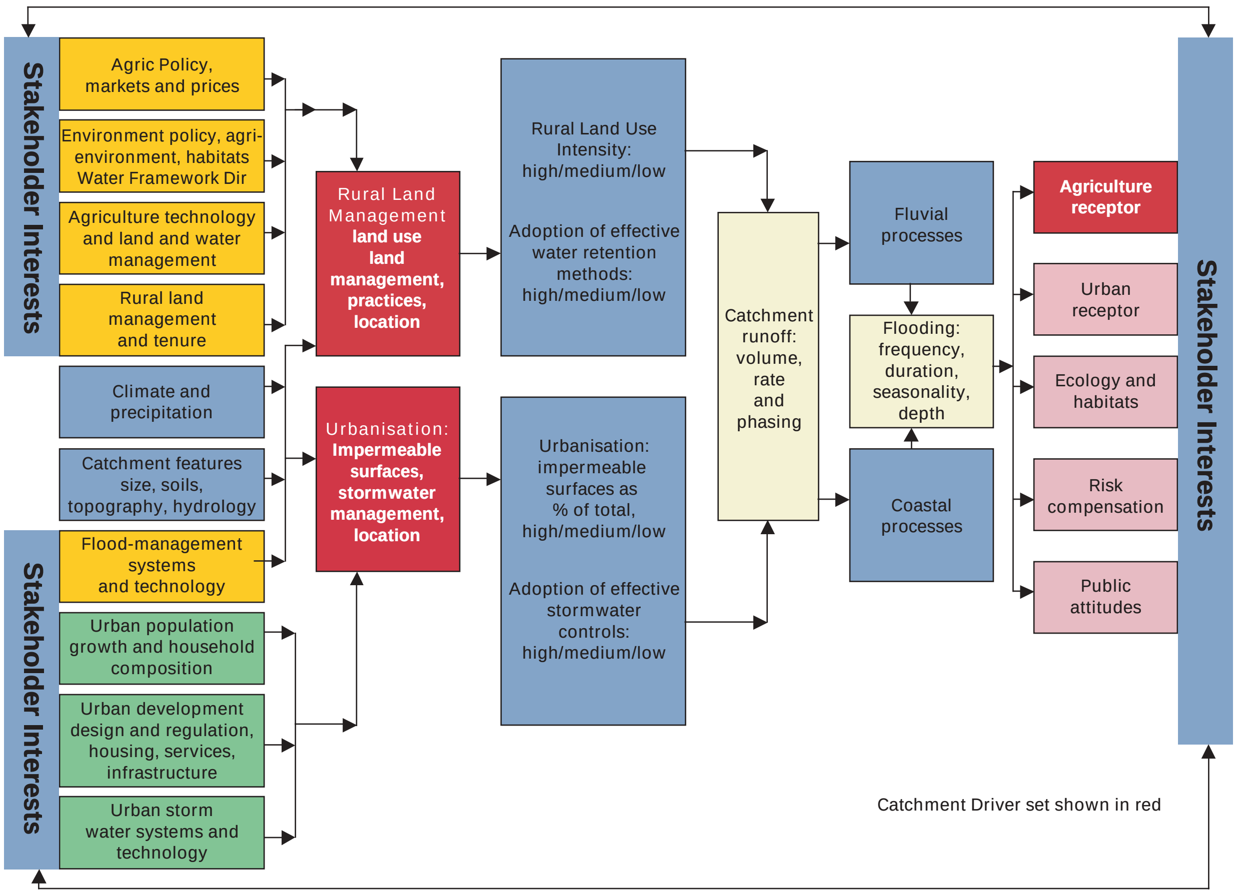
The studies followed a common approach for each driver:

- Review the drivers and write detailed descriptions with comments on: their operation and interaction with other drivers (e.g. Figure 2.1); robustness; and the need for further research.
- Select appropriate ‘native parameters’ to characterise drivers. These native parameters translate the driver into quantified changes in future flood risk.
- Determine how changes in native parameters will affect flood risk.
- Assess the local and national risk multipliers for each driver and rank them according to change in national flood risk.
- Develop a method to express uncertainty and, where practical, break this down according to the sources of uncertainty.

Finally, these qualitative studies also helped to determine input parameters for the modelling tools that were used to support spatial analysis and quantification of flood risk in the future scenarios (see Chapter 4).

Figure 2.1 **There are complex interactions between the drivers of flood risk. This diagram illustrates those interactions for the driver set 'Catchment runoff'**

Driver set 5 – Catchment runoff (Rural Land Management, Urbanisation and Agriculture (receptor)) and linkages



2.3 The relative importance of drivers

The descriptions of catchment-scale drivers provide valuable insights into how drivers operate and, in qualitative terms, their potential impacts on flood risk. However, any analysis of changing flood risks requires insights into the relative importance of different drivers.

While the project has constructed a model for quantifying flood risk at the catchment scale (see Chapter 4), the model does not enable the influence of individual drivers to be easily disaggregated. Moreover, existing risk-analysis tools cannot resolve the effects of the wide range of drivers under consideration.

To provide insights into the importance of individual drivers to the overall flood risk, the project scored each driver according to an expert assessment of its impact on flood risk within the area affected by that driver. The results are referred to here as impacts on local flood risk. These represent the changes in flood risk experienced by an individual or organisation located in a particular geographical location or operating in a particular sector of the economy. Driver scores were derived for the four future scenarios under consideration, in the 2050s and the 2080s.

However, flood risk is, of course, multi-dimensional. It involves not just economic losses but also health, social and environmental impacts. Economic, social and health impacts were considered in scoring driver impacts. The environmental dimension of flood risk is dealt with in Chapter 7.

2.3.1 Calculating multipliers of local flood risk – methodology

As stated above, the drivers were scored according to their likely effect on flood risk for each future scenario and time slice. Scores for each driver were expressed as a 'multiplier' of the current flood risk in the area affected. Scores were derived using the following process steps:

- Specialists selected one or more 'native parameters' to represent each driver. These native parameters enable changes in the driver to be translated into changes in future flood risk. For example, the native parameter relating to the driver 'Surges' is 'water levels for different return period storm events'.
- The drivers were analysed, within the context of each scenario, to determine how the native parameters might change for the 2050s and 2080s. Analytical approaches varied, depending on the nature of the driver and whether the selected native parameter was qualitative or quantitative. For example, for drivers in the driver sets Climate Change and Coastal Processes we calculated parameter changes using numerical analysis of the available data. On the other hand we determined the equivalent changes in the driver sets Human behaviour and Socioeconomics through careful reasoning based on a blend of theory and experience.

- We converted the changes in native parameters to changes in flood risk using a simple definition: *'Flood risk is a function of the probability and consequences of flooding and can be taken as (probability x consequence).'*

- When envisioning flood risk in the 2050s and 2080s, experts considered how the two sides of risk, probability and consequence, may change. For example, if the probability of an event in a given year rises from 1 in 20 to 1 in 10, then this represents a two-fold increase in probability and, therefore, a two-fold increase in risk. Conversely, if the damage due to a 1-in-20 event will, in the 2050s, be ten times greater than today, this represents a ten-fold increase in consequence and therefore risk. Thus we assessed the impact of drivers on the basis that source and pathway drivers alter flood risk through their impact on the *probability of flooding*, while receptor drivers alter flood risk through their impact on the *consequences of flooding*.

- The ratio of future flood risk to the present-day risk yields the driver multiplier.

In scoring the economic consequences of flooding, we applied the valuation of future flood risks and the baseline assumption on flood management described in Chapter 1. We further assumed that present concepts of economic valuation of flood losses still apply in the 2050s and 2080s. An alternative view is that, in a future focused on sustainability, flooding in a river catchment or along a coastline could become a valuable asset, rather than a cost (O'Riordan 2003). Such an outcome would depend on changes in the governance of flood-defence, policy, management and infrastructure – these are explored in Volume II.

In the scoring exercise, we included all the drivers, both direct and indirect, to ensure that their importance was fully recognised. However, it must be borne in mind that the two indirect drivers (Public Attitudes and Expectations and Science and Technology) actually influence flood risk via other drivers. We have grey-toned their rows in the scoring tables to reflect this.

Clearly, the scoring of the drivers was a complex task, which involved many value judgements. To ensure consistency of approach, checks were introduced at various stages in the process: our analysis of scoring began with an independent evaluation which produced scores that were discussed and changes made as necessary; we reviewed the scores and compared them with the results of quantified risk analysis; and, the scores and the final results were subjected to wider scrutiny via stakeholder groups and peer review.

2.3.2 Multipliers of local flood risk – results

We present the primary results of the driver assessment in the form of local risk multipliers for each of the drivers (see Table 2.2). The multipliers are local in that they reflect the change in risk within the geographical area affected by pathway drivers or the sector of the economy affected drivers that change the consequences of flooding. Scaling of these local scores to reflect driver impacts nationally is dealt with in Section 2.3.4 of this chapter.

Table 2.2 **Summary results for driver impacts on local flood risk: the numbers in the table are multipliers of current flood risk**
(note: drivers that are grey-toned affect flood risk indirectly via other drivers and so are not scored)

Driver type	Name	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
		2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Climate change									
S	Precipitation	4	5.7	2.8	4	2.8	4	2	2.8
S	Temperature	1	1	1	1	1	1	1	1
Catchment runoff									
P	Urbanisation	2.8	4	2.8	4	0.7	0.5	0.7	0.5
P	Rural Land Management	1.4	2	1.4	2	0.7	0.5	0.7	0.7
R	Agricultural Impacts	0.7	0.7	1.2	1.7	1	0.85	0.7	0.5
Fluvial processes									
P	Environmental Regulation	1	1	1	1	1.4	2.8	2	4
P	River Morphology and Sediment Supply	1	2	1	1	2	4	1.4	2.8
P	River Vegetation and Conveyance	1	1.4	1	1.4	1	2	2	5.7
Coastal processes									
S	Waves	3	10	2	5	1	3	1	2
S	Relative Sea-Level Rise	5	20	4	13	3	10	3	7
S	Surges	5	20	3	9	2	5	1	2
P	Coastal Morphology and Sediment Supply	5	10	4	7	3	4	2	2
Human behaviour									
P	Stakeholder Behaviour	2	2.8	0.5	0.33	0.25	0.2	0.25	0.2
R	Public Attitudes and Expectations	Known to be important but not quantified							
Socioeconomics									
R	Buildings and Contents	6.0	17.0	2.2	3.1	3.0	4.8	2.5	4.8
R	Urban Impacts	5.0	19.8	1.8	3.6	3.0	4.8	2.2	3.9
R	Infrastructure Impacts	7.1	24.0	2.2	3.6	3.0	4.8	2.5	3.9
R	Social Impacts	6.0	19.8	2.2	3.6	3.0	6.1	2.2	3.2
R	Science and Technology	Known to be important but not quantified							

2.3.3 Coastal flood risk

From the point of view of the probability of a coastal flood occurring, extreme water level is the key parameter. Extreme high water levels result from the combined impacts of two drivers (the rise in relative sea level and the increased frequency and intensity of surges), plus tidal effects. However, tidal effects are not a driver as they are not predicted to change during the remainder of this century.

Waves are a separate driver from Surges and Relative Sea Level Rise because they may increase the risk of coastal flooding in different ways to extreme water levels. Mean sea level, tidal fluctuations and surges together define the still-water level at any time. The resultant still-water level can in itself give rise to flooding. However, waves act on the still-water level and can cause flooding even when it is insufficient to inundate the coastal floodplain directly. This may occur by waves either overtopping defences, or damaging them sufficiently to cause a breaching failure.

Rising relative sea level also affects flood risk through changes in coastal features such as saltmarshes. Saltmarshes respond to their position relative to mean sea level, but if the rate of sea level rise is rapid, and saltmarshes cannot keep pace, then the risk of flooding behind the saltmarsh increases. These longer-term impacts on flood risk are included within the driver Coastal Morphology and Sediment Supply.

2.3.4 Multipliers of national flood risk – results

The impacts of some drivers on national flood risk are markedly different to their local impacts on individuals or organisations. For drivers that alter the probability of flooding this is because they affect only a proportion of the total area of the UK. For drivers that alter the consequences of flooding it is because they affect only a particular sector of the national economy.

Adjustments for spatial distribution were applied to drivers in the Climate change, Catchment runoff, Fluvial processes and Coastal processes driver sets. Local scores were reduced to take account of the facts that Climate change, Catchment runoff and Fluvial processes drivers affect only inland flooding while coastal drivers affect only coastal flooding. Sectoral scaling was applied to local scores for impacts associated with Buildings and Contents, Agricultural, Urban and Infrastructure Impacts drivers, based on the proportion of that sector within the national economy.

The results of the driver assessment in the form of multipliers adjusted to represent impacts on national flood risk are listed in Table 2.3.

Table 2.3 **Summary results for river impacts on national flood risk: the numbers in the table are multipliers of current flood risk**
(note: drivers that are grey-toned affect flood risk indirectly via other drivers)

Driver type	Name	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
		2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Climate change									
S	Precipitation	3	3.6	2.2	2.7	2.2	2.7	1.7	2.0
S	Temperature	1	1	1	1	1	1	1	1
Catchment runoff									
P	Urbanisation	2.2	2.7	2.2	2.7	0.8	0.7	0.8	0.7
P	Rural Land Management	1.3	1.6	1.3	1.6	0.8	0.7	0.8	0.8
R	Agricultural Impacts	1	1	1	1	1	1	1	1
Fluvial processes									
P	Environmental Regulation	1	1	1	1	1.4	2.8	2	4
P	River Morphology and Sediment Supply	1	1.6	1	1	1.7	2.7	1.3	2.0
P	River Vegetation and Conveyance	1	1.2	1	1.2	1	1.6	1.7	3.6
Coastal processes									
S	Waves	1.7	5.1	1.3	2.8	1	1.9	1	1.5
S	Relative Sea-Level Rise	2.4	9.6	2	6.4	1.7	5.1	1.7	3.7
S	Surges	2.4	9.6	1.7	4.6	1.3	2.8	1	1.5
P	Coastal Morphology and Sediment Supply	2.4	5.1	2.0	3.7	1.7	2.4	1.3	1.5
Human behaviour									
P	Stakeholder Behaviour	2	2.8	0.5	0.3	0.3	0.2	0.3	0.2
R	Public Attitudes and Expectations	Known to be important but not quantified							
Socioeconomics									
R	Buildings and Contents	4.0	6.4	3.2	4.5	0.9	0.7	1.5	1.9
R	Urban Impacts	1.6	2.0	1.4	1.6	1	1	1.1	1.1
R	Infrastructure Impacts	4.7	9.0	3.2	5.2	0.9	0.7	1.5	1.5
R	Social Impacts	6.0	19.8	2.2	3.6	3.0	6.1	2.2	3.2
R	Science and Technology	Known to be important but not quantified							

2.3.5 Ranking the national importance of the drivers

The purpose of scoring driver risk impacts nationally (as in Table 2.3) was to support the targeting of responses in Phase 3 by identifying those drivers that are most important in changing flood risk nationally. However, given the high uncertainty associated with many of them, it would be unrealistic to develop a complete ordering of drivers. To give a more robust assessment of which are the most important drivers, we have arranged them according to bands. In this context we take 'importance' of a driver to be the magnitude of the change (which may be an increase or a decrease) in flood risk caused by that driver, for the UK as a whole.

The complete spreadsheets produced by the ranking exercise are very large and are not easily amenable to reproduction in this report. We therefore summarise the rankings in Tables 2.4a (which relates to the 2050s) and Table 2.4b (2080s). In these tables, drivers are colour coded according to their level of impact and whether they act to increase or decrease flood risk.

- Red – drivers with risk multipliers greater than 2. These correspond to **High Increase drivers**.
- Yellow – drivers with risk multipliers between 1.2 and 2. **Medium Increase drivers**.
- Green – drivers with risk multipliers between 0.83 and 1.2. **Low Impact drivers**.
- Blue – drivers with risk multipliers between 0.5 and 0.83. **Medium Decrease drivers**.
- Purple – drivers with risk multipliers less than 0.5. **High Decrease drivers**.

2.3.6 The nature of the driver ranking results

Some key points to note from Tables 2.4a and 2.4b are as follows:

- The Social Impacts driver dominates the top of the ranking table, indicating high increases in the consequences of flooding to people and communities expressed in terms of the health and social dimensions of flood risk.
- Under the baseline assumption, the future with regard to the Social Impacts of flooding is bleak, especially under the less socially resilient futures, World Markets and Local Stewardship. This reflects the significant impacts on individuals, households and communities (in addition to their financial losses) caused by societal changes that tend to increase the number and/or vulnerability of people at risk, and the increased frequency and severity of flooding.
- The nature and extent of Social Impacts will be partly determined by political, cultural, public health and social factors, and will be realised differently under the four scenarios. There are, though, commonalities such as an ageing population that will become increasingly susceptible to flood impacts.
- The Precipitation driver generates high increases in flood risk under all scenarios, generally ranking just below the Stakeholder and Socioeconomic drivers, but above the Coastal drivers. Precipitation impacts are greatest under the High emissions scenario (associated with World Markets) and least under the Low emissions scenario (associated with Global Sustainability). An increased risk of inland flooding in the 2080s by between 4 and 6 times over present levels could result. This would reduce the standard of protection (SoP) of a defended area from 1 in 100 years to 1 in 17 years under the World Markets scenario. This corresponds to a trebling of national flood risk.
- Drivers connected with the impacts of climate change on coastal flood risk – Relative Sea-Level Rise, Coastal Morphology and Sediment Supply, and Surges – and to a lesser extent Waves – result in high increases in risk under most scenarios. Impacts are much worse under the High emissions scenarios (World Markets and National Enterprise) and intensify after the 2050s. These are also drivers of increasing coastal erosion risk. If the current expenditure on coastal defences were continued, a time would come when it would not be possible to maintain the present SoP,

and there is the potential for a twenty-fold increase in local risk in the coastal floodplain. This scales to nearly an order of magnitude increase in the national risk in the 2080s.

- Stakeholder Behaviour promotes large reductions in flood risk under all but the World Markets scenario by bringing about changes in the exposure to and consequences of floods. The impacts of Stakeholder Behaviour suggest that a high priority will be given to actions to reduce flood risk in all scenarios except World Markets, where the behaviour of stakeholders is less strongly focused on flood risk reduction.

- The rankings of a group of socioeconomic and catchment drivers, including Buildings and Contents, Infrastucture Impacts, Urban Impacts, Urbanisation and Rural Land Management, are very strongly scenario dependent. Under the two consumerist scenarios, World Markets and National Enterprise, urban sprawl and poor rural land management lead to increased runoff that increases the probability of flooding downstream. At the same time, new developments and weak planning controls on the types, densities and numbers of new buildings increase losses in those floodplains.

- Conversely, under Global Sustainability and, particularly, Local Stewardship futures, strong urban planning laws, the application of Sustainable Urban Drainage Systems (SUDS) and high levels of land stewardship reduce catchment runoff. Also, lower numbers of new properties and schemes that avoid placing developments in areas at risk from flooding combine to produce marked reductions in flood losses.

- The outcomes of these divergent futures for these drivers are clear in the increases in flood risks associated with World Markets and National Enterprise futures and reductions in flood risk under Global Sustainability and, particularly, Local Stewardship scenarios.

- Environmental Regulation, River Morphology and Sediment Supply and Vegetation and Conveyance drivers produce low impacts and cluster around the middle of the ranking table under the consumerist scenarios World Markets and National Enterprise. However, they score and rank much higher under the two more environmentally-oriented scenarios, Global Sustainability and Local Stewardship, owing to regulatory frameworks that restrict the use of rivers for flood-defence purposes and promote restoration of their natural attributes – including the natural process of flooding.

- The message that emerges here from the scoring and ranking of these drivers is that to avoid increasing flood risk, care would have to be taken to factor in the flood-defence function of rivers in futures where environmentally-led river management is the norm and channel restoration is commonplace.
- Two drivers, Temperature and Agricultural Impacts, have low impacts across all scenarios. The effects of temperature on flood risk are important but mainly operate indirectly through the Precipitation driver (see the summary driver description in Appendix A). National risk scores of unity for Agricultural Impacts stem from scaling local impacts sectorally. This reflects the small proportion of Gross Domestic Product (GDP) generated by agriculture in the UK as a whole. This is not to say that local impacts are insignificant. For example, under National Enterprise, the push for national self-sufficiency in food would have impacts on risk in the farming sector through increasing the exposure of crops to damage and livestock to flooding (see Table 2.2).
- Conversely, reductions in agricultural losses in Northern Ireland under World Markets and Global Sustainability scenarios (see Chapter 8), are significant not only because they indicate the ameliorating effect of restricting farming to grade 1 and 2 land, but because the signal the vulnerability of farming communities to the loss of subsidies under reforms of the Common Agricultural Policy (CAP).

There are two unquantified drivers that warrant explanation:

- As noted in section 2.1.3, Public Attitudes and Expectations is, in a sense, a virtual driver – reflecting public opinion and high level of outrage that fuel the demand that ‘something should be done to reduce flooding’. This is impossible to quantify in the same way that we have quantified other drivers. Although the Public Attitudes and Expectations driver was therefore not scored, it was recognised that the public and their elected representatives could be particularly effective in persuading and empowering stakeholders to generate large reductions in flood risk by altering Stakeholder Behaviour under all but the World Markets scenario. Its impacts are, therefore included within the scores for Stakeholder Behaviour.

- Similarly, as noted in section 2.1.4, the Science and Technology driver acts via other drivers and again could not be scored in this study. However, in a high-technology future the vulnerability of electronic, electro-mechanical and computer-controlled assets to damage by flooding could lead to very large increases in risk. For example, the late twentieth century witnessed transformations in the numbers and complexity of telecommunication, transportation and computer systems and these trends are set to continue for at least the first half of the 21st century. This is likely to generate the potential for major increases in losses related to Science and Technology. These will be due not only to direct damage but also to wider disruption of integrated networks, the efficient operation of which relies on remotely-sensed data and centrally-controlled and co-ordinated operation of complex systems (see Section 2.6 for examples from transport). The impacts of Science and Technology are therefore partly responsible for the high scores recorded for the Buildings and Contents, Infrastucture Impacts and Urban Impacts drivers. However, this trend may not continue, and flood resilience should eventually increase as data-collection and system-control mechanisms become wireless and/or satellite-based.

Table 2.4a **National ranking of catchment-scale drivers – 2050s**

	World Markets	**National Enterprise**	**Local Stewardship**	**Global Sustainability**
	2050s	**2050s**	**2050s**	**2050s**
1	Social Impacts	Building and Contents	Social Impacts	Social Impacts
2	Infrastructure Impacts	Infrastructure Impacts	Precipitation	Environmental Regulation
3	Buildings and Contents	Social Impacts	Relative Sea Level Rise	Relative Sea Level Rise
4	Precipitation	Precipitation	Coastal Morphology and Sediment Supply	Precipitation
5	Relative Sea Level Rise	Urbanisation	River Morphology and Sediment Supply	Vegetation and Conveyance
6	Coastal Morphology and Sediment Supply	Relative Sea Level Rise	Environmental Regulation	Infrastructure Impacts
7	Surges	Coastal Morphology and Sediment Supply	Surges	Buildings and Contents
8	Urbanisation	Surges	Waves	Coastal Morphology and Sediment Supply
9	Stakeholder Behaviour	Urban Impacts	Urban Impacts	River Morphology and Sediment Supply
10	Waves	Rural Land Management	Vegetation and Conveyance	Urban Impacts
11	Urban Impacts	Environmental Regulation	Temperature	Surges
12	Rural Land Management	Vegetation and Conveyance	Agriculture Impacts	Waves
13	Vegetation and Conveyance	River Morphology and Sediment Supply	Infrastructure Impacts	Temperature
14	River Morphology and Sediment Supply	Waves	Buildings and Contents	Agriculture Impacts
15	Temperature	Temperature	Urbanisation	Urbanisation
16	Agriculture Impacts	Agriculture Impacts	Rural Land Management	Rural Land Management
17	Environmental Regulation	Stakeholder Behaviour	Stakeholder Behaviour	Stakeholder Behaviour
	Science and Technology – known to be important but not quantified			
	Public Attitudes and Expectations – known to be important but not quantified			

Table 2.4b **National ranking of catchment-scale drivers – 2080s**

	World Markets 2080s	National Enterprise 2080s	Local Stewardship 2080s	Global Sustainability 2080s
1	Social Impacts	Relative Sea Level Rise	Social Impacts	Environmental Regulation
2	Relative Sea Level Rise	Infrastructure Impacts	Relative Sea Level Rise	Relative Sea Level Rise
3	Surges	Surges	Environmental Regulation	Vegetation and Conveyance
4	Infrastructure Impacts	Buildings and Contents	Surges	Social Impacts
5	Buildings and Contents	Coastal Morphology and Sediment Supply	Precipitation	Precipitation
6	Coastal Morphology and Sediment Supply	Social Impacts	River Morphology and Sediment Supply	River Morphology and Sediment Supply
7	Waves	Precipitation	Coastal Morphology and Sediment Supply	Buildings and Contents
8	Precipitation	Urbanisation	Waves	Infrastructure Impacts
9	Stakeholder Behaviour	Waves	Vegetation and Conveyance	Coastal Morphology and Sediment Supply
10	Urbanisation	Urban Impacts	Urban Impacts	Surges
11	Urban Impacts	Rural land Management	Temperature	Urban Impacts
12	Rural land Management	Vegetation and Conveyance	Agriculture Impacts	Waves
13	River Morphology and Sediment Supply	Environmental regulation	Infrastructure Impacts	Temperature
14	Vegetation and Conveyance	River Morphology and Sediment Supply	Buildings and Contents	Agricultural Impacts
15	Temperature	Temperature	Urbanisation	Rural land Management
16	Agriculture Impacts	Agriculture Impacts	Rural land Management	Urbanisation
17	Environmental Regulation	Stakeholder Behaviour	Stakeholder Behaviour	Stakeholder Behaviour
	Science and Technology – known to be important but not quantified			
	Public Attitudes and Expectations – known to be important but not quantified			

Legend

Driver Impact Category	Risk Multiplier (M) Range	Colour Code
High increase	M ≥ 2	Red
Medium increase	2 > M ≥ 1.2	Yellow
Low impact	1.2 > M ≤ 0.83	Green
Medium decrease	0.83 ≥ M ≥ 0.5	Blue
High decrease	M < 0.5	Purple

2.4 Driver uncertainty

There is inevitable uncertainty in assessing the future impacts of drivers – in some cases this can be considerable. For this reason, the range of uncertainty in the influence of each driver was assessed.

Specialists were asked to estimate upper and lower uncertainty bounds when scoring each driver impact. These bounds were produced using the same approach and spreadsheet as those applied to produce best estimates of driver impact on local flood risk. In so doing, the upper and lower bounds defined a band of uncertainty around the best estimate. The specialists also analysed the sources of the uncertainty, and analysed the processes by which they affected flood-risk estimates (see Appendix A).

In producing guidance for analysing the causes of uncertainty, we recognised that the wide variation in the nature and style of drivers makes it impossible to be prescriptive. Hence, specialists were asked to use the insights gained through describing drivers, selecting native parameters, evaluating driver impacts and estimating uncertainty to produce a flow chart, rich picture or other illustrative product that captured and synthesised the interactions of the drivers. They then used this analysis to indicate the breakdown of uncertainty by source within the interacting framework. As an example of this method, Table 2.5 presents the breakdown for the component sources of uncertainty for drivers in the driver set ‘Catchment runoff’, and Figure 2.1 provides the corresponding flow chart of driver interactions.

As in the case of driver ranking, the complete spreadsheets produced in the uncertainty ranking are very large and are not amenable to reproduction in this report. We therefore present here summary results for all drivers (Tables 2.6a and 2.6b).

The order of the drivers within the Tables 2.6a and 2.6b corresponds to that used in Tables 2.4a and 2.4b, respectively. In this way, the drivers most important in increasing flood risk are at the top. However, in Tables 2.6a and 2.6b, the colour coding now represents the uncertainty in the driver multipliers and, therefore, uncertainty in the driver ranking. In particular:

- Red – drivers with uncertainty bands wider than 3 indicating a **High Level of uncertainty**.
- Yellow – drivers with uncertainty bands between 1.5 and 3 indicating a **Medium Level of uncertainty**.
- Green – drivers with uncertainty bands narrower than 1.5 indicating a Low **Level of uncertainty**.

Two points are particularly worth noting in Tables 2.6a and 2.6b. Firstly, we are most uncertain about a large proportion of the drivers that potentially have the strongest influence on national flood risk. Secondly, by identifying drivers that are both important and uncertain, the analysis indicates where future research can usefully be focused in order to reduce uncertainty in predicting future flood risk (see Appendix D on recommendations for future work).

Table 2.5 **Uncertainty tracking for the Catchment runoff driver set**

Driver		**Linking components**	
Description of source or uncertainty	**Quantification of uncertainty**	**Description of source or uncertainty**	**Quantification of uncertainty**
Rural Land Management (Pathway)			
Impact of soils and land management practices on run-off	High: high uncertainty at local and catchment scale	Research and testing of effective and suitable land management practices	Moderate to high, dependent on funding and research products
Willingness of land managers to adopt land-use and management practices to control run-off (also see reference to wetland/washland options under agriculture receptor)	High: depends on acceptability and incentives to land managers	Extension services and incentive schemes to promote adoption Use of regulation or compliance requirements	High: dependent on funding and willingness to adopt, and on use of regulatory methods/ compliance requirements
Urbanisation (Pathway)			
Precision in the estimation of catchment scale effects	High: precision of estimates currently vary according to scale, surface and event characteristics; Precision depends on proportion of urban area in catchment, catchment size, drainage design and location aspects	Urban growth and regulation Aggregate catchment scale effects	High: dependent on social and economic drivers affecting urbanisation, and regulation of urban development
Estimation of stormwater solutions	High: uncertainty regarding performance of stormwater solutions (CSOs, SUDs) for different scales and pluvial events	Effective stormwater solutions Adoption of stormwater solutions	High: dependent upon funding and research products, and voluntary or compliance-driven implementation of solutions

Table 2.5 **Uncertainty tracking for the Catchment runoff driver set** *(continued)*

Driver		Linking components	
Description of source or uncertainty	**Quantification of uncertainty**	**Description of source or uncertainty**	**Quantification of uncertainty**
Agricultural Impacts (Receptor)			
Estimation of flood (and waterlogging) damage costs by frequency, duration, seasonality and depth of inundation (and excessive soil water)	Low to medium: water regime requirements of commercial crops relatively well known and observable, but knowledge gaps given new technologies, farming practices and systems	Prediction of land use, management practices and farming systems (linked to rural land management as a pathway) Strategic food security issues	Low to Medium: function of agricultural and related policy, markets and prices, including agri-environmental options, land tenure systems, and response/coping strategies of land managers Potential damage to strategic assets
Feasibility of integrated wetland/washland management options which deliver flood management, bio-diversity and rural livelihood benefits	High: limited empirical or research evidence to support potential opportunities for integrated rural land management	Integration of policy objectives and instruments: agriculture, agri-environment, flood management Development, testing and guidance on interventions and management practices to achieve potential synergy	Medium to high: need to develop and test new land-use and management practices, which seek to promote multi-functional floodplain land use Feasibility of 'joined-up' floodplain management strategies Willingness of land managers to engage

Table 2.6a **Uncertainty in catchment-scale drivers ranked by national flood risk – 2050s**

	World Markets 2050s	National Enterprise 2050s	Local Stewardship 2050s	Global Sustainability 2050s
1	Social Impacts	Buildings and Contents	Social Impacts	Social Impacts
2	Infrastructure Impacts	Infrastructure Impacts	Precipitation	Environmental Regulation
3	Buildings and Contents	Social Impacts	Relative Sea Level Rise	Relative Sea Level Rise
4	Precipitation	Precipitation	Coastal Morphology and Sediment Supply	Precipitation
5	Relative Sea Level Rise	Urbanisation	River Morphology and Sediment Supply	Vegetation and Conveyance
6	Coastal Morphology and Sediment Supply	Relative Sea Level Rise	Environmental Regulation	Infrastructure Impacts
7	Surges	Coastal Morphology and Sediment Supply	Surges	Buildings and Contents
8	Urbanisation	Surges	Waves	Coastal Morphology and Sediment Supply
9	Stakeholder Behaviour	Urban Impacts	Urban Impacts	River Morphology and Sediment Supply
10	Waves	Rural Land Management	Vegetation and Conveyance	Urban Impacts
11	Urban Impacts	Environmental Regulation	Temperature	Surges
12	Rural Land Management	Vegetation and Conveyance	Agriculture Impacts	Waves
13	Vegetation and Conveyance	River Morphology and Sediment Supply	Infrastructure Impacts	Temperature
14	River Morphology and Sediment Supply	Waves	Buildings and Contents	Agriculture Impacts
15	Temperature	Temperature	Urbanisation	Urbanisation
16	Agriculture Impacts	Agriculture Impacts	Rural Land Management	Rural Land Management
17	Environmental Regulation	Stakeholder Behaviour	Stakeholder Behaviour	Stakeholder Behaviour
	Science and Technology – known to be important but not quantified			
	Public Attitudes and Expectations – known to be important but not quantified			

Table 2.6b **Uncertainty in catchment-scale drivers ranked by national flood risk – 2080s**

	World Markets 2080s	National Enterprise 2080s	Local Stewardship 2080s	Global Sustainability 2080s
1	Social Impacts	Relative Sea Level Rise	Social Impacts	Environmental Regulation
2	Relative Sea Level Rise	Infrastructure Impacts	Relative Sea Level Rise	Relative Sea Level Rise
3	Surges	Surges	Environmental Regulation	Vegetation and Conveyance
4	Infrastructure Impacts	Buildings and Contents	Surges	Social Impacts
5	Buildings and Contents	Coastal Morphology and Sediment Supply	Precipitation	Precipitation
6	Coastal Morphology and Sediment Supply	Social Impacts	River Morphology and Sediment Supply	River Morphology and Sediment Supply
7	Waves	Precipitation	Coastal Morphology and Sediment Supply	Buildings and Contents
8	Precipitation	Urbanisation	Waves	Infrastructure Impacts
9	Stakeholder Behaviour	Waves	Vegetation and Conveyance	Coastal Morphology and Sediment Supply
10	Urbanisation	Urban Impacts	Urban Impacts	Surges
11	Urban Impacts	Rural Land Management	Temperature	Urban Impacts
12	Rural Land Management	Vegetation and Conveyance	Agriculture Impacts	Waves
13	River Morphology and Sediment Supply	Environmental Regulation	Infrastructure Impacts	Temperature
14	Vegetation and Conveyance	River Morphology and Sediment Supply	Buildings and Contents	Agriculture Impacts
15	Temperature	Temperature	Urbanisation	Rural Land Management
16	Agriculture Impacts	Agriculture Impacts	Rural Land Management	Urbanisation
17	Environmental Regulation	Stakeholder Behaviour	Stakeholder Behaviour	Stakeholder Behaviour
	Science and Technology – known to be important but not quantified			
	Public Attitudes and Expectations – known to be important but not quantified			

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

2.5 Flooding outside the Indicative Floodplain

While the foregoing analysis considers catchment-scale flooding, it does not consider explicitly the mechanisms and importance of flooding outside river and coastal floodplains. These issues are considered in this section.

2.5.1 Evaluating the amount of flooding outside the floodplain

Indicative Floodplain Maps, published by the Environment Agency and the Scottish Environment Protection Agency, provide an indication of areas at risk from river and coastal floods. New flood maps, using better data and modelling tools, are in preparation for England, Wales and Scotland.

In this study, information was compiled from official reports of the Autumn 2000 flood (Environment Agency 2001) and from the insurance industry concerning the number of properties that flooded and the number of flood insurance claims that arose *outside* the areas on the Indicative Floodplain Maps. The findings revealed wide discrepancies.

- Postcode analysis suggesting that only 1% of the properties reported by the Environment Agency as flooded in Autumn 2000 or the subject of insurance claims lay in postcode districts entirely outside the Indicative Floodplain.
- According to the Environment Agency (2001), the total number of properties flooded in Autumn 2000 due to ‘non-river’ causes was 709 out of 5,085 (14%). This figure understates the problem in that it is based only on locations where more than 20 properties were flooded. On the other hand, the Autumn 2000 floods were of a pluvial nature, often not involving large-scale river flooding, which would tend to produce a greater proportion of non-river flooding than the average.
- Anecdotal evidence from the insurance industry suggested that up to 40% of claims made to them were for properties outside the indicative floodplain. Research indicates that many of these claims may relate to flooding from smaller watercourses that feed into the river system. As the rivers flood, all watercourses (including culverts and small streams) leading into them ‘back up’ and flooding then happens in areas not included in the indicative floodplain maps. This would be consistent with the findings of the postcode analysis.

2.5.2 The mechanisms of flooding outside the floodplain

A limited assessment has been undertaken of the mechanisms or pathways of flooding outside the Indicative Floodplain and this is described in Appendix C. Although it was impossible to quantify the drivers and future risks, the assessment follows the headings established for the qualitative driver investigations reported elsewhere in this report.

A number of pathways were identified for flooding outside the Indicative Floodplain:

- Reported flooding adjacent to indicative floodplains, associated with errors in the maps or when water levels exceeded those used to define the floodplain or associated with the flooding or backing up of minor watercourses.
- Flooding associated with high groundwater levels in the vicinity of aquifer outcrops.
- ‘Muddy floods’ where direct runoff from adjacent fields, commonly accompanied by soil erosion, causes severe flooding (e.g. as in the South Downs, Sussex).
- Failure of small-scale infrastructure (e.g. ponds, bunds) during extreme rainfall events.
- Flooding associated with larger-scale infrastructure such as the canal network and ordinary watercourses and which is variably defined as floodplain flooding in some situations, but not in others.

2.5.3 Flooding outside the floodplain: assessment

This brief analysis shows that there is a complex variety of causes of flooding outside the Indicative Floodplain and large discrepancies in estimates of the magnitude of the risk. This has particular implications for the quantitative analysis of flood risk undertaken in this project, which applies only to areas within the indicative floodplain. Much more work needs to be done to clarify the facts and causes.

2.6 Transport implications of future flood risks

The above ranking of the drivers was based on estimates of future flood risk based on economic, social and health damages caused directly by flooding. However, flooding can also have additional indirect consequences – some of which can be considerable and long-lasting. This section explores one of those: consequences of disruption to the transport infrastructure.

Present-day and future systems of transport and telecommunications exist to provide connectivity and hence access between people, goods, services and opportunities. These systems are essential to economic and social well-being in the UK. There is growing importance attached to understanding and managing how these systems are operated and used. However, it will remain the case that transport and telecommunications systems and, in turn, their users, are heavily dependent on the systems' infrastructure – which in turn is vulnerable to evolving flood risks.

The set of transport modes available in the UK, and their infrastructures for the movement of people, goods and information, has seen significant developments over the last century. In the past 50 years, movement of goods by road (tonne-km) has increased dramatically, as has movement of people (passenger-km) by car and latterly by air. In the last decade, we have witnessed the rapid adoption of the Internet as a means of attaining *virtual* mobility. Significant future expansion of road and rail infrastructure in the UK is unlikely for reasons of cost and land availability coupled with the encumbrances of UK and EU legal systems. However, pressure for domestic-air-travel growth has the potential to lead to an increase in the number and size of airports, with requisite investment in strategic improvements to surface access. Telecommunications infrastructure is likely to see substantial growth in extent and use.

The extent of UK society's dependence on motorised mobility was highlighted by the September 2000 fuel crisis. Though the episode was only short-lived, it exposed the vulnerability of supply chains to disruption, notably affecting food and healthcare. For example, there was an instance during the fuel crisis of surgical operations being halted for lack of hypodermic needles, due to a shortage of high-grade packaging materials which, in turn, was due to staff absences at the plant manufacturing the packaging material. In general, however, individuals exhibited more versatility by using alternative means of travel, choosing not to travel or using telecommunications alternatives.

In the absence of the imposition of extensive restraint measures, UK reliance on and use of motorised mobility across the range of journey lengths will continue unabated over the next 30-100 years and in the face of a growing reliance, in parallel, on virtual mobility. Disruption through flood risk to the infrastructures supporting these forms of mobility could be serious or even catastrophic. Crucial to the severity of impact associated with transport and telecommunications systems will be their collective resilience to damage. The term 'collective' refers to their ability as a set of systems to maintain acceptable levels of connectivity for the movement of people, goods and information in the face of partial damage. The September 2000 fuel crisis emphasised that even temporary disruptions of modest duration (a few days) to communications networks can have serious impacts and knock-on effects.

The Internet's genesis, in the context of the defence sector, stemmed from achieving resilience to damage. Such resilience, notwithstanding electrical failure due to flooding, of telecommunications nationally and regionally is likely to grow rather than diminish. Moreover, while the connectivity of the road network has increased in the past 50 years, parts of both local road networks and the strategic road network still offer only limited rerouting options (this is also true for rail). For example, a large flood on one of our main rivers seriously damaging a motorway or mainline railway bridge would effectively cut off parts of the UK from the rest for surface access, with serious and sustained consequences. With a growing dependence on domestic air travel, serious or sustained damage to a regional airport also has an increasing likelihood of severe impact.

A brief commentary on the transport aspects of each of the future scenarios under consideration is as follows:

- *World Markets:* consumerist values and materialist social values will result in high levels of consumption and mobility. Dependence on communications infrastructures will be high. In turn, flood consequences will be high, thereby increasing flood risk.
- *National Enterprise:* economic growth is slower. Transport infrastructure maintenance and renewal is consequently more limited, resulting in a system that is more overloaded and unreliable than in the World Markets scenario. Goods movement is heavily dependent on the road network. The system is therefore more vulnerable to serious disruption with the effect of increasing flood risk.

- *Local Stewardship:* regionalisation prevails, with the flow of culture, people, capital, goods and services across economic and political boundaries being constrained. There is lower demand for mobility and an emphasis on avoiding the need to travel. There is also an emphasis on switching to greater use of non-motorised modes in the face of a planning system working to move facilities closer to where people live. The impacts of flooding are likely to be much more localised and contained in this scenario, with a more limited contribution of transport to flood risk.
- *Global Sustainability:* the transport and communications systems will have evolved with the twin goals of providing high-quality access and low environmental impact. Goods movement will have shifted towards rail and water (use of coastal shipping and inland waterways) with lower relative growth in the movement of goods by road and air. Virtual mobility will play a major role in providing connectivity alongside physical mobility. With the use of communications networks in this scenario being more versatile, susceptibility to significant disruption will again be more limited.

2.7 Extreme events

Much of the analysis in this chapter has focused on well-established drivers of flooding in the UK. However, there are other events which have a much lower probability of occurrence, but whose impact, if they should occur, could be considerable. Table 2.7 illustrates some of those potential events and discusses their mechanisms and their consequences.

In addition to these extreme events, we must not forget the possibility of a repetition of a major event such as the 1953 flood. In this case, a storm surge overcame the defences (which were not in a good condition at that time) along the east coast of England, flooding 600 square kilometres and taking over 300 lives. Such events lie somewhat between the 'normal' events (that flood management usually addresses) and the extreme events in Table 2.7. We call such intermediate events 'extreme normal events'. Such an event – with climate change and greater economic and societal vulnerability and with higher water levels overtopping and breaching the defences once again – could cause long-term regional damage and disruption to health, infrastructure and economic activity. We assess the potential impacts of 'extreme normal events' in Section 4.6 of Chapter 4.

Table 2.7 **Extreme events – mechanisms and consequences**

Extreme event	Description/cause	Flood risk impact
Tsunami	Huge floodwave (often termed a 'tidal wave' in popular press), caused by: Massive seismic/volcanically-induced landslide in the Canary Islands or along the Norwegian coast. Meteorite impact in ocean/sea.	Wave perhaps over 100m high sweeps inland to cause widespread, devastating inundation of coastal areas and their hinterlands.
Climate regime shift	Radical change in the long-term UK climate associated with a change in the general circulation of the atmosphere. Could be caused by: Change in North Atlantic Oscillation. Effects of methane-hydrates, released from ice melt. Mega volcano – dust driven climate change.	Climate change alters flood risk in a manner not predictable based on current climate models.
Ice age	Return to 'ice age' conditions in northern Europe due to collapse of the thermo-haline circulation in the North Atlantic.	Alteration of flood-risk environment to something resembling Canada or Iceland.
Excessive sea level rise	Sea-level rise greater than predicted due to collapse of West Antarctic ice sheet.	Permanent inundation of low-lying coasts, increased coastal flood risk more generally.
Invasion by exotic vegetation	Watercourses and floodways choked by exotic or mutant plants similar to Japanese Knotweed or Canadian Balsam.	Vegetation overwhelms maintenance capabilities and controls to massively reduce flood conveyance.
River metamorphosis	Changes in climate and/or catchment runoff trigger rapid morphological responses. For example, large lowland rivers such as Trent and Severn switch from meandering to braided pattern silting beds and destroying flood-defence infrastructure.	Flood risk along rivers increases due to loss of conveyance and destruction of flood defences. Large areas of floodplain eroded and riverside settlements abandoned.
Environmental health	Environmental and public health risks associated with floods increase markedly due to: Increased levels of water-borne parasites (e.g. cryptosporidium, e-coli); Deposition of contaminated sediments (especially eroded from mining waste/soils containing lead, cadmium, zinc etc.).	Health dimension of flood risk increases disproportionately, requiring new and radical approaches to public health provision and responses to flood events.