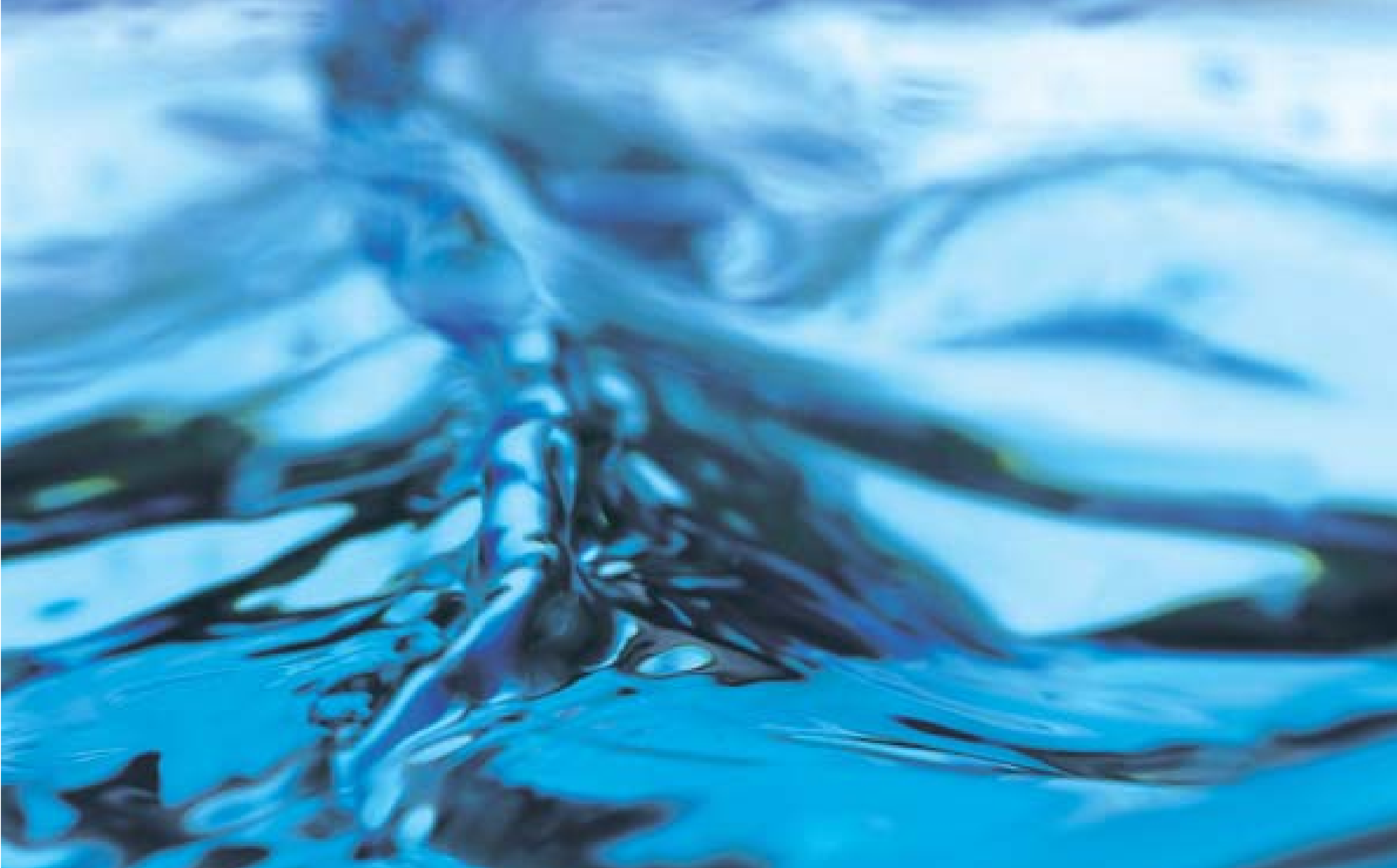

Chapter 2

Responses to future risks of flooding and coastal erosion

This chapter analyses responses that could be implemented to manage the increased risks of catchment-scale flooding and coastal erosion reported in Volume I:

- 80 possible responses were identified and are placed in 26 functional response groups to simplify their assessment. These groups are in turn classified in five broad themes.
- The 26 response groups are individually assessed and ranked according to their potential for reducing future risks in each of the four future scenarios.
- The uncertainty in the operation and ranking of the response groups is evaluated.
- The individual response groups are assessed by wider sustainability criteria (e.g. social justice and environmental quality) and the ranking reappraised.

In performing the above analysis, the aim is to identify responses which are both effective in reducing risk and score highly on wider sustainability measures.

2.1 Defining and analysing the responses

2.1.1 Methodology

A literature review and consultation with a wide range of experts and stakeholders identified 80 possible response measures, policies and interventions which have the potential to reduce the catchment- and coastal-scale risks identified in Volume I.

Responses with a common outcome in terms of flood risk reduction were then placed in 26 functional response groups consistent with the source-pathway-receptor model. The reduction from 80 responses to 26 response groups was made to facilitate high-level description and assessment in the subsequent analysis. The 26 groups were classified in five broad themes (see Table 2.1).

A small team of specialists with the relevant disciplinary background, academic skills and practical experience were then assigned to each theme. These teams produced deep descriptions of the 26 response groups – these may be found in the relevant Foresight technical documents and are provided in outline in Appendix A. These descriptions include:

- Narrative accounts which define the response group.
- Descriptions of each group's utility in managing flood risk and/or coastal erosion.
- Issues of governance and sustainability.
- Comments on costs and funding mechanisms.
- An analysis of the ways in which the response group interacts with others.
- Case examples.
- Consideration of the degree of uncertainty of each group.
- Factors that would promote or limit the implementation of the measures in each response group under each of the four Foresight future scenarios.

The specialist teams then performed the subsequent scoring of flood-risk impacts and assessed the sustainability implications for each of the functional groups in their theme. Finally, they identified further research necessary to increase confidence in their assessment of effectiveness and sustainability.

Table 2.1 **Summary of response themes and groups**

Response theme	Response groups
Managing the Rural Landscape	1. Rural Infiltration
	2. Catchment-Wide Storage
	3. Rural Conveyance
Managing the Urban Fabric	4. Urban Storage
	5. Urban Infiltration
	6. Urban Conveyance
Managing Flood Events	7. Pre-Event Measures
	8. Forecasting and Warning
	9. Flood Fighting Actions
	10. Collective Damage Avoidance Actions
	11. Individual Damage Avoidance Actions
Managing Flood Losses	12. Land-Use Management
	13. Flood-Proofing
	14. Land-Use Planning
	15. Building Codes
	16. Insurance, Shared Risk and Compensation
	17. Health and Social Measures
River and Coastal Engineering	*Fluvial defences*
	18. River Conveyance
	19. Engineered Flood Storage
	20. Floodwater Transfer
	21. River Defences
	Coastal and estuarial defences
	22. Coastal Defences
	23. Realignment of Coastal Defences
	24. Abandonment of Coastal Defences
	25. Reduce Coastal Energy
	26. Coastal Morphological Protection

The five response themes and the 26 groups they contain (listed in Table 2.1) are outlined in the remainder of this section.

2.1.2 Response Theme 1 – Managing the Rural Landscape

The response groups included in this theme are designed to influence rural pathways in the source-pathway-receptor model of the flooding system (Table 2.2).

Table 2.2 **Managing the Rural Landscape**

Response group	Response measure, policy or intervention
1. Rural Infiltration: water retention and management of infiltration into the catchment	Changing tillage practice
	Extensification
	Field drainage (to increase storage)
	Afforestation
	Buffer strips and buffering zones
2. Catchment-Wide Storage: water retention through storage schemes at all scales	Detention ponds and bunds
	Wetlands and washlands
	Riparian and floodplain impoundments
3. Rural Conveyance: managing conveyance to alter the volume and timing of runoff	Management of hill slope connectivity
	Drainage channel maintenance
	Drainage channel realignment

This theme concerns changes that could be made to the way that the catchments in the UK are managed in order to promote infiltration and groundwater replenishment, retain excess surface runoff by storing water in rural areas at times of flood and manage the surface runoff that does occur by altering the conveyance properties of the land over which the water flows.

Some measures in the theme are field or farm-scale and operate close to the source of the runoff. Examples include buffer strips, detention ponds and ditches. While known to be effective locally, there is no scientific evidence as yet that confirms that small-scale, diffuse measures designed for source control are likely to be effective in addressing catchment-scale flood mitigation. This finding is consistent with the work undertaken for Defra project FD2114, but does not rule out the possibility that viable diffuse responses to catchment scale flooding will be discovered in the course of further research.

Other measures in this theme involve larger storage capacities located lower in the drainage network and concentrated upstream of receptors in flood prone areas. Examples include wetlands enhanced for flood storage, washlands and riparian/floodplain impoundments.

Although these measures are well proven, uncertainty concerning the degree to which they could reduce future national flood risk is high. Evidence shows that storage measures are highly effective, especially when applied as part of an integrated catchment management plan, but not all catchments provide opportunities for catchment-wide storage due to their terrain, scale or the extent and intensity of pre-existing development.

The links between this and other themes are strong. In the case of local measures, these link to intra-urban flooding and the management of flood losses because they may be particularly effective in controlling 'muddy floods' that enter isolated houses, small settlements or urban conurbations from adjacent rural areas, without the flood waters having followed any recognised watercourse.

The measures in this theme link strongly to rural land-use planning and management. For diffuse measures, effective implementation requires concerted action across numerous farm and land management units. To generate sufficient storage capacity, concentrated measures require land-use to be altered over extensive areas of floodplain. These factors introduce a strong degree of scenario-dependency due to the challenges of securing the governance required to deliver the measures effectively at the catchment scale.

The theme is also strongly linked to river and coastal engineering involving floodwater storage, conveyance and, particularly, the realignment of defences. For example, Engineered Flood Storage may merge with Catchment-Wide Storage when the extent of engineering structures necessary to create the storage area is large relative to the land take, and where land management issues are particularly significant. Also the Re-alignment or Abandonment of River and Coastal Defences may return land once protected to frequent fluvial or tidal inundation, creating the opportunities for coupling land use change with realignment in a multi-faceted catchment management plan.

2.1.3 Response Theme 2 – Managing the Urban Fabric

The response groups included in this theme are designed to influence urban pathways in the source-pathway-receptor model of the flooding system (Table 2.3). This distinction is important in understanding the results – it is worth taking this opportunity to explain where other aspects of urban flooding are covered.

Table 2.3 **Managing the Urban Fabric**

Response group	Response measure, policy or intervention
4. Urban Storage: increase storage in urban areas	Building design
	Urban area development
	Detention ponds
	Source control
	Underground storage
	Temporary flood storage (e.g. in parkland)
	Storage along/adjacent to flood system
	Groundwater management
	Rainwater harvesting
5. Urban Infiltration: increase infiltration in urban areas	Permeable land cover
	Building design
6. Urban Conveyance: manage conveyance of flood waters through urban areas	Design of building drainage
	Urban drainage infrastructure
	Urban area development
	Source control and local sustainable water system management
	Controlling pathways of runoff
	Multiple drainage systems
	Water reuse and recycling etc
	Managing wrong connections
	Separating foul- and storm-sewers
	Off-site pumping
	Aesthetic use of water in urban area
	Active dynamic real-time operation
	Pumping off site
	Design of roads and gully pots
	Alter river channels to improve outfalls
	Reopen culverted watercourses (daylighting)

In the Foresight project, the overall flood management system for a catchment is considered in a hierarchical manner:

- Urban areas are considered in this chapter as components in wider catchment- or coastal-scale systems – it is as *pathways* in the catchment runoff system that responses to flood flows generated in urban areas are dealt with in this response theme.
- Responses to flooding that seek to reduce risk within urban areas that are the *receptors* of flooding generated at the catchment or coastal scales (through reducing the consequences of flooding) are dealt with in Themes 3 and 4.
- Chapter 3 considers, in detail, responses to pluvial flooding that originates and remains within the urban area.

The principle applied in the present catchment-scale response theme is that the operation of the drainage system in urban areas should emulate natural drainage processes as much as possible and so prevent increasing flood risks downstream. At the catchment scale, an increase in flood risk downstream of an urban area is a symptom of a drainage system which has failed to store or infiltrate water in the way that a natural land surface would have, and which has instead accelerated the rate at which runoff is conveyed into the receiving waters.

Urban responses designed to reduce downstream flood risk are clearly linked with responses concerned with coincident, intra-urban and peri-urban floods (Chapter 3) that originate in fringing rural areas (muddy floods). Further links exist to event management (Theme 3), measures designed to reduce exposure and vulnerability to flooding in urban areas (Theme 4), and engineering to control catchment and coastal flooding (Theme 5). The theme has strong social and economic dimensions due to large urban populations and high inventory values, together with the high impacts that individuals can have (e.g. laying drives, patios etc). Interventions in the form of engineering and softer approaches will need to be consistent with wider goals of urban planning and form, which are driven primarily by other social and economic agendas.

2.1.4 Response Theme 3 – Managing Flood Events

Managing flood events in real time can significantly reduce both the probability of flooding and the damage that is caused. Hence, measures in this theme are drawn from the whole of the hazard-management cycle and broadly fall into two categories:

- Controlling flood events (pathways).
- Changing the behaviour of people who are vulnerable to flood risk (receptors).

The response groups included in this theme are therefore designed to influence both pathways and receptors in the source-pathway-receptor model of the flooding system (Table 2.4).

While there is scope for improvements in science and technology to unlock large reductions in risk through measures concerned with forecasting and flood-fighting, it is issues of governance and stakeholder behaviour that will determine the extent to which flood-management measures in this theme can be implemented in practice. In this regard, the receptor-related response groups in this theme are closely influenced by scenario-specific public attitudes and societal values.

There are strong technical and practical links to the engineering theme (Theme 5), through the design of accurate forecasting systems and development of flood-fighting measures that are resilient and adaptable. Links to urban (Theme 2) and intra-urban responses (Chapter 3) are inevitable, as most people will continue to live in an urban area and be affected by its infrastructure and fabric during floods. Also, there is some overlap with measures in Theme 4 (Managing Flood Losses) – as there is no clear way of distinguishing between responses designed to manage a particular flood event and those designed to reduce the losses stemming from flood events more generally.

Table 2.4 **Managing Flood Events**

Response group	Response measure, policy or intervention
7. Pre-Event Measures: to ensure that people and stakeholders are prepared, mitigate negative impacts, and facilitate efficient management of the event	Flood-preparedness planning: major incident plans for flooding
	Flood-risk mapping
	Education and awareness-raising
	Family/community flood plans, flood risk logbooks
8. Forecasting and Warning: to provide sufficient time for people and organisations to take effective mitigating actions prior flood water arriving	Flood-forecasting systems: improved sensing, forecasting, modelling, and updating of model predictions during the event
	Warning dissemination systems (including take-up)
9. Flood Fighting: to manage floodwaters and defences during the event	Demountable/temporary defences
	Water-level control structures: controllable weirs and sluices
	Emergency repair/shoring-up of failing defences
	Emergency diversions: cut-through channels, breaking of dikes
10. Collective Damage avoidance actions: organised or spontaneous removal of people, assets or livestock to a safe location	Evacuation of floodplains and coastal areas at risk
	Demountable flood defences
11. Individual Damage Avoidance Actions: actions taken by individuals to reduce flood losses including preventing or delaying flood water from entering buildings, and moving people, assets or livestock to safety	Temporary floodproofing
	Moving assets to safety

2.1.5 Response Theme 4 – Managing Flood Losses

The response groups included in this theme are designed to influence receptors in the source-pathway-receptor model of the flooding system (Table 2.5).

Table 2.5 **Managing Flood Losses**

Response group	Response measure, policy or intervention
12. Land-Use Management: Reduce current exposure to flood loss associated with existing developments	Managed retreat
	Relocation of exposed structures
13. Flood-Proofing: reduce current exposure to flood loss through improved flood resilience	Retrofitted floodproofing
14. Land-Use Planning: limit increase in exposure to flood loss associated with new developments	Land-Use planning
	Financial instruments: e.g. floodplain charging
	Locate critical facilities away from floodplain
15. Building Codes: limit increase in exposure to flood loss through changing building codes and/or construction practices	Floodproofing
	Property/structure design standards
16. Insurance, Shared Risk and Compensation: facilitate economic and financial recovery from flood loss	Insurance
	State aid/compensation
	Tax relief on losses
	Public relief
	Self-insurance
17. Health and Social Measures: lessen the health, social and practical impacts of flooding	Targeted health and counselling services
	Practical aid (clean up etc)

These responses focus on changing institutional, administrative, social and stakeholder systems and activities so that the flood impacts are reduced. Receptors covered include:

- Risk to the life and health of individuals.
- Residential properties and their contents.
- Commercial properties and their contents.
- Infrastructure and communications.
- Agriculture.
- Leisure/heritage facilities/assets.

Responses fall into two major categories: those designed to reduce levels of risk to existing assets, properties and their inhabitants, and those intended to limit the increase in risk that will accompany land-use change, including urban development and the building of new properties in flood-prone areas. Similarly, there are responses that individual stakeholders may take to reduce their own risk and responses that require action by communities and higher authorities to be effective. As the outcomes will vary for individuals and organisations in the same community, analysis of these responses requires a detailed understanding of differential loss impacts.

There are strong links to the rural land use and urban fabric themes through, for example, the innovative use of landscape management, urban planning laws and building codes to reduce both the probability of flooding and its consequences. There is also overlap with Theme 3 in the area of floodproofing, which may act to reduce both the frequency with which floodwater enters a property as well the damage that accrues on those occasions when it does so.

2.1.6 Response Theme 5 – River and Coastal Engineering

The response groups included in this theme are designed to influence pathways in the source-pathway-receptor model of the flooding system (Table 2.6). They incorporate responses to coastal erosion which often accompany coastal flood risk. However, responses where coastal erosion is the primary threat, are dealt with at the end of Appendix A.

Table 2.6 **River and Coastal Engineering**

Response group	Response measure, policy or intervention
Fluvial Defences	
18. River Conveyance: alter river channel to increase conveyance of flow passed downstream	Channelisation
	Channel restoration
	Dikes and embankments
	Bypass channels/flood-diversion channels
19. Engineered Flood Storage: construct or expand reservoirs, bunds or other impounding structures to increase flood storage	Dams
	Floodplain/wetland storage
	Floodplain restoration
	Temporary channel storage
20. Flood Water Transfer: construct pipes or channels to convey flood waters to an adjacent catchment or drainage system	Pumped diversions to storage areas
21. River Defences: construct or raise linear embankments and build or enhance control structures to contain and manage flood waters	Flood defence along the river channel
	Ring dikes around vulnerable areas
	Specialist structures such as floodgates that prevent floodwater from entering specific areas
Coastal and Estuarial Defences	
22. Coastal Defences: construct or raise physical barriers to flooding and coastal erosion	Flood barriers
	Dikes and embankments
23. Realigment of Coastal Defences: relocation landwards	Change configuration of coastline
24. Abandonment (managed or unmanaged) of Flood Defences: unmanaged realignment	Change configuration of coastline
25. Reduce Coastal Energy: structures, features or devices to reduce the energy of near-shore waves and currents	Beach nourishment
	Offshore barriers
	Energy converters
	Modify morphology
26. Coastal Morphological Protection: allow or encourage changes in coastline to accommodate forcing processes	Promote formation of natural landforms to provide protection

The long-term perspective adopted for the Foresight project (30 to 100 years) means that it is not possible to make judgements about the specific flood-management infrastructure that may be implemented. Recognising this, the analysis of engineering responses in this volume must necessarily be performed at a high level, dealing with broad approaches that can in future be adapted to suit policies that will evolve in response to the relevant sociopolitical circumstances and which take advantage of technological advances.

Engineering responses nest within local and national policies that will dictate the scale of the engineering approach – for example, whether it is one, or a combination, of the following:

- A system of large-scale structures forming the defence system.
- A series of linked, smaller-scale structures.
- Dispersed, localised structures.

The choice of strategy for a municipality, region or nation within the UK will result in different local engineering futures, different physical outcomes and, therefore, variations in the resulting flood risk. Hence, responses in this theme must be examined at two levels: the first, concerned with their physical attributes, and the second, concerned with their policy context.

Nowhere is the policy framework more important than with respect to realignment of defences (in both the coastal and river environments). The decision to realign rather than rebuild on the existing alignment rests not only on the choice and construction of the type of engineering barrier or structure to be employed, but also on a plethora of other issues. For example, decision-makers must consider land use, planning laws, public attitudes and the behaviour of significant stakeholders such as the owners of land and infrastructure affected by the scheme. The management process applies to the interface between land and water, not just one or the other.

A particular form of realignment occurs when flood-defence infrastructure is abandoned, allowing uncontrolled coastal adjustment or reversion of the floodplain to its previous and natural purpose. Under some scenarios, abandonment may be the unplanned outcome of a failure to maintain defences due to lack of funding or public will. In others, abandonment may play a role within the strategic selection of schemes, such as coastal rollback, chosen because of the potential for cost savings that may be used to reimburse displaced populations and landowners.

There are numerous linkages between this response theme and the others, and, on a smaller scale, there are also numerous links between the groups within this theme. Of particular note is the fact that it is not possible to separate engineering from land-use planning and flood-defence policy, thereby implying a strong governance dimension to this theme. Often, the major objection raised to an engineering solution stems from its environmental impacts, and so sustainability is also certain to figure prominently in any debate concerning the future of engineering approaches to flood-risk management.

2.2 Scoring and ranking the response groups

This section scores and ranks the various response groups based on their ability to reduce the future flood risks identified in Volume I. The performance of responses with respect to sustainability is dealt with in Section 2.4.

Before considering the risk reductions that may be delivered by various responses, it is instructive first to recall the basis on which those 'baseline' risks were formulated in Volume I, and to recall the size of the catchment- and coastal-scale risks that need to be addressed in each of the four scenarios.

2.2.1 Background – flood-risk multipliers under the baseline assumption

In Volume I, experts assessed the future increases in flood risk that might arise in the UK under four socioeconomic/climate change scenarios – where flood risk is defined as a function of the probability and consequences of flooding (often expressed as Expected Annual Damages – EAD). Driver impacts were assessed on the basis that source and pathway drivers alter flood risk through their impact on the probability of flooding, while receptor drivers alter flood risk through their impact on its consequences.

Within the analysis and extrapolation of flood risk, two underpinning assumptions were made. These are:

1. *Baseline flood management assumption:* current flood-management and coastal-management policies and expenditure continue unchanged in the future and are therefore, the same under all scenarios.

2. *Underpinning economic assumption:*

- Inflation is excluded.
- Prices are not discounted to a present value (all analyses are undertaken as though we are in the 2050s or 2080s).
- The distribution and type of vulnerable properties (housing, industry, etc.) vary under each scenario. (An inventory of vulnerable properties and their value is projected to 2050s/2080s for each scenario. This enables the losses associated with a given depth of flooding to be established which varies appropriately between scenarios).
- Provision of government subsidies vary. (Current subsidies may differ between the scenarios, and hence the losses associated with subsidised assets may vary – for example, the current reduction of 35% in national economic losses associated with losses of agricultural production may vary due to the influence of the Common Agricultural Policy).
- Only national economic losses are considered. (This is to say that the economic principles as outlined in the Green Book and interpreted by Defra in PAG 3 hold).

The magnitude of impact on risk was expressed for each driver in terms of the change in national flood risk under each scenario at the date specified. Table 2.7 lists the national flood-risk multiplier scores for drivers that were predicted for the 2080s.

Table 2.7 **National risk multiplier scores for flood risk associated with each driver in the 2080s**

Risk driver	Driver type		Factor by which flood risk is multiplied in the 2080s under each Foresight scenario: World Markets	National Enterprise	Local Stewardship	Global Sustainability
Precipitation	F	P	3.6	2.7	2.7	2.0
Temperature	F	P	1.0	1.0	1.0	1.0
Urbanisation	F	P	2.7	2.7	0.7	0.7
Rural Land Management	F	P	1.6	1.6	0.7	0.8
Environmental Regulation	F	P	1.0	1.0	2.8	4.0
River Morphology and Sediment Supply	F	P	1.6	1.0	2.7	2.0
Vegetation and Conveyance	F	P	1.2	1.2	1.6	3.6
Waves	C	P	5.1	2.8	1.9	1.5
Relative Sea-Level Rise	C	P	9.6	6.4	5.1	3.7
Surges	C	P	9.6	4.6	2.8	1.5
Coastal Morphology and Sediment Supply	C	P	5.1	3.7	2.4	1.5
Stakeholder Behaviour	B	P	2.8	0.3	0.2	0.2
Social Impacts	B	C	19.8	3.6	6.1	3.2
Buildings and Contents	B	C	6.4	4.5	0.7	1.9
Urban Impacts	B	C	2.0	1.6	1.0	1.1
Infrastructure Impacts	B	C	9.0	5.2	0.7	1.5
Agricultural Impacts	B	C	1.0	1.0	1.0	1.0
Overall risk multiplier (EAD)			**19.7**	**14.5**	**1.44**	**4.67**

Key: F = fluvial driver; C = coastal driver; B = driver affecting both fluvial and coastal flood risk
P = driver affecting flood-risk probability; C = driver affecting flood-risk consequence

The final row in Table 2.7 provides the overall risk multiplier for the scenario derived from the quantified risk modelling described in Volume I. This represents the combined effect of all the drivers on flood risk. If all the drivers were dependent on each other, the overall risk multiplier should be the same as that for the driver having the greatest impact. Conversely, if all the drivers were independent, the overall risk multiplier would be equal to the product of the impacts of all the individual drivers. While there is a strong degree of dependence between the drivers, dependence is far from complete. Unfortunately, there is no simple relationship between the overall value and the national risk multipliers for the individual drivers.

The overall risk multipliers for each scenario are particularly important. These represent the best estimate of the values by which overall national flood risk would increase under the baseline condition (no changes in flood management) and which, therefore, provide the headline figure that the responses seek to reduce.

2.2.2 Assessment of possible flood-risk reduction for each response group

Response scoring

The specialist team for each theme considered, for each future scenario, what the effect would be if the measures in each response group were implemented (in isolation of the effects of other groups), in a manner consistent with the opportunities and constraints identified for that scenario. In particular, for each response group, they assessed the possible reduction in the flood risk by considering the effects of the measures on the predicted risk increases for each of the flood-risk drivers (as detailed in Table 2.7).

The scaled impacts of each response group were then expressed as a multiplier (S) of the overall risk multiplier that was predicted under the baseline assumption (given in the last row of Table 2.7).

Response scaling

In deriving national scores, scaling was applied to the scores for two types of response: those affecting pathways and those affecting receptors. Scores for pathway responses were scaled according to the area affected. Responses scaled this way were in the themes River and Coastal Engineering and Managing the Urban Fabric. In the River and Coastal Engineering theme, fluvial and coastal/estuarial scores were scaled according to the proportion of the predicted national EAD associated with their floodplains in the 2080s (fluvial = 55%, coastal/estuarial = 45%). In the Urban Fabric theme, scores were scaled to reflect the fact that urban areas make up a very small proportion of the runoff-generating area of the UK.

Consideration of responses in the theme Managing Flood Losses included some measures which are applicable only to existing urban areas and buildings and others which are applicable only to new developments. In assessing the overall effect on national flood risk, scores were adjusted to take account of the proportion of new and existing buildings in the floodplain expected under each scenario. Proportions varied slightly between scenarios, but were sufficiently close that it could be assumed that under all scenarios 45% of floodplain properties in 2080 would be new and 55% existing. This was justified on the basis that a small proportion of existing buildings are rebuilt each year, and so by 2080 there would have been considerable new build, even in existing urban areas. Under World Markets and National Enterprise annual rebuild of the existing stock was set at 0.5% per annum. Under Local Stewardship and Global Sustainability it was assumed to be 0.25% per annum.

2.2.3 Summary results

Response scores

The results of the scoring exercise are summarised in Table 2.8.

<table>
<tr><th colspan="5">Table 2.8 **Scores (S = multiplier on baseline risk) for individual response groups**</th></tr>
<tr><th>Response group</th><th>World Markets</th><th>National Enterprise</th><th>Local Stewardship</th><th>Global Sustainability</th></tr>
<tr><td>1. Rural Infiltration</td><td>1.00</td><td>0.90</td><td>0.90</td><td>0.90</td></tr>
<tr><td>2. Catchment-Wide Storage</td><td>1.00</td><td>0.80</td><td>0.80</td><td>0.60</td></tr>
<tr><td>3. Rural Conveyance</td><td>1.00</td><td>0.90</td><td>0.85</td><td>0.70</td></tr>
<tr><td>4. Urban Storage</td><td>0.97</td><td>0.95</td><td>0.94</td><td>0.94</td></tr>
<tr><td>5. Urban Infiltration</td><td>1.00</td><td>1.00</td><td>1.00</td><td>0.95</td></tr>
<tr><td>6. Urban Conveyance</td><td>1.00</td><td>1.00</td><td>0.97</td><td>0.95</td></tr>
<tr><td>7. Pre-Event Measures</td><td>0.86</td><td>0.89</td><td>0.81</td><td>0.80</td></tr>
<tr><td>8. Forecasting and Warning</td><td>0.81</td><td>0.88</td><td>0.81</td><td>0.76</td></tr>
<tr><td>9. Flood Fighting</td><td>0.81</td><td>0.86</td><td>0.81</td><td>0.80</td></tr>
<tr><td>10. Collective Damage Avoidance</td><td>0.95</td><td>0.93</td><td>0.88</td><td>0.86</td></tr>
<tr><td>11. Individual Damage Avoidance</td><td>0.86</td><td>0.92</td><td>0.75</td><td>0.80</td></tr>
<tr><td>12. Land-Use Management</td><td>1.00</td><td>0.96</td><td>0.60</td><td>0.61</td></tr>
<tr><td>13. Flood-Proofing</td><td>0.86</td><td>0.84</td><td>0.70</td><td>0.81</td></tr>
<tr><td>14. Land-Use Planning</td><td>0.94</td><td>0.86</td><td>0.85</td><td>0.83</td></tr>
<tr><td>15. Building Codes</td><td>0.85</td><td>0.86</td><td>0.90</td><td>0.89</td></tr>
<tr><td>16. Insurance, Shared Risk and Compensation</td><td colspan="4" rowspan="2">Note: these responses act to reduce flood risk indirectly via response groups 12, 13 and 15 and their impacts are included in the risk reduction multipliers for those groups.</td></tr>
<tr><td>17. Health and Social Measures and Policies</td></tr>
<tr><td>18. River Conveyance</td><td>0.83</td><td>0.78</td><td>0.89</td><td>0.89</td></tr>
<tr><td>19. Engineered Flood Storage</td><td>0.89</td><td>0.83</td><td>0.83</td><td>0.78</td></tr>
<tr><td>20. Floodwater Transfer</td><td>0.99</td><td>0.99</td><td>1.00</td><td>0.99</td></tr>
<tr><td>21. River Defences</td><td>0.55</td><td>0.55</td><td>0.78</td><td>0.62</td></tr>
<tr><td>22. Coastal Defences</td><td>0.64</td><td>0.63</td><td>1.17</td><td>0.68</td></tr>
<tr><td rowspan="2">23/24. Coastal Defence Realignment: split cells are for realignment (upper) and abandonment (lower) under *NE* and *LS*</td><td rowspan="2">0.71</td><td>0.68</td><td>1.30</td><td rowspan="2">0.71</td></tr>
<tr><td>0.69</td><td>1.53</td></tr>
<tr><td>25. Reduce Coastal Energy</td><td>0.71</td><td>0.67</td><td>1.37</td><td>0.72</td></tr>
<tr><td>26. Morphological Coastal Protection</td><td>0.71</td><td>0.68</td><td>1.36</td><td>0.74</td></tr>
</table>

Facets and philosophies of floodwater storage

Responses involving floodwater storage appear in three themes: Catchment-Wide Storage under Managing the Rural Landscape; Urban Storage under Managing the Urban Fabric; and Engineered Flood Storage under River and Coastal Engineering. The distinctions between these different responses are related more to the practicality of assessing future responses individually than to philosophical or material differences in the response measures themselves. According to the definitions in the relevant response descriptions (Appendices A2, A4, A19):

- Engineered Flood Storage *increases the capacity of fluvial systems temporarily to store floodwater through a variety of engineered measures, some combined with natural features of the river system and its floodplain.*
- Urban Storage *provides temporary storage to arrest large flood peaks (with) slow subsequent release.*
- Catchment-Wide Storage *seeks to retain runoff close to its source, or within the drainage and river networks, in strategic locations where this significantly attenuates flows and reduces flood peaks downstream.*

Catchment-Wide Storage has a broader definition than the other two, and indeed encompasses them within a philosophy of holistic, multi-objective catchment planning and management. The holistic approach implies not the construction of one or two engineered storage facilities in rural or urban locations and building of washlands to protect particular flood prone areas, but the creation of additional catchment-wide storage using the whole range of storage methods. These might be at a range of scales, from farm level to major impoundments, and of various types from low impact, passively controlled washlands to gated structures controlled by real time rainfall and catchment sensing networks and predictive models. Both rural and urban storage would be included. The storage facilities would be designed in such a way as to satisfy multiple objectives such as water quality improvement and biodiversity, often by integrating wetlands into the storage areas. River and floodplain restoration are likely to play an increasing role as our understanding of natural processes advances and we learn how better to use them for flood management. Although there is little evidence that marked reductions in catchment-scale flood risk can be achieved through small scale storage diffused across the catchment, these response measures may also gain prominence as research which is currently in train increases our understanding of scale effects in their efficacy.

In terms of scoring the individual response groups that invoke storage, Engineered Flood Storage predominates under World Markets which favours direct interventions in the flooding system. Engineered and Catchment-Wide response groups have similar impacts under National Enterprise and Local Stewardship, but under Global Sustainability the potential for flood risk through Catchment-Wide Storage is greater than that for Engineered Flood Storage. This reflects the high value that society places environmental quality and sustainability in a Global Sustainability future and the expectation that the governance structures that exist under this scenario permit the full and imaginative exploitation of catchment storage within the framework of integrated catchment management plans. It is, however, recognised that catchment-wide storage cannot work effectively on all catchments, which is one of the reasons for the high uncertainty ascribed to this response group (see Table 2.11).

Combining interdependent response groups

The purpose of scoring the response groups was to allow them to be ranked in order to identify which would have the greatest potential to reduce flood risk nationally under each socioeconomic/climate-change scenario in the 2080s. However, it emerged that scoring some of the response groups in isolation was unrealistic as a basis for ranking their effectiveness. The effectiveness of some responses depends so strongly on their being applied as part of an integrated approach that to rank them individually would distort the outcome of the exercise. To give a more robust and realistic assessment of which responses have the greatest potential, specialists chose to consider some of the response groups in Themes 2, 3 and 4 in association with each other (Table 2.9). The rationale behind the chosen associations follows.

Table 2.9 **Scores (S = multiplier on baseline risk) for combined response groups**

Response theme	Associated groups	Combined response group	WM	NE	LS	GS
2. Managing the Urban Fabric	4. Urban Storage	Managing Urban Runoff	0.99	0.98	0.97	0.95
	5. Urban Conveyance					
	6. Urban Infiltration					
3. Managing Flood Events	8. Forecasting and Warning	Real-Time Event Management	0.83	0.89	0.82	0.79
	9. Flood Fighting					
	10. Collective Damage Avoidance					
4. Managing Flood Losses	12. Land-Use Management	Land Use Planning and Management	0.93	0.81	0.45	0.45
	14. Land-Use Planning					
	13. Flood-Proofing	Flood-Proofing Buildings	0.71	0.70	0.60	0.69
	15. Building Codes					

Theme 2 – Schemes to increase urban storage would necessarily involve management of flood pathways and, where feasible, use pervious areas to increase infiltration. The potential for such integrated schemes to reduce flood runoff from an urban area was considered to produce combined scores for the three responses in this theme.

Theme 3 – To be effective, flood-fighting and collective-scale damage avoidance (for example, through evacuation) depend on accurate forecasting and timely flood warning. These three response groups in this theme were associated, based on their strong practical interdependence. Actions under individual damage avoidance are less dependent on warning, as damage can be averted even as floodwater enters a property.

Theme 4 – Measures involving land-use planning and management are closely related in governance terms and are better expressed as a combined response group. Also, combining them reduces uncertainty concerning the proportions of new build and rebuild in different scenarios. Flood-proofing and building codes are treated as a pair as they both relate to the fabric of structures and work much better (producing a much lower multiplier score than either acting alone) when undertaken within a coordinated policy framework.

Response ranking

The complete spreadsheets produced by the ranking exercise are large and are not easily amenable to production in hardcopy. They may be found in the relevant Foresight technical documents. Rankings are summarised here in Table 2.10. Some key points to note from Table 2.10 are as follows:

World Markets: Direct interventions in the physical flooding system through River and Coastal Engineering dominate the World Markets scenario, under which 14 of 17 available response groups have the potential to reduce flood risk. River and Coastal Defences occupy the top two ranks, with other direct interventions to Reduce Coastal Energy and increase River Conveyance and Engineered Flood Storage also expected to produce marked reductions in flood risk. A market-led approach to coastal management dictates that, except where the economic case for defence is strong, the scenario favours allowing the coast to adjust morphologically to accommodate the rapidly rising relative sea level and increased wave and storm surge activity through schemes to Realign Coastal Defences and promote Morphological Coastal Protection. Responses aimed at reducing flood losses reflect the individualistic attitudes of the scenario, with property owners taking responsibility for marked risk reductions through Flood-Proofing Buildings and Individual Damage Avoidance. Under this scenario, the Government's contribution to promoting damage reduction is limited to assisting individuals in reducing their personal risk through the provision of Pre-Event Measures and Real-Time Event Management. Predominance of the free market significantly reduces the effectiveness of Land-Use Planning and Management and attempts to Manage Urban Runoff, and prevents effective implementation of measures involving Catchment-Wide Storage, Conveyance and Infiltration.

National Enterprise: Interventions in the physical flooding system also dominate the National Enterprise scenario, but with some notable differences to World Markets that reflect the stronger role of the state in seeking to defend both the land and the national assets at risk, especially along the coast. A strong national focus in this scenario means that all 18 available responses could potentially have a positive effect. Engineering responses involving hard defences, energy reduction and realignment are expected to produce the major risk reductions, with increased River Conveyance and Engineered Flood Storage also delivering marked reductions. In this economically weaker scenario, Coastal Defence Abandonment is employed where funds are insufficient to support managed realignment. Limited technological advance reduces, but does not negate, the potential for Real-Time Event Management to reduce losses. Conversely, the stronger agricultural base, the capability of the state to incentivise rural stakeholders without breaking international agreements and willingness to control development allows the Catchment-Wide Storage and Land-Use Planning and Management responses to deliver marked flood-risk reductions.

Local Stewardship: Under this low-growth, low-technology scenario, only 12 responses have the potential to deliver flood-risk reductions. A strong commitment to locally planned responses that are environmentally benign and inexpensive reduces the effectiveness of direct interventions such as River Defences and River Conveyance, while boosting indirect and diffuse measures such as Engineered Flood Storage, Catchment-Wide Storage and Rural Conveyance. The inability to design, finance and implement coastal schemes at anything larger than the local scale entirely negates their effectiveness when scored nationally. The most effective responses in this scenario stem from loss reductions led by rigid application of Land-Use Planning and Management laws to relocate flood prone settlements and prevent any new development in floodplains. Properties remaining at risk benefit from community-based schemes involving Flood-Proofing Buildings. High public awareness of the possibility of flooding in this community-centred scenario means that Individual Damage Avoidance, Pre-Event Measures and Real-Time Event Management have the potential to produce marked risk reductions.

Global Sustainability: This scenario has the greatest number of responses (14) capable of producing major or marked reductions in flood risk. The integrated approach favoured under this scenario is illustrated by the top six ranks, which feature pairs of responses coordinated to: reduce losses (Land-Use Planning and Management, Flood-Proofing Buildings); manage runoff (Catchment-Wide Storage and Rural Conveyance); and, reduce residual risk in key areas to acceptable levels using physical barriers (River and Coastal Defences). Application of the other responses has the capability to produce marked reductions in flood risk, with the exception of Rural Infiltration, Managing Urban Runoff and Flood Water Transfer. The low ranks of these responses reflects physical and technical constraints on their effectiveness that are inherent to the UK.

Table 2.10 **Response groups ranked by potential for flood-risk reduction in the 2080s**

Rank	World Markets	National Enterprise	Local Stewardship	Global Sustainability
1	River Defences	River Defences	Land-Use Planning and Management	Land-Use Planning and Management
2	Coastal Defences	Coastal Defences	Flood-Proofing Buildings	Catchment-Wide Storage
3	Flood-Proofing Buildings	Reduce Coastal Energy	Individual Damage Avoidance	River Defences
4	Reduce Coastal Energy	Realign Coastal Defences	River Defences	Coastal Defences
5	Morphological Coastal Protection	Morphological Coastal Protection	Catchment-Wide Storage	Flood-Proofing Buildings
6	Realign Coastal Defences	Coastal Defence Abandonment	Pre-Event Measures	Rural Conveyance
7	Real-Time Event Management	Flood-Proofing Buildings	Real-Time Event Management	Realign Coastal Defences
8	River Conveyance	River Conveyance	Engineered Flood Storage	Reduce Coastal Energy
9	Individual Damage Avoidance	Catchment-Wide Storage	Rural Conveyance	Morphological Coastal Protection
10	Pre-Event Measures	Land-Use Planning and Management	River Conveyance	Engineered Flood Storage
11	Engineered Flood Storage	Engineered Flood Storage	Rural Infiltration	Real-Time Event Management
12	Land-Use Planning and Management	Real-Time Event Management	Manage Urban Runoff	Pre-Event Measures
13	Manage Urban Runoff	Pre-Event Measures	Floodwater Transfer	Individual Damage Avoidance
14	Floodwater Transfer	Rural Conveyance	Coastal Defences	River Conveyance
15	Catchment-Wide Storage	Rural Infiltration	Realign Coastal Defences	Rural Infiltration
16	Rural Conveyance	Individual Damage Avoidance	Morphological Coastal Protection	Manage Urban Runoff
17	Rural Infiltration	Manage Urban Runoff	Reduce Coastal Energy	Floodwater Transfer
18		Floodwater Transfer	Coastal Defence Abandonment	

Legend

Interpretation	Colour code
Major reduction in flood risk ($S < 0.7$)	
Marked reduction in flood risk ($0.7 \le S < 0.9$)	
Moderate reduction in flood risk ($0.9 \le S < 1.0$)	
Ineffective ($S = 1.0$)	
Liable to increase in flood risk ($S > 1.0$)	

2.3 Analysis of uncertainty in the response groups

Throughout the Foresight project it has been recognised that considerable uncertainty exists regarding practically all aspects of flood risk change in the next 30 to 100 years. An important aspect of the work has therefore been to understand the nature and extent of the various uncertainties – so that they can be addressed, either through further research, or by the development of policies that are robust to the various uncertainties.

2.3.1 Identifying uncertainties inherent in response groups

Scientific uncertainty concerns our lack of understanding of physical processes in fields such as hydrology and imperfect ability to describe the physics of flooding mathematically. However, uncertainty does not stem only from limited scientific knowledge and must be more broadly defined (Wynne 1995). In fact, all the possible flood- management responses will have uncertainties associated with them – some of which may be science-related and others not. For example, there will be uncertainty whether, under a given scenario, there is likely to be a competent authority to ensure that appropriate activities are undertaken when and where they are required for a given response to be effective. Thus, questions of uncertainty are strongly linked to questions of governance, which are explored further in Chapter 8. Uncertainty concerning individual response groups is discussed in Appendix A.

2.3.2 Uncertainty scores and ranking

Uncertainty was further considered in scoring the reductions in national flood risk that could potentially be achieved by each response group under each of the socioeconomic/climate-change scenarios.

To account for uncertainty in assessing the impact of responses, expert teams were requested to add upper- and lower-bound estimates to their best estimate of the flood risk multiplier (S) for each of the response groups in their theme. The upper-bound estimate for each scenario was then divided by the lower-bound estimate to define a geometric band of uncertainty for each response group under each scenario.

The results of the uncertainty assessment are shown in Table 2.11. The complete results may be found in the relevant Foresight technical documents. For ease of comparison with their rankings in Table 2.10, responses are listed in the same order in Table 2.11. This table shows that there are a number of potentially important responses (i.e. appearing towards the top of the table) that are also relatively uncertain (i.e. coloured red). High-ranking responses with high uncertainty include:

- Land-Use Planning and Management.
- Flood-Proofing Buildings.
- Catchment-Wide Storage.
- Rural Conveyance.

Table 2.11 **Uncertainty associated with response groups (note: the order of response groups in this table reflects their flood-risk impact ranks, as listed in Table 2.10)**

Rank	World Markets	National Enterprise	Local Stewardship	Global Sustainability
1	River Defences	River Defences	Land-Use Planning and Management	Land-Use Planning and Management
2	Coastal Defences	Coastal Defences	Floodproofing Buildings	Catchment-Wide Storage
3	Floodproofing Buildings	Reduce Coastal Energy	Individual Damage Avoidance	River Defences
4	Reduce Coastal Energy	Realign Coastal Defences	River Defences	Coastal Defences
5	Morphological Coastal Protection	Morphological Coastal Protection	Catchment-Wide Storage	Floodproofing Buildings
6	Realign Coastal Defences	Coastal Defence Abandonment	Pre-Event Measures	Rural Conveyance
7	Real-Time Event Management	Floodproofing Buildings	Real-Time Event Management	Realign Coastal Defences
8	River Conveyance	River Conveyance	Engineered Flood Storage	Reduce Coastal Energy
9	Individual Damage Avoidance	Catchment-Wide Storage	Rural Conveyance	Morphological Coastal Protection
10	Pre-Event Measures	Land-Use Planning and Management	River Conveyance	Engineered Flood Storage
11	Engineered Flood Storage	Engineered Flood Storage	Rural Infiltration	Real-Time Event Management
12	Land-Use Planning and Management	Real-Time Event Management	Manage Urban Runoff	Pre-Event Measures
13	Manage Urban Runoff	Pre-Event Measures	Floodwater Transfer	Individual Damage Avoidance
14	Floodwater Transfer	Rural Conveyance	Coastal Defences	River Conveyance
15	Catchment-Wide Storage	Rural Infiltration	Realign Coastal Defences	Rural Infiltration
16	Rural Conveyance	Individual Damage Avoidance	Morphological Coastal Protection	Manage Urban Runoff
17	Rural Infiltration	Manage Urban Runoff	Reduce Coastal Energy	Floodwater Transfer
18		Floodwater Transfer	Coastal Defence Abandonment	

Legend	Uncertainty bandwidth (B) (B = ratio of upper to lower bound estimates of flood risk impact multiplier)	Colour code
	B ≥ 1.5	
	1.5 > B ≥ 1.1	
	B < 1.1	

2.4 Sustainability aspects of the response ranking

2.4.1 Introduction

In the previous sections, catchment- and coastal-scale response groups have been outlined and appraised in terms of their potential to reduce flood risk. While the effectiveness of response groups in reducing national flood risk is of interest, their performance in terms of sustainability is no less important. Here we provide a summary of how the response groups perform when assessed and compared in terms of flood-risk reduction and the metrics of sustainability introduced in Chapter 1:

- Environmental Quality
- Cost-Effectiveness
- Social Justice
- Robustness
- Precaution

2.4.2 Assessing the sustainability of response groups

The sustainability performance of response groups as represented by each metric was scored on a positive/neutral/negative scale. This allows comparisons to be made across the scenarios, and also permits evaluation based on the threshold of acceptability for each metric. Sustainability performance included consideration of flood-risk reduction, with the scores in Table 2.8 converted to the positive/neutral/negative scale. The scoring scale is summarised in Table 2.12 and described in detail in Table 2.13.

Table 2.12 **Scale of measurement for metric impacts**

Sustainability metric score	Description	Equivalent flood risk reduction multiplier (S)
++	Major reduction in floodrisk	$S < 0.7$
+	Marked reduction in floodrisk	$0.7 \leq S < 0.9$
0	Moderate reduction in floodrisk	$0.9 \leq S < 1.0$
–	Ineffective	$S = 1.0$
– –	Liable to increase in floodrisk	$S > 1.0$

Table 2.13 **Descriptors of the sustainability criteria scoring scale**

Score	Robustness	Precaution	Social Justice	Cost-Effectiveness	Environmental Quality
++	The action can be implemented in all four socioeconomic/climate scenarios, and successfully addresses flood risk.	Justifications for pursuing the response action (and alternatives), as well as its potential risks, are systematically and openly scrutinised. Although some risks associated with action are unknown, expert and local knowledge is sought to address ignorance in ongoing regulatory appraisal, including the strategic anticipation of serious events. Monitoring and hazard warning systems are in place for timely responses when concerns are identified. Values and concerns of different social groups are taken into full consideration.	The action increases the capacity to deliver improved standards of social justice (fairness in distribution of benefits and costs, and in engagement), promptly, and with associated progressive re-evaluation.	The action is highly cost effective, with substantial net benefits.	The action strongly enhances biodiversity, improves environmental quality (habitats, water quality).
+	The action can be implemented in all four scenarios.	Risk assessments for the action and some ongoing monitoring activities are carried out; regulatory appraisal is timely.	The action provides some capacity to deliver improved standards of social justice.	The action is cost-effective, with some net benefits.	The action has a positive effect on biodiversity and environmental quality.
0	The effect of implementing the action is scenario-independent.	Existing precautionary approaches are adopted unchanged. No effect on society's ability to cope with uncertainties, including those relating to climate change.	No deterioration of social justice.	The action is marginally cost-effective.	No effect on biodiversity indices or environmental quality measures.
–	The action cannot adequately be implemented under one or more scenarios; or implementing the action has a mixed effect (social, economic or environmental) depending on the scenario.	Implementation of response action is not accompanied by ongoing technological and regulatory appraisal of risks and benefits. Inadequate research into early warnings and a non-inclusive approach to information gathering restricts timely responsiveness to emerging concerns.	The action reduces capacity to deliver minimum standards of social justice.	The action is costly and benefits are very limited.	The action causes some loss of biodiversity.
– –	The action is impossible to implement under one or more scenarios; implementing the action has a strongly adverse effect under one or more scenarios.	Implementation of response action has inadequate technological and regulatory appraisal of risks and benefits. Inadequate research into early warnings, limited information gathering, and failures in institutional communication means that risks are not understood until the costs and impacts are very severe.	The action strongly reduces capacity to deliver minimum standards of social justice, which causes measures of social justice to worsen.	The action is costly, and benefits are unlikely to be realised.	The action causes severe loss of biodiversity and negative impacts on habitats and water quality.

In assessing sustainability, response groups were considered individually, rather than in the combinations given in Table 2.9. This was done so that details of the sustainability performance of each response group were retained in the resulting ranking table. Table 2.14 therefore shows the 24 response groups that act to impact flood risk directly (excluding response group 16 – Insurance, Shared Risk and Compensation and 17 – Health and Social Measures, which act indirectly) ranked in terms of their potential to reduce flood risk, but with their colour codes modified to reflect their performance in terms of sustainability.

Where a response group fails to meet the threshold of acceptability in either Precaution or Robustness, its colour intensity is downgraded. Where a response group fails to meet the acceptable threshold in one of the major sustainability metrics (Cost-Effectiveness, Environmental Quality or Social Justice), its colour is further downgraded and if it fails two or more metrics, its colour is removed. The sustainability performance of individual response groups is considered in detail in Appendix A.

Table 2.14 **Sustainability performances of responses groups ranked by potential flood risk reduction. The small left-hand panel (solid colours) in each column indicates the potential for flood risk reduction, while the right panel (using both solid and degraded colours) shows the effect of failing to meet one or more of the thresholds of acceptable performance in sustainability.**

World Markets	National Enterprise	Local Stewardship	Global Sustainability
River Defences	River Defences	Land-Use Management	Catchment-Wide Storage
Coastal Defences	Coastal Defences	Floodproofing	Land-Use Management
Reduce Coastal Energy	Reduce Coastal Energy	Individual Damage Avoidance	River Defences
Morphological Coastal Protection	Realign Coastal Defences	River Defences	Coastal Defences
Realign Coastal Defences	Morphological Coastal Protection	Catchment-Wide Storage	Rural Conveyance
Forecasting and Warming	Coastal Defence Abandonment	Pre-Event Measures	Realign Coastal Defences
Flood Fighting	River Conveyance	Forecasting and Warming	Reduce Coastal Energy
River Conveyance	Catchment-Wide Storage	Flood Fighting	Morphological Coastal Protection
Building Codes	Engineered Flood Storage	Engineered Flood Storage	Forecasting and Warming
Individual Damage Avoidance	Floodproofing	Rural Conveyance	Engineered Flood Storage
Pre-Event Measures	Flood Fighting	Land-Use Planning	Pre-Event Measures
Floodproofing	Land-Use Planning	Collective Damage Avoidance	Flood Fighting
Engineered Flood Storage	Building Codes	River Conveyance	Individual Damage Avoidance
Land-Use Planning	Forecasting and Warming	Rural Infiltration	Floodproofing
Collective Damage Avoidance	Pre-Event Measures	Building Codes	Land-Use Planning
Urban Storage	Rural Conveyance	Urban Storage	Collective Damage Avoidance
Floodwater Transfer	Rural Infiltration	Urban Conveyance	Building Codes
Catchment-Wide Storage	Individual Damage Avoidance	Urban Infiltration	River Conveyance
Rural Conveyance	Collective Damage Avoidance	Floodwater Transfer	Rural Infiltration
Rural Infiltration	Urban Storage	Coastal Defences	Urban Storage
Urban Infiltration	Land-Use Management	Realign Coastal Defences	Urban Infiltration
Urban Conveyance	Floodwater Transfer	Morphological Coastal Protection	Urban Conveyance
Land-Use Management	Urban Infiltration	Reduce Coastal Energy	Floodwater Transfer
	Urban Conveyance	Coastal Defence Abandonment	

Major reduction in flood risk ($S < 0.7$)
Marked reduction in flood risk ($0.7 < S < 0.9$)
Minor reduction in flood risk ($0.9 < S < 1.0$)

Fails on Precaution or Robustness

Fails on 1 of Cost Effectiveness, Environmental Quality or Social Justice

Ineffective in reducing flood risk or where colour is degraded fails on 2 of cost effectiveness, environmental quality or social justice

2.5 Commentary

Table 2.15 shows failures in sustainability performance of the response groups by scenario (rows) and by sustainability metric (columns).

Table 2.15 **Summed failures on sustainability criteria**

Scenario	Cost Effectiveness	Environmental Quality	Social Justice	Precaution	Robustness
WM	3	5	12	6	5
NE	2	5	14	8	5
LS	1	2	2	5	5
GS	1	1	0	0	5

Overall, sustainability performance is closely related to scenario, with the two higher emission, consumer oriented futures failing on many more metrics than the lower emission, community centred scenarios. Provision of social justice in flood management is a particular problem in the World Markets and National Enterprise scenarios that stress development and autonomy. Interestingly though, the market oriented scenarios (World Markets and National Enterprise) also fail to meet sustainability targets in cost effectiveness, environmental quality and precaution much more often than the more community centred scenarios (Local Stewardship and Global Sustainability).

Unlike the other metrics, failure to meet the robustness metric is uniform across scenarios. The five response groups that consistently failed this metric were:

- Rural Conveyance.
- Rural Infiltration.
- Urban Conveyance.
- Urban Infiltration.
- Floodwater Transfer.

These responses share a reliance on the active participation of multiple stakeholders while being, at best, capable of producing only moderate reductions in flood risk. They rely on integrated flood management, with strong and participatory governance, to generate a modest return in terms of flood-risk reduction. Lack of robustness reflects comparatively weak performance of these measures and their unattractiveness as responses under all scenarios.

Responses that perform poorly (lose all their colour) in Table 2.14 tend to be those that manipulate flooding pathways through engineering interventions in natural systems (for example, River and Coastal Defences, River Conveyance, Engineered Flood Storage and Floodwater Transfer). These mostly fail on grounds of environmental quality or social justice. However, a response such as River Defences is capable of providing a major reduction in flood risk while also meeting sustainability criteria when implemented as part of an integrated portfolio of measures under the Global Sustainability scenario. This demonstrates that physical interventions are not inherently unsustainable. In fact, it is the policy framework within which engineering responses are conceived, the extent to which they are used as the primary response to increased flood risk and the manner in which they are implemented that govern their sustainability.

Coastal Defences generally performs worse in terms of environmental quality than River Defences. This reflects the fact that morphological dynamism is generally more important to coastal ecosystems in the UK than their fluvial counterparts. It suggests that there may be considerable benefits in terms of biodiversity in finding alternatives to structural flood defences along coasts.

Sustainability cannot be guaranteed through the adoption of non-interventionist responses that reduce risk by managing the consequences rather than the probability of flooding. Under the higher-emissions/consumerist scenarios (World Markets and National Enterprise) Pre-Event Measures, Forecasting and Warning, Flood Fighting, Collective and Individual Damage Avoidance, Land-Use Management and Flood-Proofing fail to meet acceptable thresholds in Social Justice and/or Precaution. The message here is that to meet sustainability thresholds, the adoption of policies based on reducing national losses must recognise the disproportionately high impacts of relatively small losses on vulnerable and disadvantaged communities and individuals.

Consideration of sustainability performance seriously reduces the range of responses available in some scenarios. Under World Markets the two response groups capable of delivering major reductions in national flood risk are both unsustainable. Eleven groups are capable of producing marked or moderate reductions in risk, but only three (Building Codes, Individual Damage Avoidance and Land-Use Planning) pass all sustainability thresholds. This reflects the strongly individualistic nature of society in a World Markets future. The outcome is similar under National Enterprise, with only four response groups being sustainable (Catchment-Wide Storage, Land-Use Planning, Building Codes and Urban Storage).

In contrast, under Global Sustainability 3 responses are capable of producing major reductions in risk that meet sustainability thresholds (Coastal Defences fails on environmental quality), while no less than 13 response groups could generate marked reductions in flood risk that are sustainable, and Rural Conveyance fails only in robustness. Local Stewardship features 11 response groups with the potential to produce sustainable reductions in flood risk.

In summary, this analysis has shown that:

- The effectiveness and sustainability of different flood-management responses depends strongly on matters of governance, policy and the manner they are implemented. The same response group may either have a broad range of negative consequences or meet the main pillars of sustainability, depending on the social backdrop and policy context.
- Under some scenarios, adverse impacts in terms of social justice and environmental quality severely restrict the options available for flood management and set bounds on the implementation of options that might otherwise be feasible.
- In the scenario-based approach to analysis adopted here, Global Sustainability and Local Stewardship futures would support many more sustainable responses than would World Markets or National Enterprise.
- However, in practice, the application of the principles of social equity and precautionarity in the design and implementation of responses to flood risk would improve sustainability irrespective of the wider socioeconomic scenario.