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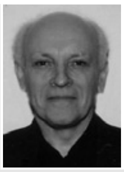




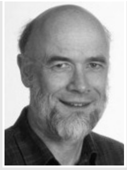

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Future flood risk management in the UK

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The Foresight Future Flooding project has analysed future flood risk in a scenario framework for the whole of the UK. The analysis predicts increasing flood risk unless current flood management policies and investment levels are changed, with up to a twentyfold increase in economic risk by the 2080s. The increase is attributable to a combination of climate change and increasing value of household, industrial and infrastructure assets. Potential responses are assessed in terms of the three pillars of sustainability: social, environmental and economic. The work described has formed much of the evidence base for the new government strategy for flood risk management in England, 'Making space for water'.

1. INTRODUCTION

This paper summarises some of the results from the Foresight Future Flooding project[1,2] in which scenario analysis was used to inform the strategic choices that should be made now if the increased flood risk that may occur in the future is to be addressed. The potential future drivers and impacts of flood risk are assessed for a simple baseline assumption under which the presentday approach to flood management and expenditure is held constant under the four Foresight Futures.[3] This might at first appear to be at odds with scenario analysis in that the approach to flood management might be expected to differ in each scenario, but provides a baseline against which the effectiveness of different flood management programmes can be judged. It also answers the simple question: what might happen to flood risk under different future scenarios if current flood risk management strategies continue unchanged?

The assessment of responses used a similar scenario framework, but in this case the approach to flood management and expenditure was allowed to vary in a way that was consistent with the storylines in each of the four scenarios.

2. THE ANALYSIS OF CHANGING FLOOD RISK

Change in the flooding system can be conceptualised using the pressure–state–impact–response (PSIR) model.[4,5] Typical variables describing the flooding system state might be extreme water levels, flood defence levels and numbers of properties in the floodplain, while any phenomenon that could change the time-averaged state of the flooding system is referred to as a 'driver'.

The flooding system can be further analysed using the source–pathway–receptor (SPR) model.[6] The SPR model is a well-established framework in environmental risk assessment which is based upon the causal linkage between the source of environmental hazard, the mechanism by which it is transmitted and the receptor, which suffers some impact. Thus in the case of flooding

(*a*) sources are the weather events or conditions that may result in flooding (e.g. heavy rainfall, rising sea level)
(*b*) pathways are the mechanisms that convey flood waters that originate as extreme weather events to places where they may impact upon receptors: these include fluvial flows, overland urban flows, coastal processes and failure of fluvial and sea defence structures or urban drainage systems
(*c*) receptors are the people, industries and built and natural environments that may be impacted upon by flooding.

The division between sources, pathways and receptors is not crisp and depends upon the context of the analysis. For example, an urban area can be both a pathway and a receptor.

2.1. Scenario analysis

The use of scenarios for policy analysis far into the future has been stimulated by the long-term uncertainties surrounding climate and socio-economic change. Flood risk analysis involves the use of two different types of scenario.

(*a*) Climate change projections are based on emissions scenarios. Climate change is the key driver relating to the flooding 'source' variables in the SPR model. The UKCIP02 climate scenarios for the UK[7] have been used.
(*b*) Socio-economic scenarios provide the context in which flood management policy and practice will be enacted and relate to the extent to which society may be impacted upon by flooding. The Foresight Futures socio-economic scenarios[8] are intended to suggest possible long-term futures, exploring alternative directions in which social, economic and technological changes may evolve over coming decades (Fig. 1). Under the Foresight Futures, one futures axis is concerned primarily with the scale of governance from global to local, while the other reflects values from those that are community orientated to individual consumerism.

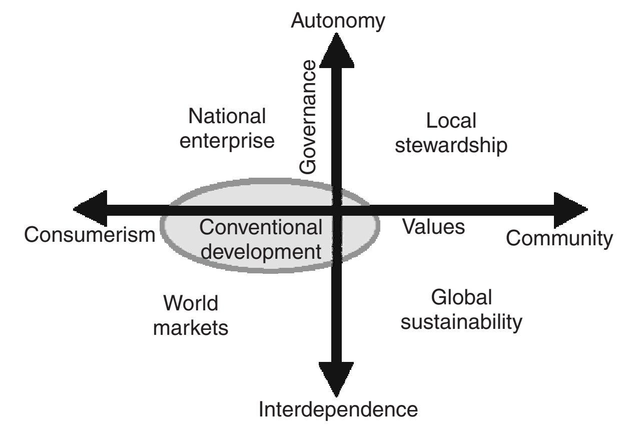

Fig. 1. Foresight Futures

There is no unique correspondence between the climate and societal scenarios, but that adopted for the purposes of the Future Flooding project is described in Table 1.

2.2. Quantitative flood risk assessment

Hall *et al.*[9] developed a quantitative model for assessment of flood risk from rivers and the sea that makes use of national databases of floodplain extent, flood defence asset type and condition and floodplain occupancy. The model uses information of river channel location, floodplain type and flood defence standard and condition to construct an estimate of the probability distribution of the depth of flooding on grid squares of up to 1 km × 1 km. This is then combined with census data and commercial databases of property and population location, together with relationships between flood depth and economic damage[10] to estimate flood risk at time points in the future. The results have been aggregated and are reported on a 10 km × 10 km grid. An estimate of the risk to lives, health and communities was obtained by analysing population density and census data indicating the potential vulnerability of different sectors of the community to flooding.[11]

The input data required by the risk assessment models do not correspond exactly to the information provided in either the climate change or socio-economic scenarios. It was therefore necessary to construct approximate relationships between the variables for which scenarios information was available and the variables required for flood risk analysis. While no claim is made to the uniqueness of these results, they do illustrate some striking contrasts between different scenarios of change and provide the basis for exploring responses to flood risk that are robust across plausible futures.

In the primary analysis of the drivers described here current flood defence alignment and levels of investment in maintenance and renewal were kept the same across all scenarios, as noted above. The results of the national-scale flood risk assessment are summarised in Table 2.

Greater climate change by the 2080s, together with increased floodplain occupancy, mean that the 'world markets' and 'national enterprise' scenarios will see more than a doubling of the number of people at high risk from flooding. In all scenarios other than the relatively low-growth 'local stewardship' scenario, annual economic flood damage is expected to increase considerably over the next century under the baseline flood defence assumption, owing to a combination of increased economic vulnerability and increasing flood frequency.

SRES[12]	UKCIP02	Foresight Futures 2020	Commentary
B1	Low emissions	Global sustainability	Medium–high growth, but low primary energy consumption. High emphasis on international action for environmental goals (e.g. greenhouse gas emissions control). Innovation of new and renewable energy sources
B2	Medium–low emissions	Local stewardship	Low growth. Low consumption. However, less effective international action. Low innovation
A2	Medium–high emissions	National enterprise	Medium–low growth, but with no action to limit emissions. Increasing and unregulated emissions from newly industrialised countries
A1FI	High emissions	World markets	Highest national and global growth. No action to limit emissions. Price of fossil fuels may drive development of alternatives in the long term

Table 1. Correspondence between UKCIP02 and Foresight Futures

	2002	World markets 2080s	National enterprise 2080s	Global sustainability 2080s	Local stewardship 2080s
Number of people within the indicative floodplain: millions	4·5	6·9	6·3	4·6	4·5
Number of people exposed to flooding (depth > 0 m) with a frequency > 1 : 75 years: millions	1·6	3·5	3·6	2·4	2·3
Expected annual economic damage (residential and commercial properties): £billion	1·0	23·8	15·7	4·8	1·6
Annual economic damage relative to GDP	0·10%	0·16%	0·32%	0·06%	0·06%

Table 2. Summary of baseline flood risk assessment for England and Wales

Change in the ratio of flood risk to per capita gross domestic product (GDP) provides an indication of how harmful (in economic terms) flooding will be to the UK. In the 'world markets' and 'national enterprise' scenarios flooding is expected to remove a greater proportion of national wealth than it currently does (and thus merit a greater investment to reduce risk). In the 'local stewardship' and 'global sustainability' scenarios flooding is predicted to remove a lesser proportion of national wealth since these scenarios will tend to be less vulnerable to flood damage and are expected to be subject to somewhat less climate change.

The spatial distribution of flood risk based on 2002 data is presented in Fig. 2. Highest economic risk is located in floodplain areas of high economic value, notably Greater London, despite very high standards of flood protection (Fig. 2(a)). The distribution of the increase in expected annual economic damage for the 'world markets' 2080s scenario, relative to 2002 is illustrated in Fig. 2(b). London and the Thames Estuary (owing to rapid urbanisation), the south-east coast (owing to rising relative sea levels) and urban areas of northern England (owing to high predicted increases in intense rainfall) stand out as areas where the growth in economic risk will be greatest.

2.3. Qualitative analysis of drivers

In order to provide an insight into the importance of individual drivers to the overall flood risk a ranking methodology, based on expert judgement, was employed. First, the drivers of changing flood risk were identified in a brainstorming session and clustered into a manageable number of driver sets (Table 3). The future change in each driver was described and where possible quantified using evidence from the literature. As in the quantitative flood risk analysis described above, flood management activities were assumed to remain constant and were excluded from this stage of the analysis.

Drivers were ranked according to an expert assessment of their impact on total flood risk in England and Wales at two specified times in the future (the 2050s and 2080s) under four scenarios. For the purposes of this analysis flood risk was defined as the product of the likelihood and consequences of flooding, using economic damage as a representative metric, with the impact of the driver expressed as a multiple of presentday risk. Thus a source driver, such as a climate-induced change in precipitation that increased the frequency of flooding on average by a factor of 1·9 nationally, would be scored as having a multiplier of 1·9 on flood risk. A driver that increased the quantity of receptor assets at risk in the floodplain by a factor of 1·6 on average nationally, would be scored as having a multiplier of 1·6 on flood risk. The scores for each driver are presented in Table 4 as multiples of presentday national flood risk.

Of the drivers of increased flood frequency, precipitation and relative sea level rise emerge as the most influential. Even though relative sea level rise influences only 22% of UK floodplains, the sensitivity of the frequency of flooding to changes in mean sea level means that sea level rise will be an important driver of flood risk nationally. Increasing relative sea levels interact with increasing storminess and continuing reduction in sediment volumes at the coast with the consequence that coastal waters become deeper, allowing larger waves to penetrate near the coast.

Fig. 2. Schematic maps showing: (a) annual average economic damage, 2002; and (b) increase in baseline annual average economic damage, 'world markets' scenario, 2080s compared with 2002

Driver set	Drivers	SPR classification	Explanation
Climate change	Precipitation	Source	Quantity, spatial distribution of rainfall and intensity
	Temperature	Source	Influence of temperature on runoff
Catchment runoff	Urbanisation	Pathway	Changes in the area of impermeable surfaces that increase runoff
	Rural land management	Pathway	Effects of rural land management practices that affect runoff generation
Fluvial processes	Environmental regulation	Pathway	Future legislation that may influence policy on flood management
	River morphology and sediment supply	Pathway	Changes in river morphology that influence flood storage and conveyance
	River vegetation and conveyance	Pathway	Vegetation and micro-morphology may affect flood conveyance
Coastal processes	Relative sea level	Source	Increases in mean sea level owing to climate change. Uplift/subsidence of land
	Waves	Source	Wave height and direction
	Surges	Source	Temporary increases in sea level above astronomic tide level, resulting from reduced atmospheric pressure and strong winds
	Coastal morphology and sediment supply	Pathway	Changes in the nearshore seabed, shoreline and estuaries. May be the consequence of anthropogenic activities such as dredging
Human behaviour	Stakeholder behaviour	Pathway	Behaviour of floodplain occupants before, during and after floods can significantly modify losses
	Social impacts	Receptor	Changes in social vulnerability to flooding, for example due to changes in health and fitness, equity and systems of social provision
Socio-economics	Buildings and contents	Receptor	Changes in the cost of flood damage to buildings and contents (e.g. owing to increasing wealth)
	Urban impacts	Receptor	Changes in the number and distribution of domestic, commercial and other buildings in floodplains
	Infrastructure impacts	Receptor	Changes in systems of communication, energy distribution and so on, and the extent to which society is dependent on these systems
	Agriculture impacts	Receptor	Changes in agriculture, including removal of agricultural land from production

Table 3. Summary of drivers of changing flood risk

Precipitation is the leading driver of increasing fluvial flood frequency, though the increase in rainfall frequency and intensity is not projected to be uniform across the UK. The influence of river morphology, vegetation and conveyance on flood risk is scenario-dependent. In 'global sustainability' and 'local stewardship' scenarios regulatory restrictions on channel maintenance and the wish to renaturalise rivers might reduce channel conveyance and hence increase flood frequency unless

	World markets		National enterprise		Local stewardship		Global sustainability	
Name	2050s	2080s	2050s	2080s	2050s	2080s	2050s	2080s
Climate change								
Precipitation	3	3·6	2·2	2·7	2·2	2·7	1·7	2·0
Temperature	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0
Catchment runoff								
Urbanisation	2·2	2·7	2·2	2·7	0·8	0·7	0·8	0·7
Rural land management	1·3	1·6	1·3	1·6	0·8	0·7	0·8	0·8
Fluvial processes								
Environmental regulation	1·0	1·0	1·0	1·0	1·4	2·8	2·0	4·0
River morphology and sediment supply	1·0	1·6	1·0	1·0	1·7	2·7	1·3	2·0
River vegetation and conveyance	1·0	1·2	1·0	1·2	1·0	1·6	1·7	3·6
Coastal processes								
Waves	1·7	5·1	1·3	2·8	1·0	1·9	1·0	1·5
Relative sea-level rise	2·4	9·6	2·6	4·0	1·7	5·1	1·7	3·7
Surges	2·4	9·6	1·7	4·6	1·3	2·8	1·0	1·5
Coastal morphology and sediment supply	2·4	5·1	2·0	3·7	1·7	2·4	1·3	1·5
Human behaviour								
Stakeholder behaviour	2·0	2·8	0·5	0·3	0·3	0·2	0·3	0·2
Social impacts	6·0	19·8	2·2	3·6	3·0	6·1	2·2	3·2
Socio-economics								
Buildings and contents	4·0	6·4	3·2	4·5	0·9	0·7	1·5	1·9
Urban impacts	1·6	2·0	1·4	1·6	1·0	1·0	1·1	1·1
Infrastructure impacts	4·7	9·0	3·2	5·2	0·9	0·7	1·5	1·5
Agricultural impacts	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0

Table 4. Expert assessments of driver impacts on national flood risk

alternative measures are taken. Rural land management and its consequent impact on runoff is predicted to have only a small impact on flood frequency.[13]

The influence of drivers that are a direct consequence of climate change differs across scenarios, depending on the climate projections, being most influential in the 'world markets' scenario, which corresponds to high greenhouse gas emissions.

The rising economic impacts of flooding are driven by increasing wealth and hence increasingly valuable contents and fabric of domestic and commercial buildings and increasingly vulnerable infrastructure. These increases are particularly marked in the 'world markets' scenario. However, as noted in the previous section, the increase in flood damage as a proportion of national wealth will be much smaller.

The increase in risk from new urbanisation is dramatic where the urbanisation takes place and practically irreversible. Flood impacts on infrastructure are recognised as an important driver in societies that will be increasingly dependent on these infrastructures, which, owing to increasing use of technology, may become increasingly vulnerable to flood damage.

Social vulnerability to flooding is expected to increase across all scenarios.

3. RESPONSES TO RISING FLOOD RISK

The assessment of responses used a similar scenario framework, but in this case the approach to flood management and expenditure was allowed to vary in a way that was consistent with the storylines in each of the four scenarios. The definition of a driver can be extended to encompass responses if they are considered to differ only in their susceptibility to our control, as illustrated in Fig. 3.

The possible range of responses to increasing flood risk is shown in Table 5. Some 80 individual responses were considered, but here only groups of responses are addressed.

3.1. Assessment of individual responses

The responses were first assessed and ranked in a similar way to the drivers, according to their effectiveness in reducing economic flood risk. The 12 most effective responses are shown in Table 6. The scaled impacts of each response group were then expressed as a multiplier (s) of the overall risk multiplier that was predicted under baseline assumption (given in the penultimate row of Table 2). The responses vary in their effectiveness under each scenario and more effective responses are available under some scenarios than others.

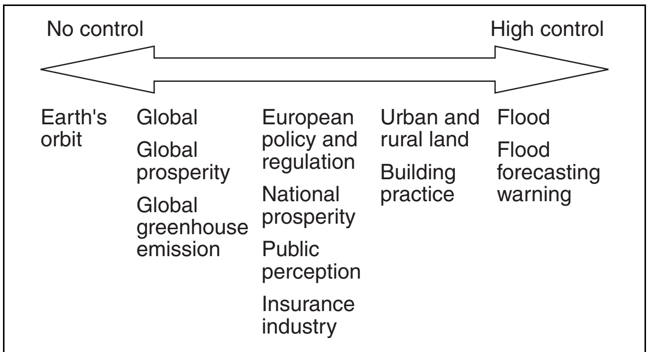

Fig. 3. The degree of control by government over different drivers of flood risk. Responses to flood risk lie towards the right-hand side

Response theme	Response groups
Managing the rural landscape	1. Rural infiltration 2. Catchment-wide storage 3. Rural conveyance
Managing the urban fabric	4. Urban storage 5. Urban infiltration 6. Urban conveyance
Managing flood events	7. Pre-event measures 8. Forecasting and warning 9. Flood-fighting actions 10. Collective damage avoidance actions 11. Individual damage avoidance actions
Managing flood losses	12. Land-use management 13. Floodproofing 14. Land-use planning 15. Building codes 16. Insurance, shared risk and compensation 17. Health and social measures
River and coastal engineering	*Fluvial defences* 18. River conveyance 19. Engineered flood storage 20. Flood water transfer 21. River defences *Coastal and estuarial defences* 22. Coastal defences 23. Realignment of coastal defences 24. Reduce wave energy 25. Coastal morphological protection

Table 5. Potential responses to future flood risks

Such a simple approach will not, however, suffice for a proper assessment of responses. Individual responses and groups of responses were therefore evaluated against a range of metrics relating to the three pillars of sustainability: environmental, social and economic. The metrics chosen were cost-effectiveness, social justice, environmental quality, flood risk reduction, precaution and robustness. The sustainability performance of response groups was scored on a simple six-point positive/neutral/negative scale for each metric. This allowed comparisons to be made across the scenarios and also permitted absolute evaluation based on the threshold of acceptability for each metric. The results of the sustainability analysis are summed up in terms of 'infractions' in Table 7: that is, the number of responses under each scenario that violated the minimum requirement for sustainability.

It is clear from this analysis that sustainability is, overall, closely related to scenario, with the two higher emission, consumer-oriented futures failing on many more metrics than the lower emission, community-centred scenarios. While no response scored highly in effectiveness and sustainability across all four scenarios, it is noteworthy that catchment-wide storage, land-use planning and coastal defence realignment potentially produce

Rank	World markets	National enterprise	Local stewardship	Global sustainability
1	River defences	River defences	Land-use planning and management	Land-use planning and management
2	Coastal defences	Coastal defences	Floodproofing buildings	Catchment-wide storage
3	Floodproofing buildings	Reduce coastal energy	Individual damage avoidance	River defences
4	Reduce coastal energy	Realign coastal defences	River defences	Coastal defences
5	Morphological coastal protection	Morphological coastal protection	Catchment-wide storage	Floodproofing buildings
6	Realign coastal defences	Coastal defence abandonment	Pre-event measures	Rural conveyance
7	Real-time event management	Floodproofing buildings	Real-time event management	Realign coastal defences
8	River conveyance	River conveyance	Engineered flood storage	Reduce coastal energy
9	Individual damage avoidance	Catchment-wide storage	Rural conveyance	Morphological coastal protection
10	Pre-event measures	Land-use planning and management	River conveyance	Engineered flood storage
11	Engineered flood storage	Engineered flood storage	Rural infiltration	Real-time event management
12	Land-use planning and management	Real-time event management	Manage urban runoff	Pre-event measures

■ Major reduction in flood risk ($S < 0{\cdot}7$)
■ Marked reduction in flood risk ($0{\cdot}7 \leqslant S < 0{\cdot}9$)
■ Moderate reduction in flood risk ($0{\cdot}9 \leqslant S < 1{\cdot}0$)

Table 6. The 12 most important responses to future flood risk, ranked by risk reduction (S, multiplier on baseline risk achieved by response under given scenario)

environmental benefits, reduce flood risk and have little or no sustainability penalties. These can therefore be considered to be reasonably robust to socio-economic and climatic change.

Engineering interventions that manipulate flooding pathways tend to perform poorly under some scenarios. Under 'world markets', for example, the two response groups capable of delivering major reductions in national flood risk (river defences, coastal defences) both fail on social justice and environmental quality. However, a response such as river defences is capable of providing a major reduction in flood risk while also meeting sustainability criteria when implemented as part of an integrated portfolio of measures under the 'global sustainability' scenario.

Sustainability, on the other hand, cannot be guaranteed through adoption of non-structural responses. Under the higher emissions/consumerist scenarios ('world markets' and 'national enterprise') responses such as land-use management and floodproofing fail to meet acceptable thresholds in social justice and/or precaution.

In summary, the effectiveness and sustainability of different flood management responses depend strongly on the manner in which they are implemented. The analysis adopted here suggests that 'global sustainability' and 'local stewardship' futures would support many more sustainable responses than would 'world markets' or 'national enterprise'. In practice, application of principles of social equity and precautionarity in the design and implementation of responses to flood risk would improve sustainability irrespective of the wider socio-economic scenario.

3.2. Effectiveness of integrated portfolios of responses

The authors' analysis is based on the construction of four portfolios to respond to future flood risk, drawn from the common menu of responses. These portfolios were designed to be internally consistent, and each is matched to one of the four socio-economic scenarios. Target levels of future flood risk were defined for each portfolio, reflecting the different values, expectations and wealth of the four future societies. In the case of 'world markets' and 'national enterprise', double the current Department for Environment, Food and Rural Affairs (DEFRA) targets were applied: under 'global sustainability' the present target levels were held and under 'local stewardship' they were allowed to fall to 75% of today's targets. The residual damages and resulting costs from a quantitative analysis of the portfolios are summarised in Table 8. Two important points emerge. First, risks can be greatly reduced by implementing a portfolio of responses. Second, in all scenarios except 'local stewardship', the benefits in terms of risk reduction clearly exceed the costs, even bearing in mind that the latter are lower limits. Costs are given in today's prices and do not include land purchase or the costs of non-structural responses.

Scenario	Cost-effectiveness	Environmental quality	Social justice	Precaution	Robustness
World markets	3	5	12	6	5
National enterprise	2	5	14	8	5
Local stewardship	1	2	2	5	5
Global sustainability	1	1	0	0	5

Table 7. Responses: numbers of sustainability infractions by scenario and metric

	Present day	World markets	National enterprise	Local stewardship	Global sustainability
Target standards of flood protection, relative to present day	1	2	2	0·75	1
Residual risks with integrated portfolio, EAD: £million/year		1 760	1 030	930	2 040
Risk reduction, EAD: £million/year		18 700	14 000	570	2 820
Flood management costs; England and Wales, fluvial and coastal; total costs: £million		75 600	77 200	22 100	22 400
Additional costs: £million/year		1 600	1 600	500	500

Table 8. Integrated portfolios of flood management—risk reduction expressed in terms of expected annual damages (EADs) and costs

3.3. Effectiveness of climate change control

The authors also quantified flood risks for a future scenario which combined the high economic growth of 'world markets' and low emissions of greenhouse gases. This showed that reducing emissions in a high-growth economy reduced annual average damages from £21 billion to £15 billion under the baseline flood management assumption. Thus, decoupling the drivers of climate change and socio-economics in this one case indicates that control of global emissions can have a stabilising effect on flood risk, reducing the damages by just over 25%. It does not reduce risk to current levels, but taken together with an integrated portfolio of other policies it offers an attractive combination of options.

4. SUSTAINABILITY OF THE PORTFOLIOS

In considering the sustainability of the response portfolios, it must be emphasised that the concept of sustainability is very different under the four scenarios. The critical differences lie in the mechanisms for achieving sustainability and the preconditions for them to work well.

In 'world markets' and 'global sustainability', the belief is that sustainability can be sought and achieved by 'top-down', large-scale strategic action (steered by the state in 'global sustainability', and driven by market mechanisms in 'world markets'), whereas 'national enterprise' and 'local stewardship' emphasise local-scale decision making, suggesting that sustainability would be constructed 'bottom-up' from many small-scale actions. The response measures analysed here range from those that require strategic vision and control (landscape-scale planning and land-use change in particular) to more locally tailored or organically evolving measures (floodproofing, damage avoidance, even abandonment). However, it is still vital to ensure that the different pieces of the puzzle do indeed add up to a coherent picture of sustainability in the more 'bottom-up' approach scenarios.

Finally, it should be emphasised that there will be a major need for engineering responses to meet the increased flood risk in all of the future worlds.

5. GOVERNANCE

The current study's analysis of the governance frameworks within each of the scenarios indicates that it is not only the choice of individual responses incorporated into the portfolios of flood management measures that is important, but also the governance environment in which they sit. Governance has traditionally been used as a synonym for 'government'—the forms and functions of the state, local, regional and central government. Nowadays it is increasingly used to refer more broadly to the multifarious ways in which the whole of society is steered. The governance framework in which flood risk management sits includes, for example, central government, local government, private utilities and the insurance industry.

A number of key points emerge from this analysis. First, governance (both governmental and non-governmental) needs to support the concept of a portfolio of responses to increasing flood risk and allow its integrated implementation. Consequently, strategies and choices for governance and responses need to be matched with the scale of future risks.

Second, investment will be needed for future flood and coastal management, to promote long-term solutions, appropriate standards and equitable outcomes. How this investment will be procured is scenario-dependent. Market mechanisms and incentives should be used under all scenarios to manage future risks, while recognising the central role of all levels of government.

6. STRATEGIC CHOICES FOR FUTURE FLOOD RISK MANAGEMENT

Choices will have to be made on a number of levels if future flood risk is to be well managed. On the whole, flood managers have to work within the economic, political and institutional constraints of the day. Yet within those constraints, the Government must decide on the risk of flooding it is prepared to accept. In summary, it can choose from a range of options.

(*a*) Maintain current flood policies and expenditure, accept reduced standards of flood protection and hence a substantial increase in flood risk, and live with the increase in expected annual economic damage.
(*b*) Reduce flood risk by the application of a portfolio of flood response measures to levels at or similar to the present.
(*c*) Reduce flood risk further, which may be difficult in economic and sustainability terms under some scenarios, but feasible under others.

If the first option is selected, significant increases in flood damages could be seen. The third option would require considerable additional investments in flood management. However, the analysis suggests that the economic benefits would be significantly greater than the costs. In the higher growth scenarios the increases would be less than the economic growth and so would be most easily affordable. Nevertheless, the challenge would remain to find the approach that is best for society and the environment.

While the second option—maintaining current risk levels—might seem reasonable, this is set against a trend in society which expects increasing standards of safety and risk reduction.

6.1. A route map for flood management

Having made a decision to reduce the increase in flood risk, how and when should responses be implemented, given the uncertainty in future flood risks? Three important dimensions emerge from this consideration.

6.1.1. Targeting responses: sustainability and robustness. Influencing where to build houses, factories and other infrastructure is a key tool in managing future flood risks. It is about avoiding building on areas at risk from flooding or, if building in areas at risk, ensuring that there is space to allow for river and coastal processes. This approach needs to be balanced against other economic, environmental and social needs, such as the demand for new housing. It also needs to take account of the benefits and disadvantages between, for example, building on brownfield sites, which tend to be on floodplains, and building on land outside floodplains, which may be greenfield locations of landscape or environmental value.

6.1.2. The time horizon of responses. Different measures have different lead times, some of which are very long. These need to be recognised in any long-term strategy. Land-use planning is an obvious example. Massive inertia in the built environment means that decisions taken now could take many decades to become fully effective. This will also affect decisions on whether to maintain flood defences in some areas as well as decisions on areas for new build. If an effective way forward is to use the realignment of defences, retreat or even abandonment of some areas, then the sooner long-term plans are in place, the easier it would be for those affected to divest assets with minimum negative impact.

6.1.3. Adaptable, reversible and irreversible responses. The uncertainty of the future is a major challenge in devising effective long-term flood management policies. It is important to decide how much flexibility is required to cope with an evolving future and to choose a portfolio of responses to achieve that. In this respect, reversible and adaptable measures would be the most robust against future uncertainties. Adaptability would include approaches such as setting aside areas in floodplains that may be used for flood storage if required, or building defences to cover the lower limits of expectations for changes in flood risk, but with the ability to upgrade if needed.

7. CONCLUSION

The Foresight study brought together 80 experts from a wide range of disciplines to study the risks of flooding and coastal erosion for the UK over long timescales. The study benefited from engagement with stakeholders from across Government and more broadly. It featured a novel use of scenarios and the first quantitative national-scale scenarios analysis. Many issues remain uncertain or unresolved—the work has identified those areas where further research could most usefully be performed. The project has provided the evidence base for the new government flood management strategy for England, highlighted in 'Making space for water'.[14,15] The choices are not easy, but this project has demonstrated how interdisciplinary science and technology can illuminate a difficult problem and play an important role in informing the development of government policies.

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