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Appendix A

Driver descriptions – catchment and coastal

Chapter 2 identified the 19 most important drivers of future flood risk at catchment and coastal scales. These drivers were identified and grouped into six sets and are listed below. In the parlance of the Source-Pathway-Receptor model outlined in Chapter 1, the drivers relate to changes in the *sources* of flooding (e.g. precipitation), changes which affect the *pathways* whereby water flows across the landscape (e.g. morphology, regulation), and changes to the *receptors* of flooding (e.g. buildings and people).

This appendix provides the following information for each of the drivers:

- A description of the driver and how it affects intra-urban flood risk.
- Its interaction with other drivers.
- Its influence on flood risk.
- Uncertainty associated with the driver.
- Case examples where appropriate.

Further descriptions of the drivers (in still more detail) may also be found in the supporting technical documentation for the Foresight Flood and Coastal Defence project.

Table A1 **Drivers of future flood risk – catchment and coastal**

Driver group	Driver	Type
Climate change	**A1: Precipitation**	**Source**
	A2: Temperature	**Source**
Catchment runoff	**A3: Urbanisation**	**Pathway**
	A4: Rural Land Management	**Pathway**
	A5: Agricultural Impacts	**Receptor**
Fluvial processes	**A6: Environmental Regulation**	**Pathway**
	A7: River Morphology and Sediment Supply	**Pathway**
	A8: River Vegetation and Conveyance	**Pathway**
Coastal processes	**A9: Waves**	**Source**
	A10: Surges	**Source**
	A11: Relative Sea-Level Rise	**Source**
	A12: Coastal Morphology and Sediment Supply	**Pathway**
Human behaviour	**A13: Stakeholder Behaviour**	**Pathway**
	A14: Public Attitudes and Expectations	**Receptor**
Socioeconomics	**A15: Buildings and Contents**	**Receptor**
	A16: Urban Impacts	**Receptor**
	A17: Infrastructure Impacts	**Receptor**
	A18: Social Impacts	**Receptor**
	A19: Science and Technology	**Receptor**

Driver

A1: Precipitation

Driver group: Climate change
Type: Source

Definition and operation

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

Nowhere is flooding a simple linear response to precipitation. We understand how precipitation is translated into river flow through modelling the hydrological runoff of rainfall. Modelling also helps us to understand how changes in all aspects of precipitation – amount, intensity, duration, location and clustering – will affect the flooding system.

Increases in rainfall at all scales will clearly increase the risk of flooding to a greater or lesser extent. However, decreases in average rainfall could increase flood risk if increases in the intensity or clustering of events accompany the mean decrease. (Both these scenarios are suggested within UKCIP02, the environmental scenarios from UKCIP, the UK Climate Impacts Programme.)

Catchments differ in how they respond to precipitation events. Smaller, steep-sided or flashy catchments – where geological or land-cover characteristics make them particularly responsive – are sensitive to changes in short-duration rainfall. Larger and rural catchments, or those with a large element of groundwater storage, flood as precipitation accumulates over longer periods.

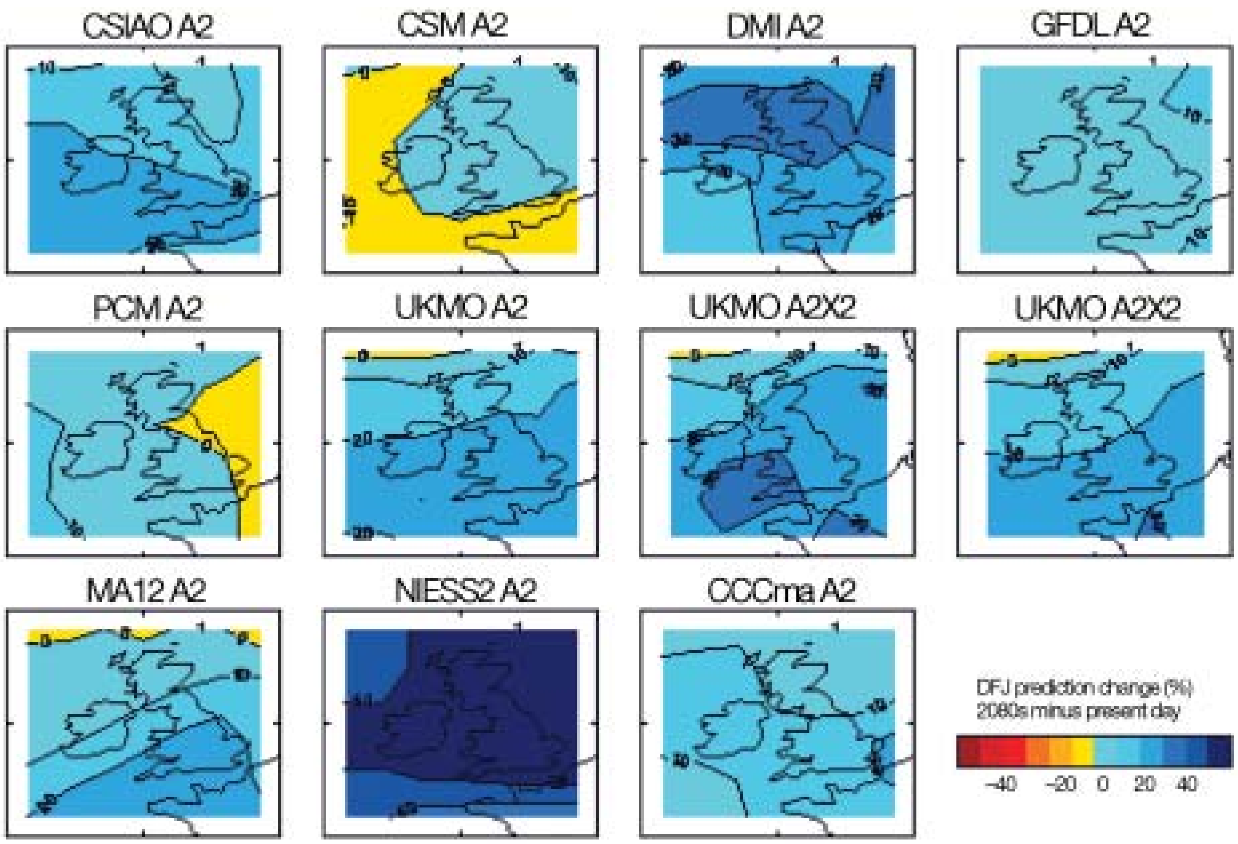
Annual and seasonal changes

The latest scenarios from the UKCIP suggest that the UK's annual rainfall will decrease by between 0 and 15% by the end of the century, depending on location and the scenario for future greenhouse gas emission (Hulme *et al*. 2002). UKCIP02 suggests that winters will become wetter and summers drier, with the greatest accentuation in the seasonal cycle in the south and east.

Long-duration rainfall

Extreme rainfall of long duration caused many of the recent severe flood events, such as the Autumn 2000 flooding (see case example). The UKCIP02 scenarios show mean winter precipitation increasing for most of the UK, typically by 20 to 30% by the end of the century, suggesting that extreme long-duration rainfall during winter might also become more frequent.

Figure A1 **Change in winter precipitation for the UK as simulated by nine general circulation models (adapted from Hulme *et al*. (2002) and IPCC (2001a))**



Short-duration rainfall

For the summer, the UKCIP02 forecast shows extreme rainfall reducing along with the mean rainfall for most of the UK. Some regions still experience an increase, however, and there is new evidence that such increases in extreme rainfall, in spite of mean seasonal reductions, could be more widespread and significant (Christensen and Christensen, 2003).

Interactions with other drivers

The Precipitation driver interacts with the Temperature driver, which determines whether precipitation occurs as snow or rain.

Precipitation also interacts with the driver groups Fluvial processes and Catchment runoff, particularly through the Rural Land Management and Urbanisation drivers.

Estimating the effects of change in precipitation on flood risk

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

Table A2 **Changes in precipitation for World Markets scenario**

Driver	Change in precipitation	
	2050s	2080s
Annual precipitation	-5%	-8%
Winter precipitation	15%	25%
Summer precipitation	-30%	-50%
Rainfall intensity – winter	12%	20%
Rainfall intensity – summer	-18%	-26%
Temporal sequencing	6%	12%
Snow	-40%	-80%
Soil moisture – summer	-20%	-40%
Spatial extent – with an increase in the number of winter storms, more of the rain will fall in larger-scale frontal-type events.	Increase	Increase

Case example

Assessment of the impact of climate change on large catchments

Table A3 **Percentage change in the peak daily discharge for a given return period under the GGx scenarios (2050s) for the Severn and Thames (Reynard *et al.* 1999; CEH 2000; Prudhomme *et al.* 2001)**

	Severn				Thames			
Scenario	**5-year**	**10-year**	**20-year**	**50-year**	**5-year**	**10-year**	**20-year**	**50-year**
GGx	14.7	16.3	17.3	19.8	10.7	12.2	13.7	15.7
GGx-c	6.2	6.6	6.7	6.9	5.0	4.5	3.9	3.2
GGx-e	16.5	17.9	19.3	21.2	13.2	14.1	14.9	15.9
GGx-p	16.6	18.6	20.7	23.6	15.5	17.0	18.5	20.5
GGx-t	7.0	7.1	6.9	6.3	2.7	3.7	4.7	5.7
GGx-u	23.7	25.0	26.4	28.2	34.1	37.6	41.5	47.0

Uncertainty

Potential changes in rainfall over the next 100 years are more uncertain than other climate variables, such as temperature. Scenarios derived from different general circulation models (GCMs) produce not only different changes in precipitation levels, but also changes in different directions (see Figure A1 (Hulme *et al.* 2002; IPCC 2001a)). There are also degrees of uncertainty depending on what aspect of the rainfall regime is being investigated.

Driver

A2: Temperature

Driver group: Climate change
Type: Source

Definition and operation

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

Scenarios suggest that climate change induced by human activity will increase average annual temperatures across the UK by between 2ºC and 3.5ºC by the 2080s (Hulme *et al.* 2002). The increases will be generally higher in the south and east of the country, and during the summer and autumn. As with all climate variables, there will be changes to the annual, seasonal, daily and sub-daily temperatures.

An increase in temperature will influence flood risk in several indirect ways. In addition to any temperature effects related to the Precipitation driver, Temperature directly affects whether precipitation falls as rain or as snow. However, the most significant impact of temperature on flood risk could be through its impact on evaporation, and hence the soil's moisture content and the amount of water available for runoff production.

Rainfall

A warmer world will change the rainfall regime. Maximum summer temperatures will increase, as well as annual averages. The scenarios in UKCIP02 suggest that, under the high-emissions scenario, in southern England an 'extremely warm' summer day in the 2080s might be 7ºC higher than at present. Put another way, the high temperatures recorded during the summer of 1995 (about 3.5ºC above normal) may occur in three years out of five during the 2080s. This could mean that a more direct effect of climate change might be an increase in the occurrence of short-duration, high-intensity convective summer storms.

The maximum amount of water the atmosphere can hold rises exponentially with temperature. Thus warmer temperatures would increase the amount of water vapour in the atmosphere, leading to the possibility of greater extreme rainfall.

Higher average temperatures will affect the type of precipitation, reducing the amount of snow. However, a more direct impact of elevated temperatures on flooding will be to reduce areas of significant snow cover for long periods of the winter. This snow contributes to spring flows as it melts. Increased temperatures therefore imply fewer snowmelt floods and a possibility of an increased incidence of winter floods induced by rainfall in upland catchments.

Evaporation

While Precipitation is the key driver for flooding, it is the effective rainfall, after allowing for evaporation, that contributes to runoff. Evaporation rates are determined primarily by temperature, along with solar radiation, wind speed and humidity. The predicted changes in these variables lead to increased evaporative losses.

Increasing temperatures, particularly during the summer will, drive up evaporative losses. It is predicted that while the absolute amount of water in the air will increase, the relative humidity will decrease during the summer, thus allowing more evaporation. Cloud cover in the summer and autumn may decrease, increasing summer sunshine and solar radiation. Wind-speed changes are notoriously difficult to predict, but indications are that they will change little.

The changes in potential evaporation will increase evaporation across the entire UK during every month. During the summer in the south and east of the country, these increases might be as large as 60% under the High-emissions scenario of UKCIP02. However, annual changes range from 20% in the north to 55% in the south.

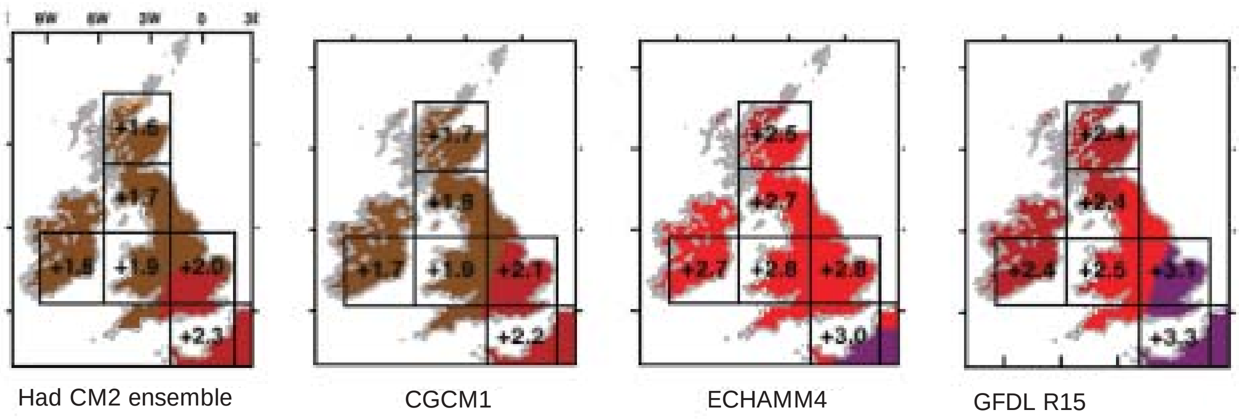
With high emissions of greenhouse gases, these evaporation rates could reduce soil moisture by up to 40% by the 2080s. This increased drying will have two impacts on flood risk: during the summer, dry baked soil is a more efficient surface for rapid runoff during storms; an extended dry season will increase soil-moisture deficits that need replenishing before effective winter runoff, or groundwater recharge, can begin. This suggests a shorter window for winter flooding, particularly for larger or slow-responding catchments.

Losses in potential evaporation also include transpiration from plants (see driver River Vegetation and Conveyance). A direct impact of temperature is the potential change in growing season and with the possibility of crop growth for 11 or 12 months of the year, potential evaporation rates will increase still further.

Importance and uncertainty

Temperature is an important driver in the sense that it interacts with other climate variables. For example, temperature changes will directly affect rainfall and potential evaporation, which then change future flood risk. In this sense it is less important as a driver than either precipitation or potential evaporation.

Figure A2 **Change in annual average temperature by the 2050s, as simulated by four general circulation models. While there is some disagreement on the magnitude of the change, all point to increases in temperature**



The uncertainties described for the Precipitation driver are equally relevant for the Temperature driver. However, predictions for temperature change are regarded as more certain than for other variables, such as precipitation. This confidence derives from a more convergent view for temperature changes than for other variables from the various climate-modelling groups around the world. While there is some disagreement between models for change in annual average temperature by the 2050s, all point to increases in temperature for the UK (see Figure A2).

Driver

A3: Urbanisation

Driver group: Catchment runoff
Type: Pathway

Definition and operation

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

At one extreme, Urbanisation creates low retention and rapid runoff of water. Typically 70% of precipitation can become runoff. At the other extreme, natural forestry and wetlands retain water for much longer. The focus here is on the built environment.

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

Runoff from impermeable areas normally bypasses the soil, reducing groundwater recharge and river flows beyond the precipitation period. However, greater runoff from impermeable areas can increase discharges of secondary water from sewage treatment works, septic tanks and leaking supply pipes which may offset low flows into rivers.

Management of urban drainage systems can control runoff and its effects. Flood detention reservoirs, or temporary storage in the piped network of sewage systems, can retain potential floodwaters. Other techniques, such as soakaways and permeable pavements, seek to restore natural infiltration into the soil and to reduce water entry to the piped sewer system.

In addition, the location of urban development within a catchment can affect the hydrological impact: mitigation strategies should taken this into account. For example, increasing channel capacity through an urban area to take floodwater downstream, which has been implemented in at least one major UK river, risks aggravating the flood risk downstream. A preferable strategy might be to retain flows upstream until the downstream floodwater has been discharged.

Urban development on floodplains is an important component of the Urbanisation driver. It increases runoff, reduces available storage and impedes conveyance. Flood-defence schemes to protect urban areas in floodplains may transfer the flood risk elsewhere.

Interactions with other drivers

There are strong links between Urbanisation as a driver of flood risk and socioeconomic drivers, which determine the rate and type of urbanisation. Socioeconomic drivers also influence the design and operation of urban infrastructure, especially flood management and drainage systems. The Urbanisation driver is strongly associated with flood management, especially regarding the design of flood-control solutions and the regulation of floodplain development.

There is also a strong link between urban areas as pathways and receptors, particularly with respect to non-fluvial flooding and storm (and sewage) water surcharge. Urbanisation as a pathway, and a potential receptor, is strongly linked with rural land as a receptor, with the latter often used for sacrificial storage. Climate change can increase the risk of runoff in urban areas in the absence of mitigation measures.

Case examples

The impact of urbanisation on flood depends on a catchment's characteristics. An example calculation for a small 19 km^2 catchment in north-west England, based on UK practice (Hall *et al.* 1993), shows that development of 48% of the catchment could double the mean annual flood. However, impacts can be much greater, particularly for catchments on permeable ground. The effects, however, tend to decrease with increasing severity of rainfall event when land use as a whole has reduced impact on runoff and flood risk.

Flood seasonality may also change (Institute of Hydrology 1999). Rural catchments typically have major floods associated with wet conditions in winter. In contrast, summer thunderstorms with high rainfall intensity may be more critical for urban areas.

The Windsor and Maidenhead flood relief scheme for the River Thames, which opened in 2002, is an instructive example of floodplain development and its impacts. Progressive housing development on the floodplain at Maidenhead, against hydrological advice, eventually created the situation where the potential costs of flooding justified flood-protection measures. A parallel channel to the main River Thames was constructed. While this worked effectively in the floods of winter 2002/3, downstream residents are concerned that the operation of the channel and the loss of floodplain storage could increase flood risk for them.

Driver changes and flood risk

The rate and type of urbanisation varies under different scenarios from the Foresight Futures, as does the design and implementation of urban water-management systems.

The utilitarian futures of World Markets and National Enterprise are associated with increased urbanisation, weak regulation and considerable pressure on floodplain development. High to medium impacts on climate change exacerbate flooding problems.

The conservationist scenarios of Global Sustainability and Local Stewardship place greater emphasis on sustainable urban development and design, and have strong regulatory systems. They promote sustainable urban drainage, rainwater harvesting for individual properties, and recycling of 'grey water'. In the Global Sustainability scenario there is more integrated management of water quantity and quality in urban water systems, including the reduction of uncontrolled overflows of stormwater from sewers into rivers under storm conditions. Catchment-scale impacts of development will depend on the detail of urban water, and particularly stormwater management, which vary among scenarios.

Importance and uncertainty

There is considerable uncertainty surrounding pluvial flooding in urban areas. Storm sewers are often designed to accommodate only a two- to three-year event. The relationship between this criterion and the frequency of surface flooding is variable and poorly understood. There are no adequate techniques to simulate urban flooding (Wheater 2002). However, storm drainage systems have very limited capacity to accommodate extreme events.

Urban development can have a large local impact on flood response. Increased runoff volume and reduced travel time could easily increase flood peaks by several hundred percent. At large catchment scale, however, the importance in terms of runoff generation is less clear. For example, historical analysis of Thames flows (CEH 2000) shows no detectable effects of 30 years of urban development. This is attributed to the fact that urban development has been accompanied by engineered solutions, such as detention storage ponds, to the relatively small proportion of the catchment which is urban, and to effects of heterogeneity at catchment scale.

Native parameter

The indicators used to represent this driver are the relative proportion of the total catchment area that is urban land use and the adoption of stormwater management within urban areas. The effects of urbanisation will vary according to scale. Local management of storm water can help to mitigate flooding, but mostly at a local scale.

Recommendations for research

The effects of urbanisation are well known in principle. Regional analysis has characterised these risks for the UK at small catchment scale, albeit relatively crudely (NERC 1975; Institute of Hydrology 1999). However, there are two important methodological gaps. First, we need tools to simulate urban flooding at local, street, scale, and thereby design appropriate mitigation measures. Second, we need for tools to represent the impact of urbanisation at the catchment-scale. These have been identified as research priorities by the research consortium on Flood Risk Management set up by Defra, the Environment Agency and the EPSRC.

Driver

A4: Rural Land Management

Driver group: Catchment runoff
Type: Pathway

Definition and operation

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

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

Runoff from rural land is associated with soil type, land use, the adoption of land-management practices that induce or mitigate runoff, and location within the catchment, whether upland or lowland (and related topography). Generally, the risk of runoff is greater where hill slopes are steeper, soils less permeable, land use more intensive and there are no measures to control runoff.

Runoff pathways range from rapid overland flow to slow groundwater discharge. The functions of surface and sub-surface pathways depend on topography, soils, vegetation and such interventions as cultivation and drainage. Thus the management of rural land can have major effects on the volume, pathways and timing of floodwater runoff. The current level of soil moisture also influences surface runoff, and this depends on evaporation, which in turn is also determined by land surface conditions and processes. In the floodplain, land management influences the storage and conveyance of floodwater.

Interactions with other drivers

There are strong interactions with agricultural and rural land as a receptor. Pathway and receptor functions often overlap.

The generation of flood risk in rural areas is strongly influenced by socioeconomic factors, especially the motivation of land managers, land tenure and prevailing agricultural and environmental policy (Boardman *et al.* 2003b).

Rural Land use has strong links with flood management drivers. It defines standards of flood defence for agriculture as well as the choice of methods to manage flood risk from rural land, whether by regulation or economic incentive. There are strong links between land use and fluvial processes, especially sedimentation associated with runoff, and with localised coastal and estuary processes.

Case examples

Agricultural policy and economic incentives have led to important changes in land management, with concerns for impacts on the local environment and flooding. An increase in excess overland flow of water has been associated with conversion of grassland to arable cropping, and increased stocking rates of grazing animals (Evans 1996, Defra, 2003). Anecdotal evidence, largely from England, suggests that soils are becoming less permeable through a combination of surface capping and top-soil compaction. As a consequence, the response of rivers to rainfall events is becoming more rapid in intensively farmed areas.

In the case of upland land management and grazing, a ‘grass-roots’ initiative at Pontbren in Wales involves 10 hill farms and over 1,000 ha of agriculturally improved pasture, along with areas of semi-natural land and woodland. The area has a silvopastoral system – forested buffer strips provide animal shelter, timber and woodchip for livestock bedding and protection for watercourses. Experimental studies indicate infiltration rates close to zero for grazed pasture in comparison with 100 cm/hour in wooded areas (Bird *et al.* 2003). This suggests that current grazing patterns seriously affect runoff, and that management interventions can rapidly reduce this impact.

Some arable agricultural systems pose particular problems for soil structure, mainly due to limited vegetative cover for soils at particular times and the use of heavy machinery on the land when it is wet. These systems include autumn-sown crops such as cereals and late-harvested crops such as potatoes, sugar beet and field vegetables (Holman *et al*, 2000). Field trials of maize crops, for example, show that soil compaction can greatly increase runoff, particularly on normally free-draining soils (Smith 2003). In some cases, land kept fallow under temporary set-aside has led to increased runoff.

Experimental studies have provided a good understanding of the qualitative impacts of agricultural drainage on flooding (Robinson 1990, Robinson and Rycroft 1999). For heavy clay soils, agricultural drainage reduces surface runoff and hence the risk of flooding. Conversely, for more permeable soils, sub-surface drainage can increase flood risk by reducing the time it takes for water to pass through the soil to a watercourse. Flood risk depends strongly on the combination of soils, drainage systems, storm rainfall and antecedent conditions such as soil wetness.

Although we can expect afforestation to reduce catchment runoff in the long term, due to increased evaporation, this effect depends strongly on climate. Experimental research at Coalburn in northern England, however, has shown that drainage practices previously used to establish forests in the UK uplands can increase storm runoff in the short and medium term (Robinson 1986). The likely effects of broadleaf afforestation are unclear. Current studies from southern England (Black Wood, Hants) and the Midlands suggest opposing effects on evaporation, soil moisture and runoff.

Driver changes and flood risk

Rural land use varies between Foresight Futures. For example, under the World Markets scenario, agriculture is characterised by internationally competitive, large-scale farming with an increased risk of runoff in intensively farmed areas, although some marginal land, including uplands, is no longer worth farming. Global Sustainability, requires farmers to comply with good practice to reduce runoff. National Enterprise gives priority to farming, with guidance on best practice. Local Stewardship involves relatively extensive, small-scale farming, with an intrinsic concern for soil and water conservation. Thus the risk of flood generation differs under each scenario, as do the strategies and policies to manage flood risk.

Uncertainty

Although there is much concern about the potential link between land management, runoff processes and flooding, the nature of these relationships remains uncertain. For example, a recent survey of soil degradation commissioned by the Environment Agency at the time of the Autumn 2000 floods reported extensive soil degradation, for example, in up to 33% of the land in the catchments studied (Holman *et al.* 2000). However, the research could only speculate on the effects at a catchment scale, suggesting an increase of 12% or greater in runoff volume.

There is unknown linkage between local, field-scale, effects and large catchment-scale impacts. Analysis of 30 years' change of land use on the Thames, for example, showed no discernable effects at large-catchment scale (Crooks *et al.* 2000). The impact of land-use practices will probably have a small effect on flood generation during extreme precipitation events, especially when these occur on already wet soils. They can, however, alleviate flood risk at a local level, especially when associated with 'muddy floods', which can result in significant local damage.

Recommendations for research

Recent reviews and consultation exercises highlighted land use and land management as priorities for research due to the perceived importance for flooding, the lack of an appropriate science base to quantify local effects and the lack of suitable modelling tools to support management on a catchment scale (Calver and Wheater 2002 EPSRC 2002 Defra 2003). There is, therefore, an urgent need to determine the link between rural land use and flood generation at the catchment scale, supported by computer models to connect land use with catchment hydrology. There is also a need to demonstrate the efficacy and practicability of intervention measures to reduce and retain runoff. Given the diffuse nature of land use and the influence of land tenure, research is required to determine factors influencing farmer motivation and their willingness to adopt on-farm soil- and water-conservation measures, as well as to design appropriate policy instruments to encourage best practice suited to local conditions.

Driver

A5: Agricultural Impacts

Driver group: Catchment runoff
Type: Pathway

Definition and operation

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

Intensive agriculture depends on protection against flooding and managed water regimes, typically by artificial land drainage. Generally, the higher the crop value, the greater the degree of flood defence and land drainage that is required and justified. Habitats also depend on water regimes and are sensitive to too little or too much water, as well as the quality of water. Seasonality and the duration of flooding are critical factors that affect the impact of flooding and waterlogging on agriculture and habitats.

Flood defence for agriculture, as for most land activities, refers to acceptable levels of flooding above and below the surface of the ground: waterlogging. Similarly, changes in flooding and ground-water levels can affect the type and quality of a wetland habitat in a location.

A change in flood risk can have three main types of impact on agricultural land at farm level:

- Reduction in the value of crop and livestock outputs due to damages or productivity losses associated with surface flooding and/or waterlogging.
- Increased costs to mitigate or defend against the risk of flood and waterlogging.
- Loss of value-added associated with a switch to less intensive, flood-tolerant land uses, for example, from arable to grassland.

From the perspective of the broader national economy, rather than the individual farmer, impacts depend on whether crops produced elsewhere in the country can replace crops lost due to flooding.

Interactions with other drivers

There is a strong link between agriculture as a pathway and as a receptor. The two often overlap. Increased urbanisation of a catchment can increase flood risk to farm land, possibly with the latter purposely managed for flood storage. There are very strong interactions with socioeconomic drivers, which define the motives of, and the incentives to, land managers, especially through agricultural and environmental policy.

The driver is strongly linked to climate change with its potential to modify patterns of land use as well as increase flood risk. There are also strong links with the management of fluvial processes, not only to provide flood protection for rural land but also to manage the storage and conveyance of flood water in rural areas to reduce the risk of urban flooding. There are strong potential links between farming and ecology in floodplains through the creation and management of wetlands.

Table A4 **Estimates of the cost of a single annual flood event occurring in any month of the year on different land classes and land use types (Penning-Rowsell *et al.* 2003). Flood costs on grassland are relatively small, especially if flooding occurs in winter.**

Land Class		Land use					Average Flood Cost £/ha/yr
		Horticulture	Intensive Arable	Extensive Arable	Intensive Grass	Extensive Grass	
1	% of area	5%	85%	10%			
	Flood cost (£)	4800	1030	450			**1161**
2	% of area	5%	60%	35%			
	Flood cost (£)	3080	780	433			**774**
3a	% of area		30%	70%			
	Flood cost (£)		530	350			**404**
3b	% of area			50%	50%		
	Flood cost (£)			270	50		**160**
4	% of area				100%		
	Flood cost (£)				45		**45**
5	% of area					100%	
	Flood cost (£)					20	**20**

Case examples

There is strong evidence that flood risk is a major determinant of the type of rural land use, but this is modified by incentives for land management. A review of 22 agricultural flood-defence schemes constructed between 1950 and 1980 confirmed the benefits to farmers, and to the nation at that time, associated with the conversion of grassland to arable farming, and the intensification of existing arable land (Morris 1992). The impact of flooding on agricultural land varies according to land class and land use (see Table A4). An example of this is the Beckingham Marsh Scheme on the River Trent in Nottinghamshire (see Figure A3).

Figure A3 **The Beckingham Marsh Scheme on the River Trent in Nottinghamshire was constructed in 1960 to provide flood-protection benefits to 1000 ha of agricultural land which supported conversion to arable production, as well as providing flood storage to help to protect Gainsborough. In recent years, in response to changing land-use priorities and incentives to land managers, half the area has been returned to grass, and negotiations are underway to create a wetland site operated under agri-environmental agreements, retaining the flood-storage facility.**

Driver changes and flood risk

Agricultural impacts vary between the Foresight Futures and their rural sector characteristics. For example, under the World Markets agriculture is characterised by large-scale intensive farming. The case for protection will depend mainly on economic criteria. Global Sustainability promotes integrated floodplain management through incentive to land managers. National Enterprise gives high levels of protection to agricultural land. Under Local Stewardship, agriculture operates in harmony with the natural environment. Nature conservation, including managed wetlands, is a key feature. Strategically important agricultural land is protected under all scenarios. Thus the impact of flooding under these scenarios will differ, as will the coping strategies and policy responses to changes in flood risk.

Uncertainty

Most uncertainty arises from links with other drivers, notably the impact of changes in the motives of land managers and changes in agricultural and rural policy. There is generally good understanding, based on empirical evidence and scientific research, of the impact of flooding on commercial agriculture. It is possible to prescribe the tolerances of crops to flooding and waterlogging, and the consequences for physical and financial productivity of increased exposure to flooding and waterlogging risks. There is an emerging but incomplete understanding of the water regime required by natural habitats. Hence there is some uncertainty about whether forms of agriculture that are flood tolerant and compatible with wetland can provide the basis for sustainable livelihoods.

Native parameter

The driver parameters reflect the likely cost of flood damage to agricultural land use. Flood-damage costs are strongly positively correlated with quality of agricultural land and actual land use. These qualitative indicators can be quantified in terms of estimated crop-damage costs for a given flood event. For persistent flooding there will be a reduction in the value of land itself.

Recommendations for research

There is a need to:

- Develop catchment-level protocols to assess the potential contribution of rural land to sustainable flood management, particularly its ability to deliver cost-effective, multi-purpose benefits.

- Determine and assess the efficacy of land-management regimes within receptor areas that can integrate flood management, agricultural systems and biodiversity.

- Develop land management, administration and funding mechanisms to support the implementation of such regimes.

- Determine the efficacy of policy options for land use, including the scope for policy integration, to achieve flood-management and other objectives.

Driver

A6: Environmental Regulation

Driver group: Fluvial systems and processes
Type: Pathway

Definition and operation

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

Environmental Regulation can affect a river channel's capacity to carry floodwaters, and hence the flood risk. It appears as a pathway, as well as a receptor, because it has a direct influence on other pathways.

Future decisions supporting increased biodiversity and habitat protection may restrict flood-management policy. The purpose of river management has now shifted from simple utilitarian needs associated with river-channel engineering for flood and erosion/sedimentation control towards the addition of a range of goals. Measures that were once optional, such as accommodating ecological concerns, are now obligatory.

As this purpose has changed, so the number of interest groups associated with the management process has increased. The Environment Agency now explicitly recognises that the river has multiple users and that the needs of all of these users must be integrated to identify an optimal solution for river management. This will be greatly promoted by the requirement of the European Water Framework Directive (WFD) to produce river-basin management plans for all major rivers in all member and candidate countries by 2010.

This policy change recognises that one of the clearly defined 'user groups' is now the river's fauna and flora, introducing a strongly environmental 'requirement'. This is also increasingly legislated – under the requirement of the UK's Habitat Regulations (1994), for example – to protect sites of nature conservation interest. This clearly makes the environment an important receptor. However, it is also an important pathway as decisions made about habitat and habitat protection may have important implications for river channel and floodplain conveyance (see the driver River Cegetation and Conveyance). Thus, this driver determines aspects of river and floodplain management that result in implications for river and floodplain conveyance.

Understanding the operation of this driver has three main aspects. First, it is necessary to consider a series of institutional and legislative changes that are changing the ease with which decisions over river and floodplain management can be based on reduction of flood conveyance alone. Second, these decisions affect aspects of river and floodplain morphology which in turn influence flood conveyance. Third, aspects of river morphology may also be affected by this driver, for example, the restoration of a meandering system, such as in the River Skerne, Darlington.

The legislative changes that will influence this driver are associated with both the EU, through the Habitats Directive and Water Framework Directive, for example, and the UK, through, for example, Catchment Flood Management Plans. For instance, the UK's Biodiversity Action Plan identifies five floodplain habitats as priority restoration targets – lowland raised bogs, fens, reedbeds, wet woodland and grazing marsh – and some 500 existing Sites of Special Scientific Interest which require high water levels to sustain their wildlife interest.

Under the EU's Water Framework Directive, the UK will need to develop River Basin Management Plans to meet environmental objectives for surface water, groundwater and protected areas. Each surface water body will have ecological and chemical quality objectives which will restrict the type of management activity – dredging for example – that can be adopted.

Interactions with other drivers

The driver Environmental Regulation is strongly linked with other drivers. Its main effects will not be on flood risk directly, but on the way in which other drivers operate. Habitat protection may influence our ability to manage river morphology and sediment supply and so control the ability to respond to sedimentation problems. There will be strong links to aquatic vegetation in relation to its control on in-stream habitat. It will also influence the type of land-management activities that are adopted in rural areas, and hence agriculture and rural land management. As a driver, it may be directly influenced by droughts and storms, for example, through the use of drought orders to constrain compensation flow releases downstream from dams, which may undermine habitat improvement schemes. Public attitudes and stakeholder behaviour – through environmental values, for example – may also strongly influence the driver. These determine what is and is not acceptable in terms of river and floodplain management.

Driver changes and flood risk

As a driver, Environmental Regulation will have an indirect influence on flood risk through its effects on the operation of other drivers. Its main impact will be on: the standard of protection, through controls on the ability to manage rivers in relation to conveyance; and rural land use and land management, in terms of schemes at the farm scale that may reduce or increase runoff generation and on-farm conveyance.

Depending on the nature of the legislation and where it is applied, the driver may either increase or reduce flood risk. For instance, regulations that protect in-stream aquatic habitats and that do not permit sediment dredging will increase the magnitude and frequency of flood flows. In urban areas, or adjacent to high-value agricultural land, this represents an increase in flood risk. However, if this happens alongside low-value agricultural land, perhaps as part of a river restoration, this may lead to flood storage, decreasing flood risk downstream. Thus, the effects of these regulations can only be properly appreciated in terms of how they fit into the flooding system at the catchment scale.

Uncertainty

This is the most uncertain pathway in this driver set. The problem with assessing the effects of these legislative changes on future flood risk is that they will strongly depend on geographical context. For instance, the need to restore wetland habitat could be connected to a programme of expanding floodplain storage to reduce downstream flood risk. However, other aspects of habitat protection may exacerbate flood risk by reducing the freedom that a river manager has to embark on flood-protection measures. These uncertainties are compounded by the fact that issues tend to be negotiated locally, with environmental benefits traded against other river functions. The type of future legislation will depend greatly upon the type of future envisaged.

Native parameter

The main native parameter will be the standard of protection, although the linkage to this parameter will be weak.

Recommendations for research

The main research needed in this area will be scenario-based analysis of how different regulations influence management processes and hence affect the river floodplain system. This will require coupled modelling tools that can include the range of parameters affected by this driver, as well as feedbacks between those parameters. This will need support from the appropriate social science, in terms of understanding regulatory reforms and how they affect river managers.

Driver

A7: River Morphology and Sediment Supply

Driver group: Fluvial systems and processes
Type: Pathway

Definition and operation

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

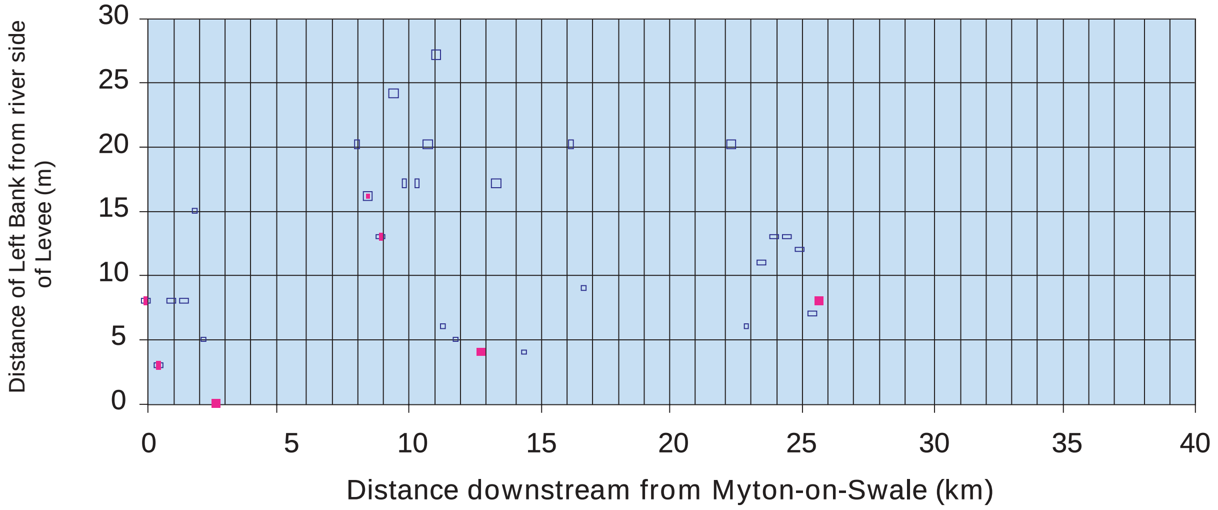
All river channels are very sensitive to the water flow that shapes and maintains the channel, known as the bankfull discharge. If climate change or land-use change increase how often the flow reaches the bankfull discharge, the natural response in the long term will be for the channel to become wider. The extent to which this happens depends on: the type of vegetation on the channel bank, with well-vegetated banks more resistant to erosion; and the level of riverbank protection.

In addition to changes in width, an increase in the frequency of bankfull discharge may also result in an increase in channel depth. This effect will be greater in channels with smaller bed material grain size.

In addition to changes in the discharge and sediment delivery within the river channel, there may also be changes on the floodplain. With water flowing over banks more often, there will more sediment deposited on the floodplain, especially if there is also an increase in the amount of sediment carried in the river flow. This, in turn, will alter the topography of the floodplain in the longer term.

Channel and floodplain changes resulting from morphological responses to changes in runoff and sediment supply may threaten the integrity of flood defences along the river (see Figure A4).

Figure A4 **Plot of distance of down the non-tidal Ouse against the distance of the river bank from flood defence infrastructure. Shaded data points are where severe erosion was recorded.**



Interactions with other drivers

There are very strong interactions with other drivers. These include:

- Environmental Regulation, as these determine the regulations that govern how river-floodplain systems are managed, whether or not they can be dredged, for example.
- River Vegetation and Conveyance, as the nature of the sediment boundary and the shape of the channel determine conveyance, as well as the type and habitat requirements of vegetation.
- Climate change (Precipitation and Temperature), especially through changes that are commonly viewed as channel forming discharges of 2 to 5-year return period and extreme events.
- Catchment runoff, especially changes in catchment sediment yield due to altered land-use or farming practices.

There may be additional influences from the Stakeholder Behaviour pathway, as this may influence perceptions about the environment, for example, the value of the aquatic habitat in a channel.

Finally, and crucially, in many parts of our river floodplain systems, there can be very strong interactions with coastal processes. It is possible that the drivers Waves, Surges and Relative Sea Level Rise have an important influence on morphology in tide dominated rivers. For instance, at Naburn, the transition between non-tidal and tidal flows, on the River Ouse in Yorkshire, there is a strong relationship between sea level and river flow that determines flood risk. Similarly, levels of transfer of fine sediment up-river from estuaries can be significant, especially when river flows are low, and which can lead to significant in-channel sedimentation.

Case example

The floods of November and December 2000 on the River Ouse and at Lewes in Sussex illustrate how severely an extreme discharge can erode river banks. In the UK, we do not undertake routine and systematic monitoring of bank-erosion rates. Most surveys of the erosion of river banks are one-off measurements, often conducted as part of a geomorphological audit or in response to particular erosion problems. There is no operational monitoring of bank erosion as there is for water quality, for instance. This can make it difficult to assess whether or not single extreme events are responsible for observed erosion problems. However, a geomorphological audit of the non-tidal and tidal Ouse in Yorkshire in February 2001 revealed widespread bank erosion on both sides of the river (see Figure A4). In some situations, there was severe erosion close enough to flood defences for undermining to be a possibility (see Figure A5).

Figure A5 **A geomorphological audit of the River Ouse in Yorkshire in February 2001 revealed widespread bank erosion on both sides of the river. This indicates channel widening in response to extreme flood events.**

Driver changes and flood risk

The impacts on flood risk associated with this River Morphology and Sediment Supply are highly uncertain. This is because of their dependence on the relative change in flow characteristics and sediment delivery, coupled with the characteristics of a river channel, for example, the geometry, perimeter sedimentology and vegetation, along the channel margins.

It is also difficult to generalise because the driver may affect two native parameters. Channel widening due to an increased frequency of bankfull flows, as we would expect under all Foresight scenarios due to changing rainfall patterns, is likely to increase bank erosion and hence, potentially, undermine defences. Such undermining will normally occur during extreme flow events, rather than during low-flow events. So the most likely impact on flood risk is a breach of defences where there has not been suitable protection against erosion.

Channel widening, and potentially deepening, in the absence of sediment supply, will increase channel capacity, increasing the probability that banks contain flows, so reducing overbank flow. However, if changing rainfall patterns and/or land management increase sediment delivery, with increased in-channel deposition, this may counter the tendency to increase channel capacity and may exacerbate lateral bank erosion, especially if coarse sediment deposits are involved.

Estuary processes, where river flow is affected by tidal activity, even if the flows are freshwater, can also play a part. The impacts on flood risk here can be severe as tidal water-level fluctuations, when combined with high river flows, may increase the frequency of bankfull flow events.

Uncertainty

Unfortunately, there is significant uncertainty associated with the driver River Morphology and Sediment Supply. This is most readily manifest in uncertainty commonly observed in relationships between discharge and sediment-transport rate.

The morphological response of a river reach depends on the interaction of water and sediment discharge. Such relationships vary geographically and through time. This is primarily because: sediment discharge is a threshold-dominated, non-linear delivery process; there is strong geographical variation in the extent to which sediment delivery is supply limited (or, *vice versa*, transport limited); and sediment discharge is highly dependent on other drivers, notably Rural Land Use Management. The practical application of existing, predictive equations can lead to different results according to what assumptions are made on the initial stability condition and which relationships are applied.

Native parameter

- Increases in channel width imply bank erosion which may erode into defences: that is, degradation of the condition of defences.

- Increases in river depth may increase channel capacity which may improve the standard of protection.

Recommendations for research

There are now good predictive models for the long-term behaviour of sediment in simple river systems. This behaviour is more complex for river networks, because of the complicating effects of sediment delivery by tributaries, and where sediment transfer is strongly coupled with lateral channel change and floodplain sediment storage. Similarly, while we know a lot about the mechanisms of sediment delivery to the drainage network, we know much less about their relative importance and sensitivity to climate change. Thus, the required research is analysis and modelling of the sediment-transfer process at the catchment scale and under different scenarios for climate and land management. There is also a serious need for a more systematic recording of river channel change as part of the operational management of river systems in response to climate and other drivers.

Driver

A8: River Vegetation and Conveyance

Driver group: Fluvial systems and processes
Type: Pathway

Definition and operation

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

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

Both vegetation and micro-morphology affect flood conveyance, in similar but different ways. First, both vegetation and micro-morphology reduce the effective volume of the channel that water can occupy, reducing the channel's capacity. Second, they both act as a source and a sink for fluctuations in the turbulent velocity of the water, which increases the effective drag on water flow.

These process interact to control water conveyance by the river channel. Floods result when the water level associated with a given discharge exceeds the height of local banks or defences. The water level associated with a given flow is determined by the conveyance, and is hence influenced by both vegetation and micro-morphology.

Vegetation reduces flood conveyance: we can represent this reduction through an increase in a hydraulic roughness parameter. Vegetation can have a far greater effect on conveyance than other components of roughness, such as bed material.

In general, an increase in vegetation should increase flood risk. Micro-morphology exists at scales smaller than the reach-scale. In addition to the skin friction associated with shear between the fluid and the channel bed, the roughness term is augmented, normally implicitly, to represent: the effects of aspects of channel geometry that are not represented explicitly as morphology, that is, as cross-sections; the effects of vertical and lateral components of mass and momentum flux on the downstream flux; and the effects of turbulent velocity fluctuations on the extraction of momentum from the mean flow, and its dissipation at smaller spatial scales.

In relation to future flood risk, micro-morphology is unlikely to have a particularly major impact. Micro-morphology, a natural consequence of the interactions between moving water and a mobile bed, is ubiquitous in most rivers. Increases in flow are unlikely to result in significant increases in surface variability, hence conveyance should not be affected greatly. Thus, the operation of this component of the driver is in terms of mediating how a given flow is transformed into a given water level. The nature of these relationships will probably not change, but understanding micro-morphology in order to specify those relationships will remain an important research goal.

Interactions with other drivers

These are strong and important. First, the amount of vegetation in a river is determined by a number of abiotic factors, notably temperature. For instance, the timing of vegetation growth and die-back depends upon the combination of light availability and water temperature. This can lead to variance of up to a month in which growth of vegetation begins, with warmer springs resulting in greater amounts of vegetation growth, and warmer autumns associated with vegetation surviving longer. Hence, there are strong links to climate change, and notably Temperature. There may be a weaker link with Precipitation. Lower river flows in summer may allow greater encroachment of vegetation into the river channel.

Micro-morphology and vegetation may be linked to the driver River Morphology and Sediment Supply, through a range of processes.

More extreme flow events may remove vegetation. Sediment delivery will change micro-morphology and may deliver sediment-bound nutrients for plants to take up. These linkages are complex and may be associated with both positive and negative feedback processes.

Both micro-morphology and vegetation are also associated with river-channel habitat, by creating a complex flow structure, environmental refugia, and the source of important components of the aquatic food chain.

The traditional engineering approach to the management of river vegetation focused on its removal. However, the growth of a more holistic approach to environmental management has questioned the extent to which this is sustainable. Thus, there will be strong links with Human Behaviour and Environmental Regulation drivers.

Driver changes and flood risk

The most likely change here is in the amount of vegetation in a river at the time of a major flood event. An increase in vegetation is likely to raise flood risk, with higher water levels associated with the impeded flow. The risks of this may be compounded by increases in the length of the growing season in a warmer world, and by summer low flows that make it easier for vegetation to establish itself. This is especially important if climate change also leads to an increase in spring or autumn flood risk. While this represents a reduction in the standard of protection, the extent to which this will occur is highly uncertain. It may be counterbalanced by the effects of extreme flowspon vegetation wash-out, which will increase the standard of protection.

Uncertainty

This driver is associated with uncertainty as, while the processes that link vegetation, micro-morphology and conveyance are well known, their manifestation in particular river contexts is much less certain and depends on other drivers, and notably the driver Environmental Regulation. Thus, it is difficult to assess how this driver links to the standard of protection. It depends on decisions about how the river corridor is managed.

The uncertainty surrounding this driver is reflected in the fact that there is considerable debate as to the role of roughness parameters in hydraulic models. There is limited confidence in how to estimate roughness, which emphasises the severe uncertainty that we have as to how to determine flood conveyance. There has been some progress in the past two years or so, with the development of a UK-specific roughness predictor.

It is difficult to represent changes in vegetative or micro-morphological roughness in a model as it is not simply a product of the characteristics of a particular river reach. In addition, there is very little research into the nature of vegetative dynamics within rivers in relation to climate change.

Native parameter

The native parameter is changes in the standard of protection as changes in conveyance determine the water level that results from a given discharge.

Recommendations for research

Further research is required into the way in which hydraulic models represent resistance and estimate conveyance, especially in relation to vegetation. However, if we are to understand how vegetation will respond to future climate change, it is more important to consider vegetation processes in rivers, and their links to abiotic and biotic processes.

Driver

A9: Waves

Driver group: Coastal processes
Type: Source

Definition and operation

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

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

Interactions with other drivers

Increasing sea levels allow waves to break nearer to the coast, causing more wave energy to reach the shoreline. This interacts with the driver Coastal Morphology and Sediment Supply.

There is some interaction between the different drivers. An increased sea level will add height to future surge levels and so will potentially increase the likelihood of flooding at some locations. This interaction will be amplified as the rise in sea-level increases.

While there may be effects on these extreme events, it could be that effects may not be as significant on normal conditions. For example, the JERICHO project, established to aid the Environment Agency in the development of its strategy for the coastal defence, aimed '…to provide improved information on coastal wave conditions…and to make progress towards a predictive capability'. Results from the project suggest that changes in sea level under the Medium-Low to High scenario of UKCIP02 will not have a significant effect on the nearshore wave height that is not beyond the observed range of natural variability (Futurecoast 2002).

Changes in the prevailing direction of major storm events could alter beach morphology and hence could significantly change the pattern of erosion and accretion around the coast. These changes will also become important at locations that presently benefit from protection from offshore features such as banks. While a feedback mechanism exists between seabed features and hydrodynamics (cf. Hulscher 1998), this feedback may maintain protection of the coastal area. In addition, if the sea level rises at a faster rate than the features can adjust, then they may become relict in terms of the protection they provide. Changes in these features may result in wave energy focusing on areas that are presently unprotected in terms of coastal defences.

Driver changes and flood risk

While there are few modelling outputs available, there is the suggestion that wave heights will increase over the long term. The Ocean-Atmospheric General Circulation Model (OAGCM) of the Hadley Centre suggests that 50-year extreme wave heights could increase over the next 100 years. In addition, projections of future climatic conditions suggest increased storm activity and more extreme winds around the UK (Hulme *et al.* 2002).

Defra's Futurecoast study (Defra, 2002) has considered the impact of changing wave conditions upon the shoreline, looking specifically at the effects on the net longshore energy and so potential littoral transport. The wave conditions that were investigated range from very small changes in wave direction – of the order of 1 to 2º change in both directions – to increased Atlantic storminess. The study concluded 'the total longshore energy is predicted to remain more or less the same as the current climate value i.e. the gross movement of sediment at the shoreline is unlikely to be significantly altered'. An investigation of larger changes in wave characteristics might modify this conclusion.

We have analysed the potential changes in flood risk caused by this driver using a scoring exercise, assuming that changes in surges and waves are linked (see Table A5). The changes are smaller than those suggested for relative sea level and surges. This driver is associated with one of the greatest levels of uncertainty.

Table A5 **Driver impact scores**

Driver	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Waves	3	10	2	5	1	3	1	2

Uncertainty

There are significant uncertainties in the models for the Waves driver. As projections, such as those in the scenarios, depend on the model, there is considerable uncertainty in predicted wave heights and frequencies at particular locations (Hulme *et al.* 2002). Studies of changes in offshore waves are currently limited (Kaas and Anderson 2001). They used simple point models or dynamic models of a region for only a short time or with inadequate driving data. There are also suggestions that there is little agreement between models predicting changes in mid-latitude storm intensity, frequency and variability (Church *et al.* 2001).

Native parameter

There is insufficient information to provide a robust quantitative native parameter for the Waves driver.

Recommendations for research

More research is required to improve understanding of how climate change may influence the offshore wave regime in terms of magnitude, frequency and, importantly, direction. This should include analysis of a range of climate models and be combined with analysis of changes to surges to generate consistent scenarios. To be of most use, this needs to be at a resolution that identifies variations around the coast.

Driver

A10: Surges

Driver group: Coastal processes
Type: Source

Definition and operation

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

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

The magnitude of surges, and other storm characteristics, show significant variability from year-to-year and decade-to-decade. There is no conclusive evidence of systematic changes in surge magnitudes during the 20th century (e.g., WASA Group 1998).

Surges act with tidal variations and changes in relative sea level to produce extreme water levels which can cause coastal flooding. The worst risk of flooding occurs when a surge is combined with a high spring tide and significant wave action. The most serious coastal flood event during the 20th century was the storm surge on 31 January/1 February 1953 on the east coast of England when about 300 people died in Britain and nearly 2,000 people died in the Netherlands (Smith and Ward 1998). The amplitude of the surge reached 2.74m at Southend in Essex, 2.97m at Kings Lynn in Norfolk and 3.36m in the Netherlands. The cause of this event was the combination of a deep depression, strong northerly winds, large waves and high tidal levels. More recent storms on the east coast have produced similar extreme water levels of 1953, but improved defences prevented significant flooding.

Interactions with other drivers

There is significant interaction with the other coastal drivers. Surges combine with Relative Sea Level Rise to produce extreme water levels. Surge events allow waves to break nearer to the coast, transmitting more wave energy to the shoreline, loading flood-defence structures and increasing risk of failure.

Driver changes and flood risk

Surge magnitudes will probably change in the 21st century due to climate change, but there is low confidence about the magnitude of this change. Further, these changes will vary around the coast, with increases in some locations and decreases in other locations. This will translate into changes in flood risk for coastal areas, all other factors being kept constant. There is some evidence of an increase in storm intensity, which suggests that surges will tend to increase, but this remains much less certain than increases in relative sea-level rise (Lowe *et al.* 2001; Flather and Williams 2001; Hulme *et al.* 2002).

We have analysed the potential changes in local flood risk by changing surges using a scoring exercise (see Table A6).

Table A6 **Driver impact scores. The values are scaled from the driver Relative Sea-Level Rise. The variable factor reflects the uncertainties discussed in the text (Hulme *et al.* 2002). In the World Markets socioeconomic scenario, the change in the Surges driver is significant and comparable to the Relative Sea-Level Rise driver, while under the Global Sustainability scenario, the Surges driver shows a small increase when compared with the driver Relative Sea-Level Rise.**

Driver	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Relative Sea Level Rise	5	20	4	13	3	10	3	7
(scale factor)	1	1	1.5	1.5	2	2	3	3
Surges	5	20	3	9	2	5	1	2

Uncertainty

There are significant uncertainties associated with future surge characteristics. These are partly a result of the limited number of existing model simulations. There is uncertainty at the regional and national scale about the overall changes in surge magnitude. There is also uncertainty at more local scales as the changes in surge magnitudes will vary around the coast.

Native parameter

Changes in surges contribute to values of extreme water level for different return periods.

Recommendations for research

Given the large uncertainty for this driver, and its potential significance in terms of increased flood risk, it is important that it receives further research. The limited number of model runs of future surge characteristics needs extending, with an emphasis on extreme events and a better analysis of the natural variability of surges versus the magnitude of climate change. More fundamentally, the conflicting results from different climate models need more detailed comparison and analysis to study the causes of these differences (Lowe *et al.* 2001). This should be combined with analysis of the Waves driver to develop consistent changes across drivers, and establish a range of better scenarios.

Driver

A11: Relative Sea-Level Rise

Driver group: Coastal processes
Type: Source

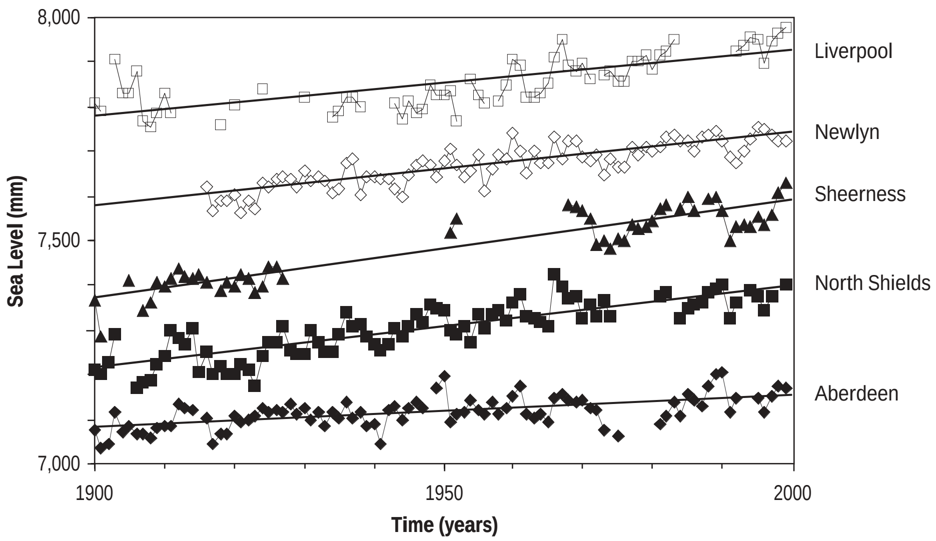
Definition and operation

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

This driver has three main components: global mean sea-level rise, which is an increase in the global volume of the ocean; regional meteo-oceanographic factors, such as variation in thermal expansion effects; and vertical land movement (subsidence/uplift) due to a range of natural and human-induced geological processes.

Long-term records, over more than 50 years, show a trend of rising sea levels up to 2 mm/yr around the UK (Figure A5). Further, satellite observations are beginning to suggest an acceleration in global rise of mean sea-level, which is consistent with the notion of human-induced global warming (Nicholls and Lowe 2004).

Figure A5 **Relative sea-level trends around Great Britain (adapted from Woodworth *et al.* 1999)**



Relative Sea-Level Rise has many effects on coastal processes. It influences coastal flood risk in a number of ways (Woodworth *et al.* 2004). In addition to raising mean water level, rising sea level also raises all the coastal processes that operate at sea level and hence directly raises the extreme water levels produced in surge events. Therefore, the immediate effect of a sea-level rise is to submerge land and increase flood risk. Longer-term effects include morphological change, particularly beach erosion and saltmarsh decline, which exacerbates the increases in flood risk due to the more immediate effects of sea-level rise.

Interactions with other drivers

There is significant interaction with the other coastal drivers as higher sea levels:

- Raise extreme water levels and hence interact with surges.
- Allow waves to break nearer to the coast and to transmit more wave energy to the shoreline.
- Promote erosion and coastal recession, interacting with the driver Coastal Morphology and Sediment Supply.

Driver changes and flood risk

We have analysed the potential changes in flood risk by extreme water levels using a scoring exercise (see Table A7). The general trend is for an increase in flood risk due to rising extreme water levels with rising relative sea levels and the effect increases with time period. The greatest increase is expected under a World Markets Scenario. It should be noted that this driver is associated with one of the highest levels of certainty.

Table A7 **Driver impact scores. The values relate to the increase in the 1 in 100-year surge levels. The detailed driver change depends on location: changes are greatest in southern Britain which is experiencing maximum subsidence. The values provide a mean change around the entire coastline.**

Driver	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Relative sea level rise	5	20	4	13	3	10	3	7

Uncertainty

While there are uncertainties concerning future sea levels, this is one of the more certain drivers considered in this project. Global mean sea level rise is certain, with a rise of 9 to 69 cm from 1990 to the 2080s (Hulme *et al.* 2002). Future rise is almost independent of climate policy to the 2050s. Therefore, the driver rankings for the 2050s are similar for all scenarios and only diverge for the 2080s.

The regional variation due to meteo-oceanographic factors is highly uncertain and could be ±50% of the global rise (Hulme *et al.* 2002). Lastly, the regional patterns of uplift/subsidence are well known (Shennan and Horton 2002).

Low-probability/high-consequence rises due to collapse of the West Antarctic Ice Sheet are possible, but considered very unlikely during the 21st Century. Hence, Relative Sea-Level Rise is considered the most important component of changes in extreme water levels at many locations around the UK.

Native parameter

Relative Sea-Level Rise is represented by mean water level for different regions of the UK in the 2050s and 2080s.

Recommendations for research

Planning for sea level rise would benefit greatly from probabilistic forecasts for future sea levels, as opposed to the scenarios presently available. This work should include the probability of all the three components of sea level rise and will require a better understanding of the causes of the spatial pattern of change due to meteo-oceanographic factors.

Driver

A12: Coastal Morphology and Sediment Supply

Driver group:	Coastal processes
Type:	Pathway

Definition and operation

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

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

Generally, flooding and coastal erosion systems are, and will continue to be, affected adversely more by the loss of material associated with morphological change than by any gain. Impacts occur in two ways:

- Directly, as erosion at the shoreline leads to the loss of land and assets or undermines existing defence structures.
- Indirectly, as loss in level increases the exposure of the shoreline to wave attack which could potentially lead to an increase in the erosion rate.

However, over a timescale of 100 years, this driver will have more significant impacts as a function of management strategies than climate change. On the assumption that the current policy on coastal flood defence continues, it is the failure of flood defences, due to changes in other drivers, that will predominantly give rise to changes to the behaviour of this driver. For example, sediment supply in some areas may increase as changes in wave/water-level regime lead to breaches in defences. Breaches may mobilise material behind the defence line, creating shoreline erosion. However, this may have positive, accretional value downdrift from this location. Alternatively, breaching may result in a sediment sink behind the defences, creating sediment starvation elsewhere.

Interactions with other drivers

The driver Coastal Morphology and Sediment Supply interacts with other drivers in several ways:

- Changes in coastal morphology and sediment supply will affect how much wave energy reaches the shoreline. For example, if the sea level rises faster than the morphodynamic system can adjust, offshore sandbanks may no longer protect the shoreline from incoming waves.
- The stability of flood defence in soft-cliff areas may be put under strain if there is increased precipitation. Soft cliffs are susceptible to erosion during storm events both as a result of increased wave action and increased precipitation levels. If defences are able to be managed and maintained, sediment release into the coastal system is more likely to be a secondary effect.
- With rising sea level, large littoral drift and an insufficient shoreface supply to balance the volume of material transported in the longshore, erosion could be expected on the beach and upper shoreface (Stive *et al.* 1990). Hence there will be an net retreat of the shoreline.

Table A8 **Driver impact scores. The impact of morphology and sediment supply is relatively low, when compared with the other coastal process drivers, although it provides a high risk with regard to other driver groups.**

Driver	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Coastal Morphology and Sediment Supply	5	10	4	7	3	4	2	2

Driver changes and flood risk

Morphology and sediment supply, while affected by climate change, will experience more significant change over the long term as a result of coastal management strategies. As with other drivers, we have analysed the potential changes in flood risk using a scoring exercise (see Table A8).

Uncertainty

Our ability to model morphological change at the timescales relevant to the Foresight Project is improving significantly. This improvement is likely to continue. However, predictions of future changes in this driver are presently more qualitative than quantitative.

Native parameter

Changes in this driver are qualitative and are described by a change from form A to form B. Changes in this driver are, to some extent, constrained by the maintenance of the present-day coastal defences, which may be both natural and artificial. However, when these defences fail, we can expect changes to the Coastal Morphology and Sediment Supply driver.

Recommendations for research

Our ability to predict changes in this driver is hampered by a lack of good long-term data sets. Thus it is difficult to observe long-term trends and to calibrate and validate long-term models with accuracy. In addition, there are uncertainties in determining the behaviour of coastal morphology beyond that observed in the data. Research agenda designed to overcome this would prove invaluable (cf. Vriend and Hulscher 2003).

Driver

A13: Stakeholder Behaviour

Driver Group: Human behaviour
Type: Pathway

Definition and operation

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

We define stakeholders as all individuals, groups, or institutions with a direct or indirect, witting or unwitting, interest in or influence on flood risk. Here they include a wide array of public and private institutions. The professions – ranging from engineering to agribusiness, law and insurance – are also important stakeholders as they bring their own sets of interests, beliefs, values and ways of working to bear. The public itself cannot be regarded as a single entity, rather as a collection of stakeholder ‘groupings’ with discrete beliefs and priorities (Schwarz and Thompson, 1990).

All stakeholder behaviour is fashioned by concerns that are motivated by a variety of factors ranging from true concern about flood risk to peripheral affairs, matters of process, or vested interests (HSE, 2002). Typically, particular stakeholders influence flood risk through pricing insurance policies, agricultural practice, food-purchasing preferences, the pursuance of ecological or other aims, and commercial self-interest as in the promotion of flood-related litigation.

The behaviours of stakeholders are interwoven and interactive (Jaeger *et al*. 2001). Each stakeholder’s actions will impinge on others such that they can be expected to adjust their own positions. This could take the form of strategic manoeuvring or simply a response to new circumstances. Stakeholders exhibit varying interests, beliefs or values, some of which are not specifically related to flood risk itself but to other aspects of the management of those risks which may figure directly or indirectly in triggering responses (see Table A9).

Interactions with other drivers

The driver Stakeholder Behaviour, because it embraces so many stakeholder groups, is embedded in a network of interacting drivers. It is also affected by the actual risk of flooding, and hence depends on all other drivers and their net effect on flood risk.

Case example

Two brief examples illustrate the complexity of this driver. Competition between supermarket chains affects food-purchasing policy, which in turn affects farming practice. This affects agricultural land-use patterns and hence runoff. Likewise, the level of blame which is directed at managers of flood and coastal risk following an incident, and hence the pressure to act, depends on how willing people are to tolerate that risk, which itself depends heavily on how the risk has been managed and communicated. In both examples, many factors, often with little connection to actuarial risk, influence how stakeholders behave.

Driver changes and flood risk

As a driver, Stakeholder Behaviour is clearly important. Apart from its own influence on flood risk, it interacts strongly with other key drivers, including all those to do with regulation. It also determines, wittingly or unwittingly, the general direction in which society progresses. However, individual stakeholders and stakeholder groups will not act in the same direction and the combined consequence may thus be less than otherwise imagined.

Table A9 **Examples of the diversity of stakeholder motivations and hence complexity of behaviour in response to flood management issues**

Stakeholder type	Sources of influence
The public	Willingness to accept risk; concept of fairness; satisfaction with decision processes; trust in flood-managing agencies; wider interests affected by flood-management interventions such as landscape and conservation
Flood risk managers (wherever located)	Ability to communicate effectively with other stakeholders including the public; professional codes of practice (formal and informal); professional beliefs
Insurers	Attitude to flood risk premia and the extent to which these are based, or seen to be based, purely on commercial self-interest
Environmental campaign groups	Through favouring particular management regimes (for reasons only indirectly founded on flood-risk concerns); exploitation of 'causes' to build solidarity
Legal profession	Promotion of flood-related litigation (in seeking out new markets to increase income generation)
Farming community	Agricultural practices in response to market forces
Media	Reporting style
Engineers	Preference for particular types of flood-management control systems
Landowners	Willingness to accept risk; priorities which do or do not accommodate periodic inundation
NGOs and local organisations	Specific agenda being pursued; willingness to countenance other agendas

Uncertainty

The drivers of stakeholder behaviour are widely and deeply rooted in society, are subject to disparate pressures, interact strongly with each other, and hence are not easily forecast. For example, at the practical level, the impacts of the 9-11 terrorist attack on the USA and asbestos-related lung disease on the insurance industry have an effect on the price and availability of insurance in unconnected markets. The current parlous state of the insurance industry may already affect the cost and availability of insurance against flood risk.

At a deeper level, theory suggests that the real problem of risk acceptance is not the substantive issue of flood risk but the wider moral questions regarding the trade offs involved in any particular decision choice and the processes by which those choices were made. The danger comes not so much from the presence of flood hazards but from the transgression of norms to which particular social groups subscribe. All of this suggests that stakeholder behaviour in respect of flood risks over the long term is not amenable to the kind of forecasting that we can apply to physical parameters of climate change.

Native parameter

Identification of a native parameter is barely feasible for this driver because of its complexity, including interactions with other drivers and internal and external feedback loops. Overall, the aim must be to predict the outcome of the convolution of the behaviours of the multitude of stakeholders.

Recommendations for research

There is a case for research to improve our understanding of the interaction of complex social systems as they pertain to the management of flood risk and coastal erosion. There is also an argument for investigating how and why stakeholders form the opinions that they do, and how this translates into behaviour.

Driver

A14: Public Attitudes and Expectations

Driver group:	Human behaviour
Type:	Receptor

Definition and operation

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

We take Public Attitudes and Expectations to signify preferences for risk management and associated factors rather than personal preferences as to, say, the desirability of living in certain types of location. Public preferences, while originating from the public, are heavily influenced by the positions and behaviour of other actors, and hence cannot be viewed in isolation. Furthermore, we recognise that ‘the public’ as such does not exist in the sense of having a single position. We can expect to see different views (Seedhouse 1997).

Opinions on risk issues are always based as much, if not more, on beliefs and values as on facts, something which applies as much to professionals as the public. Research on public attitudes to risk confirms that, while public opinions may differ from those of experts, they are nonetheless valid on their own terms (Slovic 2002).

The most obvious ways in which public preferences are likely to influence flood risk are through public reactions to alternative decisions on flood-risk management. In particular, the acceptability of any imposed regime of flood-risk management, and its associated actual risk, will depend on a number of variables including the perceived risk and its tolerability, the cost of intervention and who pays, any equity issues, any undesired consequences of interventions, alternative styles of intervention and their attributes, the process by which choices are made, and trust in the ‘system’, including the people and institutions involved.

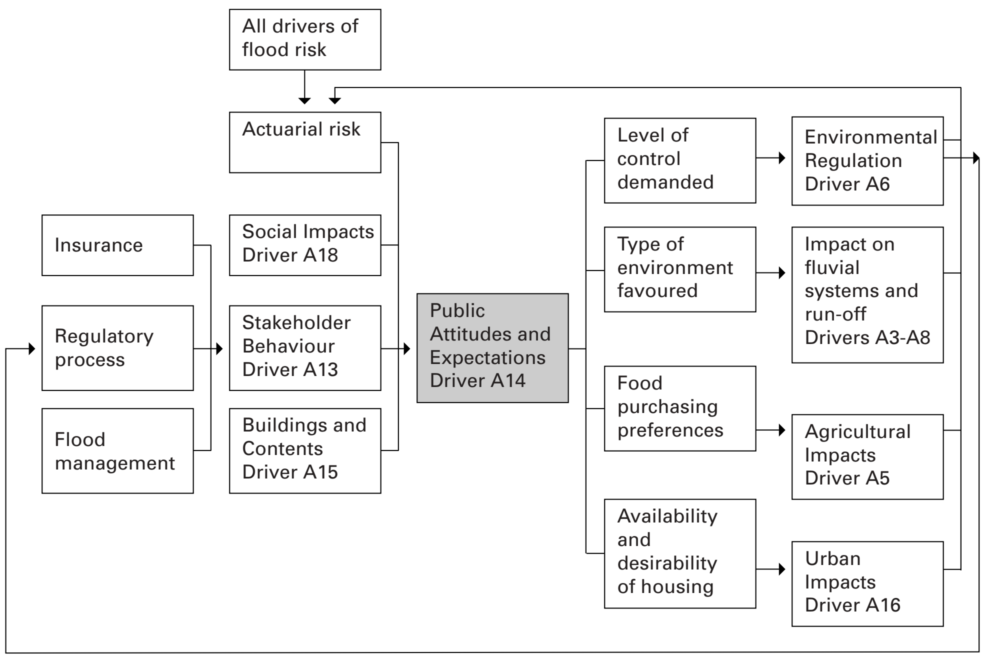
Interactions with other drivers

There are many complex interactions between the driver Public Attitudes and Expectations and other drivers (see Figure A6). Public preferences will be driven as much by process, equity and economic considerations, to name a few, as by actuarial risk. In turn, these variables and drivers are themselves driven by other listed drivers as shown on the left of the diagram. The complexity does not stop here. Public preferences feed outwards to affect behaviour and choices which impinge on other drivers. These drivers, in turn, feed back to affect, notably, actuarial risk and regulation, though their effects are more widespread.

Case example

The importance of public attitudes in framing regulatory responses is demonstrated by the US Environmental Protection Agency's review of its own priorities. The US EPA sought to determine, on a scientific basis, relative priorities for risk management intervention with respect to a host of environmental concerns under its jurisdiction. These scientifically derived priorities were found to differ substantially from those actually advanced in practice by the EPA. In fact, the priorities of the EPA were found to be based more on public perceptions than the EPA's own risk assessments (HSE 1997).

Figure A6 **The driver Public attitudes and expectations is entangled in a complex set of interactions with other drivers of flood risk**



Driver changes and flood risk

The driver Public Attitudes and Expectations is important because of its relationship with the driver Environmental Regulation. In turn, regulation is important in all the Foresight scenarios. However, Public Attitudes and Expectations can act in opposite senses. The attitude of the public to a flood risk will depend on how it is perceived. Ignoring, temporarily, the likely dominance of outrage factors, we can envisage a four-fold situation:

	Risk is small	Risk is not small
Risk perceived as small	A. Not a driver	B. Is a driver
Risk perceived as significant	C. Is a driver	D. Is a driver

In circumstance A, Public Attitudes and Expectations is not a driver of flood risk. In circumstance B, it is a driver – it exacerbates flood risk because no action is taken. Given the media interest in floods, this may not happen. In C and D, Public Attitudes and Expectations will act to try to reduce risk.

Uncertainty

The uncertainty associated with this driver is high for several reasons. The underlying causes of apparent trends in public opinion regarding flooding are related to perceived changes in flood risk, opinions on the acceptability of flood risk, procedural issues of risk management, trust in the system, and other factors. In a political climate demanding increasing openness, greater consultation, extending to partnership in risk decisions, corporate governance and the like, expectations of management standards will increase, irrespective of whether there is demand for greater safety from flooding. Reliable models of social interactions over the long term which can be linked to preferences surrounding flood risk would be at least as complex as those established for predicting the physical dimensions of climate change. Such models do not exist, although some sociological models are informative.

Native parameter

For this driver the biggest problem is its close coupling with the regulatory stance taken and its style of implementation, that is, how the latter is perceived in terms of risk tolerability and outrage factors. As a compromise we suggest that the native parameter is approximated, no more, by the actual flood risk in 2050 or 2080. Thus, if the flood risk in 2050 is xN higher than now, the tendency will be to want to reduce it by x1/N. This will be tempered by memory, public perceptions of what is reasonably achievable, the state of the economy, any active outrage factors, and other competing interests.

Recommendations for research

Research should investigate two key questions: What are the key factors determining public attitudes to flood-risk management? What are the public’s expectations, and how aware are people of the need for trade-offs?

Driver

A15: Buildings and Contents

Driver group: Socioeconomics
Type: Receptor

Definition and operation

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

Our analysis of this driver includes damage to production and household durables, as well raw materials, intermediate goods and consumption, together with the costs of recovering from the floods and the disruption caused to others in consequence of those properties being flooded.

Industrial and commercial losses

For industrial losses, changes in the magnitude of direct damages are a function of:

- The relative returns to capital and labour and changes in the capital invested per employee.
- The rate of investment in production durables.
- The susceptibility of the technologies and built forms adopted.
- The rate of replacement of existing production durables (e.g. expected life).

Changes in the scale of indirect losses are a function of:

- The degree of specialisation and concentration within industrial sectors.
- The dependency on ‘just in time’ deliveries of intermediate and finished goods.
- The time taken to repair or replace equipment and buildings affected in a flood (including cleaning up the building).

Household losses

The changes in the real loss to households from floods depend on the ratio of spending for immediate consumption to that on consumer durables, such as televisions and cookers. Although the prices of individual items should continue to fall in real terms, it is the ratio of spending on immediate consumption to that on consumer durables that determines the magnitude of flood losses. At present, the ratio of household expenditure on durables, including the dwelling itself, to flows is roughly 1:2; but since consumption durables have a relatively long life, potential losses to durables are greater than the destruction of immediate consumption items, such as food and drink.

Changes in flood losses to households depend on:

- Changes in real income.
- The relative real prices of immediate-consumption and consumption durables, with immediate-consumption items typically having a price inelastic demand.
- The life expectancy of consumption durables.
- Changes in the susceptibility to flood damage of consumption durables.

Historically, buying food took 60 to 70% of household income. The real fall in the price of food has freed income to buy household durables, including the dwelling. In turn, this means that the price of food has a significant impact on flood losses in households because the price of food affects what people have to spend on other assets, which are liable to suffer flood damage.

Interactions with other drivers

The main interactions are with the drivers Urban Impacts and Social Impacts, and with the physical form of catchments and the way that these define the floodplain – the most relevant driver is Urbanisation. Hence, wide flat areas that are densely developed are those where losses are likely to be greatest. Conversely, in steep-sided river valleys, losses are generally low because the width of the floodplain is small. The extensive use of electronics in offices and cars now means that these result in very high densities of loss, that is, the link to the driver Science and Technology.

Case examples

Two examples of the consequences of industrial concentration are: in 1953, the Unilever plant that produced 60% of the UK's margarine was flooded; likewise, the factory that produces a similar proportion of the baker's yeast for the UK lies in a floodplain.

In 2000 floods, domestic and industrial commercial losses, as gauged by insurance claims, were broadly similar, in aggregate, although more domestic properties were affected (Figure A7).

Driver changes and flood risk

The World Market scenario is characterised by a high rate of investment and, in turn, the mean life of production durables is likely to fall. Industrial and commercial activities are anticipated to be focused on the high-tech activities including biotechnology and nanotechnology.

Table A10 **Driver impact scores**

Driver	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Buildings and Contents	6.0	17.0	2.2	3.1	3.0	4.8	2.5	4.8

The global nature of the World Markets economy should be expected to be accompanied by increasing specialisation and concentration. In addition, there will be a high degree of shipping of semi- and partially finished goods between countries. Within the sector, potential flood losses should therefore be expected to increase ahead of the rate of change in the GDP and at a greater rate than in the other three scenarios.

Importance and uncertainty

The importance of this driver depends on the exposure of building and contents to flood risk (that is, the amount and pattern of urban development in the floodplain), the economic strength of society and the levels of science/technology/engineering in buildings and their contents. It is, therefore, likely to be much more important in the World Markets and National Enterprise scenarios.

For household losses, the critical long-term uncertainty turns out to be the world price of basic foodstuffs denominated by foreign exchange rate against the then dominant economic power. If these prices are high, household flood losses will fall, simply because households have less money to spend on household durables.

Table A11 **Household contents**

Losses	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Income growth (+)	Highest	Moderate	Low	Moderate
% of income spent on household durables (+)	Constant	Constant	Up	Up
Susceptibility (+)	Up	Up	Down	Up
Life expectancy of durables (-)	Down	Down	Up	Up
Real loss (£)	Up	Up somewhat	Falls	Marginally increased
Rate of change in loss relative to change in GDP/income	Above	Above	Below	Below

Table A12 **Domestic buildings: damages to fabric**

Losses	World Markets	National Enterprise	Local Stewardship	Global Sustainability
Income growth (+)	Highest	Moderate	Low	Moderate
% of income spent on dwellings (+)	Up	Constant	Up	Up
Susceptibility (+)	Up	Up	Down	Up
Real loss (£)	Up	Up	Down	Up
Rate of change in loss relative to change in GDP/income	Above	Above	Below	Above

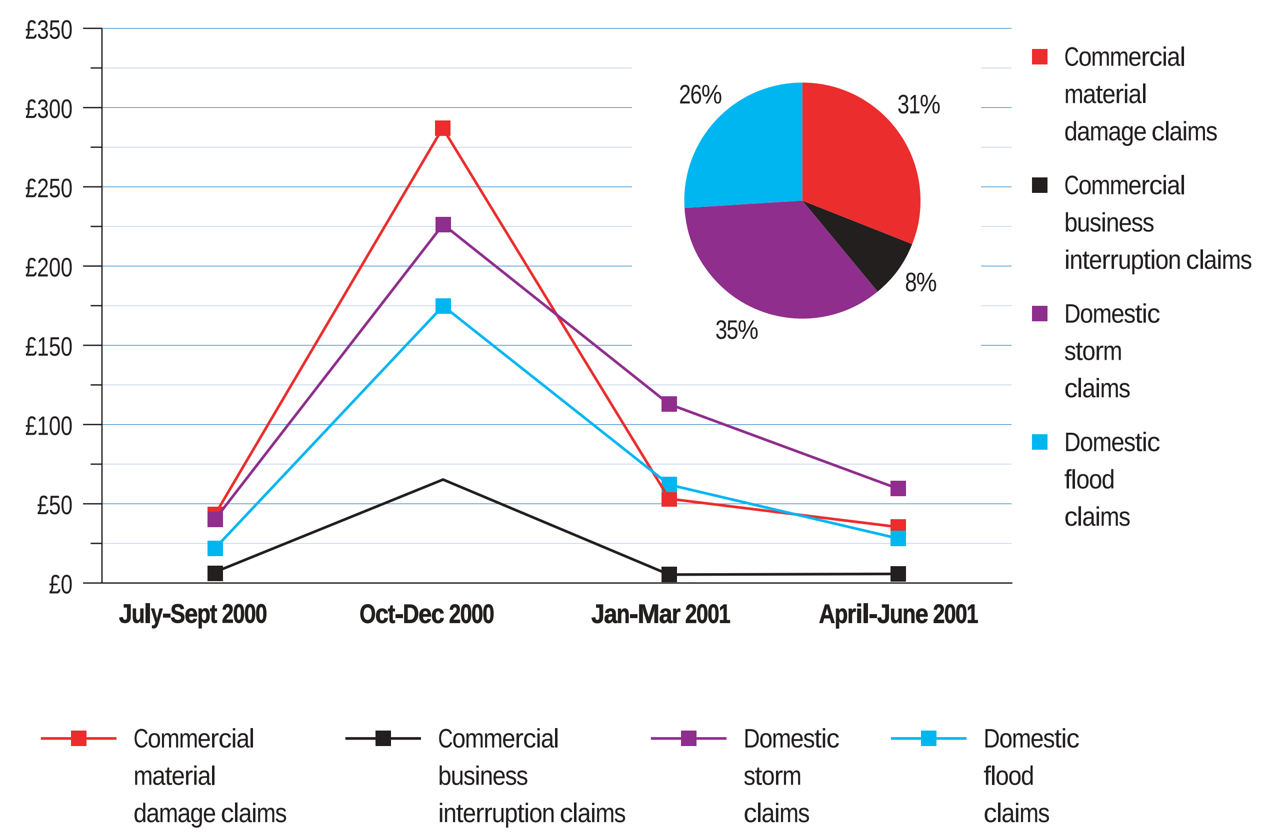
Native parameter

Buildings and Contents are input to the strategic assessment of flood risk as the annual expected losses per hectare based on the proportion of urban land use in the indicative floodplain, broken down into residential properties and non-residential properties at risk.

Recommendations for research

We still know little about the secondary or indirect effects of floods on industry and regional economies. There is anecdotal evidence that this is substantial, but the few empirical studies that exist do not support this.

Figure A7 **Losses reported by the Association of British Insurers, for floods in Autumn 2000**



Driver

A16: Urban Impacts

Driver group: Socioeconomics
Type: Receptor

Definition and operation

This driver is concerned with changes in the way in which urban areas are managed and that urbanisation is effected, and how planning and management may change due to climate- and social-change effects (e.g. renewal of existing urban spaces, new urban forms, new densities of development, more green space, encroachment into green belts, etc.).

While changes in existing urban form are certain to occur, the 'fabric' of urban areas changes relatively slowly in the UK. For example, the current rate of replacement of the housing stock is 0.1% per annum and the rate of addition to that stock is 1%. There is, therefore, considerable inertia in the urban setting. Also, 22% of all land in England is already in some urban usage and there is limited scope for further urban expansion. This limitation is compounded under some Foresight scenarios as the UK will be desperately short of land, particularly agricultural land for food production.

Interaction with other drivers

Strong interaction/coupling with Infrastructure Impacts, and Buildings and Contents. Clearly the Precipitation and other source drivers are inputs. There will also be interactive effects with Urbanisation as a pathway driver.

Case example

The town of Maidenhead in the Thames valley had its origins in the 19th century on river bluffs above the floodplain, with only sporadic development within the Thames floodplain. As the town expanded in the early 20th century, development extended into the floodplain, especially along the 'innovation corridor' along the route of the A4. The urban area was severely impacted by flooding in 1947, but development in the floodplain still continued. Recognising the risk of a repeat of the 1947 event, floor levels within the footprint of the flood were set at or above 1947 flood levels. However, when this area of Maidenhead was again flooded in 1990, the area was heavily disrupted and water still entered some properties. In a repeat of a 1947 flood, properties that were not actually flooded would still be cut off within the flooded area for up to a week. The siting of this urban area and the design of its fabric demonstrate how inappropriate location and urban design can increase risk and losses inordinately. In fact, a £100 million flood-alleviation scheme involving a large flood-diversion channel has been necessary to reduce flood risks to acceptable levels. This case study shows how urban impacts may spiral upwards unless care is taken to build flood-safe developments.

Driver changes and flood-risk impacts

In the economically strong World Markets scenario there will be a great deal of new development as well as renewal and upgrading of existing urban stock, governed by weak planning controls. The rates of internal mobility as well as emigration and immigration will be high. In turn, this population movement means that significant fractions of the existing stock of buildings will be located in the wrong places, yet it will be necessary to respond to the demand in other areas attractive to multinationals. The urban fabric will thus expand ‘unnecessarily’ and inappropriately, resulting in greater urban flood risk. Under National Enterprise there will be similar effects, but they will be more muted, in line with weaker economic and, therefore, urban renewal and growth trends.

Table A10 **Driver impact scores from Chapter 2**

Driver	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Urban impacts	5.0	19.8	1.8	3.6	3.0	4.8	2.2	3.9

Under the Global Sustainability scenario, a sustainable urban development policy will be adopted. Importing timber from unsustainable sources will be banned, energy life-cycle costing will be applied to building materials in general, and there will be a search for the ‘best environment aggregate policy’. The overall result is likely to be more limited development, with a strong preference for the redevelopment of existing settlements where appropriate, but with thorough investigation of the floodplain to ensure that development and redevelopment in flood -rone areas is avoided.

Under Local Stewardship, society will wish to minimise development on greenfield sites, and will require that authorities implement sustainable urban planning and management policies. The emphasis will be on re-using existing buildings and creating 'floodproof' urban spaces, with services, utilities and transport networks that are not vulnerable to disruption by flooding. There may be widespread floodplain de-urbanisation, or at least a lowering of urban densities there, with some development around small villages and towns aimed to increase the population to the levels necessary to support community facilities such as shops, schools and health care. In some areas, economic hardship under this low-growth scenario, coupled with the withdrawal of private insurance cover, may lead to the abandonment of floodplain settlements.

Importance and uncertainty

Many UK towns and cities have developed in floodplains. Close-packed properties, government buildings, hospitals and emergency service's headquarters occupy flood-prone locations, with the result that there are many vulnerable people in the floodplain. Current risks are low, because river and coastal defences protect most urban areas, but the probability of inundation will tend to increase as the standard of service provided by defences falls due to increased flood magnitudes and economic growth in the protected area (under the baseline assumption). In addition to increased risk to existing developments new developments, such as the proposed London Gateway development sites in the Thames Estuary, will add to the potential for flooding to have increased urban impacts.

Under the best current estimates, urban change in the future will continue to be slow, but it could potentially accelerate: if the annual rate of replacement of housing stock increased to 1%, by the 2080s the increases in losses due to urban impacts will be very significant. Major uncertainties concern whether there will be a change in preference in favour of new dwellings rather than existing ones. There are uncertainties about the way urban spaces will be constructed. There could be a policy of high-density urban development and, consequently, an increase in flood losses per hectare. Conversely, people's desire to live in small rural or semi-rural communities may predominate. Any such changes would have major implications for urban impacts as a receptor, and so uncertainty concerning its importance is high.

Native parameters

A series of native parameters was used to express impacts of catchment- and coastal-scale flooding on the urban fabric. These were:

Native parameter	*Description*
Urban area at risk	% of floodplain urbanised
Urban areas at high risk	Urban space subject to flooding over 2 metres deep (ha)
Rate of change of building stock	% per annum
Intensity of development	Floor area (m^2/ha)
Secondary hazards	Potential for release to environment of toxic, explosive, inflammable or other hazardous materials (qualitative)

Recommendations for research

Research is required to clarify likely trends in housing preferences and their effect on urban densities, flood vulnerability and the necessary damage-mitigation measures. The potential for planning the urban space to reduce urban flood impacts by ‘floodproofing’ amenities and services to facilitate community and individual-scale damage avoidance should be investigated.

Driver

A17: Infrastructure Impacts

Driver group: Socioeconomics
Type: Receptor

Definition and operation

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

The nation's infrastructure supports and enables the economy to transform raw materials into production durables, intermediate goods and final consumption. The effects of flooding on parts of these networks can have consequences that spread outside of the area directly affected by flooding,

The effect of a flood is to cut links in the network or to affect some nodes. The extent to which these effects extend beyond the flooded area depends partly on the topology of the network and on the surplus capacity in the network.

Interaction with other drivers

Infrastructure serves all land uses, and to a certain extent determines their effectiveness. It indirectly affects and interacts with the driver Rural Land Management. Disruption of power supplies can affect the driver River Vegetation and Conveyance, by affecting flood defences, for example, with the failure to close gates and sluices. Dislocation of communications can influence Stakeholder Behaviour and Public Attitudes and Expectations – by people being or feeling isolated. Infrastructure itself is highly affected by changes in the driver Science and Technology.

Case examples

Flooding can disrupt water supply. For example, until the middle 1990s, York received water from a single abstraction and treatment plant on the Ouse floodplain: there was limited capacity to transfer water to the city from other areas. In the 1947 flood, the Coppermills water-treatment plant was flooded, disrupting water supplies to east London.

Energy supplies are also prone to flood damage. For example, an explosion during a flood at the single gas plant serving New South Wales, Australia, meant that the much of the state was without gas for some weeks.

Transport systems can be seriously affected in floods. The North Circular road at Hangar Lane, London, has historically been prone to flooding, with the resulting congestion causing gridlock over a large area of north-west London. Underground railways are potentially highly susceptible to flooding; floods in Paris in 1911 closed parts of the metro network for months. The recent flooding in Prague caused disruption for some weeks.

Driver changes and flood risk

The driver Infrastructure Impacts depends very much on the scenario in question. It is highly significant as a driver in the World Markets scenario. Under this scenario, the UK's industries will become progressively more exposed to disruption as a result of natural disasters in other countries, with the relative absence of natural hazards being a potential competitive advantage for the UK. Therefore, we could expect the greatest disruption caused by flooding within the UK to be at the nodes connecting the country to the global economy.

The spread of competition will act to reduce vulnerability but, conversely, the drive to economies of scale and scope will introduce more centralised control rooms which may themselves be at risk of flooding. We can expect a broadly similar pattern under the National Enterprise scenario.

Table A12 **Driver impact scores**

Driver	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Infrastructure impacts	7.1	24.0	2.2	3.6	3.0	4.8	2.5	3.9

Under the scenario Global Sustainability, we could see a switch to a hydrogen economy and the use of bio-fuels. The implications of this in terms of flood risk require examination. We should also expect to see greater use of low-head or micro-hydro schemes which may have implications for flood management. A classic conflict is the requirement to store water to support power production versus the need to keep storage empty to accommodate a possible flood peak.

The logic of the Local Stewardship scenario is that there will be less transport of goods and raw materials, and less travel overall. In consequence, while the local effects of a flood might be marked (see Table A12), the effects on the national economy as a whole will be less (see Table 2.3). Water management will be complicated by the increased importance of rivers and floodplains for power generation, fish production and the production of vegetative material.

Importance and uncertainty

Currently, losses associated with damage and disruption to infrastructure constitute a small proportion of total flood losses. The real importance of infrastructure is then the high accumulated value of these assets – £7,000 per household in the UK for sewers alone – and slow rate of replacement. In turn, this means that both the rate of change to risk and the rate at which these systems can adapt in response to change in risk will be low.

In the Oder floods in Germany, a major problem was the contamination of flood waters by heating oil from domestic central-heating systems. It is not clear whether a switch to bio-fuels, such as ethanol, would increase the present low risk presented by gas-fired heating systems.

Native parameter

Infrastructure impacts are input in the strategic risk assessment as the value of infrastructure and both direct and indirect losses associated with its disruption within the indicative floodplain. These are difficult to account for, as disruption of some elements of infrastructure results in losses that extend well beyond the indicative floodplain, for example, to pylons or water mains crossing the floodplain.

Recommendations for research

The risk from floods to the components of the infrastructure for a hydrogen-based economy require investigation.

Driver

A18: Social Impacts

Driver group: Socioeconomics
Type: Receptor

Definition and operation

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

The driver Social Impacts is something of a catch-all term and is usually taken to include the following:

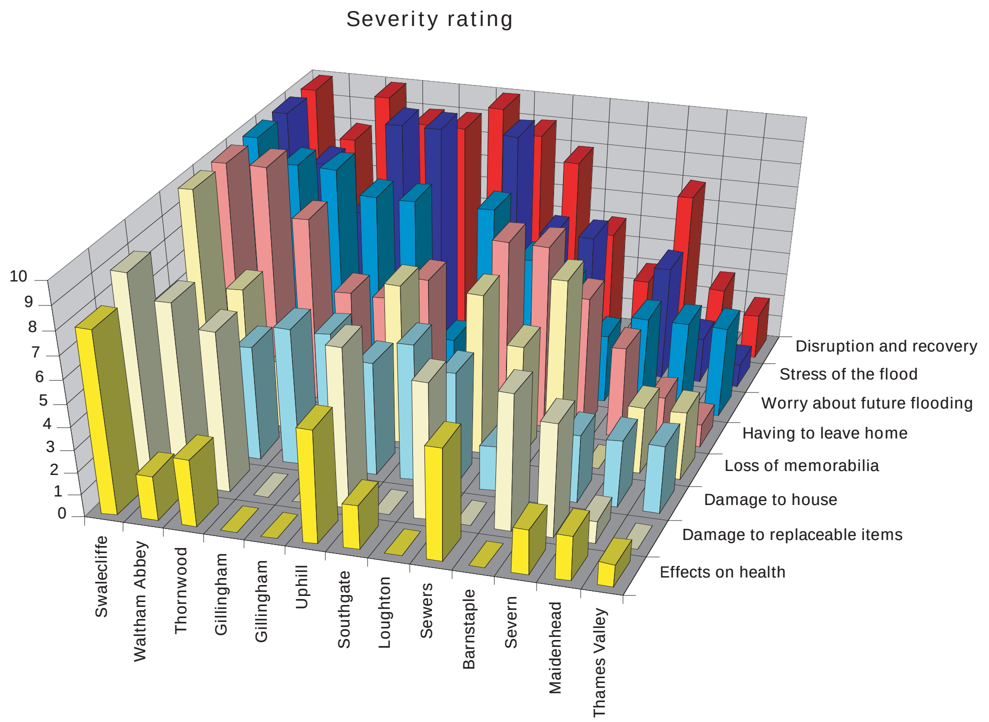
- The risk to life; the conditional chance of death should a flood occur varies dramatically between contexts.
- All of the unpriced or 'intangible' impacts of flooding on households, and specifically to include the stress caused, the damage to health and the quality of life, and the sheer disruption caused to people by flooding.
- Variations in the vulnerability of different groups within the community.
- The impact on the long-term viability of a community if some economic or other activities permanently leave the area as a result of a flood problem.

Interactions with other drivers

There are links to Urbanisation and Rural Land Management in that those more affluent, with more property assets, suffer significantly less from some of these social impacts. They recover more rapidly from flood events, thanks to their savings.

There may also be links to Public Attitudes and Expectations in that these are driven by experience of flooding, and also to insurance cover, which declines with personal and household income. The driver Stakeholder Behaviour is probably interrelated with Social Impacts – those who suffer impacts come to behave as stakeholders in a more vociferous manner than others.

Figure A8 **Subjective assessments by flood victims of the relative severity of the different impacts of flooding**



Case examples

Interviews with flood victims in the UK shows that the social impacts are very site-specific (see Figure A8). Following a flood at Uphill, Somerset, one woman spoke of her adopted son who had died when he was 18: the flood destroyed all the photographs of him and it was as if she 'had lost him twice'. Another woman lost the hand-written recipes she had collected throughout her marriage: 'her whole life gone'.

Table A13 **Driver impact scores for Social Impacts**

Driver	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Social Impacts	6.0	19.8	2.2	3.6	3.0	6.1	2.2	3.2

Driver changes and flood risk

The impacts of flooding on the population are entirely irrelevant in the World Markets scenario: in the libertarian worldview, individuals are solely responsible for taking action to manage risks. Given also that nature is seen as both there for human exploration, and to be conquered, those who fail are morally inferior. Those who are flooded and do not recover rapidly and easily will thus suffer twice.

In the National Enterprise scenario, pressure groups will be more likely to capture government policy and help will be provided through bureaucratic social services.

Under Local Stewardship, those who are flooded are seen as having ‘sinned’ by locating in an area that properly belongs to the river. However, this view will come into conflict both with the concurrent ethos of communal solidarity and the practicalities of a country that has to support a high density of population. Those who are flooded will consequently argue that they had no choice. If they are successful, they can expect support, but those who fail cannot.

The ethos of communal solidarity in the face of natural disasters that characterises the Global Sustainability scenario, and hence the duty to help each other, results in efforts to identify those most vulnerable and those least able to cope with both the risk of flooding and the occurrence of flooding.

Importance and uncertainty

To flood victims, this driver is highly important, but they form a minority within society. Those flooded almost invariably report that ‘intangible’ impacts of the flood were much more severe than their financial losses, with between 40 and 70% also reporting adverse health effects.

The risk to life in a flood is largely determined by the velocity of flow, so the risk is greatest in small, flashy catchments and behind fixed defences if those defences fail. In addition, occupied areas below ground level obviously pose a potentially catastrophic risk. Underground railway stations are an obvious example.

Vulnerability is greatest in those communities or individuals with the least coping capacity, where, conceptually, this coping capacity is a function of the degree of individual and collective resources that they can mobilise.

The flood-management community wants to promote improvements in flood management primarily to reduce the risk to life and to reduce the suffering that flooding causes to those affected by flooding. Flood and coastal defence are then justified in terms of the resulting reductions in the losses to property. The reason for this apparent paradox is that to date it has not been possible to estimate with any reliability the risk to life presented by a specific flood.

In terms of uncertainty, flood victims always report that the degree of social support they received from friends, relatives and others was very important to them in recovering from the flood. It is reasonable therefore to expect social support to be important. We should expect the extent and nature of social support, and related parameters such as social capital, to differ between the scenarios. Equally, it will vary between ethnicities. However, it has never been possible to show statistically that social support has any effect in ameliorating any effects of flooding.

Native parameter

The complex of variables in the strategic flood risk assessment known as the Social Flood Vulnerability Index is intended to capture some of these social impacts, although the results suggest that this index is not necessarily valid at a national level of analysis. It only differentiates between socially vulnerable groups at a regional/local scale.

Recommendations for research

Research in this field is in its infancy. Researchers and their sponsors need to take advantage of all flood events to collect more data that will unravel the complexities of this topic.

Driver

A19: Science and Technology

Driver group: Socioeconomics
Type: Receptor

Definition and operation

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

We pursue and deploy science and technology to advance our economies and societies. We can summarise the output (O) of an economy as being:

$O = NE * T * H * X$

Where

- NE is the natural endowment
- T is technology
- H is human inputs of labour and capital
- X is some other factor which may include institutional form as well as other factors such as social capital and social adaptability

Hence the role of T * X is to maximise the ratio of O to NE * H, given that NE is fixed and H is relatively fixed in the short term. Science and technology acts in two opposite directions:

- Usually to increase flood losses as technological advance seems typically to increase our assets' susceptibility to flood damage.
- To improve our capacity to manage floods successfully so as to increase the overall ratio of O to NE * H (this is technology etc. as a pathway variable). Our objective in flood management is to increase this ratio rather than to minimise flood losses *per se*.

Interaction with other drivers

Many other drivers interact here through scientific understanding of their operation. Science and Technology is probably correlated with Urbanisation, in that both are correlated with the economic growth of a nation, and perhaps in turn with Public Attitudes and Expectations of science-led flood protection.

Case example

Research at Middlesex University has recently shown the effect of changing technologies on flood damages. For retail shops the damage potential of flooding at depths of about 0.3 metres increased almost three-fold in real terms between 1987 and 2002. This change was a result of the near-universal shift over this period to electronic stock and sales accounting equipment (mainly electronic tills and the information processing systems that serve them), the cabling systems for which are ground-level located. The same trends were also observed in warehouses, and offices, where modern computer equipment has replaced the typewriters of 'yesteryear', thus hugely adding to flood damage potential.

Driver changes and flood-risk impacts

The form of scientific and technological effort, and consequent advance, will vary according to the scenario. Given the scenario, the areas in which innovation will take place are largely predetermined.

Thus, for example, under the Local Stewardship scenario, since fossil-fuelled vehicles could have been banned, there will be no significant development in fuel efficiency of these engines. Similarly, under the same scenario, there will be no attempt at research on the control of precipitation, as to do so would be contrary to that scenario's concept of a respect for nature. Again, there would be no research or development on geo-textiles to protect floodbanks as only natural mechanisms would be acceptable. But, since this scenario is not that of a Luddite community, there will be targeted advances in 'low' science and intermediate technology.

In the other scenarios, there would also be differences in the focus and nature of the research undertaken and the funding of research, and hence in the advancement that this effort can bring.

So, for example, in the World Markets scenario, flood research concentrates on that which can be marketed, notably flood-protection technologies for individuals, such as flood proofing. Under the Global Sustainability scenario, research concentrates on the means of reducing the risk of flooding to all, commensurate with enhanced environmental protection, for example, through wetland storage. But, irrespective of the scenario, technological advance would seem to be associated with increased susceptibility to flooding, since the character of technological advance results in smaller, purer, more-detailed products, consumer or industrial, which in turn are more susceptible to water damage and to the contaminants carried by the flood water.

However, a number of possible paradigmatic shifts are currently under way, although, like all paradigm shifts, these are contested. For example, the implications of undertaking flood management as part of Integrated Water Resources Management have yet to be fully articulated, although the Global Water Partnership/World Meteorological Organisation have sought to develop some of the implications. Similarly, it is being argued that we should shift from a largely static ‘frequentist’ approach towards risk, to a conceptualisation of risk in terms of process or change; one that, for example, takes account of antecedent conditions.

Importance and uncertainty

The driver Science and Technology potentially outweighs any other factor since it is this combination of T * X that generates the anticipated increase in real national income into the future (see above). But uncertainties here are necessarily large and the paradigm shifts are unforeseeable. It is the nature of science to discover things that we did not know we did not know. Uncertainty is inherent, and expectations are generally unreasonable.

Recommendations for research

The nature of flood management under very different scientific and technological regimes in the future warrants analysis, as does the effect of technology and engineering practice in the past on the effectiveness of different drivers and flood-management responses. We can learn much from the past when thinking about the future.