Appendix A

Response groups – catchment and coastal

In Chapter 2, we identified 80 response measures – technical solutions, policies and other interventions – that might be invoked at the catchment and coastal scales to deal with the increases in flood risk in the UK predicted in the 'Impacts' phase of the project (see Volume I). These responses were categorised into 26 response groups, sharing common outcomes in flood-risk reduction, within five major response themes (see Table A1).

Some responses to increased flood risk involve *pathways* of flooding. They reduce risk through their effect on the probability of flooding. Other responses affect *receptors* of flooding and reduce risk by decreasing flood losses.

This appendix describes each response group. In particular, where appropriate it describes:

- A definition of the response group and its function and efficacy in reducing flood risk.
- Issues of governance and performance in terms of sustainability.
- Costs and funding mechanisms.
- Interactions with other responses.
- Where appropriate a case example and comments on emerging issues concerning the response group.

The sustainability performance of each response group was considered in terms of six sustainability metrics (see Chapter 1):

- Environmental Quality.
- Social Justice.
- Robustness.
- Precaution.
- Flood risk reduction.
- Cost-effectiveness.

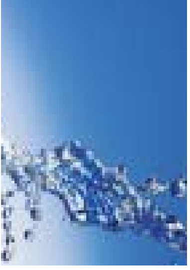


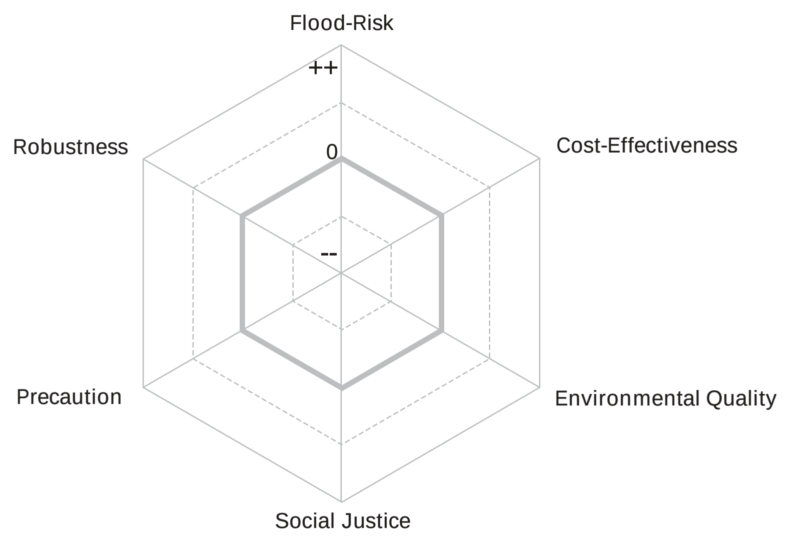
Table A1 **Responses to increased flood risk**

Response Theme	Response Group	Element of flood risk affected
Managing the Rural Landscape	A1 Rural Infiltration	Pathway
	A2 Catchment-Wide Storage	Pathway
	A3 Rural Conveyance	Pathway
Managing the Urban Fabric	A4 Urban Storage	Pathway
	A5 Urban Infiltration	Pathway
	A6 Urban Conveyance	Pathway
Managing Flood Events	A7 Pre-Event Measures	Pathway & Receptor
	A8 Forecasting and Warning	Pathway & Receptor
	A9 Flood Fighting	Pathway & Receptor
	A10 Collective Damage Avoidance	Receptor
	A11 Individual Damage Avoidance	Receptor
Managing Flood Losses	A12 Land-Use Management	Receptor
	A13 Floodproofing	Receptor
	A14 Land-Use Planning	Receptor
	A15 Building Codes	Receptor
	A16 Insurance, Shared Risk and Compensation	Receptor
	A17 Health and Social Measures	Receptor
River and Coastal Engineering	*Fluvial defences*	
	A18 River Conveyance	Pathway
	A19 Engineered Flood Storage	Pathway
	A20 Floodwater Transfer	Pathway
	A21 River Defences	Pathway
	Coastal and estuarial Defences	
	A22 Coastal Defences	Pathway
	A23 Realignment of Coastal Defences	Pathway
	A24 Abandonment of Coastal Defences	Pathway
	A25 Reduce Coastal Energy	Source
	A26 Coastal Morphological Protection	Pathway

Spider diagrams

The scores achieved by each response group (expressed in terms of the six metrics) are presented in this Appendix as spider diagrams. A sample spider diagram is shown in Figure A1.

Figure A1 **Sample spider diagram used to present the results of scoring response groups according to six metrics for sustainability**



In the spider diagram, the score for each metric is represented on a scale from '– –' to '+ +' running radially outwards from the centre of the web. The scores for each metric are joined to create a 'polygon' that represents the overall sustainability performance of that response group. On the diagrams, four separate polygons are plotted – these represent the scores for each future scenario.

When considering the polygons, a key factor is whether the perimeter falls inside or outside the neutral line, which represents a set of zero scores and indicates the threshold of acceptability in terms of the six metrics.

Responses to coastal erosion

Coastal flooding and erosion are often interlinked hazards and the summary descriptions of responses to coastal flooding already cover defences, measures and policies intended to deal with the combined risk they pose. However, along some parts of the UK coastline, land that is above flood levels is still susceptible to erosion that puts people, property and assets at risk. Such situations include, for example, retreat of 'soft' cliffs and coastal sand dunes. We describe responses to situations where coastal erosion is the primary risk in a supplementary section at the end of this appendix.

Response Group A1

Rural Infiltration

Response theme	Managing the Rural Landscape
Element of flood risk affected	Pathway

Definition

Rural Infiltration consists of responses that influence the partitioning of catchment runoff between fast, surface routes, such as overland flow, and slower subsurface routes, such as through flow.

The route that runoff follows affects the volume as well as the timing and peak discharge of storm flow. Runoff along slow routes may be delayed enough for the route to act as 'storage' on the timescale of an individual flood event. Examples of measures in this group include: modifications to arable land use, such as livestock and tillage practices; field drainage; buffer strips and buffering zones; and afforestation.

Function and efficacy

Measures in this group function on the principle that increasing the propensity for rain water to infiltrate into the soil can reduce the frequency of surface runoff and the magnitude of downstream flood peaks. The hypothesis that increased infiltration carries more water into the ground and reduces surface runoff is plausible at the farm scale, but it is as yet unproven whether these measures significantly mitigate catchment-scale flooding. Also, while increased infiltration will reduce runoff from a single storm on an unsaturated catchment, for subsequent storms, the soil will approach saturation more quickly.

Indicative simulations with a rainfall-runoff model confirm this effect and show that, while for $T \leq 2$ (T is the return period in years), a higher proportion of surface runoff leads to higher annual maximum discharges, the flood peaks are higher for $T > 2$ when there is a higher proportion of subsurface runoff (or greater infiltration). Further, increasing soil storage may lead to the soil being near saturation for longer in the winter months, increasing the risk of waterlogging and groundwater flooding. This response group may be effective, but we need better understanding of where and how this might be possible. Further, while there may be other benefits at the catchment-scale, it is by no means clear that such benefits can mitigate catchment-scale flooding in any significant way.

Governance

These measures raise two major issues of governance:

- They require active participation of a large number of land managers or farmers, distributed across the landscape.
- There may be significant spatial separation between the land managers responsible for implementing the measures, those responsible for planning managing them, and the beneficiaries.

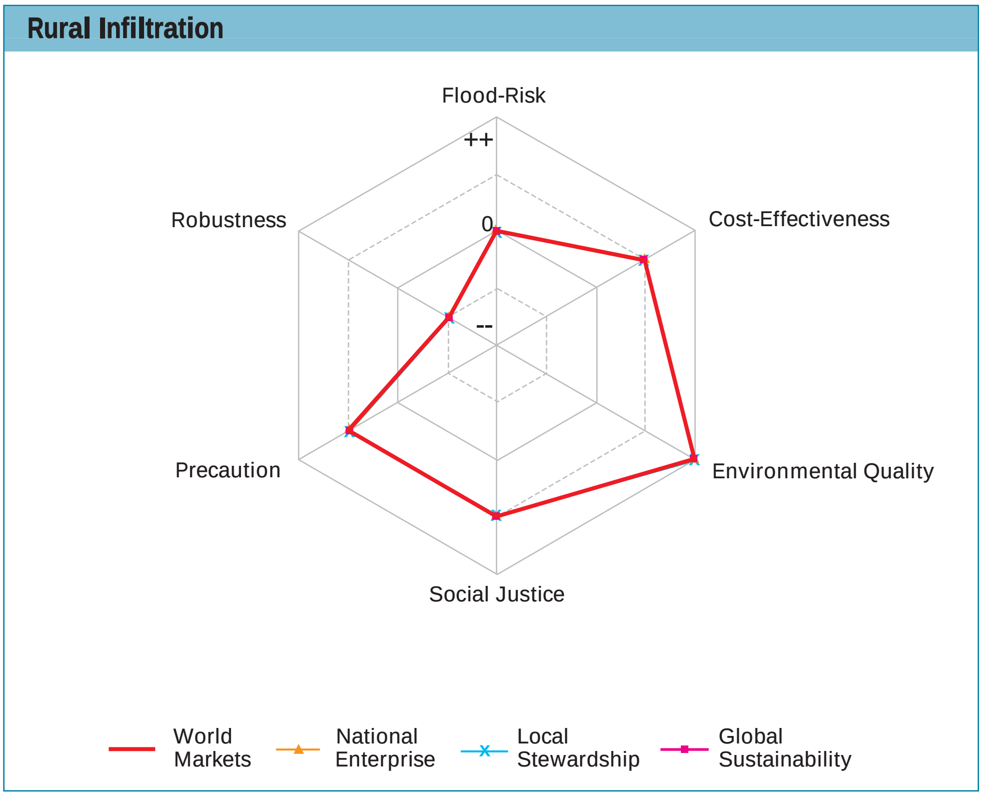
Fundamental to all of these measures are agri-environmental payment systems and their implementation. To be effective nationally, future versions of Defra, the Environment Agency and the extension services, and their counterparts in Scotland and Northern Ireland, will have to play a central role in operating catchment-wide schemes. However, even without central planning, the measures may also be delivered locally through Codes of Good Agricultural Practice.

Sustainability

Measures to promote rural infiltration score well on environmental quality. They correlate with general agricultural extensification, restoration of natural landscape wetness, reduced diffuse pollution and recreated habitat and restoration of landscape integrity. Indeed, the farm-scale land-management measures that would mitigate against flood risk may derive much stronger support from the possibility of reducing diffuse pollution and improving habitat. However, some measures, such as intensive coniferous afforestation, could cause a net reduction in environmental quality.

There should be beneficial impacts on social justice in that the measures require an integrated response, founded in shared knowledge and education among rural and urban communities. However, there may be some areas where social justice declines because many of the measures involve some form of extensification, and the rural economy will remain complex, with some households, especially non-landowners, dependent on intensive agricultural activity to maintain income.

The measures in this response group fit well with the precautionary principle. All of the responses are likely to be environmentally beneficial: other benefits from these activities are likely to be clear, not just in environmental terms, but also through the development of a different type of land or stewardship ethic.



Costs and funding mechanisms

Measures in this group are likely to be expensive in terms of both administration and auditing, although not in terms of capital expenditure. Their contribution to flood defence may be cost-effective, but only if flood-mitigation benefits can be realised. In future, environment schemes, European Regional Development Funds and local rural economic initiatives could work together to promote a mixed rural economy that suits most stakeholders and which could deliver significant returns in terms of flood mitigation.

Interactions and feedback loops

First, if these measures can play any role in flood mitigation, they are unlikely to be effective in isolation: many of these measures will be required together. It follows that a crucial requirement is to have integrated management plans at the scale of individual management units, such as farms, to identify what measures are required and where. Second, there are strong links with other aspects of environmental management, including pollution by nutrients, erosion, pesticide losses and pathogen losses. Third, there is very strong interaction with the core drivers of the agricultural economy, and notably agricultural subsidies and agri-environment schemes as the prime delivery mechanism. Fourth, there is strong feedback from other parts of the agricultural economy. For instance, general agricultural extension may need to be counterbalanced by the need to maintain agricultural intensity to protect high-grade agricultural land, as part of sustaining food supplies – this is especially important under some of the Foresight Futures.

Case example

There are almost no known examples of where measures in this group have been adopted specifically as flood-mitigation measures and where the associated flood response has been demonstrated. The River Parret study aims to investigate whether the '…water retention capacity of soils could be enhanced by a variety of affordable measures that would make a significant difference to peak flow…'. Although modelling performed in the study suggests that some decreases in flood peak might be possible, the main conclusion to date is that this is certain only at the farm scale, where there was qualitative evidence that overland flow once generated can be attenuated and reinfiltrated using simple practical measures. Indeed, most agricultural studies of land-use practice show that, where these measures have been adopted, for a range of reasons their flood mitigation impacts have not been fully demonstrated. This is true of: changing arable, livestock and tillage practice; buffer zones; land drainage; and afforestation. Evidence is conflicting, which illustrates the need for further research to improve our understanding of hydrological processes and the extent to which they are amenable to manipulation.

Response Group A2

Catchment-Wide Storage

Response theme	Managing the Rural Landscape
Element of flood risk affected	Pathway

Definition

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 to reduce flood peaks downstream.

This group of responses is distinct from the management of conveyance, which is taken to be situations where water does not go into store, rather its speed of translation is significantly reduced.

Function and efficacy

The key themes in effective operation of this response group are enhancing or restoring the natural capacity of catchments to store water and understanding the hydrodynamics of the drainage system to be able to optimise the location of flood storage sites as part of an integrated catchment management plan. To be effective, it is vital that the storage sites have sufficient capacity and are located to maximise flood attenuation in those parts of the catchment where flood risk must be reduced. Similarly, their effectiveness depends on them being managed primarily for flood storage. Optimisation of the timing of admission and release of stored floodwater is vital in this respect. This does not preclude their use for other social, economic or environmental purposes, provided such uses are compatible with their primary function for flood storage.

While the efficacy of catchment-wide storage in flood risk reduction can be very high, suitable sites for washlands and impoundments may not exist in steep, headwater catchments, where flood prone areas are close to the source of runoff, in heavily developed catchments, where settlements have already encroached widely on to the floodplains, or in the flat lower-reaches of bigger rivers.

Ponds, bunds and ditches

Small ponds and detention basins, bunds and ditches can retard flows at the subcatchment scale, usually through an outlet which may be fixed or variable. These are small-scale and diffuse elements of catchment-wide storage, often referred to as 'on-farm measures'. They also help to retain minimum low flows and water for other purposes, such as stock watering. Examples of these measures were included in the River Parret study (Morris *et al*. 2002). However, similar issues to those with infiltration management arise in scaling up effects to the catchment scale.

Wetlands and washlands

Wetlands and washlands provide natural storage for runoff both below and above ground in areas along or linked to the main river or estuary that are inundated periodically. Although the terms wetland and washland are widely used, often in conjunction, their definitions are not crisp.

A wetland is an area where the water table is either seasonally or permanently high. They naturally occur in river valleys where drainage is impeded either by topography or soil structure and they can be entirely natural or artificial. The natural capacity of wetlands may be enhanced to provide additional flood storage by engineered hydraulic controls or, where their natural capacity has been reduced by past drainage or land reclamation, wetland restoration may reinstate a historical flood storage function. Washlands are usually taken to be areas of floodplain surrounded by artificial banks that provide a low level of flood protection, so that in a flood event higher than the inlet threshold the area fills to provide temporary storage of floodwater. Hence, an area can be both a washland and a wetland. Washlands may be managed to provide wetland habitats, or for agriculture, forestry or recreational amenities that can tolerate intermittent high water tables and periodic inundation.

Washlands and wetlands that have been enhanced to create flood storage can be especially effective in reducing flood impacts (Morris *et al*. 2003) and are used extensively for additional flood storage, often in combination with other flood-defence systems, as in the River Aire valley of North Yorkshire.

Impoundments

Impoundments are artificial structures designed to store a proportion of floodwater in a way that will mitigate flooding at some point downstream. They may be either on-line (e.g. Leigh Barrier on the River Medway), where all water flows through the impoundment and water level is controlled by a dam and sluice structure, or off-line, where flow diverted from the river is controlled by a weir or sluice (e.g. River Witham/Till upstream of Lincoln, or River Irwell, Salford).

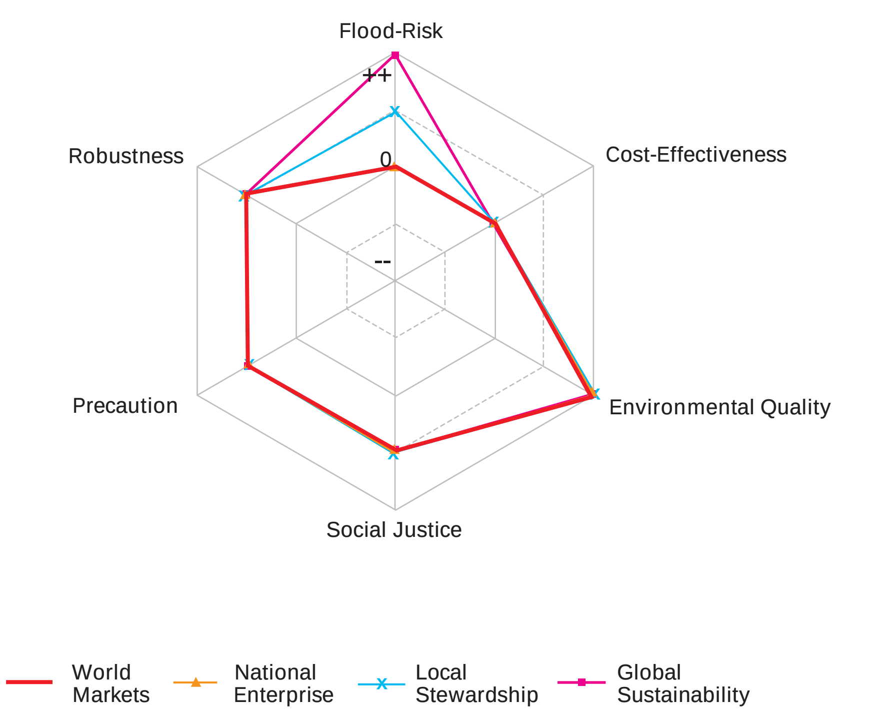
Impoundments are used in catchment flood-storage schemes where natural storage in the riparian corridor and floodplain is insufficient, but may be enhanced using some form of retention works. Retention may be created in several ways, including the lowering of ground level, construction of embankments, installation of movable barriers, and the realignment, lowering or removal of existing flood defences. This group of responses is distinct from the management of conveyance, which is taken to be situations where water does not go into store, rather its speed of translation is significantly reduced.

Governance

There is some variance in governance issues within this response group. Ponds, bunds and ditches are relatively diffuse, and would involve a large number of land managers placing them in the correct parts of the landscape. The motivation for these schemes is the same as those in the infiltration management group. Wetlands, washlands and impoundments are less diffuse.

Responsibility for wetland and washland operation normally rests with land managers, but under guidance from the Environment Agency. A broad range of landowner categories can be involved: in addition to farmers, English Nature, wildlife trusts, the National Trust and organisations such as the RSPB, which own or have management agreements on wetland and washland areas. The organisation that commissioned the impoundment would normally have responsibility for it. However, impoundments installed specifically for flood storage may come under the Reservoir Act (1975) if they retain more than 25,000 m^3 above the adjacent ground level, which will require additional and much more formal regulation.

Catchment-Wide Storage



Sustainability

These response measures score especially well in environmental quality. They have the potential to be part of catchment-scale attempts to improve water quality – such as the role of wetlands in nutrient removal – but also, and importantly, from a habitat perspective, through the restoration of wet habitats. As with the infiltration response group, there may be beneficial impacts on social justice in that the measures will require an integrated response, founded in shared knowledge and education among communities as to how their management activities may bring benefits downstream. It may provide a route for strengthening the link between rural and urban areas.

Robustness varies within the response group as the extent to which administrative influence is retained geographically varies between Flood Foresight scenarios. For these schemes to be implemented effectively, they must be applied in an integrated way. Adoption of the specific measures in this response group would fit well with the precautionary principle as the measures seek to address the root cause of the problem, by attenuating flood peaks. Most of the measures are likely to be environmentally beneficial.

Costs and funding mechanisms

The costs of the measures in this group include capital costs of design, supervision, land-take and construction costs. Depending on the frequency of use of the storage area, which will determine the uses to which the land can be put when not flooded there may be extra operating costs associated with income loss and additional management costs. In general the creation of offline washlands on riverside floodplains will not fundamentally change the flooding regime though inundation may well be less frequent though deeper and more prolonged when it happens. In-line storage created by damming river valleys may extend the area of flooding beyond the natural floodplain but the frequency of inundation of such additional areas will generally be low. Consequently biodiversity or other incidental benefits will only be generated if the floodplain area is managed e.g. through low flow water level management and whilst such management can be compatible with use as a flood storage area it does not depend on the washland or storage impoundment scheme. It is therefore appropriate to separately evaluate any scheme for biodiversity enhancement and flood alleviation. There are many examples of washland areas for which use for arable agriculture or amenity use as parkland or playing fields is fully compatible, because of their infrequent use for flood storage.

There may be scope in some floodplain areas to achieve integration of flood management and biodiversity objectives, in the same way that it has been possible to combine improved agricultural flood defence and land drainage with flood storage when needed. In the case of biodiversity gain, however, there is a need to retain the wetness of the land beyond the flood period, and this may involve some additional expenditure on engineering works. Thus the biodiversity benefits largely arise from these additional works rather than the flood-storage infrastructure. Under future scenarios such as Global Sustainability and Local Stewardship, institutional arrangements and funding mechanisms will reflect the greater importance placed on the integration of multiple land use objectives in floodplains.

Interactions

The key issue for this response group is how the storage created through a catchment-wide storage scheme acts within the drainage network to attenuate flood flows. This depends on the volume and timing of water stored, where the storage site is located within the landscape and how the storage is employed within a holistic catchment-management plan. These factors can have a major impact on its potential for flood risk reduction. It follows that major interactions occur with:

- The other responses in this theme, and particularly Rural Conveyance, through affecting the volume and timing of catchment runoff;
- Forecasting and Warning, through the need for accurate predictions of flows so that storage can be managed in an optimum fashion to attenuate flood peaks downstream.
- Urban Storage
- Land-Use Planning and Management, through legislating/empowering land owners and communities to release land for flood storage and put it to other uses.
- Fluvial and Estuarial Engineering, through the use of Catchment-Wide Storage in conjunction with River and Coastal Defences, Engineered Flood Storage and Realignment as part of an integrated scheme.

Case examples

Ponds, bunds and ditches

Examples of these measures may be drawn from on-farm, mid-catchment detention reservoirs in Somerset (Morris *et al*. 2002). Storage sites range from less than ten to over twenty hectares, providing 15,000 to 100,000 m^3 of storage. Evidence from such schemes demonstrates the benefits with respect to local flooding (including muddy floods), pollution, and erosion control, but there is as yet no scientific evidence that confirms that on-farm measures are likely to be an effective response to problems at the catchment-scale. This conclusion is supported by work undertaken for Defra under project FD2114.

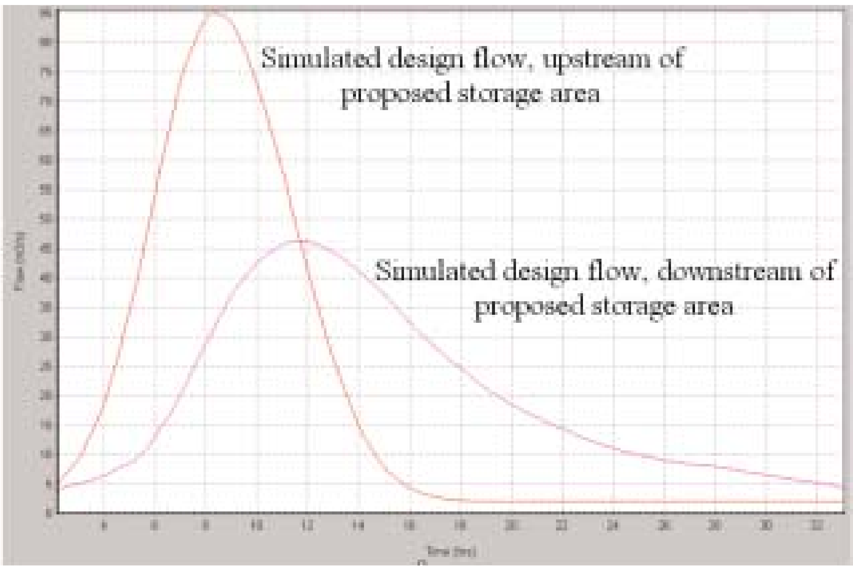
Wetlands and washlands

The Beckingham Marshes scheme, River Trent, was constructed in the 1960s to mitigate flood risks in Gainsborough and protect 1,000 ha of agricultural land by providing 2,000,000 m^3 of storage capacity (equivalent to the 10-year return period event). Hydraulic control is by a fixed level inflow and flapped outfall, supported by pumps as required. Land was purchased to create the storage area, but returned to farmers under a tenancy. Initially, land was converted from wet grassland to arable, but recently half the area has been returned to wet grass and negotiations are underway to create a wetland, operated under agri-environmental agreements and retaining flood storage as the primary function.

Impoundments

W.S. Fairhurst (2001) provide an example of an impoundment proposed for White Cart Water, Scotland, where a catchment flood storage scheme was recommended for adoption rather than relying solely on using flood defences. The catchment area is 110 square kilometres. Figure A2 shows iSIS modelling of effect of the proposed scheme on the design flood downstream of the storage area. The modelling results suggest that the peak flow could be halved, representing significant attenuation of a flow with a return period of 200-years.

Figure A2 **Modelled reduction in design flood downstream of proposed White Cart water storage area (Glasgow). Return period for design flood is 200-years (reproduced with permission from W. A. Fairhurst and Partners).**



The Lincoln flood-alleviation scheme (Wakelin *et al*. 1987) is an example of a storage scheme at the upper end of the spectrum of scales. The city of Lincoln has a population of 100,000 of whom 20% are at potential risk of flooding. The catchment area upstream of the city is 800 square kilometres. It was estimated that the pre-existing standard of flood protection was about 1 in 10 to 20 years. Options involving modifications to the River Witham and the flood defences through the historic centre of Lincoln were ruled out and a washland scheme was implemented with a standard of protection of 1 in 100 years, This gave a risk reduction factor as defined in this project of 0.1 to 0.2.

The scheme has two washlands upstream of the city, with 2.7 km of low earth banks about 2.5 metres high and active control structures. The storage created is substantial, with a combined area of 11 square kilometres and a volume of 9.5 million cubic metres

Emerging issues

In relation to on farm storage (e.g. ponds, bunds and ditches) there is no scientific evidence as yet that confirms that water retention through these measures is likely to be an effective means of addressing catchment-scale flood mitigation. This conclusion regarding local scale or diffuse interventions is consistent with the findings of Defra project FD2114. The limitation is compounded by the challenges of securing effective governance of the measures required at the level of individual farms or land management units under the more consumerist and less community minded Foresight scenarios.

In relation to catchment storage further down the drainage network, enhanced wetlands, washlands and impoundments provide powerful mitigation options, which can be fully exploited if employed as part of an integrated, holistic, catchment management plan. The extent to which integrated approaches are favoured by stakeholders, decision-makers and society varies markedly between Foresight scenarios, and this is a crucial part of determining the viability of the types of land management and planning necessary to facilitate Catchment-Wide Storage as an effective flood-management response.

These two emerging issues highlight the need for further research to elucidate issues of scale, governance and effectiveness related to diffuse and concentrated catchment-wide flood storage.

Response Group A3

Rural Conveyance

Response theme	Managing the Rural Landscape
Element of flood risk affected	Pathway

Definition

Rural Conveyance includes interventions associated with managing the timing with which runoff, once generated, is conveyed through the hill slope and channel drainage network.

This response group includes management of hillslope-channel connectivity, the management of riparian conveyance and the restoration and realignment of river channels.

Function and efficacy

These specific measures involve controlling the attenuation of a floodwave to reduce peak flows at critical points in the river system. Traditional flood-alleviation schemes seek to reduce local storage (i.e. flooding) by increasing conveyance. They achieve this using measures such as channel straightening, vegetation control, and redesign of channel shape. This reduces attenuation and leads to the well-established transfer of flood problems downstream.

This response group involves taking a catchment-scale view of attenuation, increasing it upstream of areas that need to be protected from flooding, under the premise that some rural areas (i.e. those with low value agricultural land) can, through water storage, increase flood attenuation. This may be done in one or more of three ways:

- Reduce the speed at which overland flow travels to the river network, which is a function of the hydrological connectivity within the system, for example, by blocking upland drains.
- Reduce riparian management in river reaches where temporary inundation of adjacent floodplain is acceptable, by removing the need to manage riparian vegetation, for example.
- River realignment or restoration, can also to create temporary local storage.

These three approaches have rarely been explored as possibilities for flood mitigation (but see case example below). As the first approach involves diffuse measures, scaling them up to the catchment scale is uncertain.

Governance

As with other aspects of rural land management, governance is a major issue. It may be complicated by:

- The range of landowners – for example, NGOs such as the National Trust and Wildlife Trust and landowner attitudes, as illustrated in the variable take-up of agri-environment schemes.
- The fact that planning authorities make some conveyance decisions and as such come under Planning Policy Guidance.
- The influence of agri-environment schemes, such as Environmentally Sensitive Area and Countryside Stewardship Schemes, and codes of good practice (e.g. Defra).

In relation to these issues, there is some difference between approaches. Management of hillslope connectivity is a diffuse issue: it will require the involvement of a large number of individuals, making governance much more of an issue. Both maintenance and realignment, especially where the result is to increase flooding of flood-acceptable areas, will be less diffuse. However, it requires a close partnership between the landowner, the land manager and relevant institutions, including the Environment Agency for England and Wales, councils in Scotland, and Rivers Agency in Northern Ireland.

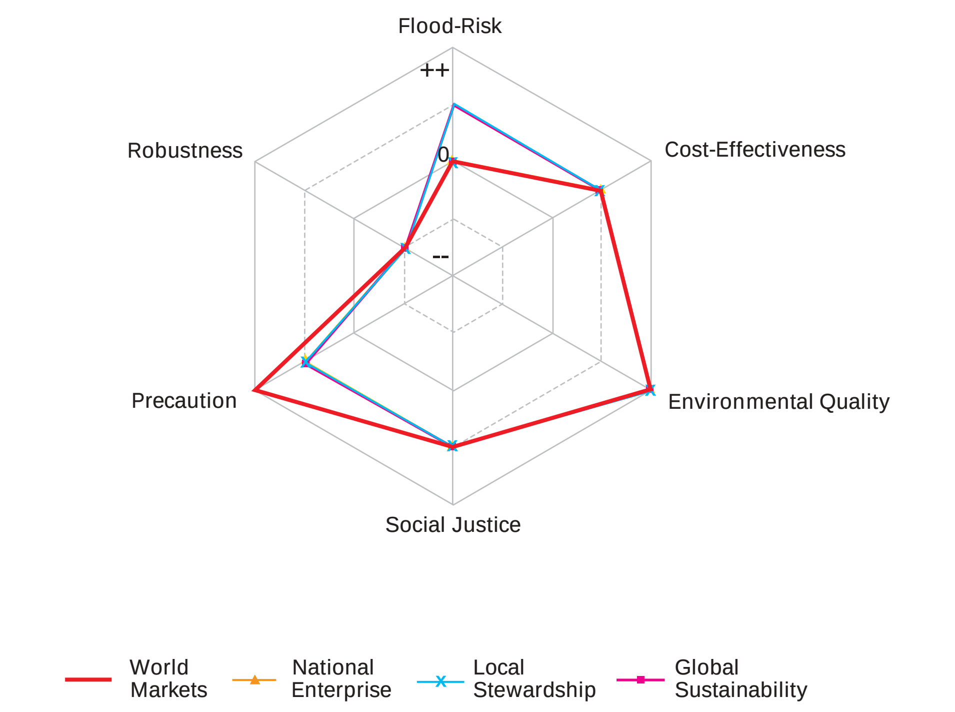
Sustainability

All three of the specific measures in this response group should enhance system sustainability, especially in the context of the Water Framework and Habitats Directives. All three measures may reduce the need for ongoing management. Blockage of upland drains will reduce the need to keep them free of vegetation. Reducing the need to manage in-stream vegetation and to dredge sediment means less in-stream habitat disturbance. Channel realignment will be particularly beneficial if it enhances the connectivity between river and floodplain.

If drainage for agricultural measures and straightening or floodplain disconnection has reduced floodplain storage, then reversing these is akin to making the 'polluter' pay. Thus, this measure contains an element of restoring social justice. As many of these projects will involve some form of environmental restoration, there may be additional benefits to social justice. Recent examples, demonstrate the significant community spirit that can, for instance, be linked to a river-restoration project.

The main challenge with the response measures involving Rural Conveyance is their robustness. Effective management of conveyance requires integrated management and planning of the catchment, with strong geographical control. This is lost under both National Enterprise and Local Stewardship, which means that even where these measures are advocated or adopted by local communities, their efficacy cannot be guaranteed. Finally, there are elements of this response group that reflect the precautionary principle. While there remains uncertainty over the catchment-scale impacts of some measures – for example, management of hillslope connectivity – there may be significant potential benefits, not just in terms of flood risk.

Rural Conveyance



Costs and funding mechanisms

Costs within the response group Rural Conveyance depend largely on the costs required to establish the management activity, as most measures require low levels of ongoing maintenance. Initial costs are variable. For instance, blocking upland drains is an expensive process unless done intelligently, that is, through the identification of exactly where it is needed – or through removing drain management activities altogether – in which case, costs are low. Similarly, the initial work required for a river-restoration scheme may be expensive. However, funding for this type of activity may be obtained through agri-environment schemes, including the ESA and CS schemes.

Interactions

There is a strong connection between these measures and the responses relating to water retention. Reducing conveyance in a rural area may lead to higher water levels and greater flooding in that area, and hence may be linked to floodplain storage. The difference is that here we consider the storage associated with slow flowing in a connected river-floodplain system, rather than in impoundments designed and managed to store water when necessary. Similarly, there is an explicit link here to the urban management issue in that if it is necessary to increase conveyance through an urban area, reducing conveyance in rural areas downstream can mitigate negative impacts downstream. This simple urban-rural division is not necessarily appropriate and a better definition may be between areas zoned as ‘flood-acceptable’ and ‘flood-protected’. For instance, Grade-1 agricultural land may be deemed to be of national strategic importance and needs to be protected even though it is ‘rural’.

Case example

The potential role of river restoration in flood attenuation has been explored using computer modelling to illustrate the effects of changes to river-channel geometry and the construction and removal of embankments on high flows. The research was undertaken for the River Cherwell in Oxfordshire.This is accompanied by a change in rural land use, in that it changes the way the river is allowed to behave as well as the magnitude and frequency of flood inundation.

Hypothetical changes to the River Cherwell between Oxford and Banbury suggest that embanking the river increases peak flows by up to 150%. Restoring the river through the floodplain to pre-engineered dimensions reduces peak flow by around 10 to 15% and increases peak flow depths locally by 0.5 to 1.6 metres. This demonstrates that where rural land use permits, river restoration and floodplain management can be part of a sustainable strategy for catchment flood management.

Emerging issues

It is vital that these considerations of conveyance are conducted at the catchment-scale. For example, increasing attenuation in one sub-catchment, immediately upstream of a flood-protected area, will delay the flood peak, potentially delivering it to the main river at the same time as the main river peak, resulting in a net increase in peak flows in the main river.

Response Groups A4, A5, A6

Urban Storage
Urban Infiltration
Urban Conveyance

Response theme	Managing the Urban Fabric
Element of flood risk affected	Pathway

Definition

Urban Storage, Urban Infiltration, and Urban Conveyance consist of measures to influence urban pathways in the source-pathway-receptor model of the flooding system.

This group of responses is concerned with the mitigation of downstream impacts from flows arising in the urban area. Note that there are overlaps with the intra-urban area response groups (see Appendix B).

Function and efficacy

The urban flood-management system combines above-ground channels and ephemeral flow paths with below-ground drains and sewers, all linked to various storage facilities. Key system attributes include:

- Storage – the capability to store and subsequently release flow at a controlled rate.
- Infiltration – the facility to allow surface water to soak into a permeable ground surface.
- Conveyance – the capacity to discharge flow downstream and/or to arrest its passage.

At the catchment scale, an increase in flood risk downstream of an urban area is a symptom of a drainage system that has failed to store or infiltrate water in the way that a natural land surface would have done. It has, instead, accelerated the rate at which runoff is conveyed into the receiving waters. Thus responses provide a means of restoring the urbanised area to an equivalent to that which pertained prior to the introduction of the impervious surfaces that accompany urbanisation. In the urban area, responses must be considered in terms of:

- If the area already exists or is planned to be newly urbanised.
- The different spatial scales relevant to local and more widespread drainage systems.

Retrospective modification of the drainage in existing areas is problematic and feasible in few instances. The typical life of urban drainage infrastructure, although designed for 30 to 50 years, is some 100+ years. Hence, it is prudent to assume that response measures through to the 2080s may need to fit within existing systems.

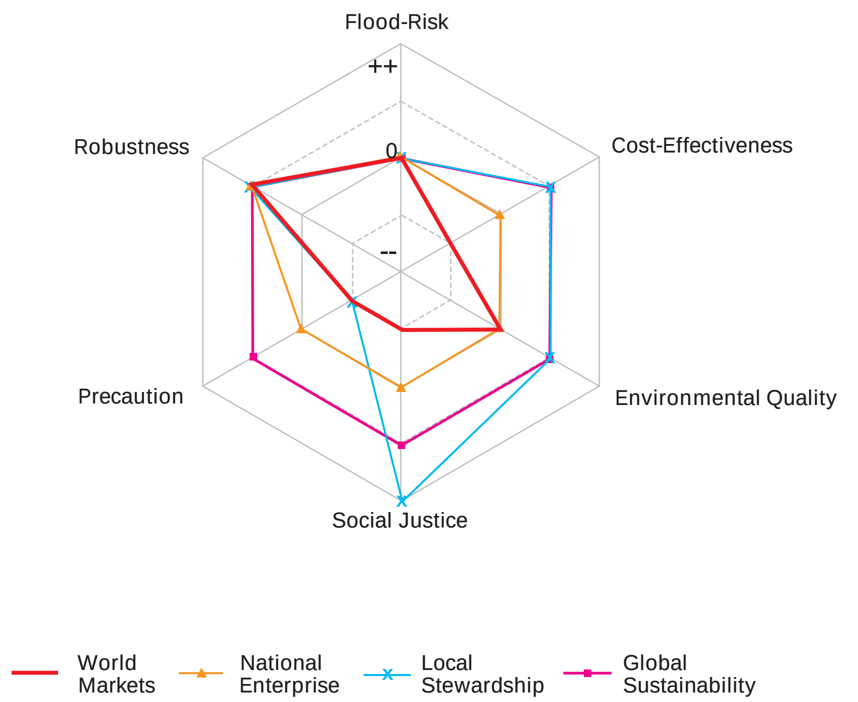
In newly urbanised areas, there may be more opportunity to be innovative. However, there are few entirely independent new developments of any scale in the UK, other than for specific developments. The most significant potential responses are ranked in effectiveness in Table A2.

Table A2 **Table of responses and their effectiveness**

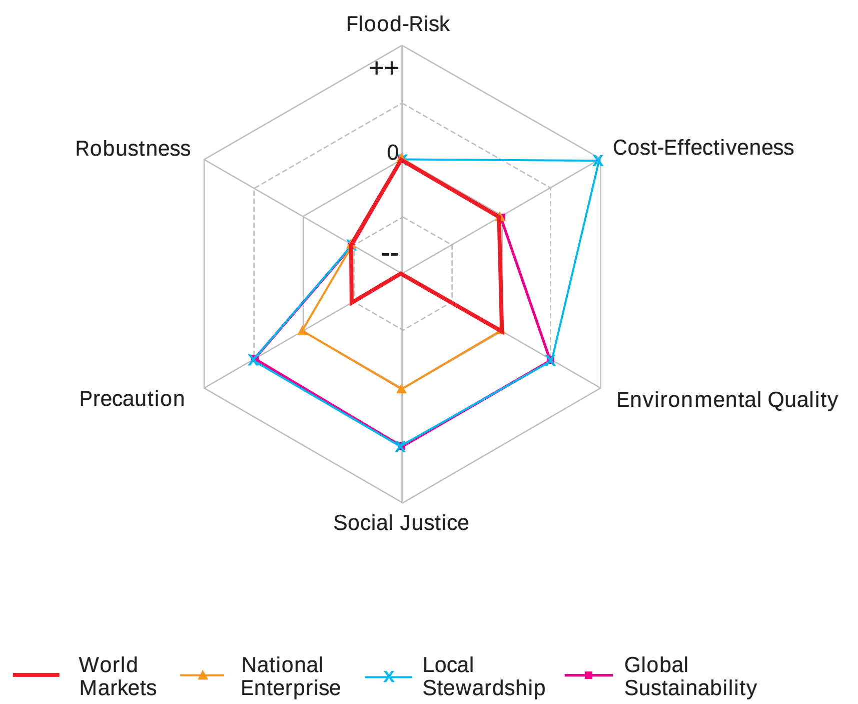
Response area	Responses	Effectiveness for downstream risk reduction	Relative order of effectiveness*
Urban-area development	Maintain/extend permeable/green areas. Control developments. Manage ‘creeping’ urbanisation	Potentially could maintain pre-development hydrology or recover some original conditions for existing urban areas	Up to 1
Increase storage	As above, also sewerage storage and RTC operation, daylighting watercourses	Provides temporary storage to arrest large flow peaks etc. Slow subsequent release	Typically 0.7
Integrated water management	Building design, regulations, water utilisation, low impact development	Locally, effective but would need to include facility for discharge during largest storms	Typically 0.1-0.2
Serviceability of assets	For existing systems, maintain and ensure assets do what they are supposed to	Probably not effective for downstream protection (as will convey flows out of urban area)	Probably up to 0.1 at best
Source control/SUDS	Includes some of the above. Also specific infiltration structures	Not likely to be effective for largest events (> 100 year storms)	Probably up to 0.1 at best

*** Scales: 1.0 represents the pre-urban condition. 0 represents a fully impervious area draining to a downstream catchment.**

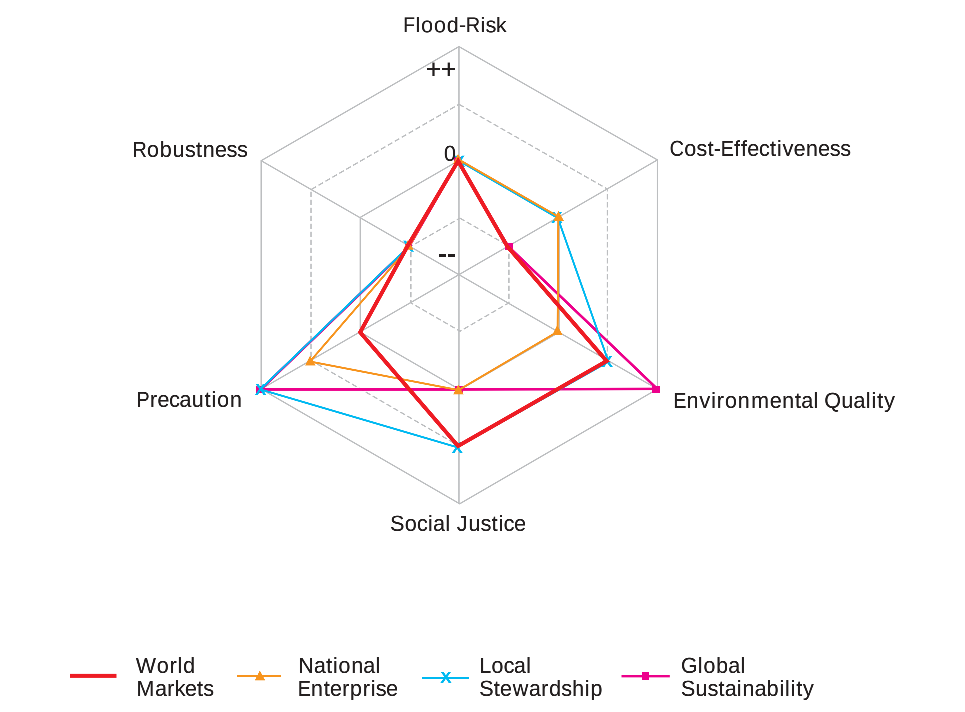
Urban Storage



Urban Conveyance



Urban Infiltration



Governance and sustainability

The most important aspect here is that of the planning system. Despite restrictions on floodplain development, this still continues in certain cases. The proposed densification of developments – see *Planning Policy Guidance (PPG) 3: Housing* – as part of the new urbanism, will also concentrate impermeable areas and runoff, transferring excess flows to downstream areas.

In the USA, green areas specifically allocated for flood storage downstream of dense settlements accompany this approach. The retention and expansion of green areas, the local aesthetic use of water in the city, daylighting and local reuse of rainwater are largely also planning driven. Local authorities have the prime responsibilities, together with specific developers, for new build. Worldwide, the introduction of Low Impact Development has the potential for greater local and on-site management of stormwater in a more sustainable way. This would require property owners and users to be more engaged in water management. Experience in the USA suggests this is best done by specific contractors.

Costs and funding mechanisms

Except for the costs associated with specific structures, as required for large-volume storage, the major costs are for land acquisition, purchase and opportunity loss, where the land is allocated either for infiltration or flood storage. However, multiple use for gardens, recreation and sport can add to the positive aspects of the cost-benefits. Other costs are associated with, for example, daylighting channels (local authority) and the new water-management systems required for Low Impact Development, which as yet are still typically more expensive (+30%) than conventional. Perspectives on whole-life costs could, however, demonstrate positive financial returns.

Interactions

Urban responses to reduce downstream flood risk are linked with responses concerned with coincident, intra-urban and peri-urban floods that originate in surrounding rural areas, muddy floods. There are further links to event management, measures designed to reduce exposure and vulnerability to flooding in urban areas, and engineering to control catchment and coastal flooding. The response themes have strong social and economic dimensions, due to high urban populations and inventory values, together with the high impacts that individuals can have, by laying drives, patios and so on. 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.

Case example

A scheme to control urban runoff addressed the effects of a rapidly urbanising catchment on the increase in flooding along the Lynne Burn in Dunfermline, Fife. This scheme, although primarily concerned with managing urban flooding in the rapidly expanding urban area, resulted in a linked group of major construction projects in the 1990s by Fife RC and the then East of Scotland Water that included using parks for flood storage, installation of on and off-line tanks and the consideration of real-time control.

Overall, the watercourse flows were maintained at a pre-development condition. In this case, the major problem was that Fife RC had only a discretionary duty to deal with flooding due to watercourses. The legal position was not clear and there was no control over maintenance or preventing culverting by developers. At the time, the council had difficulty in funding both the study and parts of the work. Recently, the duties of Scottish councils have been made firmer in this regard.

Emerging issues

Planning Policy Guidance 25: Development and flood risk, and forthcoming corollary projects are concerned with ensuring that flows, above the design criteria, are dealt with effectively, minimising downstream impacts. For effective implementation, all stakeholders need to be clear on responsibilities for managing these flows and the opportunities to do this effectively.

Stormwater management may become more localised if the UK adopts more low-impact development. This approach, which is becoming more common in the USA, Scandinavia and Germany, includes on-site recycling, reuse and direct use of, for example, roof water for flushing WCs. This may cause lower flows leading to problems downstream in large existing sewerage. However, high-density developments, sanction of floodplain development and increased urbanisation – are likely to be the greatest threats that compromise the responses. Each of these moves will force the adoption of conventional (piped, below ground and unsustainable) responses.

Response Group A7

Pre-Event Measures

Response theme	Managing Flood Events
Element of flood risk affected	Pathway

Definition

Pre-event Measures are those actions that can be undertaken prior to a flood event to ensure that people and agencies are prepared for flooding, to mitigate negative impacts, and to ensure smooth management of the event.

Measures in the response group

- Flood-preparedness planning.
- Communication, education and awareness raising.
- Flood-risk mapping.
- Flood plans.
- Flood-risk logbooks.

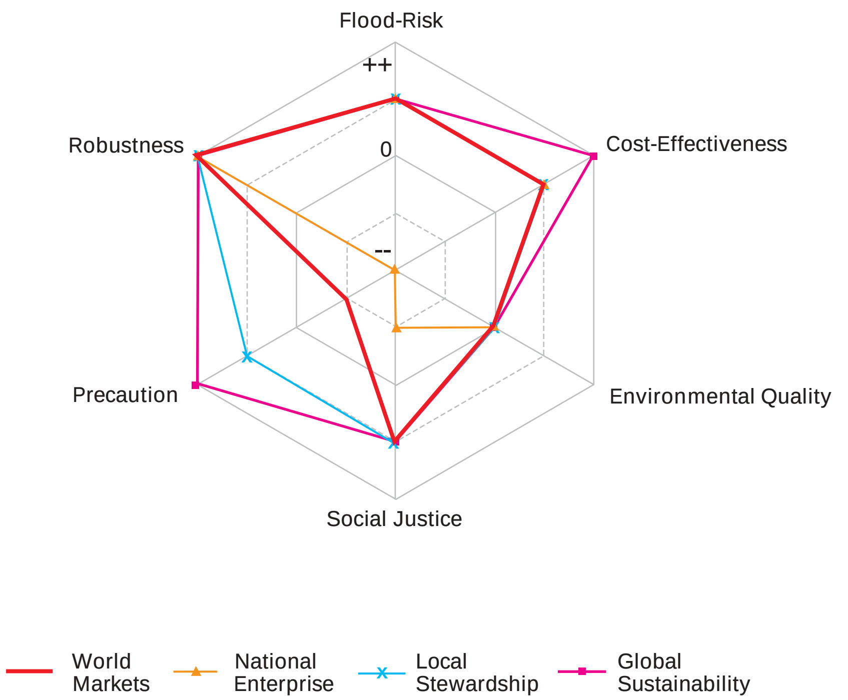
Function and efficacy

Successful emergency response through planning, communications and major incident plans can significantly reduce the impact of flooding on lives and property. Robust emergency preparedness plans, and regular exercises to test them, are essential for all flood-risk areas. If it is to be effective, preparedness planning involves close liaison and communications within and between professional partners and all organisations responding to flood events, including community groups and the media.

Education and awareness-raising on flood issues is needed to mobilise the cooperation of a prepared and responsive public in the process of flood-risk management to minimise the total damages arising from flooding. If people who live in a flood risk-area are aware of the risk, they are much more likely to be receptive to flood warnings and more inclined to protect themselves and their property. Flooding is often very localised, therefore, more locally focused and targeted campaigns are likely to be the most effective.

Despite their limitations, Indicative Floodplain Maps for England and Wales help to raise awareness of areas that are in the natural floodplain and aid in preparedness planning. The Environment Agency's recent *Flood Mapping Strategy* aims to improve and increase information on flood risk. New maps will take into account more recent information on historic floods and modelled flood outlines. The production of family and community flood plans can be effective response measures in preparation for flooding and reducing flood impacts, while Flood Risk Logbooks are likely to be less effective in the near future due to implications for the saleability of properties and for insurance cover.

Pre-Event Measures



Governance and sustainability

Apart from the general public, the Environment Agency, emergency services, local authorities, utility companies, British Waterways, voluntary organisations and the media are among the organisations responsible for responding to a major flood event in England and Wales and that need to have preparedness plans in place. The Environment Agency is responsible for education and raising awareness of flood-related issues and is the lead authority in flood mapping and assessment of flood risk in England and Wales. Local authorities may also issue flood-risk awareness information within their areas.

Pre-event measures are compatible with the Government principles for sustainable development: putting people at the centre; taking a long-term perspective; combating social exclusion and encouraging participation; using scientific knowledge; and providing information and transparency.

Costs and funding mechanisms

Each agency has its own budget for emergency preparedness planning and response. In the case of the fire brigade, which has no funding for flood events, if responding to flooding incidents became a statutory requirement, this would release additional resources and funding. Local councils and police authorities may apply for financial assistance for certain purposes in emergency situations through the Bellwin scheme, the main means of providing further grant to local authorities where problems, such as emergencies or disasters, have arisen from circumstances beyond their control. There are, however, thresholds on these claims and authorities are expected to make their own contingency provisions. The system is not easy to implement, is slow, and could be more flexible.

Interactions

These measures interact with a number of other measures – for example, they are necessary for successful warning dissemination – and with collective- and individual-scale damage-avoidance activities, including those aimed at minimising flood losses covered in the response group Urban Storage.

Case example

Public awareness campaigns have been an integral part of the Environment Agency's strategy for flood-risk management, since 1999. The latest 2003 campaign built on earlier campaigns, with a core theme of 'Act now. Be prepared for flooding'. The campaign used a mix of media to get its message across.

The Environment Agency's budget for flood awareness campaigns is £2m annually, compared with the total expenditure of over £400m on flood defence generally. The cost of awareness activity is equivalent to around £1 per year for every property at risk from flooding.

There is some evidence that public-awareness campaigns are effective, although there is room for improvement. In a recent 'At risk' survey, three in five (63%) respondents were aware that their address is in an area at risk of flooding, an increase on previous years. However, only 21% became aware of this via public-awareness campaigns. Although 96% of those at risk are said to be aware of at least one action they can take to prepare for flooding, just over 1 person in 10 has actually taken any steps to prepare themselves. Problems remain over sampling frames for the awareness surveys, as well as problems of public apathy.

Emerging issues

Much that will influence the effectiveness of pre-event response measures is uncertain. These factors include: availability of funding and resourcing; changing population demography and social and cultural values; the extent of public participation and the existence of community groups.

The flooding of Autumn 2000 was geographically dispersed. The vast majority of flood incidents involved fewer than half a dozen properties. If this pattern continues it will not be sufficient in planning actions and procedures, to focus on large areas, but it will also be important to pay attention to more local responses.

Response Group A8

Forecasting and Warning

Response theme	Managing Flood Events
Element of flood risk affected	Pathway & Receptor

Definition

Forecasting and Warning, along with flood-warning dissemination, aims to provide flood warnings in sufficient time for people or organisations to take effective actions to reduce flood risk.

Real-time flood forecasting plays a key role in the management and reduction of residual flood risk.

Measures in the response group:

- Improved sensing.
- Forecasting, modelling.
- Updating of model predictions during the event.
- Warning dissemination.

Function and efficacy

The Forecasting and Warning response group involves detection, forecast generation, uncertainty propagation, warning, dissemination and response to flood incidents. By its very nature it has to focus on fluvial, estuarial and coastal issues. The identification of the source of the risk is generally concerned with the meteorological origin of a potential event. The forecasting process then follows with its inherent uncertainty cascading through the hydrological, hydraulic, estuarial and coastal process models to generate a warning that must be disseminated.

Flood forecasting requires real-time modelling of complex non-linear systems for which often only limited measurements are available. In most cases this involves developing models on the basis of incomplete and often imprecise information. Weather radar is the primary remote sensing device for operational real-time hydrology. Although there are current limitations in sensing, the exploitation of weather radar and satellite-based remote sensing is expected to enhance flood-forecasting capabilities.

The function of systems to disseminate warning is to alert people to the possibility of flooding so that they can take appropriate actions. There are many methods for disseminating warnings. Some are simple alert systems such as a siren, while others include information on the likelihood or severity of flooding and what actions need to be taken.

Each system has its advantages and disadvantages. The receipt of a flood warning can reduce losses from flooding, and can be particularly effective in reducing the distress from loss of sentimental items.

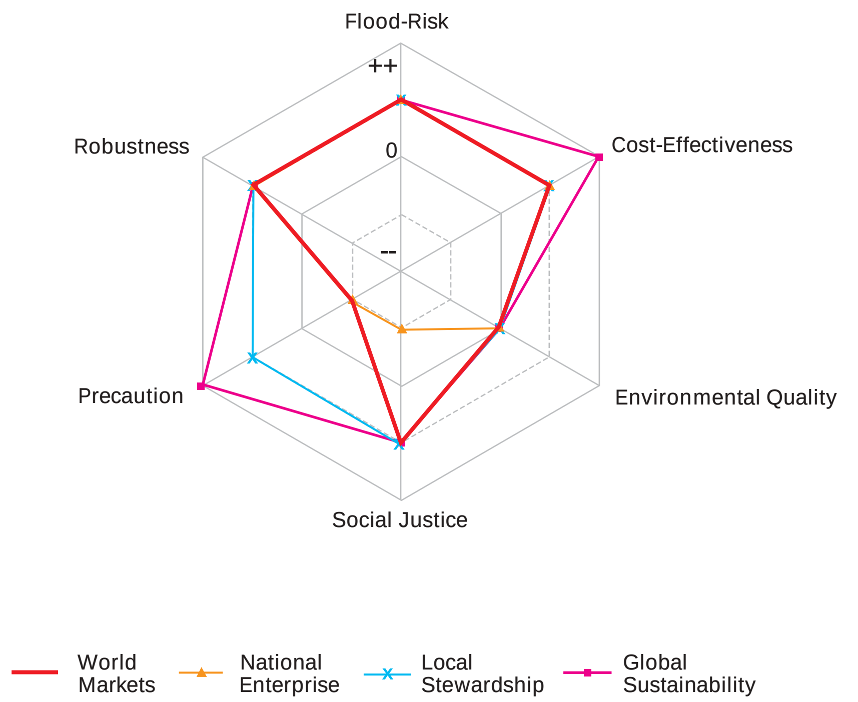
A variety of social constraints may influence to what extent these conditions are met. For example, a person's age or gender may lead to preferences for one system over another, socioeconomic status and educational attainment may affect take-up of warnings, along with income levels, ethnicity and disability. Warning lead time is also often crucial. Local circumstances are important. Different users will have different requirements, warnings therefore need to respond to local needs.

Governance and sustainability

The Environment Agency has the lead responsibility for issuing warnings in England and Wales. It aims to provide these in sufficient time for people to take effective actions. However, these warnings apply only to river, tidal and coastal flooding, and not to flooding from other causes such as surface water and drains. Targets in the Environment Agency's recently published *Strategy for Flood Risk Management* for 2007 include an improvement in the coverage of flood warning services to 77% of properties in flood risk areas, and ensuring that 75% of residents in flood-risk areas will take effective action.

Flood forecasting and warning dissemination places people at the centre of the function and recognises the Government's guiding principles on sustainability by furthering the use of scientific knowledge to follow a precautionary principle in relation to managing residual flood risk. However, not all potential recipients of warnings will have access to the same types of technology to receive the warning. This has the potential to lead to social exclusion and a divide between 'haves' and 'have-nots' in the access to new technology which would have implications for future expansion of new dissemination systems such as e-mail and the Internet.

Real-time Forecasting and Warning



Costs and funding mechanisms

In recent years the flood-warning budget has increased. For England and Wales, the Environment Agency's *New Flood Warning Investment Strategy* recommends a total investment of £247 million in the period 2003/4 to 2012/13 for flood warnings generally, including forecasting. This sum would allow improvements to address problems and difficulties encountered in floods of both 1998 and Autumn 2000.

Interactions

The response group Forecasting and Warning interacts with a number of other measures that depend on an accurate flood forecast and the effective dissemination of flood warnings. These measures include the operation of flood-defence systems, temporary flood defences, moving assets at risk, and evacuation. There are also interactions with the response theme, Managing Flood Losses, which concerns improving people's ability to recover from flooding.

Case example

In England and Wales, the Environment Agency has, since 1998, revised flood warning codes and has made a number of significant other improvements to the system. These improvements were tested in the Autumn 2000 floods and generally worked very well. The floods also saw a significant increase in the use of the agency's live Internet website. However, engagement with new flood-warning dissemination technologies to date has been slow and the exclusion rate of older cohorts is striking. A survey by the British Market Research Bureau for the Environment Agency following the Autumn 2000 floods showed that: 60% of flooded respondents had received a prior warning. The majority (74%) of those who received a warning felt they received it in the right way, and 91% claimed to have taken positive action.

Emerging issues

The degree of uncertainty in relation to the technical aspects of likely future flood-forecasting system development is relatively low because this flood forecasting system is focused on managing extreme behaviour. This implies that flood forecasting is likely to be more efficient in the future. However, there is more uncertainty regarding warning dissemination, for example, in how recipients will respond to warnings.

The effective dissemination of warnings depends on a number of conditions being met by the receivers. For example, people need to be aware of the existence of the warning system(s) available. They need to be receptive to adopting the particular systems. They need to have access to the systems. They need to be available to receive the warning and to understand the message, and to perceive it as a warning. Finally, they need to act on its receipt; and their actions need to be effective. National take-up of the current AVM warning system is low and has been linked with fear of being refused insurance cover, implications for property sales, and the 'nuisance factor' of false alarms.

While recognising that existing forecasting and warning systems can be improved, a certain number of false alarms will remain statistically inevitable, given that warning thresholds must be set at a level that provides reasonable certainty that significant events will not be missed.

Response Group A9

Flood Fighting

Response theme	Managing Flood Events
Element of flood risk affected	Pathway & Receptor

Definition

Flood Fighting involves actions to manage floodwaters and peak flows during flood events to reduce their impacts.

Measures in the response group:

- Water-level control structures.
- Demountable flood defences.
- Emergency repair of failing defences.
- Emergency diversions.

Function and efficacy

The function of water-level control structures is to regulate the level and peaking of floodwaters to reduce the impacts and intensity of flooding. There are a number of different types of structures, both fixed and moveable. These include: gates and sluices, weirs/stop logs, pumping stations, flood-storage areas, tidal barrages and barriers. Such structures can be extremely effective in controlling and regulating water levels and in reducing flood impacts.

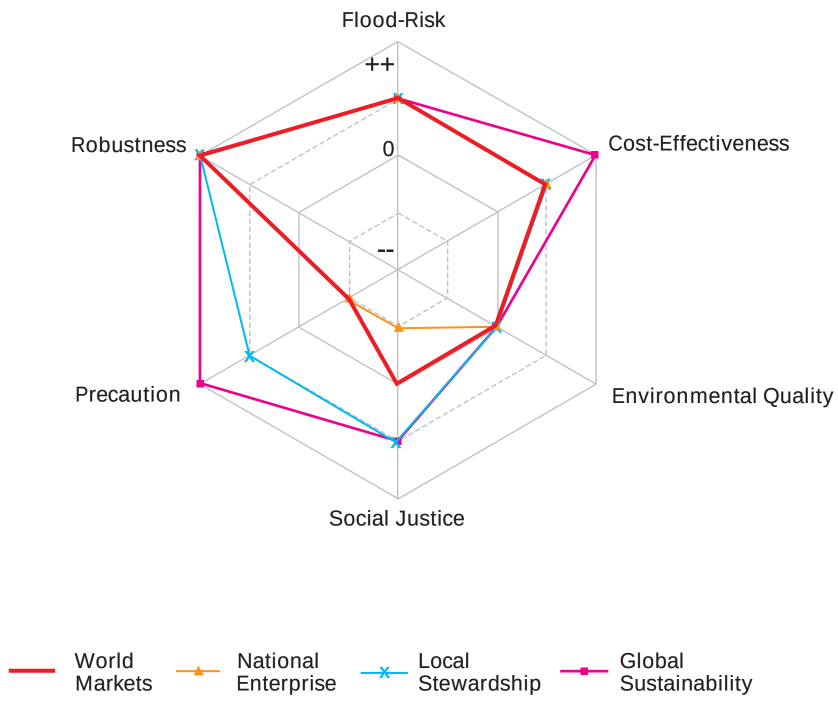
Demountable or temporary flood defences are portable free-standing barriers located at a distance from the properties to be protected. The function of these barriers is to hold back or deflect floodwater from properties or roads to reduce damage and disruption. Where there is sufficient warning, these barriers can be very effective in reducing flood risk and impacts on the lower reaches of large river catchments. However, they cannot prevent groundwater seeping up through subsoils below properties, nor can they prevent flooding as a result of backflow from an overloaded drainage or sewer system.

The function of emergency diversions – such as planned or unplanned cut through channels or the breaking of dikes – is to reduce the pressure of floodwaters on defences by either breaching existing defences or by partially diverting the water elsewhere. Some structures are designed to self-breach in extreme conditions. Diversions of floodwaters are rare and would not normally be considered except in extreme circumstances. Planned diversion channels have wider take-up. These usually have just a sweetening flow during normal operations, but in extreme events take overflow from the main channel. Flood-defence structures that fail generally do so under load. So conditions at the time of failure or impending failure generally preclude any immediate attempt at repair.

Governance and sustainability

Water-level control structures can be the responsibility of either the Environment Agency, local authorities, inland drainage boards or riparian landowners, which can have implications for their maintenance and operation. Structures on main rivers are usually owned/operated by the agency or local authorities. Where structures are also used for navigation and for water abstraction, as well as to control water levels for flooding, there may be a potential conflict of interest. Demountable barriers are still relatively new. A growing number of private companies provide these products. There is now a certification scheme in the UK for these barriers, managed by the British Standards Institution.

Flood Fighting: actions to manage floodwaters and defence during the event



Automatic water-control structures are sustainable both in terms of energy and cost. They require little maintenance and no manual input to operate. There are potential environmental impacts, negative and positive, from using water-level control structures and emergency diversions. For the latter, there is also the moral issue of who/what to save and who/what to flood. Demountable barriers are environmentally friendly and potentially cost effective. The barriers could be used in areas where traditional analysis has concluded that it would not be cost-beneficial to protect under Defra's Priority Scoring for flood-defence schemes.

Cost and funding mechanisms

The costs of these measures will vary enormously depending on their size, the type of materials used, costs of construction and maintenance. Although demountable defences have lower up-front costs than permanent schemes they have higher operational costs. The costs of these measures need to be weighed against the potential savings that they could provide – for example, from restoration of buildings, replacement of belongings, temporary accommodation, loss of earnings and business losses.

Interactions

The effectiveness of these measures depends on receiving sufficient, reliable and trusted forecasting and warning, and on the availability and training of a workforce to construct, operate, maintain and repair them. All the measures also depend on preparedness plans being in place. There are links to the response theme, Managing Flood Losses on response measures to reduce flood magnitudes, for example, and insurance, and to the response theme River and Coastal Engineering to complement permanent engineered structures and floodwater transfer.

Case example

One type of temporary barrier – the 'Pallet Barrier', Kitemarked in May 2003 – successfully protected a row of houses from being flooded in White Colne, Essex, over the Christmas/New Year period 2002/03. The barrier, purchased earlier that year, was kept as a temporary mobile protection, should a flood occur. The barrier gave effective protection until 4 January, when it was dismantled and returned to the storage depot.

Emerging issues

There are not likely to be any great changes to the use of water-level control structures, emergency repairs and diversions in the UK in the foreseeable future. The adaptability and much lower up-front costs of temporary barriers will make them a serious measure to consider. A mixture of permanent and temporary defences is likely to be the way forward in the UK in the longer term.

Response Group A10

Collective Damage Avoidance

Response theme	Managing Flood Events
Element of flood risk affected	Pathway & Receptor

Definition

Collective Damage Avoidance is action through a publicly organised or spontaneous removal of people, pets, or livestock from properties and areas at risk from flooding to a safe location.

Measures in the response group

- Evacuation of floodplains and coastal areas at risk.

Function and efficacy

The function of evacuation is to save lives and reduce the danger to people and animals during a flood event. Evacuation measures are normally taken only during serious flood events, when it would not be safe or practicable for people to remain in their properties, or for those living in ground-floor flats, bungalows or mobile homes. Evacuation plans need to be in place prior to flooding to enable emergency services and local authorities to provide support for the evacuation of vulnerable groups, such as residential homes, the disabled and so on. Evacuation can be effective, however, it can increase the overall disruption resulting from flooding.

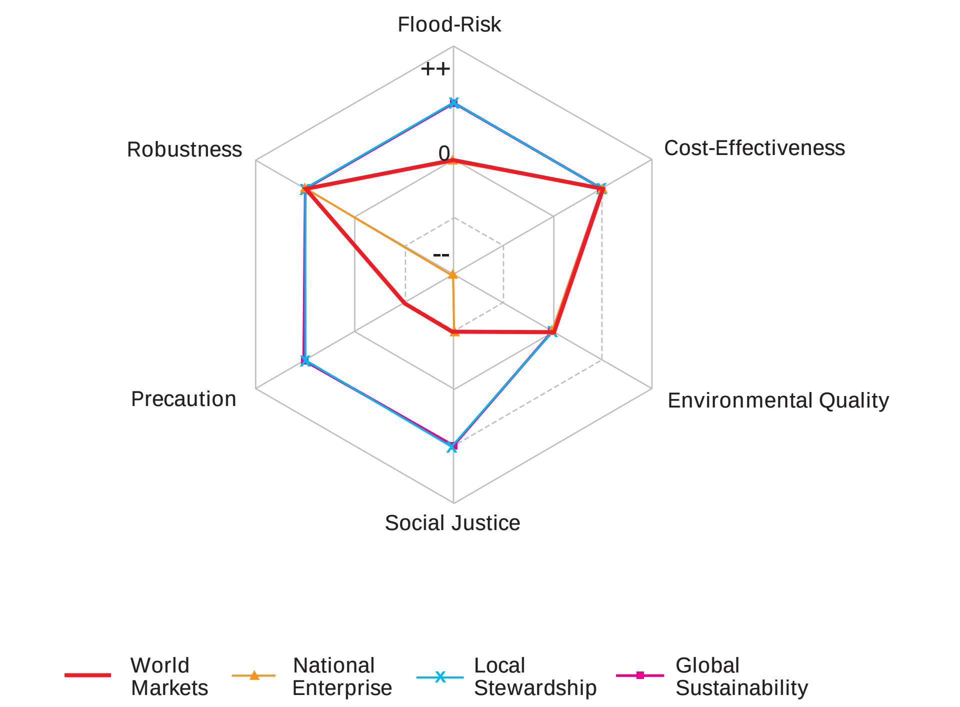
Although many people will spontaneously evacuate to relatives and friends before being asked to do so officially, there is evidence that the evacuation process is extremely distressing and worrying for people, particularly where family or social structures are disrupted. Most people do not want to leave their homes, as it is very stressful.

Governance and sustainability

In England and Wales, the police take the final decision on whether to initiate official structured evacuation, although they have no powers to enforce this unless the event is associated with terrorist activities. Firefighters and local authorities also assist in any evacuation. Local authorities have a legal duty to house those made homeless from a flood event – for example, those living in mobile homes that are destroyed. They are also obligated to their own council tenants.

This response measure is compatible with the following Government principles for sustainable development: it is a measure that puts people at the centre, it is environmentally friendly or neutral, and it maintains the precautionary principle.

Collective Damage Avoidance Actions



Costs and funding mechanisms

The costs of evacuation and providing rest centres are met by those agencies responsible – emergency services and local authorities – while the costs of temporary accommodation are met by local authorities or flood victims themselves if they are not insured. The voluntary sector may also be called on to help at rest centres and to provide feeding for emergency responders. However, some of these organisations now charge for their services, such as the Women's Royal Voluntary Service.

Interactions

The decision to evacuate is influenced by public awareness and perception of flood risk, accuracy and public trust in flood forecasting, effective flood-warning dissemination, information received about the flood, that is, the likely depth and duration, and pre-flood education and preparedness plans (official and unofficial). Warning lead time is crucial in allowing effective and orderly evacuation.

Effectiveness of response also depends on evacuees and emergency responders understanding the flood risk, what evacuation implies, what actions they need to take, how it will be organised, and whether or not the various parties trust each other, much of which is often unclear. There are additional interactions with the response theme Managing Flood Losses and the response groups related to insurance and recovery.

Case example

Around 60,000 people were successfully evacuated in the Nijmegan region of the Netherlands in 1995 during extensive flooding. As the area was the first to evacuate, it triggered a sequence of evacuation decisions throughout the province. This was aided by extensive media coverage that convinced people in other regions of the danger of flooding so that they too agreed to evacuate.

In total, 250,000 people and hundreds of thousands of cattle were evacuated to safety. Overall the evacuation operation was deemed successful.

The slow onset of the flood and long warning allowed time to prepare. The level of public co-operation surprised the authorities and operational services, the public's behaviour and discipline during evacuation were praised and said to be a contributing factor to its success. In this case, the population was largely homogeneous and did not require special attention for ethnic-minority groups such as immigrants.

Emerging issues

One issue relating to evacuation – and effective mitigating action generally – is that frequently people will not be prepared to leave their homes unless flooding is likely to result in risk to life, unless it is certain and imminent, or until it has been confirmed by another trusted source, all of which make the process more difficult for the responding agencies. This could change if there was more faith in the system and those managing it – that is, greater system reliability and better co-ordination between emergency services, local authorities and the public.

Reluctance to evacuate is not uncommon. Many flood victims from the Autumn 2000 floods commented that although they had evacuated on that occasion, they would not do so in the event of future flooding. During the 1995 floods in Limburg, in the Netherlands, where the flooding was not life-threatening, people were more reluctant to leave their homes.

Response Group A11

Individual Damage Avoidance

Response theme	Managing Flood Events
Element of flood risk affected	Receptor

Definition

Individual Damage Avoidance involves temporary floodproofing, or removable household products, that seal or delay potential flood routes into buildings.

Along with the removal of belongings and assets to safety out of the reach of floodwaters, these measures help to mitigate flood damage and losses.

Measures in the response group

- Temporary floodproofing.
- Moving assets at risk to safety.

Function and efficacy

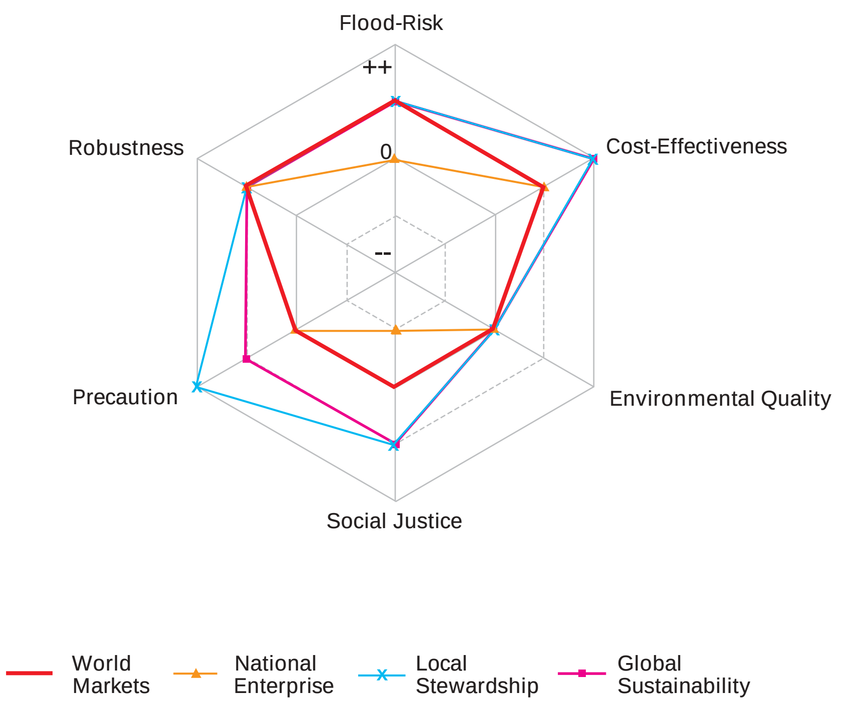
The function of temporary floodproofing measures is to reduce the ingress of floodwaters into properties, or at least to hold back floodwaters long enough to enable homeowners to move belongings and pets to a safe place, thereby reducing damage. Measures include plastic, wooden or metal products that are temporarily fitted to the building, such as floodgates on external doors, windows and patio doors, covers on airbricks, flexible plastic 'skirting' systems, and non-return valves. These measures can be very effective for short-duration shallow floods and may mean the difference between minimal flood damage or a large-scale clean up and restoration.

These products cannot, however, prevent seepage of groundwater through subsoils into properties in areas where this is likely, due to geological characteristics, nor can they prevent flooding as a result of backflow from an overloaded drainage or sewer system (unless a non-return valve is fitted), or penetration of floodwater through a party wall of an adjacent property. Therefore, a pump, and preferably also a sump, should ideally be installed to remove any leakage.

Some products also require a separate sealant. The products are not usually suitable for floods deeper than one metre above floor level as the building structure may not be able to withstand the load. Sandbags are another measure. However, floodgates and airbrick covers offer much better protection and are easier to use than traditional sandbags, which can contain bacteria from floodwaters.

Moving assets at risk to safety either to a higher location on upper floors or to another location can be extremely effective in reducing flood losses. For homeowners, this could mean moving personal belongings, items of sentimental value, personal papers and cars. For farmers it could mean machinery and livestock, while for businesses it could mean stock, equipment, raw materials, papers, vehicles, etc. The measure can make a significant difference to reducing flood losses, and to the distress caused to flood victims due to lost or damaged sentimental possessions.

Individual Damage Avoidance Actions



Governance and sustainability

There is now a certification scheme for removable products, such as floodgates. The British Standards Institution approves products, awarding them a BSI Kitemark or symbol of quality. Several products have now received this Kitemark in the UK. There is, however, an allowed leakage on these products of one litre of water per metre of panel per hour.

These response group measures are sustainable in that they are environmentally friendly and encourage people to think about the longer term perspective of helping themselves and creating more resilient communities. Moving assets is relatively easy to implement. However, households may need support where they include people who are elderly, disabled, or who live alone.

Costs and funding mechanisms

One drawback with floodproofing products is their cost, which puts them out of reach for those on low income. The cost of fitting a 760-mm floodgate to a standard doorframe with one company is £390, and for a standard air vent is £60. Costs for an average home are around £2,000. It is, however, possible for householders to make their own gates more cheaply.

There is currently no grant system available for these products from local authorities, although it has been called for by community action groups, and is being considered in Wales. Removing assets may not incur any direct costs except for commercial or public organisations, except to local authorities that may provide support to others – although this may be supplied through the voluntary sector.

Interactions

Both temporary floodproofing of properties and moving assets at risk depend on accurate and respected flood forecasting and early receipt of a flood warning. The measures also depend on people knowing what actions to take on receipt of such warning and on people's ability to take such actions. In the case of very elderly people or those with physical or mental disabilities, help may be required to move possessions. Therefore, awareness of flood risk is essential, along with pre-existing preparedness plans.

A well-rehearsed flood plan for the installation, use and removal of floodproofing products will enhance the effectiveness of these measures. It also needs to be made clear to purchasers of these products that they do not guarantee to stop floodwater from entering premises. There are also interactions with the response theme Managing Flood Losses on more permanent floodproofing to properties.

Case example

An example of the effectiveness of moving assets to a place of safety can be illustrated in the case of the 2003 flooding in Bewdley on Severnside. Members of one family could move all of their own belongings from the ground floor of their property to upper floors, along with those from four other neighbouring houses. Where lack of space permitted moving all assets to upper floors, these were raised on breeze-blocks out of reach of the floodwaters. These actions resulted in substantial financial savings for the households involved, as well as reduced stress and anxiety to those concerned. The removal of these assets was made possible by knowledge of the flood risk, accurate flood forecasting, and a long warning lead time. It was also facilitated by having preparedness plans in place. However, for moving furniture on to breeze-blocks an accurate prediction of final flood level is necessary.

Emerging issues

There is currently uncertainty over wider adoption of floodproofing measures, although it is highly likely that take-up will increase. Many of these products are recently developed. There is still widespread ignorance concerning them. Climate change such as increased drought years may also act to convince people that these measures are not necessary.

More research is needed into the effectiveness of these measures and on how they can be improved and encouraged. It is more likely that people will continue moving assets at risk to a place of safety. However, people will often wait until they perceive flooding to be ‘certain’ before taking any mitigating actions, particularly those with no previous flood experience and commercial companies/public institutions concerned at lost customer confidence and profit/operations. This means that when actions are taken they are less effective due to lack of time for implementation.

More awareness of flooding issues and increased confidence in the forecasting and warning system might lead to earlier and more effective response in the future. However, the issue of ‘false alarms’ can lead to people becoming complacent.

Response Group A12

Land-Use Management

Response theme	Managing Flood Events
Element of flood risk affected	Receptor

Definition

Land-Use Management seeks to reduce the effect of flooding on existing property and infrastructure simply by relocating away from flood-prone areas.

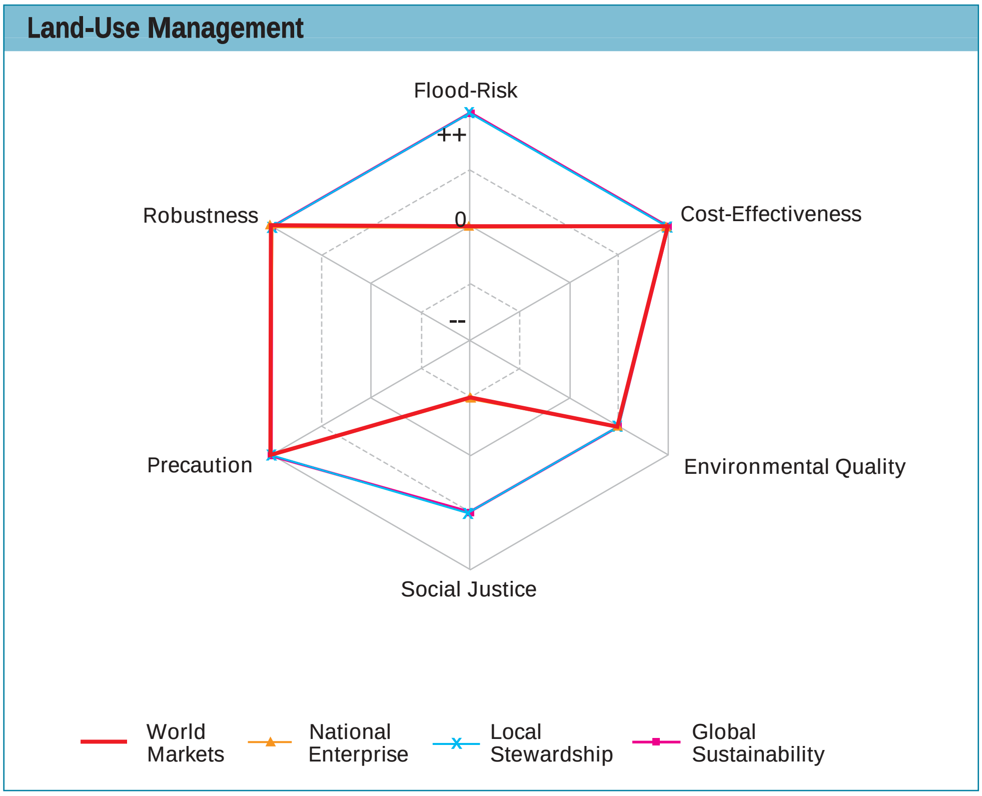
Measures in the response group

• Voluntary relocation	Individual occupants decide to relocate, after a flood or on receipt of information about risk, for example.
• Encouraged relocation	Occupants encouraged to relocate by measures such as public purchase of property, grant aid to relocate, higher insurance premiums, conditions on reconstruction after damage.
• Compulsory relocation	Planning policies prevent reconstruction in a flood-prone area after loss or condemn exposed property: compulsory purchase.

Function and efficacy

Requires credible definition of flood-prone areas. While relocation may reduce flood losses, there may be sound economic reasons for locating in flood-prone areas, such as access to river frontage. Location elsewhere may increase costs.

Governance and sustainability



Costs and funding mechanisms

Relocation involves direct costs of removal and reconstruction, offset to a certain extent by sale of the original assets. Relocation may also involve indirect economic costs, if the new location is less suitable than the original. Potential funding mechanisms include public grants or loans available through a variety of agencies. However, the issue of whether the availability of grants or loans in one location would imply liability for all flood-prone properties needs to be addressed.

Interactions

'Encouraged relocation' would be very much influenced by the procedures in place to provide for financial recovery from flood loss, including insurance. High premiums or excesses could be used to discourage rebuilding, for example. There is a link to the response theme Managing the Urban Fabric with respect to the compulsory purchase of property subject to foul or pluvial flooding where the cost of remedial action exceeds the market value of property.

Case example

The floodplain of the Irwell at Salford is largely occupied by low-grade commercial units, many thousands of largely local authority houses and high rise flats occupied by low income families. Wholesale redevelopment and regeneration of the floodplain is one option to reduce flood risk, where structural improvements would be expensive and could be uneconomic.

Emerging issues

- Identification of flood-prone areas.
- Linkages with measures to reduce physical flood hazard, the response theme Managing the Urban Fabric.
- Role of insurance incentives.
- Equity: the possibility that relocation might create blight.

Response Group A13

Floodproofing

Response theme	Managing Flood Events
Element of flood risk affected	Receptor

Definition

Floodproofing seeks to reduce the effect of flooding on established property and infrastructure by changing the characteristics of the exposed structures through 'retro-fitting'.

Measures in the Floodproofing response group

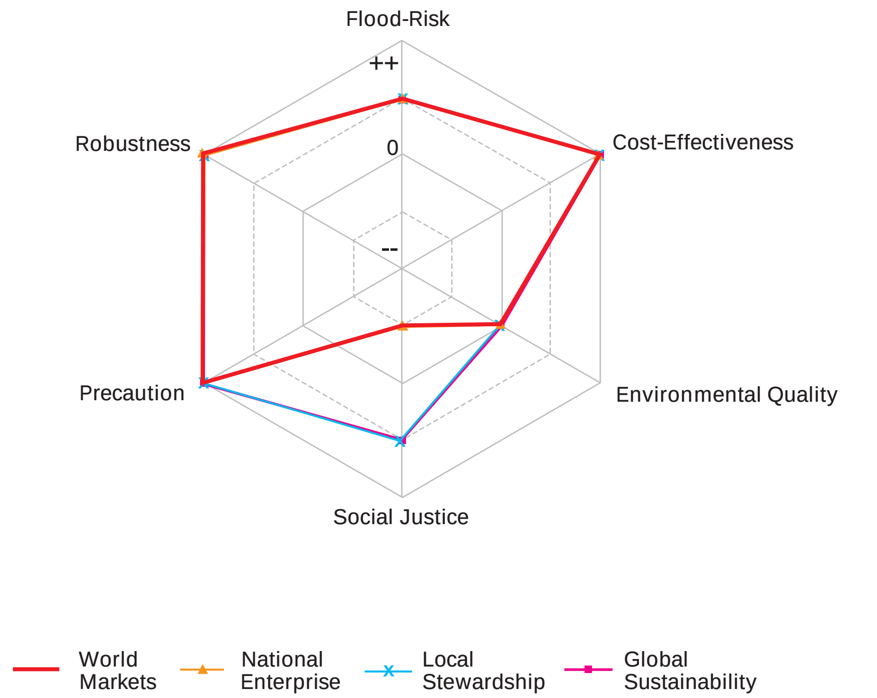
• Permanent floodproofing	Permanent alterations to established property and infrastructure, such as raising electrical sockets or equipment.
• Temporary floodproofing	Measures that can be implemented on receipt of a warning: may require some advance preparation, such as window and door barriers.

Function and efficacy

These depend on the rate of uptake and efficiency of measures. Rate of uptake may depend on flood experience, availability of incentives – through insurance, for example – and funding. Two broad factors affect efficiency: it is difficult to floodproof properties in the UK to more than 1 metre (however, flood depths are rarely greater than this); or against long-duration/high-velocity flooding. Temporary measures require accurate and timely warning.

Governance and sustainability

Floodproofing



Costs and funding mechanisms

Costs will vary with type of protection. They may be borne by individual occupant/property owner, but could in principle be covered by public grants or loans.

Interactions

The effectiveness of temporary measures depends on flood warning (see the response theme Managing Flood Events). Take-up will depend on financial incentives, through insurance, for example. There are also links with measures to reduce the effect a property/structure has on physical flood hazard (see the response theme Managing the Urban Fabric).

Case example

Many case examples are given in guidance books prepared by the Environment Agency, DTLR and CIRIA.

Emerging issues

- Technological innovation.
- Role of insurance incentives.
- Linkages with measures to reduce runoff-generation potential.

Response Group A14

Land-Use Planning

Response theme	Managing Flood Events
Element of flood risk affected	Receptor

Definition

Land-Use Planning seeks to reduce exposure to flood loss through planning future land use.

Measures in the response group

• Public planning policies	Prevent development in defined areas.
• Incentives	Discourage development in defined areas through charging or other mechanisms.
• Voluntary	Decisions made by developers and others to avoid risk areas.

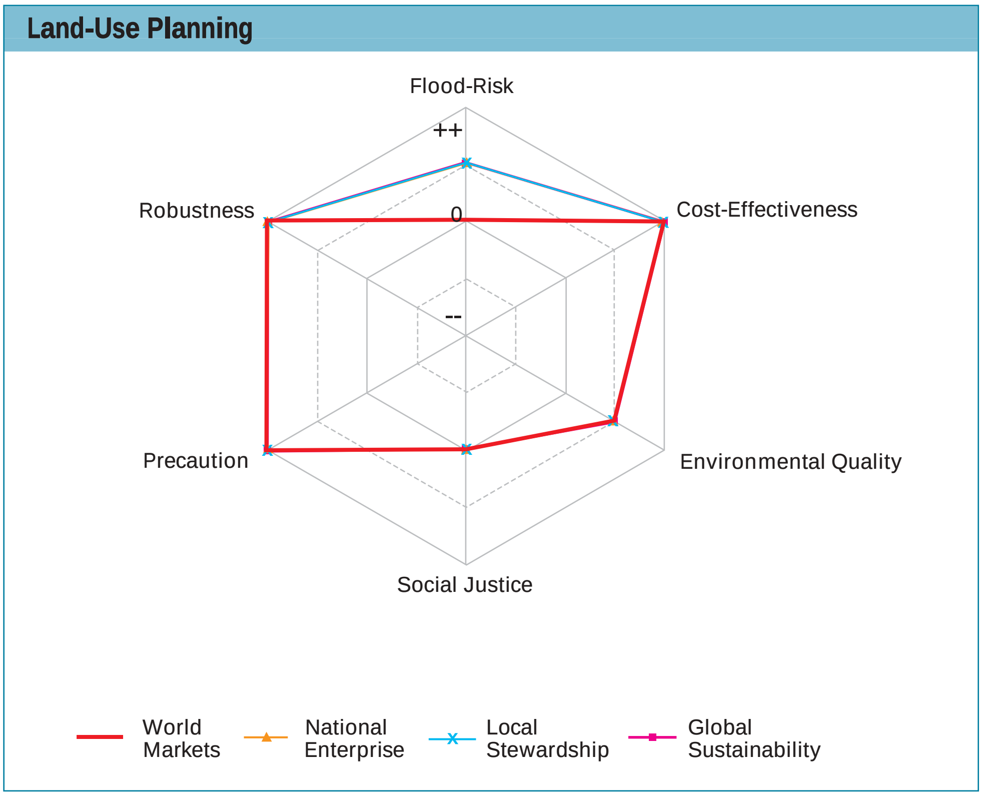
Function and efficacy

Effectiveness depends on: credible identification of flood-prone areas; and degree of enforcement of the measures.

Governance and sustainability

The spider diagram shows the effect of this response on UK flood risk, which arises from both existing development and new development. Under the Foresight Futures Global Sustainability and Local Stewardship there is very little new floodplain development. The effect of measures to reduce risk to new development is therefore very small. The measures are in fact implicit in the baseline.

Under the World Markets and National Enterprise scenarios there are few attempts to manage future use of land on floodplains.



Costs and funding mechanisms

For public measures, such as land-use planning and incentivisation, the costs are simply those of running the scheme. However, if developers are deterred from locating in the most cost-effective place, then developments will incur additional costs, both for construction and over their lifetime.

Interactions

There are close links with response group A16 Insurance, Shared Risk and Compensation and other measures to allow financial recovery from loss. Financial incentives can be used to encourage land-use planning. There are also close links with measures to reduce the generation of runoff from new development, see the response theme Managing the Urban Fabric.

Ideally, land-use planning policy should also include measures to curb increases in flooding downstream and off-site and should reduce exposure to flood loss. Finally, there are very close and important linkages between Land-Use Planning and development control, as in response group A15 Building Codes.

Case example

The Environment Agency's Indicative Floodplain Map is used increasingly to guide land-use planning. The developing Catchment Flood Management Plans provide a context for land-use planning.

Emerging issues

- Credible identification of flood-prone areas.
- Development of incentive schemes.
- Enforcement and implementation.
- Linkages with measures to reduce the physical flood risk.

Response Group A15

Building Codes

Response theme	Managing Flood Events
Element of flood risk affected	Receptor

Definition

Building Codes includes measures that seek to reduce flood losses by ensuring that new buildings and infrastructure are designed to be resilient to damage.

Measures in the group

• Building codes	General codes applied to all construction.
• Individual property design	Design of individual structures to reduce losses, by elevation on piles, for example.
• Development control rules	Conditions on planning permission to require adherence to building codes or specific designs.

Function and efficacy

In principle, it is possible to design building codes and new buildings to reduce significantly losses during flooding and exposure to risk. In practice, measures implemented will be determined by the balance between cost and benefits in terms of reduced losses.

Governance and sustainability

The spider diagram shows the effect on flood risk in the UK arising from existing and new development. Under the scenarios Global Sustainability and Local Stewardship there is very little new floodplain development – so the effect of measures to reduce risk to new development is therefore very small (the measures are in fact implicit in the baseline).

Costs and funding mechanisms

Costs would largely be borne by developers. There are also operating costs for development control.

Interactions

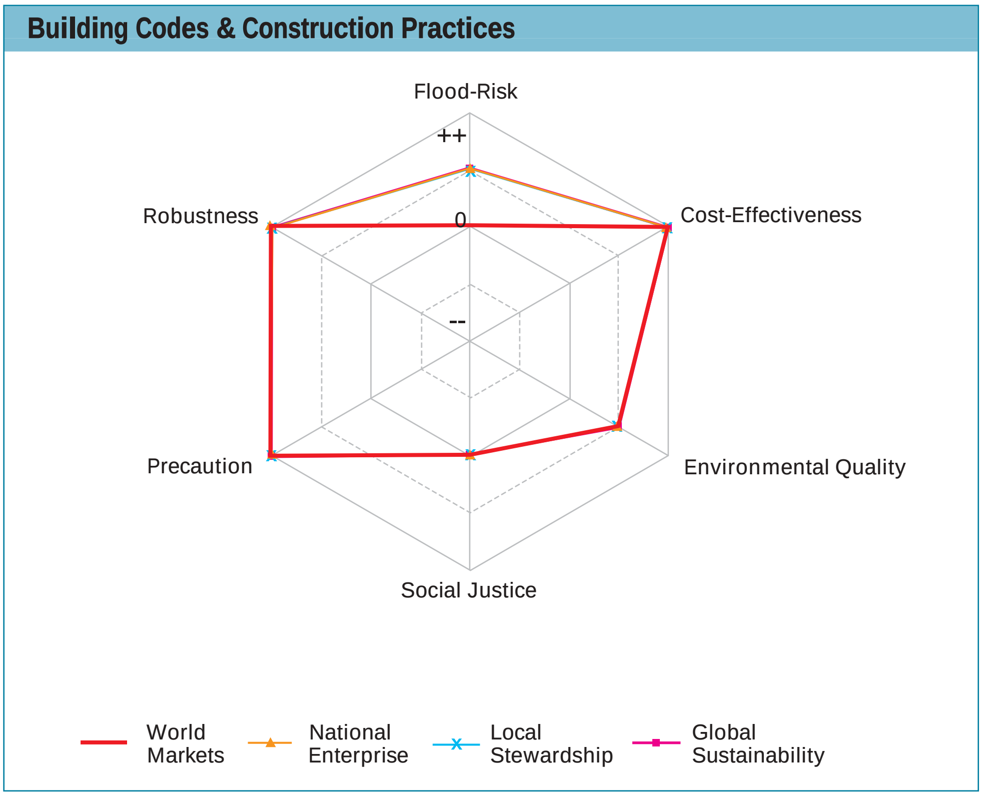
As with response group A14 Land-Use Planning, there are close linkages and interactions with: measures to reduce the generation of runoff, the response theme Managing the Urban Fabric; and measures to enable financial recovery from loss, particularly insurance.

The effectiveness of some measures may also depend on flood forecasting and warning – the response theme Managing Flood Events.

Case example

Although agencies such as the EA and CIRIA provide a number of advice guides concerning floodproofing from both a homeowner and developer perspective, there are few case examples of flood-orientated building regulations. Although the inquiry of the House of Commons Select Committee on Environment Transport and Regional Affairs into the 2000 floods recommended that the government produce tougher building regulations in flood-hazard areas, to date the changes have influenced only Part H Building Regulations, which examined rainwater drainage issues, and Part C Building Regulations, which examined the protection of new buildings from moisture. Unfortunately, these regulations are relatively new so there has been no research into their impact on either developers' behaviour or the reduction of flood losses.

It is worth highlighting, however, that a lack of effective guidance in this area may also prompt the insurance industry to take a lead, as happened in the USA and Australia, where insurance companies and mortgage lenders produced a set of building standards that they expect from any new development or building upgrade. If a development does not adhere to these standards it may be difficult to obtain insurance and mortgages. Consequently, some building regulations have become irrelevant as developers follow these industry-led guidelines.



Emerging issues

- Technological innovation.
- Role of incentives.
- Enforcement.

Response Group A16

Insurance, Shared Risk and Compensation

Response theme	Managing Flood Events
Element of flood risk affected	Receptor

Definition

Insurance, Shared Risk and Compensation includes measures that allow, and assist, flood victims to recover from the financial and economic impacts of flooding.

Measures in the response group

• Insurance	Policyholders receive reimbursement for loss if they pay a premium for cover. Insurance may be provided by the private sector, public sector or a combination.
• State aid or compensation	Public aid through grants, loans or tax relief.
• Public charitable relief	Loans or grants from charities.
• Self insurance	Occupants of flood-prone areas formally decide to bear risk of loss themselves.

Function and efficacy

In themselves, these measures do not reduce flood risk in quantitative terms. They do reduce the impact of a given flood event. The measures can be designed, however, to respond to increasing flood risk by encouraging stakeholders to take other actions to reduce flood losses in three main ways:

- Through imposing conditions on the eligibility for aid, for example, recipients must adopt floodproofing measures or live in communities with clear flood-management policies.
- Through imposing conditions on payments, such as requiring implementation of new measures or policies.

- Through raising awareness of risk, through premium pricing for example.

The effectiveness of these measures in reducing risk depends therefore on the degree to which the measures can be used to incentivise risk-reducing measures, and the effectiveness of these measures.

Measures to facilitate recovery from flood loss, however, can also encourage unwise use of the floodplain. Reimbursement of loss without obligation to reform can be seen as a subsidy to floodplain occupation.

Governance and sustainability

Some measures in this group must be implemented by public organisations, while others, specifically insurance, can be implemented by the private sector. However, the effectiveness of measures will be strongly influenced by the linkages between the private and public sector. For example, public-sector measures to provide flood relief could conflict with private-sector flood insurance.

The key sustainability issue relates to access to support for financial recovery. Any system that did not provide support for all could increase poverty and social exclusion.

Table A3 **Funding mechanisms and their costs**

Funding mechanism	Costs	Example magnitudes
Insurance	Premium costs to policyholder. Government subsidy to insurance company	Flood insurance premiums for domestic properties can be up to £400 per year. In the form of catastrophe reinsurance if neccessary
State aid	Grants or loans to flood victims	Average loss per residential property around £28,000
Tax credits	Lost tax revenue	Depends on size of credit, but average residential property loss is around £28,000
Charitable relief	Non – money raised voluntarily	?
Self-insurance	Average annual damages	Depends on size of loss

Interactions

Measures to facilitate recovery from flood loss will lead to a reduction in flood risk only if they are coupled with other flood risk responses, as discussed above. Central to this response group, therefore, is the ability to use measures to facilitate recovery from loss to encourage the adoption of flood-loss reduction measures.

There are also key interactions between response measures within the group. Specifically, the relationship between private-sector insurance and state assistance to flood victims is crucial.

Case example

The UK is rare in having private-sector flood insurance, covering houses and businesses. Flood insurance is provided to domestic properties bundled in with other perils in a comprehensive policy. It is sold for commercial properties as part of a comprehensive package. The current policy of the insurance industry is to provide cover where defences to a defined standard exist or are planned by 2007, but not to guarantee cover otherwise. The industry currently uses the Environment Agency's Indicative Floodplain Map to identify postcode zones at risk of flooding.

The US National Flood Insurance Program is rather different. Floodplain occupants can buy cover only if their community has adopted floodplain land-use planning. There are, in principle, sanctions on the availability of financial support, before or after a flood, to floodplain occupants who could buy flood insurance but do not. There are procedures to encourage relocation away from high-risk areas. However, flood-insurance penetration remains very low.

Emerging issues

- Financial sustainability of private-sector flood insurance.
- Encouraging individual and collective measures to reduce flood risk through insurance.
- Providing support to the uninsured and underinsured.

Response Group A17

Health and Social Measures

Response theme	Managing Flood Events
Element of flood risk affected	Receptor

Definition

Health and Social Measures Set out to alleviate the effects on the physical and psychological health of those affected by flooding.

Economic and financial losses are not the only, or necessarily even the most important, impacts of flooding. Flooding often affects physical and psychological health. While measures to reimburse financial losses may alleviate some of these health impacts, other measures also need to be put into place to reduce the overall impact of flooding.

Measures in the Health and Social Measures response group

- Assistance with handling insurance claims – professional advice and guidance, publicly funded or funded by insurance companies.
- Assistance with repair and rehabilitation of property – public and volunteer groups provide recovery assistance.
- Practical support for vulnerable groups, such as moving furniture and cleaning up – public and volunteer groups provide recovery assistance in the immediate aftermath of flooding.
- Counselling for disaster victims – professional support for flood victims.

Function and efficacy

As with measures to facilitate financial recovery from loss, measures to lessen health effects and social impacts do not in themselves change flood risk. In contrast with the financial measures, however, it is difficult to see how these support measures can provide an incentive for continued occupation of flood-prone areas or encourage the adoption of mitigating measures.

The value of counselling in general is unclear. It is arguably less important than other practical measures.

Governance and sustainability

The ways in which these measures are provided will depend on the configuration and capabilities of local health and social services, and on the presence and strength of community groups. Measures to reduce the non-economic impacts of flooding are consistent with the principles of sustainability, particularly the aim of combating social exclusion.

Costs and funding mechanisms

Funding for the provision of health and social services would generally come from the relevant public authorities. It will therefore compete with other services. National guidelines would probably be necessary to ensure consistency between different authorities. It may also be necessary for central government to fund defined actions. Central government can already allocate additional emergency funds to councils following major flood events.

Practical assistance could come from public authorities, but this would obviously be a burden on local taxpayers. Charities could provide some practical assistance.

Interactions

Measures to reduce the long-term health and social impacts of flooding need to be integrated with emergency relief activities, the response theme Managing Flood Events.

Case example

There have been few case studies of the effectiveness of the different ways of encouraging recovery from loss. Most evidence is anecdotal. However, a survey following the 1993 Midwest floods in the USA showed that the rate of recovery of flood victims – as measured in terms of psychological and physical ill health – improved when trained respected community leaders provided counselling.

Emerging issues

- Effectiveness of counselling services after flooding.

Response Group A18

River Conveyance

Response theme	River and Coastal Engineering
Element of flood risk affected	Pathway

Definition

River Conveyance includes engineering measures to increase the capacity of rivers and floodplains to convey floodwater.

Measures in the response group River Conveyance:

- Improving the hydraulic capacity of existing channels by altering their hydraulic geometry and removing excess vegetation.
- Canalisation of, or creation of multi-stage, river channels to improve their hydraulic geometry.
- Forming flood-bypass or diversion channels by opening up old channels or creating new channels on the floodplain.
- Enhancing the conveyance of natural or artificial flow paths on the floodplain by discouraging inappropriate vegetation and/or removing natural or man-made obstacles to flow.

Function and efficacy

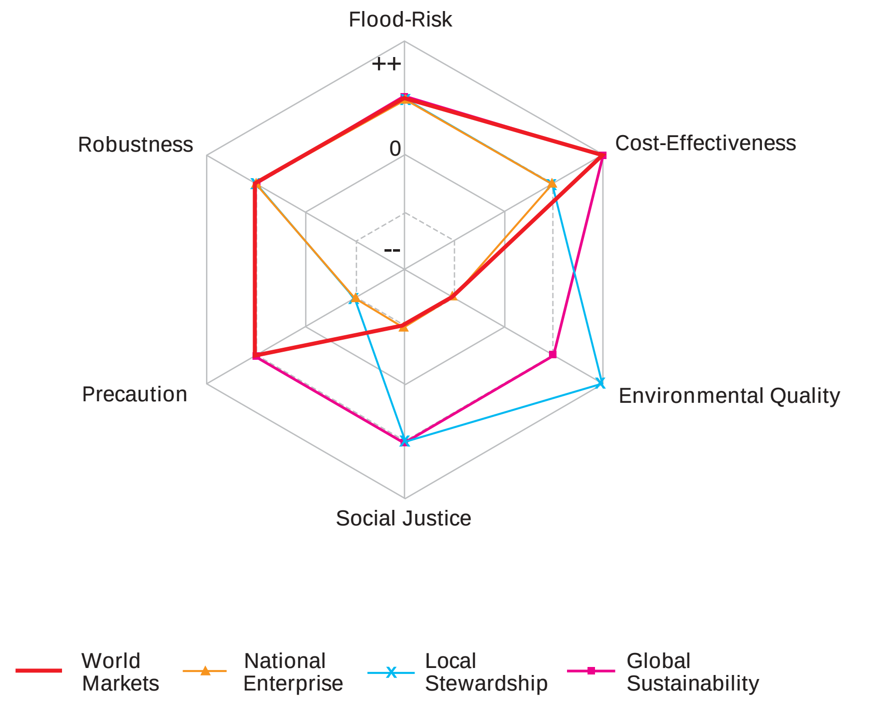
The objective of increasing conveyance is to improve the rate at which the river system can carry floodwater through and away from a flood-prone area. Improved conveyance can reduce the frequency, extent and duration of flooding by lowering floodwater levels in the river system and on the floodplain, thus reducing the area flooded.

The efficacy of measures to increase channel conveyance is limited by what is feasible and sustainable. In some cases improved conveyance may reduce the attenuation of the flood wave, increasing floodwater levels downstream of a river reach.

Governance and sustainability

In England and Wales, Defra has responsibilities for flood management, while the Environment Agency has permissive powers to undertake flood-defence work on main rivers but is not subject to legal duties to do so. Hence there is no public right to flood protection. In Wales the Environment Agency shares responsibilities with the National Assembly of Wales. In Scotland, duties and responsibilities for flood defence are distributed between riparian owners, central government, local authorities and the Scottish Environmental Protection Agency. The statutory flood-defence authority for Northern Ireland is the Rivers Agency, within the Department of Agriculture and Rural Development.

River Conveyance



The sustainability of improving conveyance under the Foresight Scenarios is indicated in the spider diagram. Sustainability is potentially highest in the community-orientated scenarios, Global Sustainability and Local Stewardship, but with some relative reduction in efficacy and precaution under the Local Stewardship future. Sustainability is threatened by issues of social justice and environmental quality under the consumer-orientated scenarios World Markets and National Enterprise, but improving conveyance may nevertheless be an effective option in urban areas where available land is limited and potential damages are high.

Costs and funding mechanisms

The costs of measures to increase conveyance depend on the type and scale of the works, and are difficult to generalise. Costs generally increase with capacity but depend on many factors, including type of material, its disposal, numbers of structures involved, bridges for example, and land compensation. Capital costs range from tens to hundreds of thousands of pounds per kilometre of river to cover initial scheme implementation. This may be followed by periodic interventions to maintaining conveyance, at an annual cost of 1% to 5% of capital cost.

Funding for measures to increase conveyance generally comes from the public purse, subject to meeting economic, social, and environmental criteria. Costs are currently not recovered directly from beneficiaries.

Interactions

Measures to improve conveyance can be implemented individually or as part of an integrated package. They are often implemented in conjunction with linear flood defences along the river to confine flood conveyance to the river channel(s) and adjacent areas of floodplain. This creates a set of potentially complex interactions. Measures can initiate feedback loops within the dynamics of fluvial systems, such as:

- Enhancing river-channel conveyance locally could influence the dynamics of sediment erosion and deposition on a broader scale, leading to unwanted changes in the characteristics of the river, in the medium to long term.
- Enhancing floodplain conveyance locally could influence the dynamics of floodplain morphology on a broader scale, leading to unforeseen changes in floodplain topography, in the long term.

Broader feedback loops within the ‘response-risk reduction-response’ cycle could be created. An increase in flood risk downstream of the conveyance measures, or changes in the character of the river and its floodplain, could change stakeholder attitudes to the use of conveyance measures.

Case example

The recently completed Maidenhead, Windsor and Eton scheme is a good example of increased conveyance for flood alleviation.

Emerging issues

Increasing conveyance measures are generally robust and positive in reducing flood risk, and cost-effective. There is some uncertainty over the potential for morphological and environmental change, and the recurrent maintenance costs that may be associated with large-scale works of the type associated with the World Markets and National Enterprise scenarios. These concerns are easier to deal with on smaller schemes of the type that might be expected with the Local Stewardship scenario, where environmental criteria carry more weight in decision-making.

Response Group A19

Engineered Flood Storage

Response theme	River and Coastal Engineering
Element of flood risk affected	Pathway

Definition

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.

Measures in the response group Engineered Storage

- Creating a flood-storage reservoir through the construction of a dam or a flood barrier.
- Creating washlands on floodplains through the construction of embankments.
- Enhancing the natural storage provided by floodplain topography.
- Developing artificial storage sites near the river system, above or below at ground level.

Function and efficacy

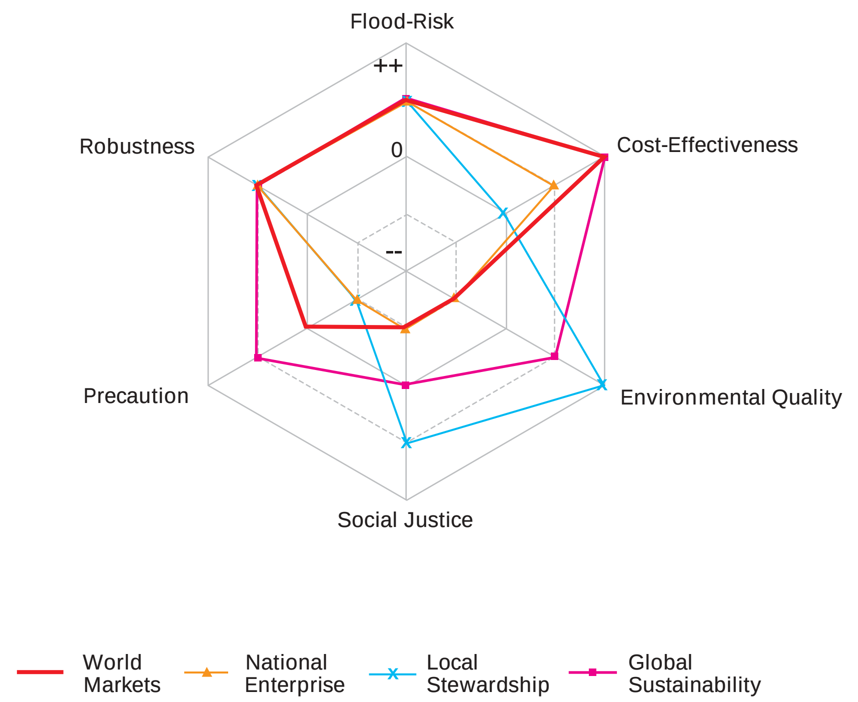
The primary function of increased storage is to temporary retain floodwater, reducing the threat of flooding downstream. Some reservoirs have multiple functions. As well as flood prevention, these can include improved water-resources management and water supply, generation of hydroelectric power and improvement of river navigation upstream of the dam.

While offering a potentially significant reduction in flood risk for large downstream areas, increasing storage alone may not provide complete and cost-effective flood protection. The available flood-storage capacity can vary with the time of year and may turn out to be inadequate in the event of a flood greater than the design event. Other uses of the scheme can also affect available storage, which can also reduce with time through, for example, deposition of sediment at the storage site.

Governance and sustainability

Measures to increase storage are co-ordinated or implemented by a public authority, although there is in principle no restriction on the potential ownership of a scheme. Creation of storage requires a change in land use, which may affect access rights and land values. It may create the need for restrictions and stakeholder responsibilities to ensure effective flood control. Planning permission is required, which involves compliance with planning procedures, environmental assessment and consultation.

Engineered Storage



In England and Wales, Defra has responsibilities for flood management. The Environment Agency has permissive powers to undertake flood-defence work but is not subject to legal duties to do so. In Wales, the Environment Agency shares responsibilities with the National Assembly of Wales. In Scotland, duties and responsibilities for flood defence are distributed between riparian owners, central government, local authorities and the Scottish Environmental Protection Agency. The statutory flood defence authority for Northern Ireland is the Rivers Agency, within the Department of Agriculture and Rural Development.

Various types of storage allow different forms to be adopted to suit the values and governance under each Foresight scenario. The effectiveness of storage in reducing flood risk is therefore ‘reasonable’ to ‘good’ under all the scenarios (see spider diagram above). Under the more consumer-orientated scenarios, National Enterprise and World Markets, there may be a stronger preference for dams and offline storage than for washlands and wetlands. The latter measures might be favoured in the more community-focused scenarios, Global Sustainability and Local Stewardship. The overall sustainability of engineered-storage measures looks most promising under the Global Sustainability and Local Stewardship futures.

Costs and funding mechanisms

The capital cost of dams, reservoirs and embankments varies significantly, and depends on the topography of the storage site. There may be high threshold costs and economies of scale, up to a limiting storage volume.

The capital cost of a dam, reservoir or engineered storage facility may be several millions of pounds, compared with hundreds of thousands of pounds for the creation of a washland. Topography, location, and damage avoided determines value for money. Annual operation and maintenance costs can range from 1% to 5% of the capital cost, and may be proportionately higher for a washland than for a dam.

Funding for storage schemes used primarily for flood defence currently comes from the public purse. In the case of schemes with several functions, different stakeholders may share costs.

Costs for flood defence are not usually recovered directly from beneficiaries. Schemes with multiple functions, and washlands create the possibility for income generated from other uses.

Interactions

Large dams can be implemented individually for flood control. Smaller reservoirs and washlands are usually combined with other measures, such as linear flood defences and improved conveyance.

Measures to improve storage can initiate feedback loops within the dynamics of fluvial systems. For example, providing online storage influences sediment transport through erosion and deposition on a broader scale, creating the potential for unwanted changes in the characteristics of the river, especially, in the medium to long term, downstream. Enhancing floodplain and wetland storage could also influence the dynamics of floodplain morphology and ecology on a broader scale, leading to unforeseen changes in the floodplain environment in the long term.

Broader feedback loops within the 'response-risk reduction-response' cycle include an increase in flood risk upstream of the storage; changes downstream in the character of the river and its floodplain; or conflicts of interest among uses which could change stakeholder's attitudes to the use of conveyance measures.

Case example

The Leigh Barrier in Kent is a good example of a reservoir with a primary purpose of flood control. The barrier on the River Medway creates the largest online flood control reservoir in Europe at 278 ha, and, together with existing flood walls, improves the level of protection against floods in Tonbridge from a 10-year event to approximately a 150-year event. The barrier was operated several times during the Autumn 2000 floods, but with some conflict of interest between protection of Tonbridge and alleviating flooding at Yalding.

Emerging issues

The concept of flood storage may appear to offer opportunities for sustainable flood alleviation. However, certain forms, such as dams and washlands, are potentially more sustainable than others under some of the Foresight scenarios. As in the case of flood defences, it may be technically feasible and cost effective to respond to increased flood risk by simply raising the height of storage structures, but it may not be desirable or sensible to do so. Factors such as the 'escalator effect' (see note on flood defences), stakeholders' attitudes, concerns over public safety in the event of dam failure, and morphological impacts of changes imposed on the river regime, especially by large dams, could limit the sustainability of the large structural forms of on-line storage.

More sustainable approaches may involve embanked washlands where land is available, perhaps combined with relocation of flood defences to allow river and floodplain restoration, and improved conveyance through urban areas.

Response Group A20

Floodwater Transfer

Response theme	River and Coastal Engineering
Element of flood risk affected	Pathway

Definition

Floodwater Transfer involves engineered measures to convey excess water from one river system to another system that is better able to deal with the floodwater and the associated flood risk.

Measures in the response group Floodwater Transfer

- Engineering works to allow pumped or gravity transfer of floodwater via natural or artificial channels to a receiving water system.
- 'Compensatory' works in the recipient system to control the resulting flood risk – these works could include increasing conveyance, flood embankments, and the provision of flood storage.

Function and efficacy

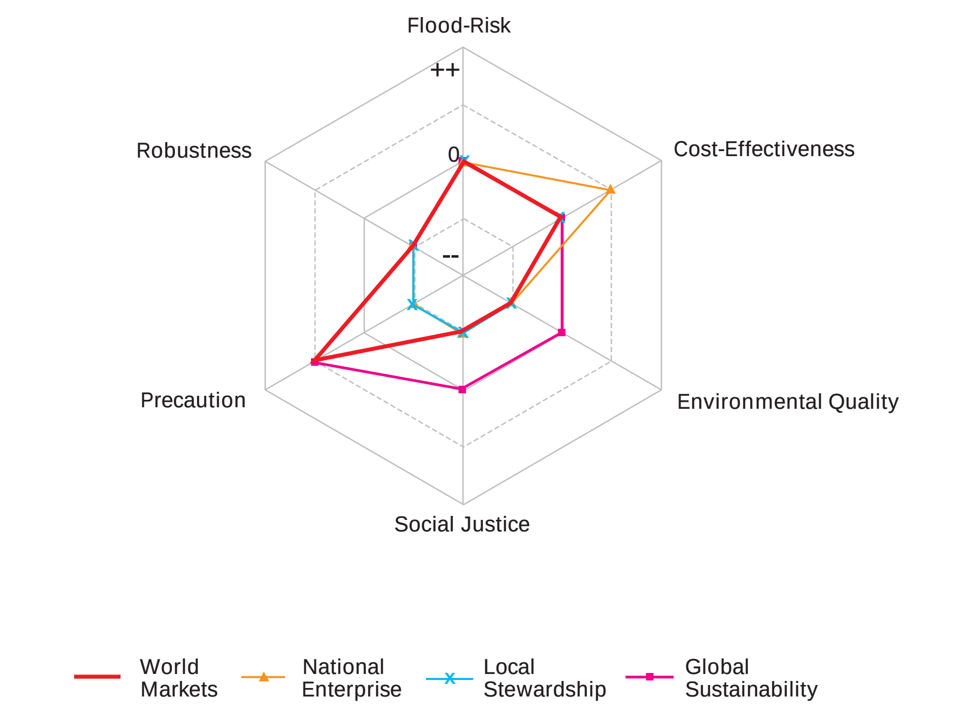
The primary function of floodwater transfer is to convey excess floodwater and flood risk from one system to another. Transfer of floodwater is not a common means of alleviating flooding because of practical difficulties in meeting all the potential hydraulic, social, economic and environmental requirements.

While potentially offering a significant reduction in the level of flood risk in the source system, floodwater transfer in itself is unlikely to provide cost effective and complete flood protection. The efficacy of floodwater transfer could decline with time if there are more frequent or higher flood levels in the source system; or if the physical condition and/or capacity of the transfer system deteriorates; or if the ability of the receiving system to accept the floodwater at an acceptable level of risk reduces with time.

Governance and sustainability

Floodwater transfer schemes would be co-ordinated or implemented by a public authority. Planning permission is required, involving compliance with planning procedures, environmental assessment, and stakeholder consultation. Floodwater transfer implies a change in the spatial distribution of flood risk, which may affect land values and create the need for restrictions and new stakeholder responsibilities to ensure effective flood control.

Floodwater Transfer



In England and Wales, Defra has responsibilities for flood management and the Environment Agency has permissive powers to undertake flood defence work but is not subject to legal duties to do so. In Wales the Environment Agency shares responsibilities with the National Assembly of Wales. In Scotland, duties and responsibilities for flood defence are distributed between riparian owners, central government, local authorities and the Scottish Environmental Protection Agency. The statutory flood defence authority for Northern Ireland is the Rivers Agency, within the Department of Agriculture and Rural Development.

The potential for floodwater transfer in the UK is limited by topographical and hydraulic factors as well as environmental concerns. As indicated in the spider diagram, the sustainability of floodwater transfer is not high under any Foresight Scenario. This is due to concerns over the robustness of this form of intervention, the environmental implications of transfer between river basins and social concerns over the equitable redistribution of flood risk. The broad regional scale of works would make them particularly unattractive in the Foresight Future Local Stewardship.

Costs and funding mechanisms

There is a threshold in terms of transfer capacity below which floodwater transfer is not worth the necessary investment. Costs would then rise non-linearly with the size of the transfer scheme. The capital cost of transfer works and compensatory measures could range from a few to many millions of pounds. Annual operation and maintenance costs could range from 1% of the capital cost, increasing to up to 10% if significant pumping is involved and maintaining enhanced conveyance forms a principal compensatory measure.

With few exceptions, funding for floodwater transfer currently comes from the public purse, subject to meeting economic, social, and environmental criteria. Costs are not recovered directly from beneficiaries.

Interactions

Floodwater transfer schemes can involve a variety of linked hydraulic and flood-control measures. These measures can initiate feedback loops within the dynamic processes of the source and receiving systems, such as:

- Transferring floodwater can influence the dynamics of sediment transport (erosion and deposition) in the source and receiving systems, creating the potential for unwanted changes in the characteristics of both systems (in the medium to long term).
- The mixing of water from two systems could influence the ecological dynamics of the receiving system, leading to unforeseen long-term changes in its environment.

Broader feedback loops within the 'response-risk reduction-response' cycle could arise. An increase in the flood risk imposed on the receiving system could create conflicts of interest, leading to changes in stakeholders' attitudes to the use of floodwater transfer measures.

Case example

As already noted, Floodwater Transfer is not a common means of flood control in the UK. There are also few international examples of such schemes. The use of the Fossdyke Canal to convey flood flows from the River Till system, to the North West of Lincoln to the River Trent was considered as an alternative to the provision of a washland. This option proved uneconomical due to the need for pumping, the cost of compensatory works on the Trent, and major improvements to the Fossdyke Canal itself.

Emerging issues

The potential for floodwater transfer in the UK is limited. The sustainability of this group of measures is not high under any futures scenario. Its potential might be greatest under the National Enterprise scenario.

Response Group A21

River Defences

Response theme	River and Coastal Engineering
Element of flood risk affected	Pathway

Definition

River Defences are artificial structures, sometimes combined with natural formations, whose main purpose is to confine floodwater to specific areas, preventing it from spreading.

Measures in the response group River Defences:

- Flood embankments and walls along the river channel, sometimes with associated river-training measures.
- Ring dikes around vulnerable areas.
- Specialist structures – for example, demountable defences, flood gates – to prevent floodwater entering specific areas.
- Linear infrastructure such as road and rail embankments designed also to act as flood defences.

Function and efficacy

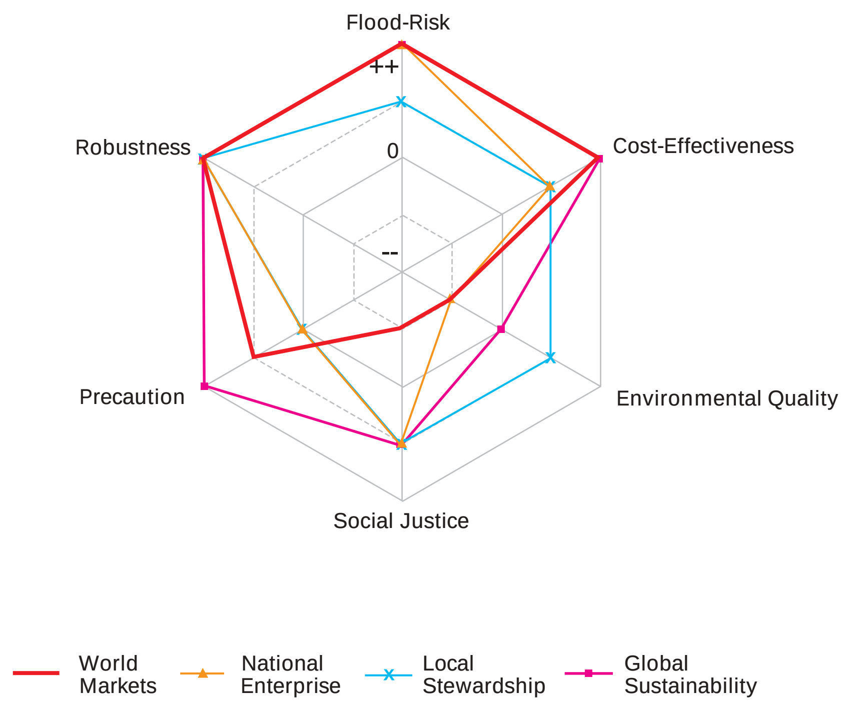
The primary function of flood defences is to reduce the frequency of flooding, usually to a specified standard of protection commensurate with the potential level of flood damage. This group of measures can rarely remove the risk of flooding entirely and cost effectively. There always remains a chance of overtopping, and structural or operational failure.

The efficacy of flood defences can decline if flooding is more frequent and there are higher flood levels in the future, or if their physical condition deteriorates. Linear flood defences along a river can raise floodwater levels both upstream and downstream, potentially increasing flood risk in these areas. Linear flood defences that cut across drainage lines need to incorporate provisions (such as gravity or pumped drainage structures) to ensure that drainage is not impeded.

The construction period of flood defences is relatively short (once the land on which they are to be built has been acquired), their benefits are immediate, and their economic life can be long provided that they are adequately maintained.

But, the presence of flood defences can encourage increased floodplain occupancy by creating a sense of security based on the perception that they have removed the flood risk almost entirely. This false sense of security may leave those living behind flood defences ill-prepared for extreme flood events that could overtop and/or breach the defences, unless their awareness of this risk is fostered.

River Defences



Governance and sustainability

In England and Wales, Defra has responsibilities for flood management, and the Environment Agency has permissive powers to undertake flood defence work but is not subject to legal duties to do so. Thus there is no specific right to flood protection. In Wales the Environment Agency shares responsibilities with the National Assembly of Wales. In Scotland, duties and responsibilities for flood defence are distributed between riparian owners, central government, local authorities and the Scottish Environmental Protection Agency. The statutory flood-defence authority for Northern Ireland is the Rivers Agency, within the Department of Agriculture and Rural Development.

Some flood embankments in Britain are over 400 years old. This indicates historical but not necessarily inherent sustainability. While the effectiveness of flood defences would be high under all the Foresight Scenarios (see spider diagram), the reduced value placed on the environment and social justice under the more consumer-orientated scenarios World Markets and National Enterprise, could threaten their sustainability without specific safeguards in place. Sustainability looks more promising under the community-based scenarios (Global Sustainability and Local Stewardship), but with concerns over cost-effectiveness, stakeholder attitudes and morphological change.

Costs and funding mechanisms

While the costs of flood defences vary linearly with the length of works, they rise non-linearly with the scale of the works. Capital costs per kilometre of defence vary from a few hundreds of thousands of pounds for low earth embankments, to a few million pounds for high embankments, to tens of millions of pounds if river training works have to be provided to protect the flood defences. Annual operation and maintenance costs range from 1% to 5% of the capital cost, depending on the form of construction of the works and the inclusion of river training works.

Funding for flood defences currently comes from the public purse, subject to meeting technical, economic, environmental and sustainability criteria. Costs are not recovered directly from beneficiaries. The current Defra appraisal rules place more emphasis on economic efficiency than on social equity, which can work to the disadvantage of small settlements and poor neighbourhoods.

Interactions

Flood defences can be used alone, but it is increasingly common to combine them with other forms of flood-risk management. Flood-defence measures can initiate feedback loops within the dynamics of fluvial systems. For example, they can confine the floodwater to the river channel and a small portion of floodplain which influences sediment erosion and deposition, leading to unwanted changes in the characteristics of the river in the medium to long term. The presence of barriers on the floodplain can also impede the transfer to the floodplain of fish, sediments and nutrients carried by the floodwater. This impediment could, in the longer term, influence the lifecycle of certain fish and the floodplain environment, leading to unforeseen changes.

Broader feedback loops within the ‘response-risk reduction-response’ cycle are created. An increase in flood risk downstream of flood embankments could change stakeholders’ attitudes to flood defences. The presence of defences can encourage increased occupancy of the floodplain by creating a perception that the flood defences have removed the flood risk. An increase in the level of development of the floodplain can, in turn, be used to justify higher flood defences – the so-called ‘escalator’ effect.

Case example

Raised flood defences are a key response to flood control along a number of British rivers. Flood walls are widely used where rivers pass through towns and cities. There are also flood embankments along many rivers that pass through valuable agricultural areas. One of the most widespread applications of flood embankments is in Hungary, where over 4000km of primary flood embankments and flood walls, some up to 6 metres high, are the principal response to flood-risk management along its major rivers.

Emerging issues

While it is technically possible and potentially cost-effective to respond to the predicted increases in inland flood risk by simply raising the height of defences, it may not be desirable or sensible to do so. Factors such as cost-effectiveness, if the economic value of flood damage falls, the ‘escalator effect’, stakeholder attitudes and morphological effects could limit the sustainability of raising defences.

More sustainable approaches may involve relocation of flood defences to allow river and floodplain restoration in certain areas, and the integration of flood-defence measures with complementary structural and non-structural measures.

Response Group A22

Coastal Defences

Response theme	River and Coastal Engineering
Element of flood risk affected	Pathway

Definition

Coastal Defences are structures or features that prevent water from entering a defined area or limit the action of coastal erosion.

To fulfil their purpose, coastal defences must be high enough to prevent water flowing over their crest and of a design that limits the amount of wave overtopping.

Measures in the Coastal Defences response group

- Flood embankments or dikes.
- Seawalls.
- Revetments.
- Demountable flood walls.
- Tidal barriers.
- Beaches.

Function and efficacy

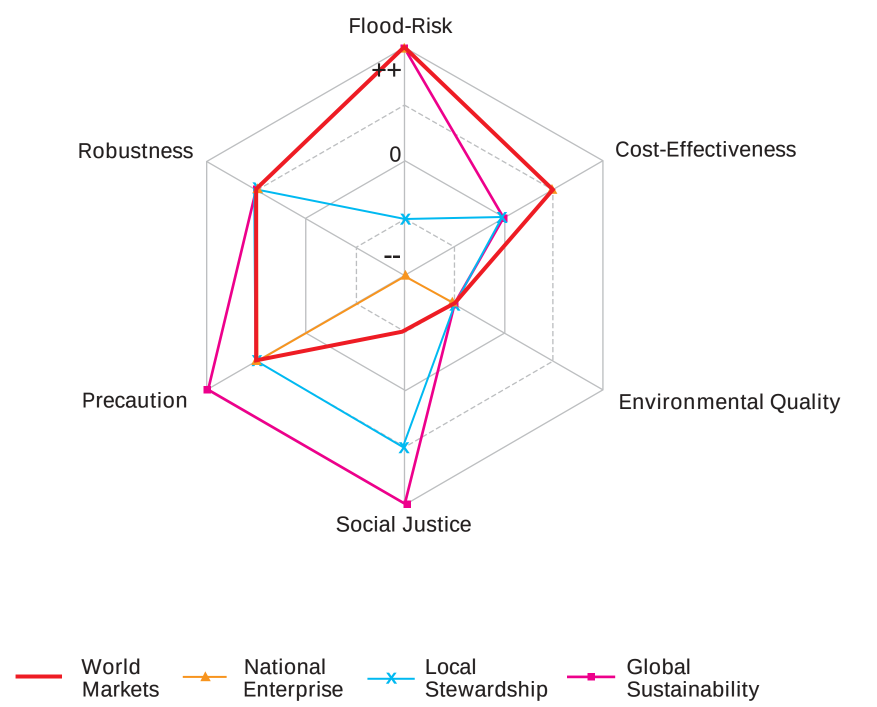
Barriers operate by reducing the probability of flooding or erosion, usually to some specified standard of protection. This standard can vary according to the type of asset they protect. However, protection structures need to be provide a uniform defence to a given area to avoid the defence system failing at ‘weak points’. All defences of this type have a finite design life, typically 20 to 50 years. This type of structure can fail if excess water overflows or overtops the defences, through breaching, or undermining of the toe through loss of the sediment forming the foreshore/beach. Barriers, like all structures, require periodic maintenance and repair to keep them operating as designed.

Governance and sustainability

The Environment Agency is responsible for reducing the risk of tidal flooding in England and Wales and typically governs the construction of embankments and other barriers in estuarine locations and along sections of low-lying coast. Local maritime authorities are responsible for protection against coastal erosion, typically, although not exclusively, along higher areas of open coast, including sea cliffs. These responsibilities not only involve the design, construction, operation and maintenance of coastal defence schemes, but also the regulation of schemes proposed by other operators – such as Network Rail and British Energy – or private owners through the land-use planning and development-control system.

Most barriers have a relatively short and certainly finite life and provide an immediate and medium-term solution that may or may not be sustainable over the longer term. Barriers are likely to have a continuing role in each of the future scenarios, albeit to a lesser or greater extent, dependent on the precise balance of economic, social and environmental factors within each scenario.

Coastal Defences



The spider diagram illustrates the scoring against a number of metrics. The results suggest that for all future scenarios, physical barriers are likely to provide a robust and cost-effective means of reducing flood risk. The degree of precaution and in particular the social justice afforded by this approach is seen to be highly variable under the different scenarios, whereas the environmental quality scored consistently low under all scenarios.

Costs and funding mechanisms

The costs of coastal defence schemes depend on the type, design and location of the barrier. For 'conventional' seawalls, revetments and embankments, costs can generally be reasonably well defined in terms of costs per metre run.

While structure costs vary very approximately with the square of their height, the exposure of the structure can have a much more dramatic influence on costs. Hence an embankment behind saltmarshes will typically cost an order of magnitude less per unit length than a structure on the open coast.

Examples from around the world highlight the fact that physical barriers remain an option even in the most extreme circumstances – it is usually feasible to put in some form of engineered structure. Whether or not this is economical, however, depends entirely on the level of assets to be protected. Given the change forecast over the next 100 years, the continued use of physical barriers is likely to remain a feasible option for most sites.

Funding is presently largely co-ordinated through grants from central government that cover a percentage of the capital costs, with the remainder being met by the relevant Environment Agency Flood Defence Committee or local authority council. Other operators, developers or private owners can fully fund barrier responses that obtain the necessary planning consents and approvals in line with existing planning guidance and legislation. Physical barriers also require recurrent funding for maintenance, usually at a rate of about 3% of the capital cost per annum. Maintenance costs for movable barriers are typically greater than those for fixed structures, at around 5-10%.

Interactions

The main interaction for this response group is likely to be with the prevailing coast/estuary processes which have the potential to alter the morphology not only in the immediate vicinity of the scheme but also further afield. Thus, coastal barriers can alter the form of the beach, cause downdrift erosion and cut-off the supply from eroding cliffs. Within estuaries the effect can be local or over the whole estuary, depending on the extent to which the structures alter the tidal characteristics. Whether this is seen as positive or negative is highly dependent on the prevailing social values.

Case example

There are many examples of coastal defences, such as the embankments around many estuaries, the Hull and Thames Barriers, groynes and seawalls along many developed sections of coast.

The Thames Barrier became operational in 1982. It is designed to prevent extremely large surge events (up to 1 in 1000 year return period) that build in the North Sea from propagating up the Thames and flooding London. Inevitably, this type of structure has a finite life and planning is already underway to establish how best to meet future needs.

Emerging issues

The use of physical barriers is likely to play a part in reducing flooding and coastal erosion risks under all four future scenarios. It is certainly the case that if no other response was adopted, then continuing to provide barriers as a form of defence is likely to remain feasible from both an engineering and cost perspective. The indicative costs of simply raising the defences everywhere on the coast are of the order of £8-9 billion and do not appear to be overly sensitive to any given scenario.

The other issue that emerges from an examination of the existing protection measures around the coast, is the extent of defences that exist to protect infrastructure that runs along the coast, such as roads, railways, pipelines, etc. If these could be relocated landward, it would significantly reduce the need for substantial lengths of defence. This is addressed further as part of the realignment response under the response group A23 Realignment of Coastal Defences.

Response Group A23

Realignment of Coastal Defences

Response theme	River and Coastal Engineering
Element of flood risk affected	Pathway

Definition

Realignment of Coastal Defences entails shifting defence infrastructure landward to provide a wider and more resilient foreshore that can act as a natural buffer zone against flooding or erosion.

This response could seldom be implemented in isolation. Implicit in the underlying rethink is the fact that considerable existing infrastructure drives the need for protection of long stretches of coast that would have to be relocated inland as part of schemes involving major realignment of flood and coastal defences.

Measures in the response group Realignment of Coastal Defences

- Managed retreat to high ground.
- Managed realignment of existing defences to a landward location.
- Rolling back natural features such as gravel barriers or dunes to a landward location.
- Relocating existing shoreline and hinterland infrastructure to landward locations.
- Planned abandonment – see also the response group Abandonment of Coastal Defences, for undesired/unplanned abandonment.

Function and efficacy

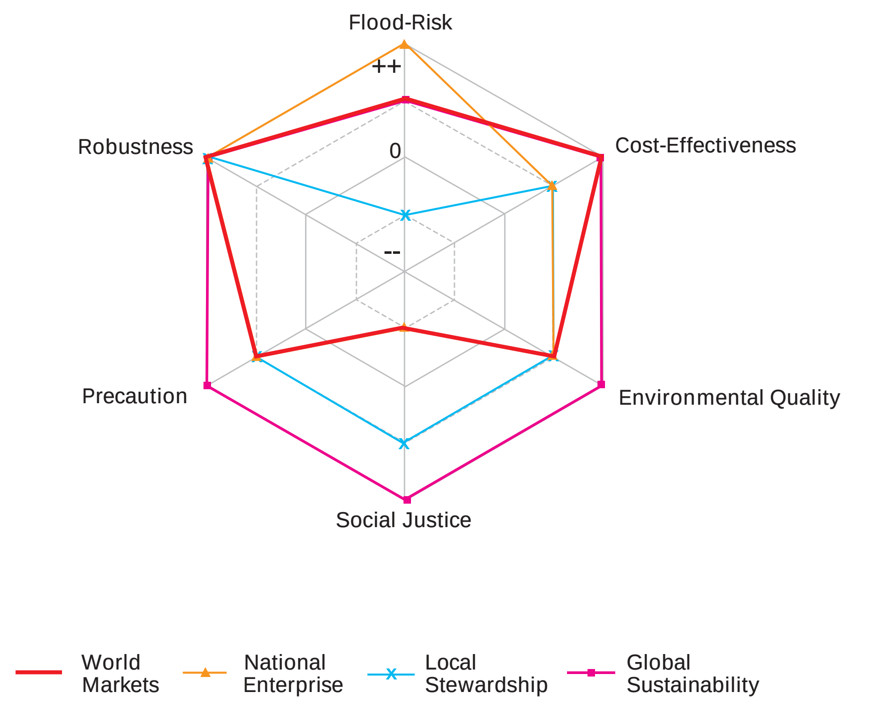
Removal of existing infrastructure from flood or erosion risk zones is a wholly effective way of separating the receptors of flooding from the sources of flood risk, although its implementation has clear logistical challenges.

Removing or realigning defences or rolling back natural features creates a wider intertidal area. This can be used for the attenuation of wave and tidal energy, thereby reducing risk to adjacent hinterland, or for the storage of floodwaters, thereby reducing risk within the wider physical system.

Governance and sustainability

At present, realignment schemes are predominantly undertaken by the Environment Agency. Local authorities can consider this option within coastal towns but would need to be able to plan retreat and roll back over a long timescale for the economic and environmental benefits to balance the costs – current planning horizons are too short. It is likely that the Highways Agency and the Strategic Rail Authority, together with future owners of roads and railways, may have major roles to play in implementing responses that involve realignment of coastal defences, as relocating linear infrastructure could only occur within the long-term cycle of expenditure planning and infrastructure renewal.

Realignment of Coastal Defences



In terms of sustainability, a key issue is that this response enables the maintenance or restoration of the natural dynamics of coastal and estuarine systems, providing a longer-term functional sustainability, but its social and economic acceptability is much more variable. Consequently, this response depends on the balance between economic, social and environmental drivers under different future scenarios.

The spider diagram illustrates the scoring against a number of metrics. This response is seen to score well under all scenarios. However, the option is perceived to have a low level of social justice under the more capitalist scenarios represented by World Markets and National Enterprise. In contrast, it may offer a much reduced level of flood-risk management under the Local Stewardship scenario.

Costs and funding mechanisms

A wide range of bodies, from both the public and private sectors, already fund managed realignment. For the realignment of infrastructure, there may be scope for use of Public Private Partnerships, but much of the funding is likely to have to be public. There is a need for a long-term perspective when assessing costs to demonstrate how the large short-term costs associated with moving infrastructure, for example, can be offset by the longer-term cost savings associated with removing the need for defences or structural modifications.

Interactions

This response interacts with existing land use behind the defences. If agricultural demand were to change then the importance of these currently protected areas may also change. Conversely, more extensive intertidal habitats will increase the fauna, bird feeding and nursery areas for fish. In extreme, some elements of the communications network could be abandoned, with implications for local communities and the movement of commodities.

Case example

An experimental managed realignment scheme was implemented at Tollesbury over 10 years ago. This has provided valuable information to advance the science and engineering of such schemes. Since then there have been numerous schemes around the country, particularly on the east coast.

One of the most recent schemes is on the Humber at Paul Holme Strays. This created some 70 hectares of managed intertidal habitat to offset the losses caused by coastal squeeze – the loss of intertidal land due to the existing flood defences preventing the saltmarsh and mudflat from migrating landwards naturally under the influence of sea-level rise. A new embankment has been built landward and the original defences have recently been breached.

Emerging issues

There is a conflict between the potential need to retain agricultural land – or use the land to meet local needs – and the potential to implement managed realignment. The need to limit the extent of coastal squeeze, where the width of the intertidal zone is reduced as sea levels rise, by moving some of the defences landward, is becoming acute, particularly in our estuaries. The desire to retain a good range of intertidal habitats is likely to continue to be one of the key drivers behind the policy of managed realignment.

Realignment of infrastructure, such as roads and railways, could substantially reduce the extent of coastal defences, but funding mechanisms are currently difficult to envisage, except possibly under the Global Sustainability scenario. This is because this response is desirable for sustainability and environmental reasons but is unlikely to be economical unless the particular infrastructure is due to be replaced in any event.

Response Group A24

Abandonment of Coastal Defences

Response theme	River and Coastal Engineering
Element of flood risk affected	Pathway

Definition

Abandonment of flood defences is a form of realignment – it involves a conscious management decision not to maintain existing defences. For example, a storm can create a natural breach and financial constraints may mean that existing defences are not maintained or repaired to the desired standard.

Measures in the group Abandonment of Coastal Defences:

- Management decision not to maintain existing defences.
- Desire to maintain defences/repair breaches, but inability to do so due to financial or other constraints.

Function and efficacy

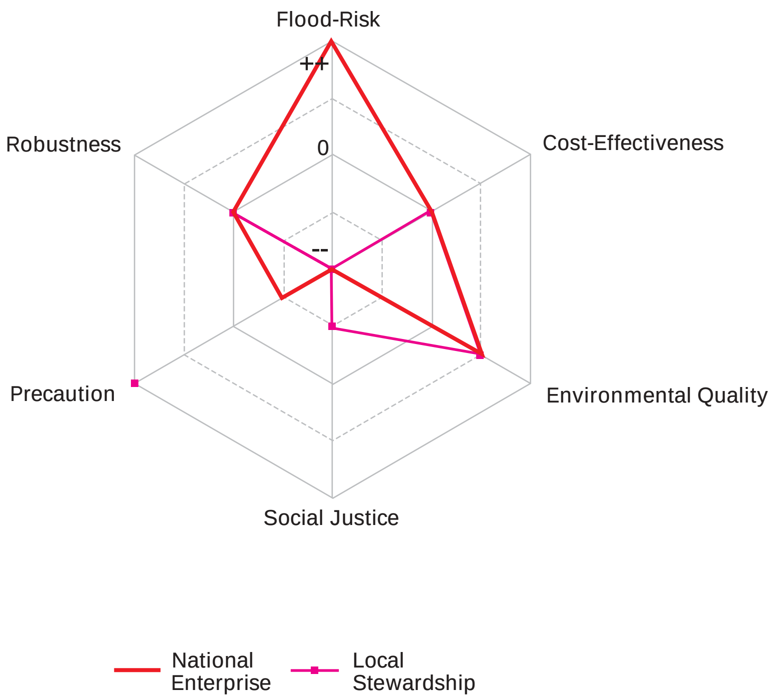
A key difference between managed realignment and abandonment of defence maintenance is that ultimately the latter is an unmanaged process. Under some circumstances, this could result in flooding or erosion, with severe effects on existing land uses or infrastructure and could present an increased risk to human life.

Governance and sustainability

Operating authorities such as the Environment Agency and local maritime authorities, and to a lesser extent private owners, have responsibility for maintenance of flood and coastal defences. They may decide to abandon maintenance activities, primarily for financial reasons.

Rather than being a response in itself that requires an assessment of sustainability, in a sense abandonment demonstrates the unsustainability of other responses under different future scenarios. For example, under the scenarios National Enterprise and Local Stewardship, maintenance of barrier responses may be unsustainable, because there is limited funding available to maintain them to the desired standard. Abandonment then becomes a default situation, rather than a planned response.

Abandonment of Coastal Defences



The spider diagram illustrates the scoring against a number of metrics. The option Abandonment of Coastal Defences was considered to apply in only two of the scenarios and hence the diagram shows only two sets of results. It is evident that this is generally a neutral or negative response, but it does give rise to some environmental benefits and, under the National Enterprise scenario, does help to ameliorate flood risk.

Costs and funding mechanisms

In some cases, abandonment may be a no-cost option, but most cases are likely to involve some costs, for example, relating to ensuring that remaining sections of defences do not present a health and safety hazard to shoreline users, such as signage, fencing off breached areas and so on.

Interactions

Abandonment has a major interaction with the natural physical processes, existing land uses and infrastructure and, potentially, adjacent shorelines. In many situations, it also represents a consequence of non-implementation of a desired response – for example, inability to maintain existing barrier-type defences due to financial constraints.

Case example

There are numerous small-scale examples of abandonment of lengths of defences. Following the infamous storm surges of 1953, there were so many breaches of defences that not all could be repaired. There are examples in the Essex and Suffolk estuaries, in particular, of abandoned flood embankments, resulting in the restoration of backing land to intertidal zones.

Emerging issues

The need to include this option arose when considering the likely opportunities to implement managed realignment. It was realised that under the scenarios National Enterprise and Local Stewardship, abandonment was a probable outcome in cases where there was limited funding so that the ability to maintain and rebuild existing defences was constrained.

Response Group A25

Reduce Coastal Energy

Response theme	River and Coastal Engineering
Element of flood risk affected	Source

Definition

Reduce Coastal Energy involves modulators to extract energy from waves and currents, so that less energy reaches the shoreline.

Measures in the group Reduce Coastal Energy:

- Foreshore recharge to improve dissipation properties of beaches or intertidal flats.
- Submerged reefs or 'baffle mats' to attenuate energy.
- Offshore breakwaters or fishtail groynes to block or divert energy.
- Energy converters.

Function and efficacy

Energy modulation can be achieved through the following approaches:

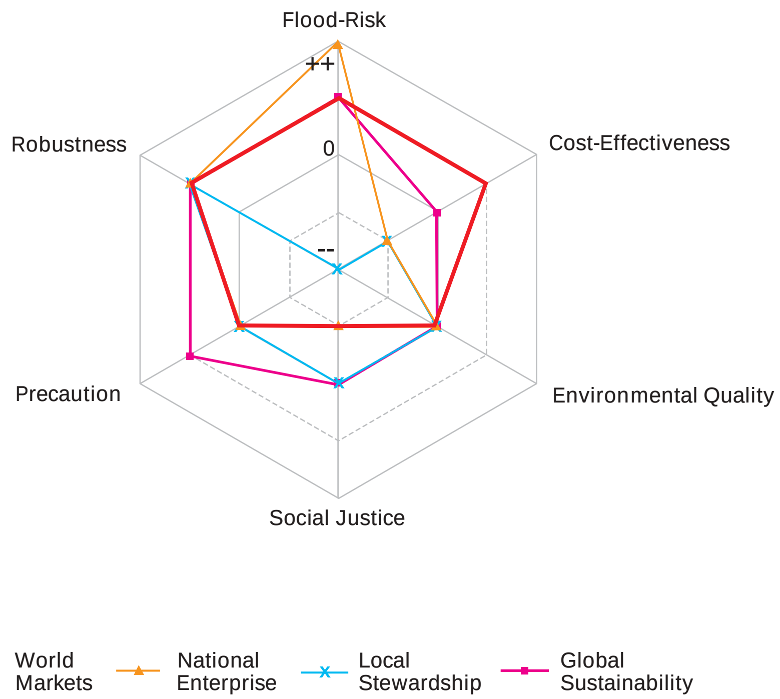
- Through the dissipating effects of the surface across which the energy propagates.
- Through dissipation effects caused by physically blocking or modifying the incoming energy at some distance seaward of the shoreline.
- By extracting and harnessing energy from waves and tides.

Enhanced energy dissipation across the intertidal surface can be achieved through changing the surface roughness, reflection or percolation properties of the intertidal zone. These effects can be through natural or quasi-natural means, such as through the introduction or restoration of saltmarsh vegetation to increase surface roughness, or through the recharge of beaches using shingle. Artificial means can also be used, including laying mats with baffles in the intertidal or near-shore sub-tidal zone.

Physically blocking or modifying incoming wave energy can be achieved through various techniques. Offshore breakwaters can reduce wave energy through reflection, percolation and diffraction through the gaps. Offshore tables mounted on piles or submerged offshore reefs can induce waves to break further offshore. Fishtail groynes can divert tidal flows away from the shoreline.

Existing energy extraction techniques include tidal turbines, wave devices, tidal impoundment schemes and tidal barrages that harness the energy to generate power and, in so doing, reduce the amount of tidal or wave energy on their shoreward side. Such devices and structures are presently being developed primarily to generate renewable energy, but there is an opportunity to combine their use with schemes for flood and coastal defence.

Reduce Coastal Energy



Governance and sustainability

For schemes that dissipate wave and tidal energy for flood and coastal defence, the Environment Agency and local authorities have principal interests, although some private owners can implement their own schemes if they obtain appropriate planning consents.

Private utilities and entrepreneurial developers are likely to be the lead organisations for energy extraction schemes. The Crown Estate has interests in the seabed below Mean Low Water: many energy modulation schemes will necessarily involve seaward consideration to beyond this limit.

This response can be used where there is a desire to maintain the shoreline and coastal assets in their present locations, enabling such activities to be sustained. However, the key sustainability benefit would lie with schemes that provide a flood and coastal defence function in combination with generating energy, hence contributing to reductions in emissions of carbon dioxide.

The spider diagram illustrates the scoring against several metrics. While the option is relatively neutral in terms of the environment and social justice across all of the scenarios, it is unlikely to be cost effective under the scenarios National Enterprise and Local Stewardship. It is likely to increase flood risks under Local Stewardship.

Costs and funding mechanisms

Public bodies, such as the Environment Agency and maritime local authorities, already fund schemes for improved energy dissipation. Typically, these schemes can range from the order of £100,000 to £10,000,000. The opportunity to use energy extraction devices both to reduce exposure to flood and to generate renewable energy could promote a Public Private Partnership – sharing funding, and possibly sharing of rewards, leading to further investment – between flood and coastal defence authorities and renewable energy developers. The developing nature of the technology means that the cost of such activities is currently so high that it requires extensive backing in the form of R&D and trials.

Interactions

There are locations where the response group Reduce Coastal Energy could be implemented alone. However more often it would be implemented in conjunction with some form of coast and estuary barrier, such as a seawall along the shoreline. For example, an offshore reef might reduce the intensity of wave attack on a coastal embankment. It could also potentially be implemented alongside realignment of defences and/or in conjunction with more extensive morphological engineering as part of a large-scale, integrated engineering approach. In such an approach, energy dissipation might steer morphological evolution of coastal features to generate a more favourable coastal configuration with respect to fixed infrastructure.

Case example

There are numerous examples of beach replenishment, offshore breakwaters and fishtail groynes used for flood and coastal defence. But there are no known schemes in the UK for the combined purpose of flood and coastal defence and renewable energy production. However, feasibility studies are investigating the potential for a range of renewable approaches, such as wave, tidal current and wind energy and tidal impoundment schemes, to aid coast protection in Bridgwater Bay, Somerset.

Emerging issues

The incorporation of renewable energy opportunities within coastal defence schemes is beginning to be evaluated, but this is targeted at wholesale replacement rather than a partial contribution to overall defence. As the market for renewable energy matures, there may be more scope for partial combinations, where the energy device reduces the exposure of the coast but does not eliminate the need for defences.

Response Group A26

Coastal Morphological Protection

Response theme	River and Coastal Engineering
Element of flood risk affected	Pathway

Definition

Coastal and estuarine morphology can be 'engineered' so that natural features are developed, enhanced or re-created to provide increased protection to the shoreline.

Measures in the group Coastal Morphological Protection

- Saltmarsh, dune or gravel barrier management.
- Creation of new tidal inlets and associated spits or deltas.
- Engineering an embayed shoreline planform.

Function and efficacy

Morphological features provide a substantial and effective form of natural protection to the coast. Coastal features develop and evolve continually in response to changes in the coastal system, particularly relating to forcing conditions and sediment supply. Thus while the standard of protection provided by morphological features may vary in the short term, the longer-term resilience of the coastal system is maintained. Implicit in the use of morphological engineering is recognition of the need for the natural buffer zones to respond dynamically to changing conditions.

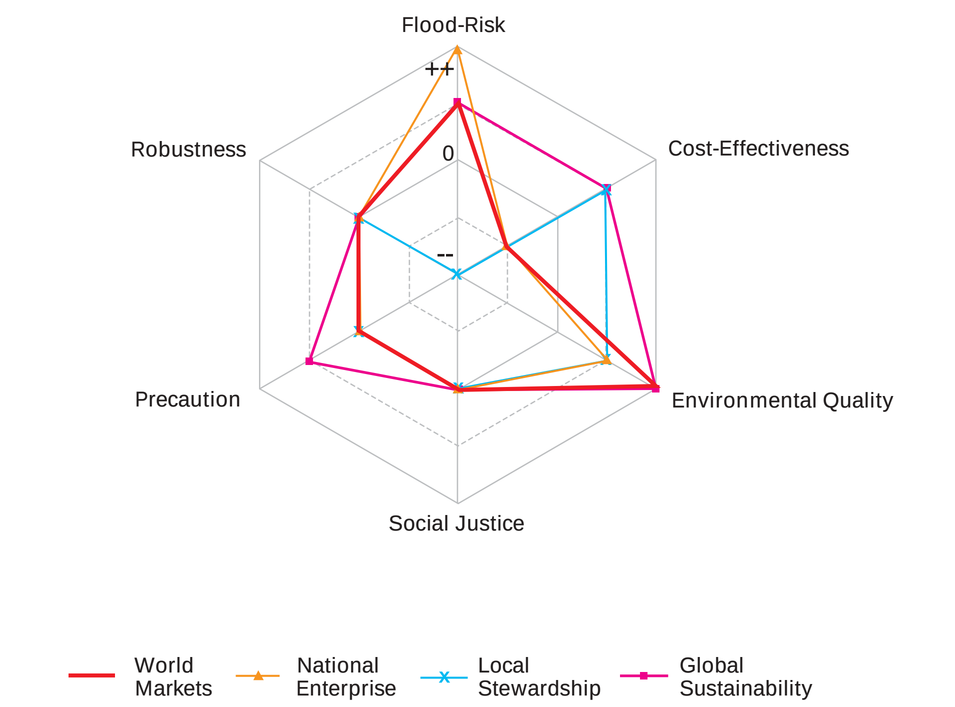
There is a time lag implicit to responses in this group. While engineering may prompt or trigger favourable morphological change, natural processes achieve the desired result. The timescale for significant morphological changes depends on the occurrence of suitable forcing events. Hence, there may be a considerable delay between the initiation of a flood- and coastal-defence scheme based on morphological engineering and achieving the intended standard of protection.

Governance and sustainability

The management of morphological features for flood and coastal defence is principally governed by the Environment Agency and local maritime authorities. Statutory bodies, such as English Nature, the Countryside Council for Wales and Scottish Natural Heritage, and non-statutory conservation bodies, such as the RSPB and National Trust, have advocated such approaches. These organisations manage some features specifically for nature conservation and earth-science heritage purposes.

This response group recognises that coastal systems are dynamic environments. They function and evolve in a self-regulating manner and consequently posses longer-term sustainability. However, under certain future scenarios short-term variations in morphology are often perceived as ‘problems’ in need of solutions, rather than natural events that will ultimately recover.

Morphological Coastal Protection



The spider diagram illustrates the scoring against a number of metrics. This is seen as a positive option in terms of flood-risk containment and environmental quality across most scenarios. It is, however, unlikely to be cost-effective under the scenarios National Enterprise and World Markets. Furthermore, under Local Stewardship there is a likelihood that it will have a negative effect on flood risk.

Costs and funding mechanisms

At present, the Environment Agency and local authorities have principal responsibility for these responses, as nature conservation bodies provide management purely for reasons of nature conservation and earth-science heritage. Morphological engineering schemes with benefits for flood and coastal defence should be eligible for grant funding from central government to cover part of their costs.

Capital costs could range from minimal amounts, for example, for the creation of a new tidal inlet by excavation of a breach and channel in an existing sea defence of through an existing natural landform, to larger sums where greater structural intervention is required, for example, the construction of hard points to engineer an, ultimately, stable embayment downdrift.

Interactions

The intention of measures in this response group is to interact with the wider coastal and estuarine processes to drive morphological responses. For example, the creation of a new tidal inlet would be designed to lead to the formation of ebb- and flood-tide deltas which would, in turn, shelter the shoreline along the neighbouring open coast and in the estuary mouth. However, these features would store sediment that may otherwise accumulate elsewhere in the natural system. This could suppress or reverse the growth of sedimentary features at those locations to good or ill effect. The flow created through the inlet could also intercept littoral sediment drift, potentially flushing shoreline sediments offshore. Clearly, while interaction is the aim of geomorphological engineering, a thorough and complete knowledge of the interaction and feedback loops so generated is an essential prerequisite.

Case example

A natural breach in 1996 of the gravel barrier at Porlock, Somerset was left unrepaired to determine whether morphological features would develop naturally. Spits and tidal deltas have begun to develop since formation of this new inlet. The benefits for flood defence are that there will no longer be a need to artificially maintain the shingle bank and it should, in time form a natural self-sustaining system.

Emerging issues

Morphological adaptation has the merit of delivering a high degree of long-term sustainability, but it can conflict with other interests and drivers in most scenarios. While this response is seen as highly desirable from many perspectives (see spider diagram), it often requires a cross-sectoral or cross-agency effort to promote such a scheme. Consequently, most efforts to date have been relatively small-scale. For this approach to make a significant contribution to the overall management of the coast and reduce the need to provide hard defences, some larger-scale initiatives will need to be promoted.

Responses to coastal erosion

Definition

A large proportion of the coastline and estuaries of Great Britain that would naturally be eroding is currently protected by engineered coastal defences. Long-term strategic approaches are required to avoid environmental degradation as well as the excessive financial commitment associated with heavily defended coasts, whilst at the same time, sustaining coastal economies, communities and cultural heritage.

Future coastal erosion

Investigations conducted during the first phase of the Foresight Flood and Coastal Defence project suggest that coastal erosion will increase substantially compared to present erosion rates under all future scenarios. It follows that approaches to the management of coastal erosion that are effective, economically justifiable and sustainable will be required throughout the remainder of the 21st Century.

Coastal erosion and flooding are often interlinked hazards, so erosion management is often a fundamental element in schemes that are primarily a response to flood risk, such as the well-known recent schemes at Hurst Spit, Hampshire, Hayling Island in Hampshire, Pevensey in East Sussex, Sea Palling in Norfolk, and Skegness and its environs in Lincolnshire.

In such situations, the summary descriptions of responses to coastal flooding (see previous sections of this Appendix) already cover defences, measures and policies intended to deal with the combine risk of coastal erosion and flooding. This section deals with responses where coastal erosion is the primary problem.

This situation will occur where the land behind the coast remains above flood levels but is susceptible to erosion. It includes retreat of ‘soft’ cliffs, which are mainly along the east coast of England and south coasts of England and Wales, and extensive coastal sand-dune systems, which are in many locations including, for example, the coasts of Lancashire and Lincolnshire. Erosion of beaches backed by ‘hard’ cliffs is also likely to worsen with important implications for tourist beaches at their base. However, it is of less concern to coastal defence, as any resulting cliff-top retreat is likely to be minor. Lastly, the Futurecoast Project identified a few sites in England and Wales where erosion might lead to major coastal reorientation and geomorphological change: such as Chesil Beach in Dorset, the Selsey Peninsula in West Sussex and the Sea Palling area of Norfolk.

Responses to coastal erosion

Coastal erosion is the physical removal of erodible coastal materials both above and below high water. It is intrinsically a natural process due to gradients in sediment transport, driven by marine processes including the action of waves, tides and currents, as well as sea-level rise.

Changes in sediment supply are also important. Anthropogenic sediment starvation due to coastal protection has exacerbated coastal erosion in many locations around the UK. In general terms, possible responses to coastal erosion fall into three categories:

- Preventing further erosion by hardening the shoreline to increase its erosion resistance, or reducing the intensity of the driving forces.
- Replacing eroded material.
- Allowing the coastline to erode and adjust to the driving forces while managing the impacts on coastal assets and populations (see Table A4).

In practice, schemes may employ measures from multiple categories in combination.

In the UK, responses to coastal erosion have historically concentrated on schemes designed to prevent local-scale erosion using sea walls, revetments, breakwaters and groynes. However, recently the scale of analysis has become broader and the other options in Table A.4 are being considered and increasingly being selected. For example, beach recharge and recycling and allowing erosion are increasingly applied, as is illustrated by beach nourishment at Bournemouth and prohibition on planning permission or development along eroding cliff-tops on the Isle of Sheppey and in north Norfolk.

Broader-scale approaches are favoured by shoreline management planning based on sediment cells and sub-cells. Such broad-scale analyses reveal the wider impacts and 'costs' of stopping erosion at one location in a connected coastal system, promoting more sustainable solutions.

As the areal extent of coastal zones at risk of erosion are much smaller and better defined than those at risk of flooding, managing erosion is likely to become an increasingly attractive option. Adaptive management, with the aim of allowing the coastline to adjust to the forcing drivers of erosion, may become widespread. Where conventional defences have proven ineffective or uneconomical, abandonment may have the same outcome, albeit in a less managed fashion. For example, cliff defences have been abandoned at some locations in the past few years, most notably at Happisburgh in Norfolk.

Table A4 **Categories of erosion response**

General Options	Structural Interventions, Measures, and Policies	Advantages	Disadvantages
Preventing erosion	Sea walls, revetments, geotechnical cliff stabilisation, breakwaters, groynes	Well-established approach, with detailed design guidance available. Proven to be locally effective.	Generates wider consequences within coastal cell and region, particularly through sediment starvation downdrift. Life of defences limited, especially by foreshore steepening.
	Offshore structures	Proven to be effective, especially in areas of low tidal range. Less visually intrusive than shoreline defences.	Limited experience and design guidance. Liable to produce unexpected outcomes (e.g. Sea Palling, Norfolk). Structure design life unknown.
	Wind and wave energy extraction	Treats the causes of erosion direct by reducing intensity of erosion drivers. May generate useful, renewable energy.	Limited experience, no general design guidance, and long-term performance is unproven.
	Artificial headlands	Extent of construction, volume of material and environmental impacts reduced as only point defences required.	Limited experience, no general design guidance. Uncertain magnitude and rate of erosion between headlands (see 'Allowing erosion' below). No long-term proof of concept yet available.
Replacing eroded sediment	Beach recharge and recycling	Counters direct effect of erosion and restores beach resource. Visually appealing. Sympathetic to natural processes, provided appropriate sediment used.	Sometimes difficult to find suitable sources. May become more difficult in future as Holocene sediment sources become depleted, and environmental concerns about seabed impacts of extraction increase. Repeated recharge required.
Allowing erosion	Building setbacks, land use planning, managed retreat, coastal rollback, abandonment	Does not require intervention in natural coastal systems, sediment supply downdrift continued or restored. Allows coastline to adjust to forcing drivers.	Loss of coastal land including all assets in eroded area. Landowner opposition, lack of public understanding. Requires consent among multiple stakeholders.

This full-scale experiment raised important questions about shoreline response to defence removal following many years of a 'hold the line' approach. Initial cliff retreat following abandonment was dramatic, and the observed net change appears to exceed the net change predicted if 'natural' retreat rates (measured before protection) had continued to the present. However, the rate of retreat now appears to be slowing towards the much lower rates observed prior to this coast being defended, about a metre a year. This suggests that after a rapid period of adjustment, the coastline is increasingly able to accommodate the forcing drivers. However, before widespread adoption of such responses could be recommended, we need much better understanding of coastal adjustment and evolution at the local to sub-cell and cell scales.

Potential for application under each scenario

The four Foresight Futures would present different opportunities and constraints to application of the various responses to coastal erosion.

World Markets

Under World Markets, protection of coastal land and assets will be driven primarily by economic analyses of the alternatives. The extent and intensity of increases in the forcing drivers under this high-emissions scenario will increase erosion at many locations, and erosion will continue to be prevented only where the economic case is clear. Hence renewal of existing coastal defences in front of developments and urban areas is expected and land with particular value for tourism and recreation may be protected, for example, high cliffs with coastal vistas. Siting new developments in coastal areas at risk from erosion is likely, given weak controls on land use, leading to demands for increased coastal protection, combined, where appropriate, with beach recharge and recycling.

Due to these overall demands and high economic growth, this Future scenario would prevent erosion more than the other scenarios. Therefore, the coast would probably experience much greater sediment starvation than today. If beaches are to be maintained, this would require extensive beach recharge and recycling, mainly from external sources, offshore, for example, with high costs. Tourism and recreation benefits will probably justify such investment, but on a piecemeal basis with the promoters of such schemes using engineering structures to retain the sediment in specific locations.

National Enterprise

Under National Enterprise there will also be urban development in coastal areas, together with marked expansion of tourism and recreation pressures due to reduced access to overseas coastal destinations, especially in North America, the Caribbean, the Far East and others. Under this medium-high emissions scenario, erosion would be both more intense and extensive than today. The result would be to favour local solutions aimed at stopping erosion at key sites. Given a chronic shortage of land for food production and urban expansion, there would be strong resistance to the loss of ‘valuable’ land to the sea in any form of managed retreat. However, relatively low economic growth and harsh economic realities might lead to unmanaged abandonment of defences in poorer areas, with little regard to social equity.

Local Stewardship

Under Local Stewardship, approaches based on anything but local solutions would be hampered by lack of strong regional planning and governance. This would make it difficult to implement integrated responses based on cells and sub-cells. At the same time, weak economic growth and lack of inward investment may make all but the major coastal settlements vulnerable to increased erosion risks due to abandonment of defences.

A shift to managing erosion in remaining settlements, particularly tourist resorts such as Bournemouth, is most likely under this future, as their economic base would significantly decline. If technically feasible, erosion responses based on extraction of wind and wave energy are likely to develop under this scenario, given the strong market for local development of renewable sources of energy.

Global Sustainability

Under Global Sustainability, erosional problems could still be significantly higher than today. However, the response to this problem would place great emphasis on sustainability of coastal management, favouring approaches based on a broad policy of managed retreat. National and local governance would promote land-use planning to avoid placing new coastal developments at risk of future erosion, and also to progressively relocate existing infrastructure, assets and even whole settlements along eroding coasts to safe inland locations.

Stakeholders would proactively plan this managed retreat using improving knowledge and models of coastal evolution from local to cell scales. However, it is likely that important seaside resorts such as Bournemouth, Brighton and Blackpool would have sufficient socioeconomic significance to continue to receive protection through a combination of engineering interventions to prevent erosion and beach recharge and recycling to counter foreshore steepening and maintain tourist beaches.

Beach recycling within sub-cells and cells would be particularly favoured where it is technically feasible. Exploitation of renewable energy sources such as wind and wave power may have some benefits in reducing erosion as part of multi-purpose schemes, but the economic viability of such schemes, as well as their environmental impacts, are likely to limit opportunities in a Global Sustainability future.

Conclusion

A wide range of approaches are available to counter coastal erosion. If these are developed and implemented appropriately they provide the basis for responding to the increases in erosion under all scenarios predicted in the Impacts phase. The widest distinctions in responses between the four Foresight Futures are likely to centre on issues of governance and sustainability with an emphasis on stopping erosion locally at key locations under World Markets and National Enterprise, and an emphasis on managed retreat under Global Sustainability and Local Stewardship. Some beach recharge and recycling is likely to feature in all cases, but with important differences in the balance between external sources and recycling within natural sediment systems.