Foresight
Future Flooding

Scotland

Alan Werritty with John Chatterton

This report has been produced by the Flood and Coastal Defence project of the Foresight programme. Foresight is run by the Office of Science and Technology under the direction of the Chief Scientific Adviser to the British Government. The findings contained in this and other project reports do not constitute Government policy. Foresight creates challenging visions of the future to ensure effective strategies now.

Chapter 1

Introduction

A great deal has already been achieved by the authorities in Scotland to understand and manage flood risk. However, the potential effects of climate change will pose particular challenges for the region in the future. It was therefore decided to build on the work of the rest of the Foresight Flood and Coastal Defence project and deepen the analysis specifically for Scotland. This report presents that further analysis and should be read in conjunction with the other reports (see page 69).

We analyse the drivers of future flooding and coastal erosion identified in Volume I of the project to:

- Indentify how they operate and interact differently in Scotland.
- Assess the magnitudes of their impacts on flood risk.
- Rank the importance of the drivers for Scotland for four future scenarios over the period 2030 - 2100.

We also assess the possible future economic dimensions of flooding in Scotland. In so doing, the work takes special note of climate change, relative sea-level change, differences in the institutional framework and land use. This study compared the findings for the whole of the UK with the literature on flood risk and coastal-defence risk in Scotland to ascertain similarities and differences.

The authors are grateful for advice from the following experts who were consulted in meetings and in writing:

- Philip Wright (Scottish Executive)
- Alan Burdekin (Scottish Executive)
- David Faichney (Scottish Environment Protection Agency)
- Dr Jim Hansom (Glasgow University)
- Dr Andrew Black (Chairman, Scottish Hydrological Group, Dundee University)
- Professor Alan Ervine (Chairman, Department of Civil Engineering, Glasgow University).

The authors also acknowledge a major contribution made by Entec in sections 3.1 and 3.2 which is derived from Werritty *et al.* 2002.

Chapter 2

Drivers for future flood risk and coastal-defence risk in Scotland

2.1 Flood management

The history of managing flood risk in Scotland has been strikingly different from that in England and Wales. As early as the 1800s, drainage of wetlands, bank revetment and the construction of flood embankments on fertile valley floors by private landowners had reduced flood losses and resulted in the local stabilisation of active gravel-bed rivers (Werritty and Hoey 2002; Smout 2000).

The equivalent of the Inland Drainage Boards in parts of England never developed in Scotland. The costs of flooding, while locally significant, only rarely attracted regional or national attention, for example, the Borders flood of 1948 and the Moray floods in 1956 and 1970. The drive to drain wetlands and increase the productivity of arable agriculture after the Second World War was much less in Scotland than elsewhere in the UK.

The history of hydrometry in Scotland was also different. The pioneering work of McClean from 1915 onwards primarily set out to promote the hydroelectric power generating potential of the Highlands.

It was not until the 1950s, following the creation of River Purification Boards, that the development of an extensive river gauging network to assist in regulating water quality and sustaining commercial fisheries became a national priority. Flood-warning schemes, based on this hydrometric network, came much later, in the 1970s, following a series of damaging floods. The Scottish Environment Protection Agency (SEPA) came into being in 1995 and inherited its predecessors' permissive powers to operate flood-warning schemes.

The Flood Prevention (Scotland) Act 1961 provided discretionary powers to local authorities, which could be used outside a council's administrative boundary, to mitigate the flooding of non-agricultural land in their areas.

In contrast with England and Wales, flood-risk management is less centralised in Scotland. Duties and responsibilities are distributed between riparian owners, central and local government, and SEPA.

The Scottish Executive Environment and Rural Affairs Department (SEERAD) is responsible for developing national policy on flood prevention and flood warning and provides 50% grant aid for confirmed flood-prevention schemes developed by local authorities.

Local authorities: lead on developing flood-prevention schemes; are responsible for town and country planning and the maintenance of watercourses whose condition could cause flooding of non-agricultural land; and (with the emergency services) co-ordinate emergency action during and immediately after floods.

SEPA is a statutory consultee on planning applications where a flood risk is identified. It provides general flood alerts for the whole of Scotland via a *Floodwatch* service and operates local flood-warning schemes in partnership with local councils and the emergency services.

The Water Environment and Water Services (Scotland) Act 2003 (WEWS) introduced a general obligation on Scottish Ministers, SEPA and responsible authorities to promote sustainable flood management in the discharge of their relevant functions. It is intended to designate local authorities and other relevant public bodies as responsible authorities.

2.2 Flood prevention

Under the *Flood Prevention (Scotland) Act 1961,* flood prevention on non-agricultural land is a discretionary power of local authorities. Confirmed flood-prevention schemes meeting the Scottish Executive's criteria are eligible for 50% central government grant aid.

With the *Flood Prevention and Land Drainage (Scotland) Act 1997,* additional duties were placed on local authorities. The most important is the duty to maintain urban watercourses free of obstructions and to assess the flood hazard. Seventy flood-protection schemes have been built under the 1961 Act, providing protection to less than 10% of the 77,191 properties estimated to be at risk from inland flooding (Werritty *et al.* 2002). This contrasts with schemes in England and Wales, which provide protection to approximately 70% of the 1.74 million properties potentially at risk from inland and coastal flooding.

The Scottish Executive has substantially increased the resources made available to local authorities since 1999 when annual capital expenditure on flood prevention/coast protection was £4 million. Some £40 million is to be spent over the period 2003-2006 providing protection for a further 1,850 properties. Some recent schemes have combined upstream storage with local flood embankments. This programme of flood prevention is set to continue for the foreseeable future, providing the schemes meet national standards and the required benefit-cost ratios.

At present, there is no detailed inventory of existing flood-protection schemes – location, standard of protection and number of properties protected. However, a national flood defence database should exist by 2005 as part of the *National Flooding Framework.*

2.3 Flood-risk assessment

Most flood-risk assessment undertaken in conjunction with planning applications are subject to the *SEPA-Planning Authority Protocol* (SEPA, 2000). *Scottish Planning Policy* 7 (SPP 7) *Planning and Flooding* (Scottish Executive 2004) says that new development should not take place if it would be at significant risk of flooding from any source or would materially increase the probability of flooding elsewhere. For watercourse and coastal flooding it sets out a 'risk framework' which defines undeveloped areas with a flood probability above 0.5% as medium to high risk and generally unsuitable for new development. When SEPA is consulted on flood risk to new development and recommends refusal, but the planning authority wishes to approve, they have to notify the Scottish Ministers who may call in the case for their own decision. Planning applications for sites potentially at risk should be accompanied by a flood-risk assessment. This can variously be based on methods recommended in the *Flood Estimation Handbook* (Institute of Hydrology, 1999), the *Flood Studies Report* (Natural Environment Research Council, 1975) or, where neither of these is deemed suitable, an appropriate rainfall-runoff model. In judging such assessments, local authorities seek guidance from SEPA as a statutory consultee, often using Indicative Floodplain Maps based on the *Institute of Hydrology Report 130* (Morris and Flavin, 1996), extended to Scotland in 2000, and augmented by data on historical flood events. These are the only nationally consistent flood-risk maps producing flood depths for a flood with a nominal 100-year return period. However, they are highly generalised, take no account of existing flood defences and exclude the coastal tidal zone.

Second-generation Indicative Floodplain Maps based on Synthetic Aperture Radar (SAR) are planned for the whole of Scotland by the end of 2004. Given a much improved vertical resolution of about 1 metre, they will delineate the 1 in 100-, 200- and 1,000-year flood outlines. Maps delineating existing flood defences will accompany these maps of flood outlines. As with the Environment Agency's existing flood-risk maps, these second-generation Indicative Floodplain Maps will be available to the public on the Internet.

Since the first national policy guidance was published in1995, most local authorities have convened Flood Appraisal Groups (now called Flood Liaison and Advice Groups). The groups provide a forum for key public and private interests to share knowledge and offer advice on a wide range of flooding issues. The groups now cover more than 98% of Scotland's population and have successfully allowed effective representation of diverse institutional stakeholder interests at the local and regional level (Tavendale and Black, 2003).

These groups, which are unique to Scotland, have not been introduced in England and Wales, and have attracted positive comments from the insurance sector (Werritty *et al.* 2001, Crichton; 1998).

Pluvial flooding away from the floodplain is difficult to characterise in terms of flood risk. It typically occurs in built-up areas where urban drainage is poorly maintained or overloaded. While Sustainable Drainage Systems (SUDS) are now frequently required for new developments, they are primarily designed to improve water quality rather than provide flood protection. However, when combined with soft engineering – the provision of detention ponds, for example – they can ensure that new development does not significantly increase flood risk.

Scottish Water's current investment programme includes end-of-life replacement of aged urban infrastructure and a programme of drainage area studies to inform future investment needs. Having identified locations where pluvial flooding is a significant and recurrent risk, local remedial solutions are being developed. Pressure is also likely to fall on local authorities to improve and upgrade their maintenance programmes for urban watercourses in conjunction with Scottish Water.

Scotland has led the rest of the UK in developing SUDS. By placing a duty on Scottish Water to take over the maintenance of SUDS schemes in the *Water Environment and Water Services Act, 2003,* it is anticipated that the risk of pluvial flooding will be ameliorated in new and future developments.

Given Scottish local authorities’ wider flood-management responsibilities for flood prevention, planning and emergency response, there are no specific proposals to develop Catchment Flood Management Plans in Scotland, comparable to those developed by the Environment Agency. Instead, ‘sustainable flood management’ will be achieved within the River Basin Management Plans required by 2009 under the EU Water Framework Directive.

2.4 Flood warning

Following the introduction of *Floodline* in Scotland in November 2001 and the development of *Floodwatch,* flood warnings are now available across the whole of Scotland, based on the service initially developed by the Environment Agency for England and Wales. In addition, SEPA uses permissive powers to operate 42 more detailed flood-warning schemes which provide a minimum of three hours’ warning.

In general, these schemes have been reactive, following major floods. They are based on simple rainfall-runoff models, whereby upstream rainfall and flow levels are modelled and routed downstream. Weather radar is also used qualitatively to improve flood forecasts. These more detailed flood warnings, also available via *Floodline,* use the three standard codes – ‘flood warning’, ‘severe flood warning’ and ‘all clear’ – which apply across the whole of Great Britain and are broadcast on radio and television.

Flood warning is more problematical for pluvial flooding in urban areas. However, given recent improvements, it should soon be possible to provide warnings derived from quantitative estimates of rainfall based on weather radar.

Hitherto, the police have disseminated flood warnings to the general public. This provision is under review and has already been withdrawn in some parts of Scotland. With advances in automatic voice messaging services, responsibility for the dissemination of flood warnings to the public may, in the near future, pass directly from the police to local authorities, which will arrange for their wider dissemination.

2.5 Coastal flooding

As with inland flooding, under flood-prevention legislation, local authorities can apply for grant aid to undertake coastal defence works to prevent flooding. Private developers can also provide coastal flood protection but require planning approval from the relevant local authority which will seek guidance from SEPA in accordance with *Planning and Flooding (SPP7,* Scottish Executive, 2004).

Local authorities with coastal frontage also have powers under the *Coast Protection Act 1949* to undertake coast protection works where there is a threat of shoreline erosion. Grant aid of between 20% to 80% is available for such schemes, which require planning permission.

There are few Shoreline Management Plans (SMPs) in Scotland for several reasons. This is partly because the concept of coastal cells, to which they often attached, is less well suited to the Scottish coastline, and partly because the link between SMPs and grant aid from central government is less well developed in Scotland than in England and Wales (McGlashan, 2002). Scottish Natural Heritage (SNH) has facilitated coastal fora to promote integrated coastal-zone management, but these bodies lack statutory powers and long-term funding.

Managed realignment of the shoreline is beginning to emerge as a strategy to help to meet the UK's biodiversity targets under the EU Habitats Directive (RSPB, 2002). Given potential sea-level rise by the 2080s, especially in some Firths, and the continued decline in the condition of private, agricultural defences, (see section 2.8.1) managed realignment of these may also emerge as a limited flood prevention strategy later this century.

Since 2000, SEPA has operated one coastal flood-warning scheme, on the Clyde estuary. This was in response to annual flood losses exceeding £0.5 million in Saltcoats, Tarbert, Rothesay and Dumbarton. The threat posed by rising sea levels and increased storm surges will also increase the flood risk for low-lying coastal areas in the major estuaries and those parts of Edinburgh, Glasgow and Dundee lying below 5 metres (Werritty *et al.* 2002).

2.6 Fluvial systems and processes

2.6.1 Morphology

Scottish rivers display a greater range of morphologies than exists across much of the UK. This reflects a higher proportion of active, gravel-bed rivers, many originating in the uplands. These rivers, with steeper gradients and coarser bed materials, have the ability to rework their valley floors unless constrained by bank reinforcement.

Scotland has proportionately fewer examples of the sand/silt-bedded inactive channels, common throughout lowland England, that have undergone large-scale channelisation and drainage. Many of Scotland's largest rivers – the Tay, Dee, Spey and Tweed – retain gravel beds to their marine limits and contribute significant volumes of sediment into their estuaries.

Many gravel-bed rivers in Scotland have exhibited significant lateral shifts during 'flood-rich periods' since the 1850s. If this continues into the warmer, wetter Scotland predicted for the 2080s under the World Markets High emissions scenario, this shift could locally place the river outside its indicative floodplain. This behaviour is especially evident in active upland rivers with minimal bank reinforcement (Werritty and Leys, 2001).

Channel shifting has also been reported on alluvial fans (Werritty, Hoey and Black, 2000) where localised aggradation and channel instability often increases the flood risk, resulting in dredging, channelisation and bank reinforcement. Most alluvial fans within Scottish valleys have been repeatedly engineered to mitigate these effects. This form of river management may become more prevalent in the Scottish uplands if flood flows and sediment yields increase through to the 2080s. While reducing flood risk, such river engineering is often inimical to biodiversity and continues to be contested by SNH and environmental NGOs.

Larger rivers, such as the lower Tay and the Aberdeenshire Dee, display a higher degree of stability. In part, this reflects piecemeal river engineering that dates back many decades (McEwen, 2001). As a result, there is no evidence of consistent channel widening, like that reported on the non-tidal Yorkshire Ouse (Lane, 2001), during the most recent ‘flood-rich’ period. Indeed, a recent investigation of Scottish rivers – for long-term widening, channel migration or incision – found few such trends and reported instead high variability within the same river from time to time and from place to place (Werritty and Hoey, 2002). Despite widespread overtopping and breaching of embankments during recent major floods – for example, on the Tay in 1990 and 1993 (Gilvear and Winterbottom, 1992) – there is also no evidence of either degradation of flood defences by channel widening or an increase in the standard of protection by channel deepening in recent decades.

2.6.2 Conveyance

Flow conveyance depends, in part, on vegetation in stream and within the channel. Management of seasonal within-channel vegetation to improve flow conveyance – characteristic of fine grained, stable rivers in lowland England – is not a major issue in Scottish rivers. This may reflect, in part, the lower levels of eutrophication generally reported for Scottish rivers and lakes (Harriman and Pugh, 1994) with only a few sites reporting significant enrichment by nitrates (Ball and MacDonald, 2001).

More significant in terms of potential flood damage is the loss of riparian trees, generally alder, during major floods. These trees can constrict flows through bridges and can create local flow surges as temporary timber dams break. The statutory requirement on riparian landowners to keep watercourses free of such obstacles reflects the potential occurrence and damage associated with the loss of riparian trees.

2.6.3 Environmental Regulation

The key drivers here are the EU Water Framework Directive and Habitats Directive and legislation passed by the Scottish Parliament. The Water Framework Directive has already passed into Scottish law, through the *Water Environment and Water Services (Scotland) Act, 2003 (WEWS).* The resulting River Basin Management Plans, due by 2009, will require rivers, lakes, estuaries and coastal waters to achieve good ecological status by 2015.

Scotland has no statutory requirement for Catchment Flood Management Plans. However, WEWS does require ‘sustainable flood management’ to be implemented by the responsible authorities. For some rivers, this may be achieved by restoring wetland habitats and by enlarging floodplain storage, reducing flood risks downstream.

In recent Scottish schemes the appropriate solution has often been a combination of upstream storage and downstream flood embankments. This looks set to continue and possibly increase given the need to protect physical habitats under various EU Directives and to achieve UK targets in terms of Biodiversity Action Plans. Under current legislation, environmental remediation to existing flood defences are unlikely as these are already covered by derogation powers or heavily modified waters provisions. However, new flood-protection schemes may be required to meet more demanding ecological objectives. The link between this driver and regulation makes it very sensitive to different Foresight Futures.

2.7 Climate change (inland)

Predicting the impact of climate change on flooding in Scotland inevitably draws upon much of the same literature as that summarised for England and Wales. In particular, future flood flows are based, in part, on the UK Climate Impacts Programme 1998 (UKCIP98, Hulme and Jenkins, 1998), the UK Climate Impacts Programme 2002 (UKCIP02, Hulme *et al.* 2002) and the Hadley Centre’s global circulation models, HadCM2 and HadCM3. However, the Scottish Executive also commissioned a special study based on the regional climate model (HadRM2) with a spatial resolution of 50 km. This provided improved precipitation characterisation for Scotland in the 2080s, based on UKCIP98 scenarios (Hulme, Crossley and Lu, 2001) in advance of the release of the UKCIP02 findings.

2.7.1 Precipitation

Annual and seasonal changes

Annual and seasonal changes in precipitation for Scotland, in terms of UKCIP02, vary greatly according to location and scenario. Annual changes are from 0 to -10% for all scenarios across the whole of Scotland, but this becomes sharply differentiated at the seasonal level. The most extreme seasonal changes for low emissions are in the winter where, by the 2080s, increases of 10 to 15% are predicted for the east of Scotland, declining to less than 10% or even within natural variability for the west. However, it is important to note that in absolute terms the west remains markedly wetter than the east on account of the marked west-east precipitation gradient.

High emissions of greenhouse gases, under the World Markets scenario, will accentuate these contrasts by the 2080s, with winter increases exceeding 25% in the east but being less than 15% in the north-west. Again, this means the west will still be substantially wetter than the east in absolute terms, and thus more likely to experience winter floods.

Summer precipitation decreases of 10-20% in the north and 20-30% in the south of Scotland are predicted by the 2080s under the low emissions (Global Sustainability) scenario. These become reductions of 20-40% in the north and more than 40% in the south under the high-emissions World Markets scenario.

Long-duration rainfall

The Autumn 2000 floods in England and Wales were the result of extreme long-duration rainfall. Under UKCIP02, one might expect such events to increase, especially in the winter half of the year. However, floods caused by long-duration rainfall are rare in Scotland. More typical is the slow-moving frontal system with embedded high-intensity cells of rainfall but rarely lasting more than 48 hours. When associated with an already wet catchment, such frontal systems can generate severe regional flooding, such as the Strathclyde floods in 1994. The frequency of such extreme 48-hour rainfalls is likely to increase by the 2080s, especially in the west during the winter months when a stronger westerly airflow over Scotland is anticipated.

Changes in daily and short-duration rainfall

Daily and short-duration rainfall is very important. Culverts and urban drainage systems are designed to cope with daily rainfalls likely to occur once in n years. The 'once in two-year daily rainfall' varies from 50 mm in Highland Scotland to 20 to 25 mm in south-east England in winter. By the 2080s, all of the UK, apart from north-west Scotland, is likely to see an increase in the 'once in two-year rainfall', according to UKCIP02. This increase could exceed 20% in eastern Scotland under the medium-high emission (National Enterprise) and high emission (World Markets) scenarios. In summer, this is predicted to reverse, with daily rainfall intensities falling by 10-30%. More detailed studies (Lang, 2003) on short duration storms in the 2080s suggest that the two-hour duration (1 in 30 year) rainfall could increase by 60% in Edinburgh, overwhelming the capacity of the current urban drainage systems.

Effect of changes in precipitation on floods

Various groups have investigated the impact of climate change on floods in Scotland (Werritty *et al.* 2002; Price and McInally 2001; and Reynard and Brown 2003; see also Volume I of the main Foresight FCD report). In the first of these studies, working with UKCIP98 scenarios, values for the 1- in 10-, 20-, 50- and 100-year floods were determined for nine river basins, based on predictions of future rainfall for the 2020s, 2050s and 2080s, using a lumped conceptual rainfall-runoff model (Arnell, 1996) and standard flood-frequency analyses, fitting a General Extreme Value distribution to the annual maximum series. Six of the nine basins reported a marked increase in the size of the t-year flood by the 2080s for the high emissions (World Markets) scenario: 8-28% for the 1 in 50-year and 8-29% for the 1 in 100-year flood. When converted into a reduction in the standard of protection, the 1 in 50-year flood was reduced to within the range of the 1 in 17 to 37-year event (Table 1).

Table 1 **Revised return periods (in years) for selected rivers basins using four scenarios in the 2050s and 2080s based on the flow for the present-day 50-year flood in each basin (Werritty *et al.* 2002)**

Foresight Futures 2002	**River Findhorn**	**River Don**	**Ruchill Water**	**River Almond**	**Lyne Water**	**River Clyde**
2050s						
World Markets	38	42	43	38	31	26
National Enterprise	39	44	43	40	33	28
Local Stewardship	42	46	45	42	36	32
Global Sustainability	46	48	47	45	40	37
2080s						
World Markets	30	32	37	31	20	17
National Enterprise	32	34	38	32	22	19
Local Stewardship	40	44	44	40	33	28
Global Sustainability	46	48	47	44	37	34

A simpler analysis, based on the rainfall-runoff model in the *Flood Studies Report* (NERC, 1975), noted that a 10% increase in depth of rainfall generated an 11.5% increase in peak flows (Price and McInally, 2001). Using the north of Scotland growth curve, such an increase in flood flow reduces the 1 in 50-year event to a 1 in 30-year event. This scales to a 1 in 40-year event when storm rainfall is increased by 5%, and a 1 in 15-year event when storm rainfall is increased by 30%. In the Foresight FCD technical documents, Reynard and Brown report changes in the 1 in 50 year flood for the north of Scotland and south of Scotland based on UKCIP02 scenarios for the 2050s and 2080s (see Table 2).

This work is based on perturbing a continuous rainfall-runoff model previously used to assess the impact of climate change on the Severn and Thames (Reynard, 2001). It is striking that under the high emissions (World Markets) scenario they predict a 25-30% increase in the 1 in 50-year peak flows in north and south Scotland, broadly in line with the two earlier studies. Their values of a 18-20% increase in peak flows by the 2050s is consistent with the reported 8-28% increase in the 1 in 50-year floods (Werritty *et al.* 2002). All three studies stress the provisional nature of their findings and urge caution in interpreting them. However, within a few years it should be possible to conduct a more robust analysis of regional change in peak flows using the UKCIP02 scenarios and continuous rainfall-runoff models.

2.7.2 Temperature

Across the UK as a whole, annual warming of between 1° and 5°C is predicted for the 2080s under UKCIP02. However, there is pronounced north-west/south-east gradient with the south-east warming by more than 4°C by the 2080s under the high emissions (World markets) scenario.

For Scotland, the comparable predictions are annual warming up to 3.5°C, with up to 4°C in the summer, in the east, but only up to 2°C in the winter. This implies that the increased soil moisture deficits, which it is anticipated will reduce summer floods in southern England, will not be so highly developed in Scotland. However, the increase in average temperature could impact on high-intensity rainfalls given an increased water-vapour content. Thus, Hulme *et al.* (2001) note that the 1 in 2-year daily precipitation in Scotland is set to increase by 15% for each 1°C of warming in the autumn. Given the sensitivity of urban drainage systems to high intensity storms, even modest increases in temperature could quickly affect urban flood risk.

Table 2 **Percentage change in peak flow for 10 hydrometric regions (compared with baseline period 1961-90) representative of changes in 1 in 50 year flood (Reynard, Foresight FCD technical documents)`**

Hydrometric region			World Markets	National Enterprise	Local Stewardship	Global Sustainability
1. N Scotland	2050s		18	14	11	8
		2080s	25	21	16	12
2. S Scotland	2050s		20	16	13	10
		2080s	30	25	20	15
3. Northumbria	2050s		9	7	6	5
		2080s	11	9	8	7
4. Trent	2050s		5	5	4	4
		2080s	10	8	7	5
5. Anglian	2050s		3	2	1	0
		2080s	6	5	4	3
6. Thames	2050s		1	1	0	0
		2080s	2	1	-1	-3
7. Southern	2050s		-6	5	-4	-3
		2080s	-12	-10	-8	-6
8. South-West	2050s		8	7	6	5
		2080s	14	11	9	6
9. Wales	2050s		10	8	7	6
		2080s	18	15	12	8
10. North-West	2050s		8	7	6	5
		2080s	14	11	9	6

2.7.3 Snow

Winter floods in Scotland can have a strong snowmelt component. The 1993 flood on the Tay, the highest flow ever recorded on a British river, provided a striking example (Black and Anderson, 1994). Despite a modest increase in winter precipitation in the Scottish mountains under UKCIP02 scenarios, the increased winter temperatures mean that more will fall as rain rather than snow. Harrison *et al.* (2001) using an analogue model predict that, by the 2080s, the average number of days with snow lying at elevations above 800 metres in the Highlands will fall by 8-24% under the National Enterprise (medium-high emissions) scenario. In lowland southern Scotland, the risk of snow will almost disappear: even in the north-east snow cover between 100-400 m will fall by 40-70%. This implies a steady reduction in the risk of major snowmelt floods by the 2050s and 2080s.

2.8 Human Behaviour

2.8.1 Stakeholder Behaviour

Institutional differences in flood management (see Section 2.1) have created a different mix of stakeholders in Scotland from that in England and Wales. In Scotland, the key stakeholders, other than riparian landowners, are those whose properties are threatened by floods, local authorities, Scottish Executive, SEPA and environmental NGOs. Nevertheless, the resulting policies and their implementation reflects the common thread of public bodies with permissive powers supported by central government grant. The accompanying duties and powers of the public bodies are related, for example SEERAD vis-à-vis Defra and local authorities/SEPA vis-à-vis Environment Agency/local authorities/Inland Drainage Boards (see Section 2.1).

In rural areas, grant-aided land-drainage schemes dating back to the late 1930s have protected agricultural land against modest events, i.e. the 1 in 5 to 1 in 10-year flood. Many of these schemes, already damaged by major floods in the 1990s, have fallen into disrepair with the steady erosion of agricultural subsidies. They are unlikely to be reinstated following future floods, especially given the pressure to increase storage on the floodplain where possible.

Pressure for 'new build' within the indicative floodplains is much weaker in Scotland than in southern England. However, the need to provide new or upgraded flood defences for existing urban areas is likely to increase.

2.8.2 Social Impacts

Recent floods in Perth (1993), Strathclyde (1994) and Glasgow (2002) revealed high flood losses within low-income groups, with many uninsured households. Higher levels of mental illness were registered locally following the Perth flood. This is likely to be repeated in other areas if pluvial flooding, such as occurred in Glasgow in 2002, becomes more common.

2.8.3 Public Attitudes and Expectations

During the 1990s, public attitudes and public expectations have locally been sharpened following floods in Perth, Strathclyde, Glasgow and Elgin. Although the impacts of these floods were localised, widespread media coverage heightened public awareness of flooding. This has increased pressure on local authorities to bring forward new schemes in towns such as Kilmarnock and Elgin, and renewed demands on Scottish Water for the repair and replacement of ageing urban drainage systems.

In recent decades, Scotland resisted the imposition of neo-liberal solutions to social problems. This reflects a society in which communal solidarity is still fostered, and the promotion of unregulated self-interest is questioned. If this social fabric remains in place from the 2030s to 2100, the external imposition of a World Markets scenario would be highly problematical. Indeed, the response of a devolved Scottish Parliament could differ markedly from that which Westminster might adopt. By contrast, the current ethos of Scottish society would engage much more readily with the Global Sustainability scenario, with its emphasis on a communitarian response to natural disasters.

2.8.4 Urbanisation

Scotland is a highly urbanised society: 82% of the population live in settlements of more than 3,000 people, occupying only 2% of the land area (SNH, 2002). Scotland's population of 5.03 million in 2001 is projected to decline over the next few decades. In terms of pressure for new housing, this will be moderated by the needs of 150,000 extra single-person households, 90,000 extra adult-only households and 30,000 extra single-parent households within the next decade (Scottish Executive, 2002). Despite this pressure, the present policy of favouring brownfield sites over greenfield sites means that urban encroachment onto the floodplain should be containable through the implementation of national planning policy (notably SPP7).

The requirement to promote 'sustainable flood management,' including SUDS, as part of the process of river basin management planning by 2009 will also help to protect floodplains from unwise development. More problematic is managing the anticipated increases in the frequency and severity of urban flooding by the 2050s and 2080s. For these areas, holistic flood management, integrating urban drainage with the management of urban watercourses, is the most promising strategy. Locally this will require the upgrading of existing sewerage systems and improved storage (Lang, 2003).

2.9 Catchment runoff

2.9.1 Rural Land Management

Scotland has a varied pattern of land cover (see Table 3). Moorland and rough grazing account for 38% with improved pasture at 13%, especially in the south and west, and arable at 11%, especially in the south and east. All forms of woodland collectively constitute 15% of land cover, with coniferous plantations dominant (at 8%).

Table 3 **Scotland's land cover by broad groups (source: SNH (2002))**

Land cover group	**Area (km^2)**	**%**
Built	1,914	2
Arable	8,834	11
Grassland	19,847	25
Woodland	11,467	15
Bracken and scrub	522	1
Heather moorland	15,783	20
Peatland	13,922	18
Freshwater	1,669	2
Other	4,864	6
Total	**78,821**	**100**

The most important trends in land cover since 1950 are (SNH, 2002):

- *Intensification in agricultural land use* to maximise yields and produce cheap food. In arable areas, East Lothian for example, field sizes have increased and field trees and hedges have declined. Recent strong shift to winter cereals in Lothians, Fife and Angus.
- *Rapid expansion of coniferous plantations* (406% since 1940 mainly in the uplands) with some diversification in species planted in recent years. With harvesting of first crop, an opportunity to restructure and improve planting policy.
- *Broadleaf forests* recently promoted throughout Scotland (locally recreating former floodplain forests).
- *Peri-urban landscape* of new housing and business parks around many towns and cities replacing agricultural land-cover classes.

Since 2000, two national parks have been designated – the Loch Lomond and the Trossachs National Park and the Cairngorms National Park – but with weaker planning controls than in England and Wales. However, Scotland has 46 designated National Scenic Areas, covering 1 million hectares and with protection in terms of natural conservation.

Given this pattern of land cover and recent trends, the nature of the driver Rural Land Management in Scotland is as follows:

- *Upland land management and grazing.* The driver is broadly similar to that in Wales, where increased stocking densities are possibly linked with compacted soils and increased runoff. But this is likely to be short-lived if subsidies to hill farmers continue to decline. Indeed, were broad-leafed and coniferous forests to be re-established across rough grassland under a variety of scenarios, total runoff would be reduced due to increased evaporation.
- *Arable agriculture and soil husbandry.* The driver operates in a similar manner to that across much of lowland England. This is especially true for those parts of Scotland where winter sowing – cereals or oil-seed rape – leaves bare soil vulnerable to intense spring rainfall with ensuing erosion, causing blocked drains and culverts and localised rural flooding of dwellings and roads. But given that only 11% of land cover is arable, this is probably a less significant driver than for much of lowland England.
- *Field drainage.* This aspect of the driver is less significant in Scotland because there is less arable land on clay-rich soils to be drained. There is also less upland drainage of heather moorland than in northern England.
- *Afforestation.* This driver operates in a broadly similar manner across the uplands of Scotland, northern England and Wales. If ditching is necessary to improve drainage and thereby promote early growth, accelerated runoff will occur. However, this impact has been reduced by successful implementation of the *Forest and Water Guidelines*. Woodland is an important land cover type across Scotland, and is likely to increase if hill farming continues to decline.
- *Floodplain management.* There is at present limited use of floodplains/wetlands to provide temporary storage of floodwater. This could change with the implementation of the EU Water Framework Directive and the drive towards 'sustainable flood management'. This driver would then take on a much higher significance especially under the Local Stewardship or Global Sustainability scenarios if there is further development of upstream storage plus downstream structural defences.

2.9.2 Agricultural Impacts (receptor)

Flooding has a differential impact on agricultural and forestry land and on wildlife habitats. At present, the frequency and severity of rural flooding results in only modest losses to the agricultural sector, with reduced yields, loss of livestock and localised damage to soil structure. The increased flooding projected for all scenarios by the 2050s and 2080s will increase these losses if current agricultural activity remains unaltered. However, if there is further withdrawal of EU subsidies and pressures to use and manage floodplains in a more sustainable manner, agricultural use of floodplains could decrease over the next half century.

The impact of floods on forests varies according to species. While Scots Pines are damaged, some broadleaf species, such as Alder, thrive under periodic inundation. Projecting current policies forward, broadleafed, water-tolerant species are likely to replace more sensitive conifers in an attempt to recreate the former floodplain forests. Wetlands, such as shallow lochs and fens, benefit greatly from occasional flooding: this looks set to increase in all four scenarios.

2.10 Coastal processes

Determining future flood risk along the coastline is exceptionally complex. It requires the integration of changes in waves and surges, rising sea levels and changes in coastal morphology. For simplicity, we considered each separately below. In reality, they must be taken together and their differential operation around the coastline of Great Britain duly noted.

2.10.1 Waves and Surges

Coastal flooding is generally the result of storm surges and waves superimposed on mid-tidal levels. The most severe current storm surge elevations for the 1 in 50-year event are found along the East Anglian shoreline (2.5 m) and between Liverpool and Morecambe Bay (2 m). Comparable values for Scotland are less than 1.25 m.

Significant wave heights that are exceeded 10% of the year and that can breach structural and natural defences, such as shingle barriers or dune ridges, permitting flooding in their lee, are locally 2 to 2.5 m on the west coast and 1.5 to 2.0 m on the east coast (British Oceanographic Data Centre, 1998).

The most severe storm surge in the last century occurred in 1953. It generated elevated water levels of 2.97 m at King's Lynn and 3.36 m in the Netherlands. Given that surges in the North Sea normally intensify as they move south, elevated water levels in 1953 were much lower along the Scottish coast, with Aberdeen recording 0.6 m and Leith 0.82 m (Hickey, 2001). In general, storm surges represent a less severe threat in Scotland on account of the lower levels expected and the higher proportion of rocky coasts. Nevertheless, according to UKCIP02, storm-surge elevations, when coupled with projected sea-level rise, could increase by up to 0.8 m around Scotland by the 2080s under the worse-case (World Markets) scenario. This could reduce the return period of the current 1 in 50-year event to 1 in 5-years or less (see also Price and McInally, 2001).

2.10.2 Relative Sea-Level Rise

Relative sea-level rise for the British Isles involves the sum of global effects (mainly thermal expansion of the upper ocean), and vertical land movement (subsidence/uplift mainly due to glacio-isostatic adjustment following the melting of the last ice sheet). UKCIP02 has recently estimated the impact of thermal expansion of the upper ocean on future British sea-levels for all four scenarios for the 2080s. When combined with Shennan and Horton's (2002) revised estimate of mean uplift and subsidence during the late Holocene, sea-level rise to the 2080s (relative to 1990) can be predicted for the scenarios World Markets/High emissions and Global Sustainability/ Low emissions (see Table 4).

Table 4 **Relative sea-level rise scenarios to the 2080s and regional uplift/subsidence around the coastline of the UK. Based on Shennan and Horton (2002) replacing Table 12 in Hulme *et al.* (2002). Subsidence is negative.**

Region	**Mean uplift/ subsidence (mm/yr)**	**Relative sea-level rise scenarios to the 2080s (cm) (relative to 1990)**	
		World Markets Low emissions	**Global Sustainability High emissions**
East Scotland (Inverness to Border)	1.0	34	55
North-East England	0.2	41	62
Yorkshire	-0.5	48	69
East Midlands	-0.6	49	70
East England	-0.7	50	71
London	-0.7	50	71
South-East England	-0.5	48	69
South-West England	-1.0	53	74
Wales	-0.4	47	68
North-West England	0.7	36	57
South-West Scotland (Border to Fort William)	1.3	31	52
North-West Scotland (Fort William to Inverness)	0.7	36	57
Orkney and Shetland	0.0[1]	43	64
Northern Ireland	*na*	43	64

[1] This is updated to 'no-published estimates' in British-Irish Council (2003), p.36.

Given that global sea-level rise predicted by the IPCC varies from 9 cm under the Global Sustainability scenario to 69 cm under the World Markets scenario, differential uplift and subsidence around Britain's coast generates significant regional patterns. The east of Scotland, rising by 1.0 mm a year, is predicted to have a sea-level rise of 34 to 55 cm by the 2080s. This slightly reduces to 31 to 52 cm for south-west Scotland, rising by 1.3 mm a year, and increases to 36 to 57 cm for north-west Scotland, rising by 0.7 mm a year. Orkney and Shetland should see sea-level rises of 43 to 64 cm by the 2080s. Note, however, the absence of published information on isostatic change for Orkney and Shetland (see Table 4). With the exception of Orkney and Shetland, these predicted sea-levels rises are significantly below those anticipated for much of England.

The results for projected sea-level rise for Scotland (see Table 4) are much higher that those in Werritty *et al.* (2002) based on Dawson *et al.* (2001) which discounted thermal expansion of the upper ocean in the vicinity of the British Isles.

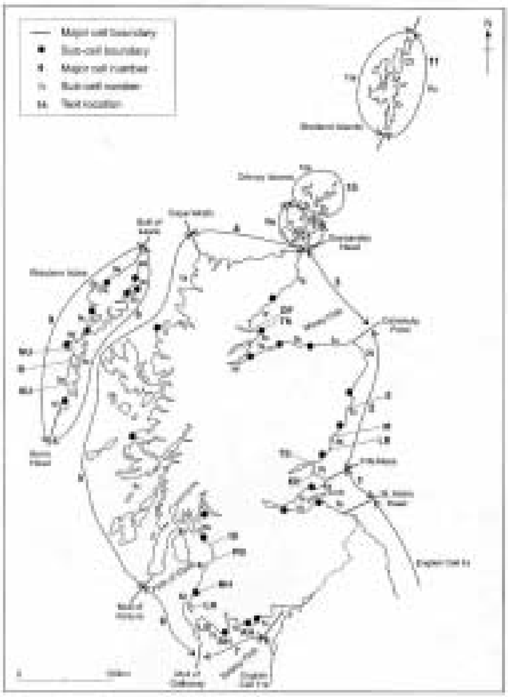
2.10.3 Morphology and sediment supply (coasts)

Coastal cells define units of shoreline within which natural longshore transport of sediment occurs. Since most cases of severe coastal erosion occur when longshore transport is interrupted, identifying coastal cells is the initial step in seeking to protect a shoreline against erosion or flooding prior to developing a Shoreline Management Plan. This procedure, funded by Defra, is now well established for England and Wales but has only been applied to Scotland in a piecemeal manner, funded by local authorities.

The rocky and highly indented coastline of mainland Scotland – especially on the west coast – and fragmented outlines of the Western Isles and Orkney and Shetland makes it difficult to define coastal cells using the criteria adopted for England and Wales (Ramsay and Brampton, 2000). The most recent attempt (see Figure 1) identifies seven cells along the mainland, reserving a further four coastal cells for the Outer Hebrides and Orkney and Shetland. For the rocky coasts of the north and west, where sediment is sparse and beaches often confined to deeply indented bays, individual cells are small and numerous. For such lengths of shoreline many small bays, or pocket beaches, are grouped together to form a much larger ‘sub-cell’ for management purposes. The hydraulic environment and general orientation of the coastline determines this grouping process.

As in England and Wales, most of the sediment reworked along the Scottish coast is fine grained and of marine origin. This includes the sand banks within the outer estuaries of the Solway, Clyde, Forth and Tay. Two exceptions are the inner Tay estuary, which is dominated by river-derived sands and gravels, and Spey Bay plus the shoreline to the west, which is constantly replenished by river gravels from the Spey (Gemmell, *et al.* 2001). Any reduction in sediment flows on the lower Spey, due to changes in runoff or land management, would starve Spey Bay and cause immediate erosion along cell 3b (see Figure 1). This, however, is a special case and more generally there is minimal coupling between fluvial and coastal morphology around the Scottish coast.

Figure 1 **Definition of coastal cells for Scotland (J Hansom, pers. comm.)**



Within these coastal cells, morphology and sediment supply operate to control the long-term patterns of coastal erosion. Quenlenuec *et al.* (1998) characterised some of these coastal cells as follows:

- Berwick to Aberdeen (cells 1, 2a, 2b and 2c): predominantly eroding but stable where there are rocky coasts or coastal defences.
- Aberdeen to Inverness (cells 2d, 2a, 3b, 3c and 3d): mainly eroding but with important river coupling (Spey Bay).
- Inverness to Mallaig (cells 3, 4 5a): stable with eroding pocket beaches.
- Mallaig to Carlisle (cells 6 and 7): predominantly eroding but stable where there are rocky coasts or coastal defences.
- Mull/Islay/Jura/Skye (cells 5b and 5c) predominantly stable but with soft coasts eroding (pocket beaches).
- Orkney (cell 10): stable with eroding pocket beaches.

Chapter 3

Economic dimensions of flooding

3.1 Scotland’s population and economy

Despite being a large landmass relative to the rest of the UK, Scotland has a small population, 5.06 million out of a UK total of 58.80 million in 2001. This equates to a population density of only 65 people per km^2, which is a quarter of the population density of the UK and half the average for the European Union. Despite this, Scotland is a highly urbanised country. More than half the population lives in the Central Lowlands, with more remote rural areas being thinly populated. Thus, Glasgow has a population density of 3,218 people per km^2. By contrast, the Highlands and Islands is the sixth most sparsely populated area of the EU, with only 9 people per km^2. However, these remoter areas are also important tourist destinations supporting seasonal increases in population and served by several strategic transport links (Werritty *et al.* 2002).

There is also a marked differentiation in economic prosperity across Scotland. The north-east has some of the most important oil and gas resources in the EU. Discounting Inner London, in 1997 Grampian was the wealthiest sub-region in the UK, with gross domestic product (GDP) per head of 127% of the EU average. By contrast, its neighbouring sub-region, the Highlands and Islands, had a GDP per head of only 76% of the EU average. In general, there is an east/west split across the country, with the eastern half having a higher GDP per head than the western half of Scotland (Werritty *et al.* 2002).

In addition to the importance of the oil and gas industries, the Scottish economy has become increasingly reliant on the service sector, which accounted for 75% of employment in 1997. The recent downturn in the Scottish economy has seen some erosion of the high-tech manufacturing base, especially in IT and telecommunications. As a result the Scottish Executive is seeking to diversify the high-tech manufacturing base into new areas, such as pharmaceuticals and biotechnology-based on knowledge transfer from leading universities and government research centres (Werritty *et al.* 2002).

Although the high-tech sector has brought many new job opportunities to the most heavily populated areas of Scotland, the food and drink processing industries are still extremely important employers and contributors to rural economies (Werritty *et al.* 2002).This is especially true of the whisky industry, which is one of the main contributors to total Scottish and UK food exports (£2.34 billion of exports in 1997).

3.2 Identification of flood-risk areas

3.2.1 Broad patterns of assets at risk from flooding

Prior to the report by Werritty *et al*. (2002) there were no summary data on the number of properties at risk from inland and coastal flooding across Scotland. The following summarises the findings of that report.

Using GIS tools, the following data sources were used to compile a first estimate of the number of residential and non-residential properties at risk from flooding by local authority area:

- Indicative floodplain datasets based on IH (Institute of Hydrology) Report 130 maps and Scottish Environment Protection Agency data on historical flood events (Figures 2 and 3 provide examples of this source). Since there are no coastal flood-risk maps for Scotland, sites liable to present and future coastal flooding were deemed to be areas less than 5m above Ordnance Datum (OD). Use of the 5m OD contour to delimit the area potentially at risk from coastal flooding is an approximation used in England that may overestimate the actual extant of flood risk in areas of Scotland where tidal ranges are lower.
- Postcode data on the location and property details for 170,000 units providing a national grid reference and the number of households within each unit.
- Prime agricultural land based on the Macaulay Institute's Land Capability classification (classes 1, 2 and 3.1). This land use occupies about 7% of the Scottish mainland and is mainly confined to the eastern areas of the central belt and lowlands.
- Local authority boundaries, urban area boundaries and protected sites under the Wildlife and Countryside Act 1981 and EU directives.
- In the GIS analysis, only postcodes located outside the indicative floodplain and at less than 5m OD were deemed to be at risk from coastal flooding. This ensured that no properties were at risk from both coastal and inland flooding.

The summary results are reported in Tables 5 and 6 and the maps in Figures 2 and 3. Inland floodplains contribute a larger area (2,950 km^2) than do coastal areas less than 5m OD (966 km^2). Many of these coastal areas – such as the Carse of Gowrie (Perth and Kinross), the lower Forth (Stirling, Falkirk and Clackmannan) and Tentsmuir (Fife) – were inundated as recently as about 6,700 years ago. They owe their current elevation above sea level to continuing isostatic uplift. They are thus vulnerable to increased coastal flooding by the 2080s (see Figure 2) given predicted sea-level rise.

Within the inland floodplains, those affected by the major floods of the 1990s stand out especially clearly – the lower Tay, Earn and Isla inundated in 1993 (see Figure 2), and the lower Kelvin inundated in 1994. The risk of urban flooding is also clear across the Strathclyde

conurbation (Paisley, Cathcart and Kirkintilloch) and in Kilmarnock (see Figure 3). For prime agricultural land, only 419 km^2 lies within flood-risk areas, that is, only 6.7% of the national supply. It is noteworthy that, although the area subject to coastal flooding is less than a third of that of inland floodplains (see Table 5), the number of residential and commercial properties potentially at risk in the coastal areas, 93,830 (see Table 7), is higher than the 77,191 at risk inland. This probably reflects the much higher density of settlement and commercial activity within the coastal zone.

Table 5 **Relative extents of floodplains within mainland scotland, on prime agricultural land, on inland areas and coastal areas (less than 5m OD)**

Locations	**Area (km^2)**
Mainland Scotland land area	78,791
Prime agricultural land	6,259
Inland floodplain – (combined IH Report 130 & SEPA data)	2,950
Coastal land below 5m OD	966
Less area of combined inland/coastal flood risk	231
Combined inland floodplain and coastal areas	3,685

Table 6 **Assets within inland floodplains and coastal areas (less than 5m OD)**

Property	**No. of properties affected**
No. of residential properties within inland floodplain	71,402
No. of residential properties in coastal areas below 5m OD	86,793
No. of commercial properties within inland floodplain	5,789
No. of commercial properties in coastal areas below 5m OD	7,037
Total	171,021
Prime agricultural land	**Area of land within floodplain (km^2)**
Area within only inland floodplain	307
Area within only coastal areas below 5m OD	71
Area within both inland and coastal floodplain	41
Total area	419

Note: In the absence of residential and commercial composition data, the properties shown to be at risk are estimated from the available postcode data. Based on national estimates, the number of properties was split 92.5% residential and 7.5% commercial. These figures are therefore illustrative and should not be used for economic assessments of assets at risk.

It is important to note that the data reported in Tables 5 and 6 and depicted in Figures 2 and 3 take no account of existing flood defences. The true levels of exposure, taking these defences into account, will be approximately 10% lower, but at present there are insufficient data to calculate the precise mitigation that such defences afford.

Figure 2 **Tayside and Fife indicative floodplains and coastal areas below 5m OD**

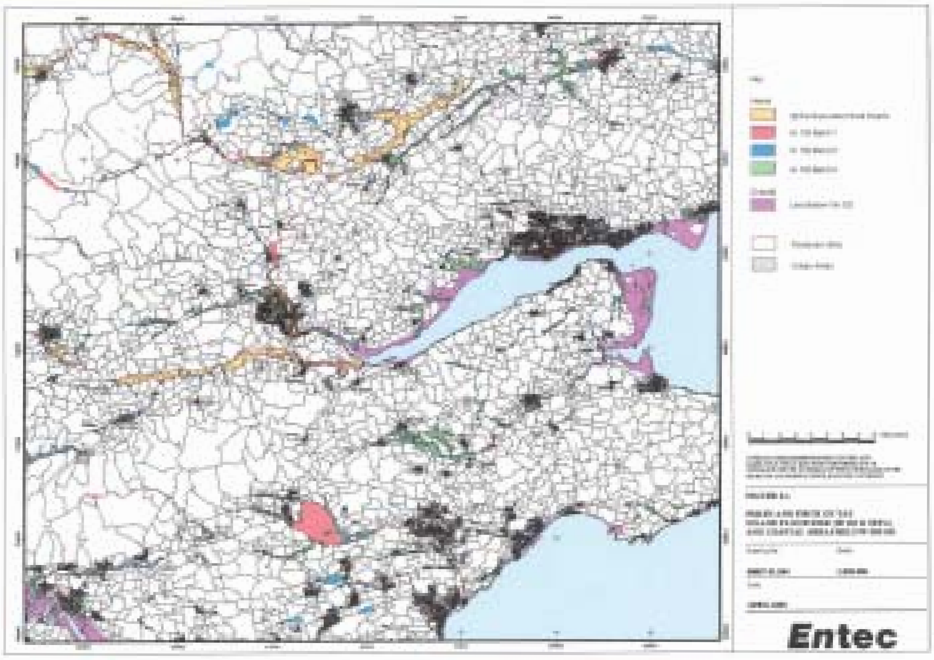
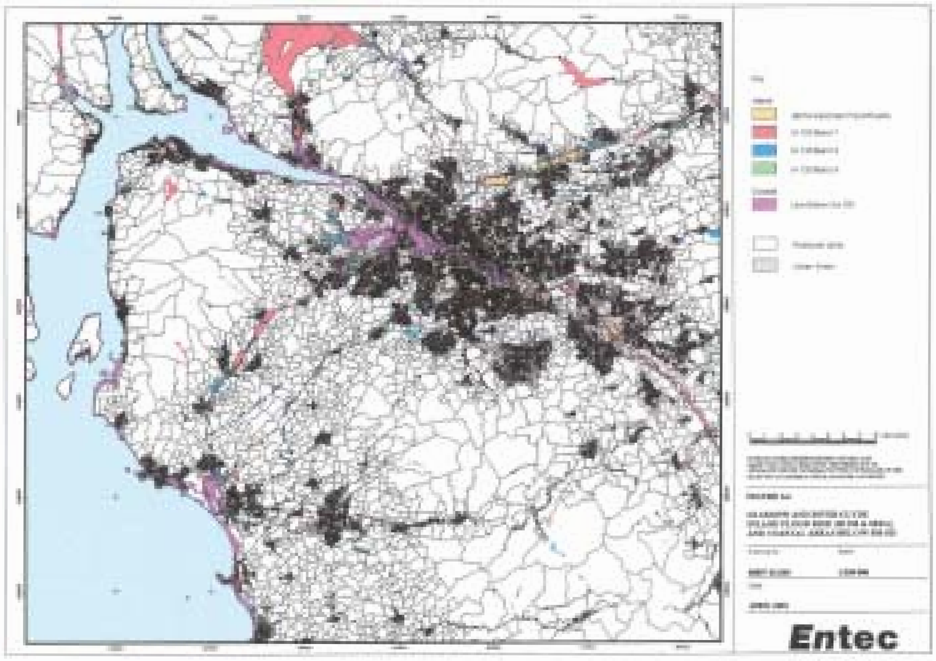


Figure 3 **Strathclyde: inland indicative floodplains and coastal areas below 5m OD**



3.2.2 Assessment of flood-risk areas by local authority area

Evaluation of data first published by Werritty *et al.* (2001), indicates that approximately 5% of the land area of mainland Scotland would be at risk from flooding in the absence of flood defences (see Table 6). This risk includes 15-20% of the properties in six local authority areas (Angus, Argyll and Bute, East Lothian, Falkirk, Moray, and South Ayrshire) and more than 5,000 properties in each of Angus, Argyll and Bute, Edinburgh, Dumfries and Galloway, East Lothian, Falkirk, Glasgow, Highland Moray, North Ayrshire, Perth and Kinross, Renfrewshire, South Ayrshire and West Dunbartonshire. It should be noted that these are first approximations in terms of overall flood risk. Any individual event, be it an inland or coastal flood, would inundate only a subset of the properties at risk.

Grouping together data for local authorities from Werritty *et al.* (2001) (see Figure 4), the main economic sectors at risk (in the absence of effective flood defences) are as follows:

- *Moray* Residential and commercial properties in Forres and Elgin were severely inundated during the 1997 and 2002 floods. There is also a long history of summer storms inundating prime agricultural land and severing important rail and road links.
- *Aberdeenshire and Aberdeen City.* There is little by way of flood risk in the catchments in and around Aberdeen and this is largely focused on agricultural land and coastal recreational areas.
- *Angus, Perth and Kinross and Fife.* Perth is the largest urban area at risk (severely flooded in 1993 but now with a much higher level of flood defence), although Crieff is also locally vulnerable plus some prime agricultural land in the Carse of Gowrie and Dundee airport. The Bridge of Earn (also flooded in 1993) will soon see its flood risk reduced by new defences. Much of the coastal zone in north-east Fife is vulnerable to sea-level rise and coastal flooding, including Tentsmuir, RAF Leuchars and the St Andrews golf links.

- *Falkirk, West Lothian, Stirling, Edinburgh and East Lothian.* The Grangemouth refinery and the Longannet Power Station are both below the 5m OD contour, as is a significant amount of residential property in Grangemouth and Stenhousemuir and residential and business properties in and around Stirling. Within Edinburgh, flooding severely affected residential properties alongside the Water of Leith in 2000. Commercial properties at Haymarket and Murrayfield are also considered to be at risk. Haddington in East Lothian has a long history of flooding and remains vulnerable to storms over the Lammermuir Hills.

- *Glasgow, East Ayrshire, North Ayrshire, South Ayrshire, West Dunbartonshire, East Renfrewshire and Renfrewshire.* Residential properties are at risk from inland flooding in Kirkintilloch, Paisley and Johnstone – all were inundated in 1994. The White Cart Water in south-west Glasgow has a history of urban flooding. Coastal flooding was especially severe in Helensburgh and Dunbarton in 1991. Coastal surges inundated Saltcoats on the Ayrshire coast in 1990s – the area is now covered by a flood-warning scheme. The River Irvine generates some inland flooding of residential and commercial properties in Kilmarnock.

- *Dumfries and Galloway.* Most of the flooding in this local authority area is on agricultural land, but urban flooding on the River Nith has repeatedly occurred at the Whitesands in Dumfries, involving many commercial properties.

Figure 4 **Percentage of properties in each local authority area located within the indicative floodplain or coastal area below 5 metres OD.**

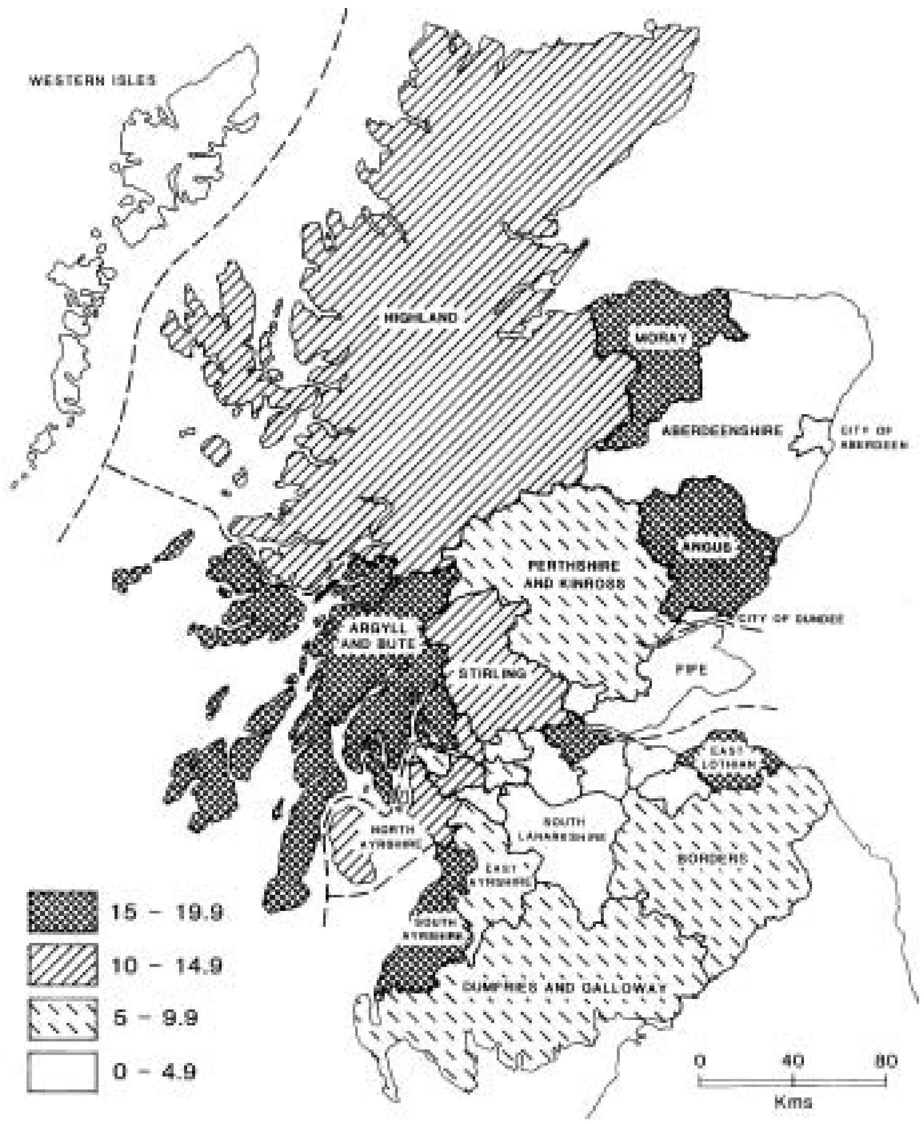


Table 7 **Properties at risk within inland floodplain and coastal areas by local authorities**

			Number of properties at risk		
Local authorities	**Area (km^2)**	**Total number of properties**	**Inland floodplain**	**Coastal (below 5m OD)**	**Total number of properties at risk**
Aberdeen City	185	104,543	309	571	880
Aberdeenshire	6,317	95,174	2,219	1,743	3,962
Angus	2,184	49,828	1,750	6,639	8,389
Argyll and Bute	7,008	45,191	1,172	5,748	6,920
City of Edinburgh	264	222,246	8,861	2,241	11,102
Clackmannanshire	159	21,170	219	533	752
Dumfries and Galloway	6,440	65,939	2,518	2,854	5,372
Dundee City	60	74,032	348	1,476	1,824
East Ayrshire	1,269	52 497	3,118	0	3,118
East Dunbartonshire	175	45,966	1,288	0	1,288
East Lothian	682	39,505	1,127	6,099	7,226
East Renfrewshire	174	36,075	409	0	409
Eilean Siar Comhairle nan	3,081	13,540	nd	347	347
Falkirk	298	64,382	7,997	4,406	12,403
Fife	1,331	162,013	1,097	2,939	4,036
Glasgow City	175	302,065	11,944	14,904	26,848
Highland	26,140	110,068	3,482	11,068	14,550
Inverclyde	163	40,479	38	2,042	2,080
Midlothian	356	33,193	130	0	130
Moray	2,241	54,967	5,355	3,780	9,135
North Ayrshire	888	62,951	2,973	4,590	7,563
North Lanarkshire	472	136,935	658	0	658
Orkney Islands	1,018	9,269	nd	89	89
Perth and Kinross	5,387	64,882	5,205	1,193	6,398
Renfrewshire	261	86,749	5,146	5,771	10,917
Scottish Borders	4,743	50,649	4,394	181	4,575
Shetland Islands	1,465	9,891	nd	nd	nd
South Ayrshire	1,221	50,112	490	7,119	7,609
South Lanarkshire	1,774	129,386	1,023	3	1,026
Stirling	2,254	36,228	1,377	2,361	3,738
West Dunbartonshire	176	43,890	2,364	2,755	5,119
West Lothian	429	65,647	163	2,378	2,541
Undefined		6,597	17	0	17
Total	78,791	2,386,059	77,191	93,830	171,021

Note: Table 6 outlines the number of properties located within the inland floodplain (as defined by IH-130 and SEPA) and low-lying coastal areas. No account is taken of the level of protection afforded to each area by flood defences and/or composition of property types (i.e. flats versus housing). No data (nd) for Eieean Siar Comhaile nan, Orkney Islands and Shetland Islands.

In general, flooding along many reaches of river poses no significant concerns for the national economy, with some notable exceptions, for example, Perth and Strathclyde, where significant areas of residential property are within risk areas. Light commercial property is also affected in such areas, though again the effects are perhaps small in the context of the national economy, but may be locally significant. Fluvial flooding also poses a risk to agricultural activity with several areas of prime agricultural land affected. The losses in such areas depend largely on the time of year when the event occurs, and its duration. In total around 7% of the prime agricultural land is at risk, though this would not all generally be affected in the same year.

Coastal flooding is perhaps of greater concern for the national economy given that the Longannet Power Station, the Grangemouth oil refinery and large parts of the residential area of Grangemouth are within coastal areas below 5m OD. A number of infrastructure sites are also within these zones, notably Dundee Airport and RAF Leuchars. New property is also affected, in particular, the change from heavy to light commercial and residential property along the Clyde in Glasgow, which all lies below the 5m contour.

3.3 Economic impacts of flooding

3.3.1 Costs of recent floods

Over the past decade, floods have affected a number of rivers, causing considerable damage to infrastructure and property. These events include the East Highland flood in 1989, the Tay/Earn flood in January 1993 and the Strathclyde flood in December 1994. Several more recent floods – in Moray July 1997 and November 2002 and in Edinburgh and the north-east, April 2000 – also highlighted the risk posed by intense rainfall in smaller river catchments. The economic losses associated with these floods have been variously estimated at £30 million for the Tay/Earn flood in 1993 and £100 million for the Strathclyde flood in 1994 (Werritty *et al*. 2002)

Predictions of sea-level rise and increased storm activity have also focused concerns on the possible increased risk of coastal flooding in Scotland. In the early 1990s, coastal flooding caused on average £0.5 million of damage a year to communities around the Firth of Clyde, including Saltcoats, Tarbert, Rothesay and Dumbarton.

These recent events prompted the Scottish Environment Protection Agency to develop the first coastal flood-warning system in Scotland. These measures have helped to reduce average annual damages by allowing precautionary action to be taken. The impact of future sea-level rises and storm surges represents a small but increasing annual risk for low-lying lands adjacent to the coast and close to Scotland's major cities, Glasgow, Edinburgh, Dundee and Inverness.

3.3.2 Average annual damage under present and future climates

To assess the economic impacts of climate change, broad estimates of the current average annual property damage posed by inland and coastal flood risk under three time periods – 2020s, 2050s and 2080s – have been produced. The analysis, undertaken by J B Chatterton Associates, is based on House Equivalents data which enable an estimate of average annual damage for a single property to be obtained with minimal information on the actual flood risk. The results reported here update and replace those provided in Werritty *et al*. (2002).

For this study, the analysis was undertaken on the following basis:

- Properties are variously protected up to the level of an inland flood with return periods of 5, 10, 20, 50, 100 and 200 years.
- For coastal flooding it assumed that 50% of properties below 5m OD will be subject to flooding.
- The residential/commercial split is 92.5%-7.5%, with non-residential properties assumed to be retail units.
- The mean size of each commercial property is 521m^2.
- No account is taken of the type of property flooded.
- No additional properties are affected.
- The damage vulnerability remains the same.

No data are available in terms of hydraulics, property-inundation thresholds and location of individual properties within the indicative floodplain or coastal areas.

For each property within the indicative floodplain, an average annual damage value is generated depending on whether it is unprotected or is behind flood defences with Standards of Protection (SoP) increasing from 2, 5, 10, 25, 50, 100 to 200 years. Using standard relationships between damage in houses for increasing flood levels, we can determine a cumulative value for annual damage by floods of increasing rarity (HR Wallingford *et al*. 2000, Ministry of Agriculture Fisheries and Food, 2000).

The analysis thus far assumes that all houses within the indicative floodplain are inundated to a given level by a flood with a specified return period. This is clearly not the case in practice. For example, the 5-year flood would inundate only a relatively small proportion of the indicative floodplain; whereas the 100- or 200-year flood would extend to the suggested limits. Thus the damage reported for 5-, 10-, and 25-year floods needs to be scaled to take into account differential inundation of the floodplain. On the basis of known inundation patterns for eight sites with flood protection schemes in place, J B Chatterton Associates propose the weightings reported in Table 8. These, however, are initial approximations and need to be subject to sensitivity analysis. Alternative weightings credible within the context of Scottish floodplains are also reported in Tables 9 and 10.

Using these annual damage values, plus the number of houses located within inland floodplains, average annual damage for inland fluvial flood risk can be determined for the whole of Scotland and for local authority areas. A similar analysis can be undertaken for the 7.5% of non-residential units – all assumed to be retail units in this analysis – with different standard relationships for damage with increasing flood levels.

Combining results for residential and non-residential units located on inland floodplains we derived an estimate of the average annual damage in 2003 for fluvial floods given varying standards of protection based on the weightings for proportional inundation recommended by J B Chatterton Associates (Table 8). Values for the 2020s, 2050s and 2080s are scaled up from the 2003 baseline by 27% (2020s), 68% (2050s) and 115% (2080s) to reflect the reduction in the return period for the current 50-year event, estimated for Scottish rivers by Werritty *et al.* (2002).

A similar analysis has been undertaken for coastal flooding using the same approach but assuming that only 50% of properties at risk are inundated (see Table 11). Values for the 2020s, 2050s and 2080s are not given as there is no credible basis for including the impact of sea-level rise on the reduced standard of protection.

There is also a geographical dimension to these findings in that flood risk is not uniformly distributed across local authority areas (Table 7, Figure 4). Those local authority areas that contain more than 75% of the flood risk within indicative floodplains or coastal areas below 5m OD are itemised in Table 12.

Local authorities with 10% or more of their area lying within the indicative floodplain or coastal zone are itemised in Table 13.

Table 8 **Inland flood risk in Scotland: residential and non-residential units (Average Annual Damages – £ million)**

SOP	2003	2020s	2050s	2080s
None	185.3	235.3	311.2	398.4
5	179.9	228.4	302.2	386.7
10	134.1	170.4	225.4	288.4
25	69.1	87.8	116.1	148.6
50	31.5	40.0	52.9	67.7
100	8.1	10.2	13.5	17.3
200	3.7	4.6	6.1	7.8

SoP – standard of protection (return period in years)
Proportion of floodplain inundated: 5-yr (0.2), 10-yr (0.35), 25-yr (0.85), 100 (0.93), 200 (1.00)

Table 9 **Inland flood risk in Scotland: residential and non-residential units (Average Annual Damages – £ million)**

SOP	2003	2020s	2050s	2080s
None	113.7	144.4	191.0	244.4
5	120.5	153.1	202.5	259.2
10	107.2	136.1	180.1	230.5
25	69.1	87.8	116.1	148.6
50	31.5	40.0	52.9	67.7
100	8.1	10.2	13.5	17.3
200	3.7	4.6	6.1	7.8

SoP – standard of protection (return period in years)
Proportion of floodplain inundated: 5-yr (0.05), 10-yr (0.1), 25-yr (0.5), 50-yr (0.93), 100-yr (0.93), 200-yr (1.00)

Table 10 **Inland flood risk in Scotland: residential and non-residential units (Average Annual Damages – £ million)**

SOP	2003	2020s	2050s	2080s
None	96.3	122.3	161.8	207.1
5	96.0	122.0	161.3	206.5
10	81.4	103.4	137.0	175.1
25	63.8	87.8	107.2	148.6
50	31.5	40.0	52.9	67.7
100	8.1	10.2	13.5	17.3
200	3.7	4.6	6.1	7.8

SoP – standard of protection (return period in years)
Proportion of floodplain inundated:
5-yr (0.05), 10-yr (0.1), 25-yr (0.25), 50-yr (0.8), 100-yr (0.93), 200-yr (1.00)

Table 11 **Coastal flood risk in Scotland: residential and non-residential units (Average Annual Damages – £ million)**

SOP	2003
None	58.5
5	58.4
10	49.5
25	77.6
50	19.1
100	4.9
200	2.2

Table 12 **Local authority areas ranked by % of properties at risk as a proportion of the national total (171,021)**

Local authority area	% indicative floodplain	Local authority area	% coastal area
Glasgow City	15.7	E Dunbartonshire	15.9
Edinburgh	11.5	Argyll and Bute	11.8
Falkirk	10.4	Midlothian	7.6
Moray	6.9	Falkirk	7.1
Perth and Kinross	6.7	Dumfries/Galloway	6.5
Renfrewshire	6.7	Aberdeen City	6.2
Scottish Borders	5.7	Moray	6.1
Highland	4.5	North Lanarkshire	4.9
East Ayrshire	4.0		
North Ayrshire	3.9		

Table 13 **Local authorities with area within indicative floodplain or below 5m OD at c.10% or more**

Local authority area	% of area within indicative floodplain	Local authority area	% of area below 5m
Falkirk	12.4	E Dunbartonshire	32.4
Moray	9.7	Orkney Isles	25.7
		Argyll and Bute	24.5
		Midlothian	21.4
		Eilan Siar Comhairle nan	20.3
		Moray	10.5
		Falkirk	10.3

The following points arise from this analysis of properties at risk in Scotland (see Tables 8-13):

- The 2003 estimated average annual damage for inland flood risk with a standard of protection of 1 in 50 years is £31.5 million. This compares well with the earlier estimate of £20 million based on a much smaller sample (Werritty *et al*. 2002).
- The 2003 estimated average annual damage for coastal flood risk with a standard of protection of 1 in 50 years is £19.1 million. This is below that for inland floodplains partly because only 50% of coastal properties were assumed to be at risk.
- Taking 2003 as a baseline, annual average damages for inland properties range from a maximum of £185.3 million (no protection) to £3.7 million (1 in 200-year standard of protection), whereas for coastal properties comparable figures are £58.5 million (no protection) and £2.2 million (1 in 200-year standard of protection).

- The proportion of the floodplain inundated during an event has a significant impact on average annual damages, especially in terms of the extent of the 5 and 10-year flood. Given the minimal data available to calibrate this relationship, the range in average annual damage is reported. The maximum value for 2003 is £179.9 million (1 in 5-year flood SoP) and £69.1 million (1 in 25-year flood SoP) assuming 20% inundation by the 5-year flood, 35% by the 10-year flood and 85% by the 25-year flood. The corresponding minimum average annual damage is £96.0 million (1 in 5-year flood SoP) and £63.8 million (1 in 25-year flood SoP) assuming 5% inundation by the 5-year flood, 10% by the 10-year flood and 25% by the 25-year flood. The halving of damage at the 1 in 5-year flood SoP, depending of the extent of inundation, reveals the sensitivity of this control. More data are clearly needed to calibrate this relationship better.

- The increased annual average damage values for inland fluvial floods in the 2020s, 2050s and 2080s is based on the estimated reduction in the 50-year return period flood to between 17 and 37 years for selected Scottish rivers (Werritty *et al.* 2002), values broadly in line with those reported by Reynard (2003) in the Foresight FCD technical reports. These results imply an increase in annual average damage of 27% (2020s), 68% (2050s) and 115% (2080s).

- Significant exposure to flood risk is focused on a relatively small number of local authorities. Glasgow City, Edinburgh and Falkirk account for 38% of the inland fluvial flood risk, while East Dunbartonshire and Argyll and Bute account for 28% of the coastal flood risk. It is also striking that Moray and Falkirk have high levels of both inland and coastal flood risk. This arises, in part, because 10-13% of the area covered by the Moray and Falkirk local authorities falls either within the indicative floodplain or the coastal area below 5m OD.

3.3.3 Uncertainties associated with estimates of annual average damage

There are many simplifying assumptions built into the analysis, so the values for average annual damage we have reported are only first-order approximations. The identification of the number of properties at risk depends on an accurate identification of the indicative floodplain or coastal area subject to flooding. The first generation Indicative Floodplain Maps – based on the Institute of Hydrology Report 130 plus historical flood outlines – do not yield accurate limits for the 100 or 200-year flood. For this we must await the second-generation maps based on Synthetic Aperture Radar (SAR) and improved hydrological and hydraulic models. Similarly, the use of the 5m OD contour as the inland limit of coastal floods needs to be refined by improved digital elevation models, which will become possible following the processing of the SAR data.

The lack of information on flow hydraulics, thresholds for water entering a property and property type forces the use of a highly aggregated model to determine property losses. This, in turn, is very sensitive to the proportion of properties inundated by floods up to the 1 in 10-year level. The assumption that only 50% of properties below 5m OD are likely to be flooded can also be questioned. The mix of properties – 92.5% residential and 7.5% non residential, all assumed to be retail units with 521 m^2 of floor space – needs to be recalibrated for different locations. We make no attempt to identify other non-residential losses, for example, commercial and industrial premises.

A final source of error for the 2003 baseline average annual damage values is the assumption of flood protection at levels ranging from the 2-year to 200-year flood. The Scottish Executive estimates that only about 10% of the 171,021 properties currently at risk are protected by existing flood-prevention schemes, whose precise location and standards of protection have yet to be recorded within a national database.

Extrapolating the 2003 annual average damage values to the 2020s, 2050s and 2080s on the basis of an anticipated reduction in the standard of protection – due to the same flood level occurring with a reduced return period – incorporates further uncertainty in terms of:

- Climate-change scenarios.
- The conversion of predicted rainfall into runoff.
- The assumption that all other controlling factors (for example, land use, house type, population characteristics, etc.) remain unaltered.

Given the uncertainty associated with the annual average damage values reported here, national and local estimates of present and future flood losses should, at best, be regarded as first-order approximations.

Chapter 4

Scoring and ranking of drivers

This section reports on the scoring and ranking of drivers as they operate in Scotland, taking into account contrasts in the behaviour of the drivers noted in the previous sections. The table below reports scores for the UK as a whole, with separate scores for Scotland where appropriate.

4.1 Commentary on scoring of drivers

This section provides a commentary on the main contrasts in scores for the UK and Scotland reported in Table 14.

4.1.1 Climate change

The Precipitation driver is slightly increased under the National Enterprise scenario and further increased under the World Markets scenario. This reflects the more severe impacts anticipated under these scenarios, especially during the winter flood season. Thus Hulme *et al.* (2002) predict increases of up to 25% in winter precipitation across parts of Scotland by the 2080s. A stronger westerly circulation is also predicted for Scotland by the 2080s. This is likely to generate more storms, higher rainfall and flooding, especially in the winter. Daily and short-duration rainfall is also set to increase in northern Scotland at rates up to twice those anticipated in south-east England. Anticipated changes in temperature are more conservative, with Scotland occupying the middle of the 1 to 5°C range anticipated for the whole of the UK by the 2080s. Accordingly, the UK and Scottish temperature drivers show no differentiation.

4.1.2 Catchment processes

The Urbanisation driver is very sensitive to the higher short-duration rainfall intensities predicted for Scotland by the 2080s. Scotland is a highly urbanised society with many 19th-Century sewerage systems proving expensive to retrofit as the urban flood risk intensifies. The risk of urban flooding is thus likely to increase at a higher rate than in England and Wales where short-intensity rainfall is set to increase at a lower rate.

By contrast, the driver Rural Land Management has a lower ranking in Scotland than for the UK as a whole. This reflects anticipated changes in rural land use as the Common Agricultural Policy is reformed, stocking densities decrease, upland woodlands become more extensive, wetlands are reinstated and floodplains are used for controlled inundation. Many of these land-use changes will be focused on the uplands rather than the lowlands. Since Scotland has a higher proportion of upland than the rest of the UK, this driver is thought likely to exercise a less important role in Scotland by the 2080s. Agricultural impacts focused on the lowlands should prove similar to those in the rest of the UK, leaving this driver unchanged.

4.1.3 Fluvial processes

By contrast with the rest of the UK, Scotland's rivers are more active in reworking their valley floors. Under the scenarios Global Sustainability and Local Stewardship, higher winter flows could relocate some rivers outside their current indicative floodplains by the 2050s, thus increasing the relative importance of the driver River Morphology and Sediment Supply. This, in turn, would generate a lower standard of protection for agricultural land and small rural settlements as existing defences would have been damaged or circumvented. Offsetting this will be the impact of less vegetation within river channels and hence better flow conveyance caused by a reduced use of fertilizers under the scenarios Global Sustainability and Local Stewardship. Given the much lower levels of eutrophication in Scotland than across much of southern and eastern England, this effect is likely to be triggered by the 2050s, especially under the Global Sustainability scenario. However, increases in floodplain woodlands – currently being promoted in Scotland – could reduce these improvements in flow conveyance, especially under the Local Stewardship scenario. Given that the EU Water Framework Directive will be fully implemented across the whole of the UK by 2015, it is unlikely that the operation of the Environmental Regulation driver will differ markedly in Scotland vis-à-vis the rest of the UK.

4.1.4 Coastal processes

The Scottish scores for drivers in the driver group Coastal Processes, are consistently below those for the whole of the UK across most scenarios. In the case of storm surges, likely elevated water levels in Scotland for the 1 in 50-year storm are less than 1.25m compared with 2.5m along the East Anglian shoreline. Projected rises in relative sea-level are also much lower, especially when compared with those for south-east and south-west England, due to the continued uplift of Scotland following the melting of the last ice sheet.

Table 14 **Summary results for UK driver impacts of flood risk (Scottish values in brackets and in bold)**

Climate change

Driver no. & type	Name	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
		2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
1-S	Precipitation	4 **(5.7)**	5.7 **(8)**	2.8 **(4)**	4 **(5.7)**	2.8	4	2	2.8
4-S	Temperature	1	1	1	1	1	1	1	1

Catchment processes

Driver no. & type	Name	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
		2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
9-P	Urbanisation	2.8	4 **(5.7)**	2.8	4 **(5.7)**	0.7	0.5	0.7	0.5
11-P	Rural Land Management	1.4	2 **(1.4)**	1.4	2 (1.4)	0.7	0.5	0.7	0.7
21-R	Agricultural Impacts	0.7	0.7	1.2	1.7	1	0.85	0.7	0.5

Fluvial processes

Driver no. & type	Name	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
		2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
7-P	Environmental Regulation	1	1	1	1	1.4	2.8	2	4
10-P	River Morphology and Sediment Supply	1	2	1	1	2 **(2.8)**	4	1.4 **(2.0)**	2.8
12-P	Vegetation and Conveyance	1	1.4	1	1.4	1	2 **(1.4)**	2 **(1.4)**	5.7 **(4)**

Human behaviour

Driver no. & type	Name	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
		2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
H6-P	Stakeholder Behaviour	2	2.8	0.5	0.33	0.25	0.2	0.25	0.2
19/20-R	Public Attitudes and Expectations	Known to be important but not quanitified							

Table 14 **Summary results for UK driver impacts of flood risk (cont.) (Scottish values in brackets and in bold)**

Coastal processes

Driver no. & type	Name	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
		2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
2-S	Waves	3 **(2)**	10 **(5)**	2 **(1)**	5 **(3)**	1	3	1	2
2-S	Surges	5 **(3)**	20 **(8)**	3 **(2)**	9 **(5)**	2 **(1)**	5 **(3)**	1	2
3-S	Relative Sea-Level Rise	5 **(3)**	20 **(14)**	4 **(3)**	13 **(10)**	3 **(2)**	10 **(7)**	3 **(2)**	7 (5)
4-P	Coastal Morphology and Sediment Supply	5 **(3)**	10 **(5)**	4 **(3)**	7 **(5)**	3 **(2)**	4 **(3)**	2 **(1)**	2 **(1)**

Socioeconomics

Driver no. & type	Name	World Markets		National Enterprise		Local Stewardship		Global Sustainability	
		2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
13-R	Buildings and Contents	6.0	17.0	2.2	3.1	3.0 **(2.47)**	4.8 **(4.0)**	2.5	4.8
14-R	Urban Impacts	5.0 **(7.0)**	19.8 **(28.3)**	1.8 **(2.52)**	3.6 **(5.14)**	2.2	3.9	3.0	4.8
15-R	Infrastructure Impacts	7.1	24.0	2.2	3.6	3.0	4.8	2.5	3.9
18-R	Social Impacts	6.0	19.8	2.2	3.6	3.0 **(2.47)**	6.1 **(5.0)**	2.2	3.2
23-R	Science and Technology	Known to be important but not quantified							

Given the hard, rocky nature of much of Scotland's coastline, the driver Coastal Morphology and Sediment Supply is less significant than in southern and eastern England, where readily eroded cliffs and major river estuaries provide large volumes of sediment to the nearshore zone. Wave heights are set to increase around the UK by the 2080s: it is possible that this could be more severe for the Western and Northern Isles of Scotland given increased storminess and an increased westerly circulation. Despite this, the Scottish scores are below UK levels as the effect is localised and the agreed scale would require an inappropriate increase in the scoring value.

4.1.5 Socioeconomics

The higher scores for Scotland for the Urban Impacts driver under World Markets and National Enterprise scenarios reflect a highly urbanised society, a marked increase in urban flooding by the 2080s, and a presumed difficulty to retrofit existing urban drainage. Given low growth and low consumption, the pressure to develop floodplains and the coastal zone, already lower in Scotland than for much of the UK, will be reduced under the Local Stewardship scenario. The higher degree of social cohesion in Scotland will reduce the adverse social impacts of floods under Local Stewardship.

Overall, the scores and rankings for Scottish drivers differ only slightly from those for the UK as a whole. Most adjustments to the scores are downwards but usually by relatively small amounts. Drivers where this is not true are the drivers Precipitation, Urbanisation and Urban Impacts – all higher in Scotland under some scenarios, and those in the Coastal processes driver group, all of which are significantly lower.

Scotland's higher social cohesion and lower development pressures on floodplains and coastal lowlands mean that the building, contents and social impacts of future flooding are likely to be proportionately lower than for more densely populated areas of the UK.

4.2 Ranking of drivers for Scotland

Ranking of driver impact scores for Scotland was performed to identify those drivers that are most important in changing local flood risk. However, given the high uncertainty associated with many them, it would be unrealistic to develop a complete ordering of drivers. To give a more robust assessment of which are the most important drivers, we have arranged them according to bands. In this context we take importance of a driver to be the magnitude of the change (which may be an increase or a decrease) in the flood risk caused by that driver, for local flood risk in Scotland.

We summarise the rankings in Table 15. In this table, drivers are colour coded according to their level of impact and whether they act to increase or decrease local flood risk.

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

Table 15a **Driver impact rankings for Scotland**

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

Table 15b **Driver impact rankings for Scotland**

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

Legend

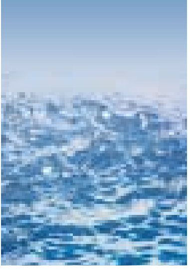
Driver impact category	**Risk multiplier (M) range**	**Colour code**
High increase	$M \geq 2$	🟥
Medium increase	$2 > M \geq 1.2$	🟨
Low impact	$1.2 > M \geq 0.83$	🟩
Medium decrease	$0.83 > M \geq 0.5$	🟦
High decrease	$M < 0.5$	🟪

Chapter 5

Recommendations for future work

Arising from this project, we make the following recommendations for future work:

- Precipitation predictions for Scotland by the 2080s are still imprecise. UKCIP02 reported the highest percentage increases in winter precipitation on the east coast but also a strengthening of the North Atlantic Oscillation Index which would imply higher percentage increases on the west coast. Given that most of Scotland's major rivers originate on the west side of the country, it is important to clarify the west-east winter precipitation gradient for the 2080s. The reconstruction and analysis of historic storms and floods across Scotland since the 1750s would help to clarify these west-east contrasts.
- High intensity, short duration precipitation is set to rise by the 2080s leading to an increase in urban flood risk. Design standards for future urban drainage systems will need to accommodate this increased risk. This will require the 2 hour duration (1in 10, 20 and 30-year) precipitation to be specified with greater accuracy and precision.
- The increased frequency of storms (with associated higher surges and wave heights) could increase coastal flood risk ten-fold by the 2080s. Models designed to improve the specification of this flood risk are needed to provide a secure basis for improved flood defences especially for the Lower Clyde estuary and the Glasgow waterfront.
- Claims are currently being advanced that wetlands and temporary floodplain storages can reduce downstream urban flood risk and locally enhance physical habitat. Given Scotland's inclusion of 'sustainable flood management' as part of its compliance with the EU Water Framework Directive, the credibility of such claims needs to be tested.
- Research programmes designed to quantify the social costs of floods and identify ways in which local communities can assist in promoting flood awareness are required to help deliver 'sustainable flood management'.



- Economic and financial losses caused by floods in Scotland are, at present, first-order approximations. Better modelling of the annual average damage to properties at risk based on localised information for frequency of inundation, the nature of the housing stock and the proportions of residential, retail, commercial and industrial properties could usefully be commissioned for both inland fluvial and coastal floods.

References

Arnell N W (1996) *Global Warming, River Flows and Water Resources*, Wiley, Chichester.

Ball D F and MacDonald A M (2001) *Groundwater Nitrate Vulnerable Zones for Scotland,* British Geological Survey Commissioned Report CR/01/50, Edinburgh.

Black A R and Anderson J L (1994) *The great Tay flood of January 1993*, 1993 Yearbook, Hydrological Data UK series, pp. 29-34, Institute of Hydrology, Wallingford.

British-Irish Council (2003) *Scenarios for Climate Change for Islands Within the BIC Region,* www.british-irishcouncil.org/climatechange

British Oceanographic Data Centre (1998) *UKDMAP: CD-ROM.* Windows 95/NT version, third edition, British Oceanographic Data Centre.

Crichton, D (1998) *Flood Appraisal Groups, NPPG 7, and Insurance*, in Faichney, D and Cranston, M (eds), Proceedings of the ‘Flood Issues in Scotland’ seminar, SEPA, Stirling, pp. 37-40.

Dawson A G, Smith D E and Dawson S (2000) *Potential Impacts of Climate Change on Sea Levels Around Scotland*, Scottish Natural Heritage, Research, Survey and Monitoring Report, No, 178.

Gemmell, S L G, Hanson J D and Hoey T B (2001) *The Geomorphology, Conservation and Management of the River Spey and Spey Bay SSSIs, Moray*. Scottish Natural Heritage Research, Survey and Monitoring Report No. 57.

Gilvear D J and Winterbottom S J (1992) *Channel Change and Flood Events Since 1783 on the Regulated River Tay, Scotland: Implications for Flood Hazard Management*. Regulated Rivers: Research and Management, 7, 247-260.

Harriman R and Pugh K B (1994) *Water Chemistry, in the Freshwaters of Scotland,* Maitland P S, Boon P J and McClusky D S (eds.), pp. 89-111, Wiley, Chichester.

Harrison J Winterbottom S and Johnson R (2001) *Climate Change and Changing Snowfall Patterns in Scotland,* Central Research Unit, Scottish Executive, Edinburgh.

Hickey K R (2001) *The Storm of 31 January to 1 February 1953 and Its Impact on Scotland*, Scottish Journal of Geography, 117, 283-295.

HR Wallingford, Halcrow Maritime and Flood Hazard Research Centre (2000) *National Appraisal of Assets at Risk from Flooding and Coastal Erosion,* Report for MAFF. Report No. SR 573 and TR 107.

Hulme, M and Jenkins, G J (1998) *Climate Change Scenarios For The United Kingdom*. UKCIP Technical Report, No. 1.

Hulme, M, Crossley, J and Lu, X (2001) *An exploration of Regional Climate Change Scenarios for Scotland*, Central Research Unit, Scottish Executive, Edinburgh.

Hulme M, Jenkins G J, Lu X, Turnpenny J R, Mitchell T D, Jones R G, Lowe J, Murphy J M, Hassell D, Boorman P, McDonald R and Hill, S (2002). *Climate Change Scenarios for the United Kingdom*.

Institute of Hydrology (1999) *Flood Estimation Handbook,* Centre for Ecology and Hydrology, Wallingford: 5 volumes.

Lang I (2003) *Climate Change and the Hydraulic Design of Sewer Systems, in Extended Abstracts of the 'Floods in Scotland' Seminar,* Scottish Hydrologic Group/Scottish Centre of the Royal Meteorological Society, pp. 20-21.

Lane S N (2001) *Geomorphological Audit of the Non-Tidal River Ouse (Yorkshire),* Final Report to Phase 1, Environment Agency Contract EA/NE/338.

McEwen L J (2001) *The Geomorphological Character of the River Dee, Aberdeenshire*, Scottish Natural Heritage Report No. F99LF05 (unpublished report).

Ministry of Agriculture, Fisheries and Food (2000) *National Appraisal of Assets at Risk from Flooding and Coastal Erosion*, Report TR 107.

Morris, D G and Flavin, R W (1996) *Flood Risk Map for England and Wales*, Institute of Hydrology Report, No. 130.

McGlashan, D J (2002) *Coastal Management and Economic Development in Developed Nations:* the Forth Estuary Forum, Coastal Management, 3, 221-236.

Natural Environment Research Council (1975) *Flood Studies Report,* HMSO, London, 5 vols.

Price D J and McInally, G (2001) *Climate Change: Review of Levels of Protection Offered By Flood Prevention Schemes*, Central Research Unit, Scottish Executive, Edinburgh.

Quenlenuec R E with collaboration with Uhel C O R and Devos W (1998) *CORINE: Coastal Erosion,* European Commission, Brussels.

Ramsay D L and Brampton A H (2000) *Coastal Cells in Scotland: Cell 11 – Shetland,* Scottish Natural Heritage, Edinburgh.

Reynard N S, Prudhomme C and Crooks S M (2001) *The Flood Characteristics of Large Rivers: Potential Effects of Changing Climate and Land Use*, Climate Change, 48, 343-359.

Reynard N and Brown S (2003) *Driver Set 3: Climate Change (Inland), Final Report Package A of Phase 2 – Deepening the Assessment of Drivers of Future Flood Risk,* Foresight Flood and Coastal Defence Project, C R Thorne.

Royal Society for the Protection of Birds (2002) *Seas of Change: the Potential Area for Inter-Tidal Habitat Creation Around the Coast of Mainland Britain*, RSPB, Sandy.

Scottish Environment Protection Agency (2000) *A SEPA-Planning Authority Protocol (Development and Risk of Flooding: Advice and Consultation). Policy No. 41*, SEPA, Stirling. (Available http://www.sepa.org.uk/policies/pdf/41.pdf).

Scottish Executive (2002) *Review of Scotland's Cities: The Analysis,* Scottish Executive, Edinburgh.

Scottish Executive (2004) *Scottish Planning Policy SPP7: Planning and Flooding*.

Scottish Natural Heritage (2002) *Natural Heritage Futures*, SNH, Edinburgh.

Shennan I and Horton B (2002) *Holocene land- sea-level changes in Great Britain*, Journal of Quaternary Science, 17, 511-526.

Smout T C (2000) *Nature Contested: Environmental History in Scotland and Northern England since 1600*, Edinburgh University Press, Edinburgh.

Tavendale A and Black A R (2003) *Planning Practice under NPPG7: Planning and Flooding*, Scottish Planning and Environmental Law, 95, 11-13.

The UKCIP02 Scientific Report. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK. 120pp.

Werritty A, Hoey, T B and Black A R (2000) *Geomorphological and Hydrological Changes at the River Feshie/Spey Confluence*, Scottish Natural Heritage Commissioned Report F98AC101 (Unpublished report).

Werritty A and Leys K F (2001) *The Sensitivity of Scottish Rivers and Upland Valley Floors to Recent Environmental Change*, Catena, 42, 2-4.

Werritty A, Black A R, Duck R W, Finlinson W, Thurston N, Shackley S and Crichton D *Climate Change: Flooding Occurrences Review*, Central Research Unit, Scottish Executive, Edinburgh.

Werritty A and Hoey T B (2002) *Trends and Issues: Geomorphological Changes and Trends in Scotland – Trends in River Channels and Processes,* Report to Scottish Natural Heritage.

List of project reports:

The following project reports and documents are available from the OST or from the Foresight website – *www.foresight.gov.uk*:

1. *Executive Summary*

2. *Key messages for stakeholders:* this is a series of information sheets for researchers, skills providers, local and regional government, and the insurance and financial services.

3. An overview of the science used may be found in:
   Scientific Summary: Volume I – Future risks and their drivers
   Scientific Summary: Volume II – Managing future risks

4. *Scotland*. This is a detailed technical report analysing the extent and nature of future risks specifically for Scotland.

5. A series of technical papers detailing the underlying work of the project.

6. *'FloodRanger'* flooding simulator: this computer based educative tool enables the operator to explore the interaction of many issues relating to future flood defence for an imaginary part of the UK – including climate change, planning, infrastructure provision and flood defences. It is of potential interest to educators and professionals interested in flooding and its interaction with society, the environment and the economy. Further details of FloodRanger are available from the developers: *www.discoverysoftware.co.uk*