APPENDIX D. **ENDOGENOUS CHANGE ADAPTATION MEASURES**

Contents

Note: In support of the analysis presented in the Climate Change Risk Assessment (CCRA) Future Flooding report, the influence of each individual adaptation measure was quantified using a combination of evidence and peer reviewed expert judgement (detailed Sayers *et al.,* 2016: Appendix E). No consideration however was given to how their effectiveness may be different in more and less vulnerable neighbourhoods. The likely effectiveness of each individual adaptation measure set out in the CCRA report is therefore revisited here, and where necessary, modified to differentiate its implementation where appropriate.

D.1 Overview

A summary of the assumed effectiveness of each adaptation measure and its representation within the FFE is given in the following tables. A detailed discussion of the rationale, and supporting evidence, for the assumed effectiveness of each individual adaptation measure and how this may vary depending upon social vulnerability can be found in the sections that follow.

Table D.1-1 Summary of adaptation measures: Reducing the chance of flooding

	Epoch					
	All other neighbourhoods			20% most vulnerable (by NFVI)		
Individual Adaptation Measure or instrument	2020s	2050s	2080s	2020s	2050s	2080s
Reducing the chance of flooding						
Construction and maintenance of river and coastal defences						
in rural areas (> 50% rural)						
% reduction in standard avoid (a 1:50 standard defence today)	50%	50%	50%	10%	10%	10%
% reduction in standard avoid (a 1:100 standard defence today)	75%	75%	75%	60%	60%	60%
in urban areas (>=50% urban)						
% reduction in standard avoid (a 1:50 standard defence today)	75%	75%	75%	60%	60%	60%
% reduction in standard avoid (a 1:100 standard defence today)	100%	100%	100%	80%	80%	80%
Managed realignment at the coast						
% reduction in standard avoid (a 1:50 standard defence today)	1%	1%	1%	1%	1%	1%
% reduction in standard avoid (a 1:100 standard defence today)	0%	0%	0%	0%	0%	0%
Upland catchment management						
Influence on peak flows during frequent events (e.g. 10 year return period event)						
% reduction in peak flow (assuming 100% BMV land)	0%	-1%	-2%	0%	-1%	-2%
% reduction in peak flow (assuming 100% non-BMV land)	0%	-2%	-4%	0%	-2%	-4%
Influence on peak flows during less frequent events (e.g. 100 year return period event)						
Reduction in the % increase in peak flow (assuming 100% non-BMV land)	0%	-1%	-1%	0%	-1%	-1%
Reduction in the % increase in peak flow (assuming 100% BMV land)	0%	-1%	-2%	0%	-1%	-2%
Urban flood management						
Take up of SUDS						
Take up amongst new development	25%	25%	25%	25%	25%	25%
Take up amongst existing development	10%	10%	10%	0%	0%	0%
Implementation of surface water management activities (other than SUDS)						
% reducton in damages (flooded more freq. 1:30 years)	5%	5%	5%	5%	5%	5%
% reducton in damages (flooded less freq. 1:30 years)	0%	0%	0%	0%	0%	0%

BMV = Best and Most Versatile land

Table D.1-2 Summary of adaptation measures: Managing the chance of flooding

	Epoch					
	All other neighbourhoods			20% most vulnerable (by		
Individual Adaptation Measure or instrument	2020s	2050s	2080s	2020s	2050s	2080s
Managing exposure to flooding						
Spatial planning						
Proportion of new properties built in the floodplain: All areas	12%	12%	12%	14%	14%	14%
Coastal floodplains: % built in areas flooded more frequently than 1:75 years	5.9%	5.9%	5.9%	5.9%	5.9%	5.9%
Fluvial floodplains:% built in areas flooded more frequently than 1:75 years	15.0%	15.0%	15.0%	6.8%	6.8%	6.8%
Surface water areas: % built in areas flooded more frequently than 1:75 years	3.2%	3.2%	3.2%	3.9%	3.9%	3.9%

Table D.1-3 Summary of adaptation measures: Reducing vulnerability

	Epoch					
	All other neighbourhoods			20% most vulnerable (by		
Individual Adaptation Measure or instrument	Present Day and 2020s	2050s	2080s	Present Day and 2020s	2050s	2080s
Managing vulnerability of those exposed						
Receptor Level Protection Measures						
Off fluvial and coastal floodplain						
*Take-up as a proportion of **new** properties - All areas*	0%	0%	0%	0%	0%	0%
*Take-up as a proportion of **existing** properties - All areas*	0%	0%	0%	0%	0%	0%
On fluvial and coastal floodplain						
*Take-up as a proportion of **new** properties - All areas*	100%	100%	100%	100%	100%	100%
Take-up as a proportion of existing properties - High probability areas	5%	7%	10%	1%	1%	1%
Take-up as a proportion of existing properties - All other areas	0%	0%	0%	0%	0%	0%
Effectiveness in reducing damages						
Where implemented % successful in reducing damage	80%	80%	80%	80%	80%	80%
where successfully deployed % reduction in WAAD (1:10 year event)						
Coastal floodplain	40%	40%	40%	40%	40%	40%
Fluvial floodplains	100%	100%	100%	100%	100%	100%
Surface water	80%	80%	80%	80%	80%	80%
Forecasting, warning and community response						
Take up in coastal floodplains	75%	75%	75%	50%	50%	50%
Take up in fluvial floodplains	50%	50%	50%	25%	25%	25%
Take up in surface water areas	0%	0%	0%	0%	0%	0%
% reduction in WAAD value (given a 1:100 year event)	5%	6%	7%	3%	3%	3%
Insurance	All other neighbourhoods			Low household income (20%ile)		
Take-up by **home owners with no direct experience of flooding**						
High probability areas (flooded more frequently than 1:75 years						
Coastal floodplain	76%	76%	76%	45%	45%	45%
Fluvial floodplains	76%	76%	76%	45%	45%	45%
Surface water	60%	60%	60%	50%	50%	50%
Take-up by those in **rented accommodation with no direct experience of flooding**						
High probability areas (flooded more frequently than 1:75 years						
Coastal floodplain	76%	76%	76%	32%	32%	32%
Fluvial floodplains	76%	76%	76%	32%	32%	32%
Surface water	50%	50%	50%	20%	20%	20%

WAAD = Weighted Annual Average Damage

D.2 Reducing the chance of flooding

Reducing the chance of flooding involves the use of a wide variety of managed measures. These can be grouped into:

- Construction and maintenance of river and coastal defences;
- Catchment and shoreline management;
- Urban management.

The role of each within Flood Risk Management (FRM), together with any evidence for a difference in more and less vulnerable neighbourhoods, is discussed below.

D.2.1 Coastal and river flood defence infrastructure

a) Overview of role in FRM

Flood defences are the primary response to flooding across the UK and various studies confirm they are likely to continue to play a significant (but not sufficient) role in the future (e.g. Evans *et al*., 2004a, b; Sayers *et al*., 2015a). The majority of investment in FRM is directed towards the maintenance and improvement of defences. For example, the Environment Agency's Long Term Investment Scenarios (LTIS) (Environment Agency, 2014), are primarily based on the on-going provision of defence infrastructure, and the political response to the 2013/14 Winter floods (Defra, 2016) led to the allocation of new government funds for flood alleviation schemes. Similarly, a review of Shoreline Management Plans (SMPs) (England and Wales only) highlighted a policy of 'hold the line' in the majority of coastal areas (ASC, 2013).

In most cases, the availability of a government grant determines the likelihood that a flood protection scheme will go ahead. This is reliant on the submission of an acceptable business case (and therefore the capacity to write one), and the ability to compete with other demands on public funds. Despite the Flood Defence Grant-In-Aid (FDGiA) formula prioritising deprived areas in England and Wales (Defra, 2011), and the release of high-level statements that aim to prioritise the most vulnerable (as discussed in Chapter 4 of this study), there is some evidence to suggest that the most vulnerable neighbourhoods are less well protected than others. Analysis by England and Knox (2015) highlighted that almost half of the planned expenditure set out in the Environment Agency's Six Year Plan (2015-2021) has been allocated to local authorities with no neighbourhoods at significant Geographic Flood Disadvantage (GFD), (i.e. neighbourhoods that have both high exposure and high social vulnerability). Furthermore, only 2 per cent is going to local authorities with high levels of flood disadvantage across 40 per cent or more of their area. England and Knox also consider the balance of funding between rural and urban areas (given the costs of protection are higher in sparsely populated areas (CIWEM, 2015), and the emphasis on household protection within the FDGiA scoring). Their analysis shows that planned expenditure per household until 2021 is in predominantly urban areas (with 66 per cent of total allocation compared to 34 per cent in rural areas). This suggests that the formal protection afforded to rural properties may decrease relative to urban areas in the future.

b***) Representation of adaptation in the FFE***

The Future Flood Explorer (FFE) incorporates the performance of defences through two variables:

- The representative **Standard of Protection** (rSOP) provided to a Calculation Area: The degree of protection afforded by a flood defence (the so-called Standard of Protection, SOP), is typically expressed in terms of the return period (in years) of a storm event that would overtop the defence, assuming it remains structurally intact. The rSOP reflects the SOP of the defences associated with a given Calculation Area, and is expressed in terms of return period. rSOP is influenced by the construction and improvement of point defences, such as barriers and pumps, linear defences and also by climate change.

  Future changes in the rSOP are therefore determined through a two-step process (Figure D-1):

  1. The change in rSOP under a given climate future and the assumption of no adaptation is calculated; for example, if the crest of a defence remains at the same level the rSOP may fall from say 1:100 to 1:10 year return period due to climate change.

  2. The influence of adaptation is then accounted for by reducing the decrease in the rSOP by a given proportion. For example, say the crest level of a defence is raised to mitigate 50 per cent of the reduction in standard driven by climate change, the future SOP of the defence in

the example above would be 1:55 years (i.e. 50 per cent of the reduction in standard (100-10 = 45 years) is avoided, leading to a future rSOP of 100-45 = 1:55 year return period).

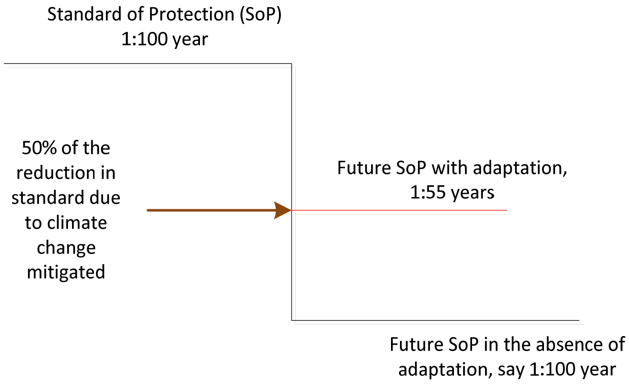

Figure D-1 Actions taken to manage the SOP of defences are characterised as a reduced impact of climate change

- The representative **Condition Grade** (rCg) of those defences: The rCg reflects the Cg of the defences associated with a given Calculation Area. Within the FFE, the rCg is used to modify the potential for defence failure. Changes in the rCg are implemented based on an assumed change in rCg between the present day and the future.

The defence length weighted average present-day values of rSOP and rCg are derived directly from the local available data (see Sayers *et al*., 2015d). This ensures that the rSOP and rCg are locally representative and hence any change reflects that local context.

Note: Both the SOP and rCg are determined at a Calculation Area scale, as used in the CCRA, rather than a Census Calculation Area scale used in the NFVI and SFRI, which are at a neighbourhood scale. This is because defences are managed at a broader scale than neighbourhoods and the Calculation Areas represent a more logical basis to consider changes in defences.

c) Future change given a continuation of current levels of adaptation

As in the CCRA (Sayers *et al*., 2015a), it is assumed here that the present-day standard indicates the strength of the case for further investment (as the locations with the lowest standards currently should be where the benefit cost for investment is weakest). The SOP in these places will reduce as investment fails to keep pace with climate change. In areas with the highest standards today (such as the Thames estuary), it is assumed that they continue to be well protected as the SOP is maintained into the future.

Evidence captured by England and Knox (2015) suggests a bias in investment towards urban areas (and away from rural areas) and towards more affluent areas (and away from deprived areas). This is reflected here in the implementation of defence measures. In terms of maintenance it is assumed that the majority of defence systems (i.e. those with an actual or target condition of rCg = 4 or higher) continue to be maintained at rCg = 4 or better regardless of location. In areas protected by defences with rCg of 5, the case for continued maintenance or improvement is assumed to be weak and with time they will deteriorate further.

Note: Population growth and development in areas of flood risk is likely to modify the investment case for raising standards in some areas. This feedback is not considered here. The quantified interpretation of this adaptation measure given the assumption of a continuation of Current Levels of Adaptation (CLA) is summarised in the tables below.

Changes in the rSOP

The proportion of the climate change driven reduction in standard that is prevented is laid out in the table below. When reading the table, please note:

- 0.0 = Standards reduce with climate change;
- 1.0 = Standards are maintained to keep pace with climate change;
- >1.0 = Standards are raised despite climate change (2 implies standards double in real terms).

Rural Areas: > 50% of Calculation Area = rural settlement type

rSOP today (years)	The reduction in standard due to climate change that is avoided					
	All other neighbourhoods			20% most vulnerable (by NFVI)		
	2020s	2050s	2080s	2020s	2050s	2080s
<10	0.25	0.25	0.25	0.1	0.1	0.1
>=10 and <75	0.5	0.5	0.5	0.4	0.4	0.4
>=75 and <500	0.75	0.75	0.75	0.6	0.6	0.6
>=500	1	1	1	1	1	1

Urban areas: > 50% of Calculation Area = urban settlement type

rSOP today (years)	The reduction in standard due to climate change that is avoided					
	All other neighbourhoods			20% most vulnerable (by NFVI)		
	2020s	2050s	2080s	2020s	2050s	2080s
<10	0.25	0.25	0.25	0.25	0.25	0.25
>=10 and <75	0.75	0.75	0.75	0.6	0.6	0.6
>=75 and <500	1	1	1	0.8	0.8	0.8
>=500	1	1	1	1	1	1

Changes in the rCg

It is assumed that condition grades remain unchanged in the future. The only exception is for the defences that have the worst condition grade today. When reading the table, please note:

- NC = no change;
- 6 = loss of all effective strength (equivalent to undefended).

rSOP today (years)	The reduction in standard due to climate change that is avoided					
	All other neighbourhoods			20% most vulnerable (by NFVI)		
	2020s	2050s	2080s	2020s	2050s	2080s
1 or 2	NC	NC	NC	NC	NC	NC
3	NC	NC	NC	NC	NC	NC
4	NC	NC	NC	NC	NC	NC
5	NC	6	6	NC	6	6

D.2.2 Management of shoreline morphology

a) Overview of role in FRM

Around half of all sea defences in England are protected and buffered against waves and storm surges by coastal habitats (ASC, 2013). As sea levels rise, beaches and coastal habitats will reduce in width as they are squeezed between the fixed backshore structures and the high-water mark (so-called 'coastal squeeze'). In recognition of the increasing cost of 'hold the line' and the environmental and downdrift gains that may be accrued by 'retreating the line' (so called Managed Retreat, MR), Shoreline Management Plans (SMPs) in England have a combined goal to realign some 9 per cent of the coastline by 2030, rising to 14 per cent by 2060 (ASC, 2013). However, the current rate of managed realignment since 2000 (in England) would need to increase five-fold, to around 30km a year, to meet this aspiration.

The Eurosion study (European Commission, 2004) estimated that 12 per cent of the Scottish coastline is eroding, and that 7 per cent of the coastline is defended; this is much less than in England. Coastal squeeze is not perceived as a significant issue in Northern Ireland with only one realignment project undertaken to date (in Kilnatierney). This was centred on environmental benefits and cost savings rather than enhancing the flood defence standard.

There is no direct evidence that the allocation of MR to a section of coastline is linked to the vulnerability of the affected coastal community. It is generally the case that MR tends to focus on rural areas where the benefits of maintaining defence lines are low, such as protection of areas of intermediate or poor agricultural land.

b) Representation of adaptation in the FFE

MR is typically not about improving the SOP but is more usually associated with reducing costs or gaining habitats (or other benefits). Within the FFE however, only the impact on SOP is considered and it is expressed as the proportion of the climate change driven reduction in standard that is avoided. The degree to which this climate change driven reduction in standard is mitigated is assumed to be a function of the percentage of the coastline realigned and the return period of the storm.

c) Future change given a continuation of current levels of adaptation

It is assumed here (as in the CCRA, Sayers *et al*., 2015a) that the targets set out within the SMPs for England (see above) are met across the UK (ASC, 2013). This acts to reduce the impact of climate change on all coastal defences with an rSOP of less than 1:75 years. The rSOP of high standard defences is unaffected.

There is no direct evidence that this intervention measure reflects the vulnerability of the affected coastal community. Therefore, no distinction is made between more coastal communities based on vulnerability or land use.

The quantified interpretation of this adaptation measure, given the assumption of a CLA scenario, is represented through the change in standard applied to an area and calculated as: rSOP = % of coastline realigned in the future / 2% (the realignment achieved in recent years) * x%

Where *x* is given in the second table below and represents the ability of MR to mitigate against the impact of climate change on the SOP.

% of coastline realigned: Rural and urban areas

% coastline realigned in recent years (based on England 1990-2016)	% of the coastline realigned					
	All other neighbourhoods			20% most vulnerable (by NFVI)		
	2020s	2050s	2080s	2020s	2050s	2080s
2%	9%	14%	16%	9%	14%	16%

Changes in the rSOP

The proportion of the climate change driven reduction in standard that is prevented for each 2 per cent of the coast (by length) realigned is given in the table below.

When reading the table, please note 0% implies no mitigation of the reduction in SOP and 100% implies full mitigation of the reduction in SOP.

rSOP today in coastal areas only (years)	% of the climate change induced reduction in the standard of protection avoided for each additional 2% of the coast realignment					
	All other neighbourhoods			20% most vulnerable (by NFVI)		
	2020s	2050s	2080s	2020s	2050s	2080s
<10	2%	2%	2%	2%	2%	2%
>=10 and <75	1%	1%	1%	1%	1%	1%
>=75 and <500	0%	0%	0%	0%	0%	0%
>=500	0%	0%	0%	0%	0%	0%

Note: It is recognised that a target of 16% for MR is unrealistic for the coastlines of Scotland and Northern Ireland given their limited exposure of soft sediments and/or salt-marshes, and their limited length of defence coastline. Nonetheless, the targets set out for England are used. Although not ideal this is considered reasonable but will lead to an inevitable overstatement of the potential impact of this measure in Scotland and Northern Ireland.

MR is usually associated with mitigating the impacts of coastal squeeze on coastal habitats, which in turn reduces the costs of maintaining defences and improves the SOP of the new defence line.

No attempt is made here to consider the environmental gains (habitat maintenance or creation or other wider benefits) or the local benefit cost case (that would vary on a case by case basis) as the nature of the analysis approach used here precludes this type of local assessment. Therefore, only the impact on standard is considered here, which, although no specific modelling has been undertaken, is assumed to be relatively small. In reality of course, local considerations and the detailed design of the MR plan will be fundamental in deciding whether, or not, MR goes ahead.

Given the limited impact on the SOP, no attempt is made to target the specific length of coast that is realigned. Instead it is assumed that all defences within a given coastal region are afforded a limited but improved SOP.

D.2.3 Management of catchment run-off

a) Overview of role in FRM

In recent years the concept of Natural Flood Management (NFM) has been increasingly recognised as a legitimate supporting measure in FRM. Indeed NFM practices (including upland storage, the management of run-off from agriculture, floodplain/river restoration, riparian tree planting etc.) are now widely promoted within various policy and guidance documents across the UK, such as the Flood Risk Management (Scotland) Act 2009 (Scottish Government, 2009), Working with Natural Processes (EA, 2010; 2014), Strategic Flood Management (WWF), Natural Flood Risk Management (NRW, 2015; WHS, 2014), Natural Flood Management (OST, 2011), 'Living with rivers and the sea' (Rivers Agency, 2008) and Slowing the Flow (Forest Research, Pickering, Yorkshire).

The desire to promote such solutions (and the multiple benefits they provide) however has not yet been matched by 'on the ground' take up. This is despite most Catchment Flood Management Plans across England and Wales including policy options for managing runoff and storage (available at Environment Agency, 2009). In part this is due to the lack of scientific evidence regarding the performance of nature-based solutions, particularly during more extreme flood events and over large areas (Dadson *et al*., 2016).

Nevertheless, experience is being gained on the effectiveness of these measures. Example pilot studies include at Pontbren; Parrett; Hooder; Pickering, Yorkshire; Elwy catchment, Wales; Clwyd catchment, Wales (Dadson *et al*., 2016). In this last case, modelling based analysis showed that if implemented across the catchment, improved land management could reduce peak flows by up to 25 per cent in the summer and eight per cent in winter.

There is no direct evidence that this intervention measure reflects the vulnerability of the affected coastal community. However, such approaches tend to focus on rural areas where the benefits of maintaining defence lines are low and the opportunity to make a significant difference to downstream flood peaks are often high.

b) Representation of adaptation in the FFE

Given that many management policies across the UK promote the role of NFM in some form, the CLA scenario includes an element of these measures. The impact of approaches to managed catchment run-off (including both NFM measures through to other, more traditional measures such as small dams) are characterised within the FFE through the percentage change in peak flow.

c) Future change given a continuation of current levels of adaptation

As in the CCRA (Sayers *et al*., 2015a) it is assumed that reductions in peak flow are greater for more frequent events (an assumption confirmed by various studies) and are likely to be more viable in catchments dominated by low-grade agricultural land.

The impact of catchment management measures is therefore restricted to reflect the limit to achieving (up to) a 5 per cent reduction on peak flows during more frequent events, reducing to 2 per cent during the more severe events (i.e. 1:100-year event) by the 2080s. It is also recognised that NFM approaches are unlikely to be viable everywhere. The degree of reduction in peak flow achieved is assumed to be twice as great in catchments dominated by Non-Best and Most Versatile (non-BMV) land as in catchments dominated by high-grade agricultural land (BMV land classes). This reflects the opportunity differential that is likely to exist.

The climate driven percentage increase in fluvial flow (in the absence of any other change) is reduced through the upstream catchment measures. The reduction in the increase in fluvial flow during the 100-year event is calculated based on the relative proportion of BMV and Non-BMV land within the catchment (with catchments defined using the European Environment Agency river catchment data set) as set out in the first table below. The potential for managing less extreme floods is then calculated based on a multiplier of the 100-year return period value (using the multipliers in the second table below).

The potential reduction in the 100-year fluvial flow:

Land type	Percentage reduction in flood flows					
	All other neighbourhoods			20% most vulnerable (by NFVI)		
	2020s	2050s	2080s	2020s	2050s	2080s
Best and Most Versatile	0.0%	-0.5%	-1.0%	0.0%	-0.5%	-1.0%
Not Best and Most Versatile	0.0%	-1.0%	-2.0%	0.0%	-1.0%	-2.0%

For other return periods, the 100-year reductions are modified per the table below.

Return period (years)	Enhanced % reduction in flow during other return period events (multiplier)
2	2.5
10	2
100	1
1000	0.5

D.3 Urban flood management practices

a) Overview of role in FRM

Widespread flooding across England in 2007 damaged 55,000 properties, with much of the damage resulting from drains and sewers being overwhelmed by heavy rain (Environment Agency, 2007). This highlights that traditional piped sewer systems cannot readily be adapted to deal with increased rainfall, particularly in dense, urban areas. Half of the national sewer network in England is reported to be currently at or beyond capacity (RSPB, 2014). There are a range of responses to help surface water flooding, the most common of which is the promotion of Sustainable Urban Drainage (SUDS) (through urban storage, green space, green roofs, soakaways, permeable paving, ponds and swales with the aim to slow down and store flood water) as well as considering the separation of foul and surface water sewers, preferential flood routing (to urban storage areas) and the deployment of temporary or demountable flood defences.

Flooding in urban areas, from intense rainstorm events rather than from rivers overflowing on to floodplains can be influenced by the adoption of many stormwater and local FRM options. In England, the Pitt Review (Pitt, 2008) recommended that unitary and county councils take a leadership role to develop local FRM plans (e.g. in England: Local Flood Risk Management Strategies). The Flood and Water Management Act 2010 established 152 lead local flood authorities (LLFAs) in England with similar statutory responsibilities of publishing local FRM strategies. However, in 2014, less than one-sixth of LLFAs had published FRM strategies. This is likely to increase to around half by the end of 2015/16 (Committee on Climate Change Adaptation, 2016). These strategies are required to include SUDS as an element leading to flood probability reduction. However, in 2016, the TCPA conducted document analysis of a sample of local plans from Local Planning Authorities in England, and found that SUDS were defined in only 56 per cent of them (TCPA, 2016). Similarly, in Scotland their Surface Water Management Planning Guidance documents outline how SUDS can be incorporated into many of the potential measures for addressing surface water flooding (Scottish Water *et al*., 2013). In Northern Ireland, the Water and Sewerage Services Act (Northern Ireland) 2016 (Northern Ireland, 2016) includes a section on ‘sustainable drainage systems’ which gives power to NI Water to adopt SUDS and require the construction of SUDS. This is backed up by restrictions on connecting new surface water sewers to the public network. Finally, in Wales, TAN 15 (Welsh Government, 2004) states that development should not create additional runoff (when compared with the pre-development situation) and encourages the use of SUDS to manage this.

b) Representation of adaptation in the FFE

The severity of surface water flooding can be influenced by the adoption of many stormwater and local FRM options. Firstly, SUDS can help avoid sewer networks being overwhelmed during periods of heavy rainfall by reducing the peak of the hydrograph. SUDS are a low-regret adaptation measure, having construction and maintenance costs similar to conventional drainage but delivering a wider range of benefits.

Anecdotal evidence suggests that in inner-city areas (where urban flooding and drainage is significant) a differential take-up of retrofitting SUDS may exist – although no firm evidence can be found. Within the analysis here it is assumed that there is no take-up in more vulnerable communities (compared to 10% elsewhere, ASC, 2014).

c) Future change given a continuation of current levels of adaptation

The quantified implementation of these changes within the FFE is summarised through two changes as set out below.

Changes in urban surface water run-off by modifying the effective urban extent due to SUDS take-up.

It is assumed here (as in the CCRA, Sayers *et al.,* 2015a) that planning policies continue to strengthen and from 2020 onwards 25 per cent of new developments will implement SUDS - up from 15 per cent in the present day (ASC, 2014). Retrofitting to existing development continues to be limited (remaining around 10 per cent by area, inferred based on the sale of permeable paving in 2013 (ASC, 2014).

Development type and take-up	Neighbourhood type					
	All other neighbourhoods			20% most vulnerable (by NFVI)		
	2020s	2050s	2080s	2020s	2050s	2080s
New						
Take-up	25%	25%	25%	25%	25%	25%
Urban extent	uX(1+3a/4)			uX(1+3a/4)		
Existing (area at significant chance of flooding)						
Take-up	10%	10%	10%	0%	0%	0%
Urban extent u	0.9u	0.9u	0.9u	0.9u	0.9u	0.9u

The influence of SUDS are represented by modelling the runoff in each Calculation Area, using the simplified rainfall-runoff relationships (Sayers *et al.,* 2015d). The runoff for a Calculation Area is the weighted sum of the runoff calculated for urban and rural areas within the Calculation Area, with the weighting taken as the proportion of the area which is urbanised, namely:

$$\text{Runoff} = \frac{Runoff_{Urban}A_{Urban} + Runoff_{Rural}A_{Rural}}{A_{Total}}$$

The effects of SUDS, which aim to reproduce rural runoff characteristics (i.e. to mimic the equivalent greenfield runoff signature) are represented as a modification to the proportion of the Calculation Area that produces urban runoff (*u*). The urban extent *u* controls to what extent a Calculation Area behaves in an urban or rural way (as shown in the Figure D-2).

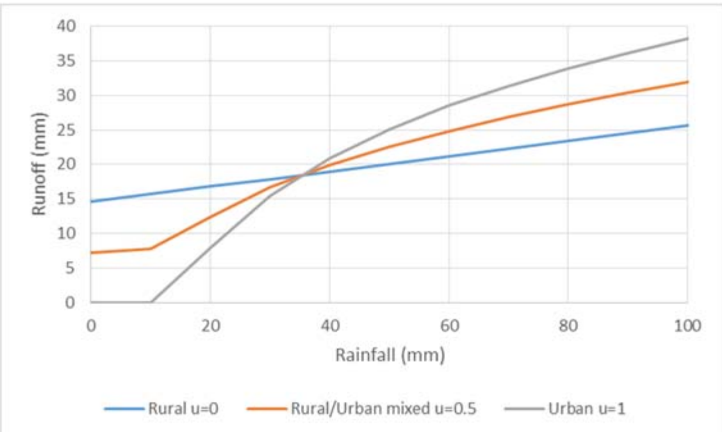

Figure D-2 Rainfall – runoff relationship for different levels of urbanisation as parameterised by u

New development with SUDS will not change the runoff characteristics of an area (as the new properties mimic greenfield runoff), whereas new development without SUDS will increase the urban area generating runoff in line with the increase in property numbers. Partial take-up of SUDS in new developments is represented by interpolating between these two cases.

For retrofitting SUDS, the effective urban area *u* is reduced as runoff characteristics return more towards greenfield runoff. This is represented as a reduction in the runoff in line with the reduction in effective urban area, which in turn depends on the take-up of SUDS retrofitting.

The resulting change in runoff is then used to move the runoff-return period curve up or down; this is equivalent to a shift in the return period for a given runoff, and hence a shift in the return period of flooding, in the same way that climate change affects fluvial flooding.

Reduction in risk from measures to manage urban surface water run-off (excluding SUDS)

Broader efforts to manage surface water are assumed to continue to have a limited impact on flood risk. Such measures (including managing overland flow and storage – such as temporary defences, improved sewer systems and maintenance, separation of foul and stormwater systems, improvement of culverts, gullies etc.) are assumed to be effective in limiting damage to properties exposed to a flood probability >=3.3 per cent (i.e. a return period of 1:30 or more frequent) by the amount shown below. Damages for properties exposed to with probability <3.3 per cent are not affected.

Probability of inundation	All other neighbourhoods			20% most vulnerable (by NFVI)		
	2020s	2050s	2080s	2020s	2050s	2080s
≥3.3%	5%	5%	5%	5%	5%	5%
<3.3%	0%	0%	0%	0%	0%	0%

D.4 Managing exposure to flooding

D.4.1 Spatial planning

a) Overview of role in FRM

Current planning policies across the UK (England: National Planning Policy (NPPF), Wales: TAN 15, Scotland: Online Planning Advice[1], Northern Ireland: PPS15) typically seek to ensure inappropriate development in areas prone to flooding is avoided, and where development is unavoidable, it is safe and does not increase flood risk elsewhere. It is clear that floodplain development continues, although probably at a far lesser rate than in past decades (Pardoe *et al.,* 2011). The Future Flood Prevention report (EFRA Committee, 2016) focused on the need for integrated spatial planning and flood resilience, moving away from the current continued enhancement of mitigation measures. It recommended that developers be held liable for any flood damage to development in floodplains, or where regulations were ignored.

Analysis by the ASC found that around 21,000 homes were built in the floodplain (defined as Flood Zones 2 or 3) every year (on average) between 2001 and 2014 in England (ASC, 2015). This makes up around 12 per cent of all new residential development in England over that time. Recent research for Scottish Government suggests that the percentage of new build in Scotland since 2009 in areas at risk from the 200 year plus climate change event is lower than 12 per cent (Kazmierczak *et al.,* 2015). Further analysis here of the new development datasets suggests that a greater proportion of development takes place in less vulnerable communities and, for the purposes of this study, values of ~11-12 per cent (less vulnerable neighbourhoods) and ~14 per cent (more vulnerable neighbourhoods) are used here.

The ASC's analysis estimates that 73 per cent of residential development in coastal and fluvial floodplain in England takes place in areas with a low chance of flooding (i.e. areas with between a 1-in-100 and 1-in-1000 annual chance of flooding). However, 27 per cent of floodplain development since 2001 (68,000 new homes) has taken place in areas subject to flooding more frequently than 1-in-100-year return period on average. Around 23,000 new homes (9 per cent of floodplain development) have been built in areas with a high chance of flooding, subject to flooding more frequently than 1-in-30-year return period on average. Development in areas with a higher chance of flooding appears to be mostly in more sparsely populated locations. This may be because community-level flood defences are more difficult to justify on cost-benefit terms in these more rural areas.

A recent report by the TCPA (2016) found that the majority of local plans assume that the level of flood risk is based solely on current understanding of floodplain boundaries, and changes in these

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[1] http://www.gov.scot/Topics/Built-Environment/planning/Policy/Subject-Policies/natural-resilient-place/Flood-Drainage/Floodrisk-advice

into the future are not taken into consideration. It highlights that including this future extent of the floodplain is critical in climate change adaptation plans as further floodplain development may increase the long-term flood risk and therefore the cost of future flood prevention.

The analysis of development data by the ASC has been extended here to determine whether development on the floodplain is undertaken disproportionately in the most vulnerable neighbourhoods and to include areas prone to surface water flooding. Under the assumption of CLA, the role of spatial planning is assumed to be as effective in future years as it has been in recent years and the results of this analysis are used directly to support the implementation of spatial planning within the FFE (see below).

Note: Despite the potential for more stringently applied planning policies in Scotland, Wales and Northern Ireland (and hence lower rates of development in the floodplain), this quantified assessment of England is assumed here to apply equally across the UK.

b) Representation of adaptation in the FFE

Exposure to flood risk can be managed by either (i) avoiding locating new development in flood-prone areas, or (ii) realigning the urban landscape to reduce the number of people and property that occupy the floodplain (White, 2010). Only the former of these has a significant role in current FRM policy and so only this is reflected in the FFE.

Analysis of new residential developments (in England only) in the period 2008-2014 undertaken for this study suggests that currently the percentage of new dwellings built within the fluvial and coastal floodplain is around 14 per cent in vulnerable areas (top 20 per cent of neighbourhoods by NFVI) and 11-12 per cent in less vulnerable areas. These percentages are significantly higher than the existing 7.5 per cent of residential properties on the floodplain, indicating that the planning process is failing to steer development away from floodplain areas.   The same analysis has also determined how properties are distributed between fluvial and coastal floodplain areas, and within three probability bands (the same bands as used for reporting).

A similar analysis for surface water risk has also been carried out, and indicates that new properties are slightly less likely to be placed in areas of surface water risk than the fluvial and coastal floodplains; this result is slightly surprising given that the planning process does not explicitly take existing surface water risk into account, but should steer new development away from coastal and fluvial floodplains.

It is assumed that future developments will follow the same pattern as those seen in 2008-14, with the same distribution of new properties on and off the floodplain, within and outside vulnerable areas, and in each flood probability band.

c) Future change given a continuation of current levels of adaptation

The quantified implementation of the influence of the spatial planning measures within the FFE are summarised below.

	All other neighbourhoods			***20%ile most vulnerable (by NFVI)***		
	2020s	***2050s***	***2080s***	***2020s***	***2050s***	***2080s***
% of all new developments built in the floodplain (2008-14)	***11.8%***	***11.8%***	***11.8%***	***14.0%***	***14.0%***	***14.0%***
Frequency of flooding (years)						
Coastal flooding (return period, years)						
<75	*5.9%*	*5.9%*	*5.9%*	*5.9%*	*5.9%*	*5.9%*
75-200	*15.5%*	*15.5%*	*15.5%*	*22.7%*	*22.7%*	*22.7%*
>=200	*23.9%*	*23.9%*	*23.9%*	*34.5%*	*34.5%*	*34.5%*
Fluvial flooding (return period, years)						
<75	*15.0%*	*15.0%*	*15.0%*	*6.8%*	*6.8%*	*6.8%*
75-200	*25.2%*	*25.2%*	*25.2%*	*23.1%*	*23.1%*	*23.1%*
>=200	*14.5%*	*14.5%*	*14.5%*	*7.0%*	*7.0%*	*7.0%*
Surface water flooding (return period, years)						
<75	*3.2%*	*3.2%*	*3.2%*	*3.9%*	*3.9%*	*3.9%*
75-200	*1.9%*	*1.9%*	*1.9%*	*2.3%*	*2.3%*	*2.3%*
>=200	*3.3%*	*3.3%*	*3.3%*	*4.0%*	*4.0%*	*4.0%*

Note: *Residential development projections:* Projections for the number of new residential properties are based on the spatially resolved population projections (see Sayers *et al*., 2015b) and implemented within the FFE as a percentage increase in the residential property numbers within a given Census Calculation Area.

D.5 Reducing the vulnerability of those exposed

Reducing flood vulnerability involves enabling individuals and communities to better prepare for, respond to, and recover from a flood as quickly as possible. Some of these processes can be autonomous, driven by awareness, but others can be planned and policy driven. The aim here is to capture the aggregate effect of both processes.

Three specific adaptation measures are considered here: (a) **Receptor Level Protection** (residential property only); (b) **Forecasting, warning and community response**; (c) **Insurance**.

A significant body of research highlights that the propensity of individual householders to adopt risk reducing measures is strongly affected by their flood experience and those without experience are much less likely to act (e.g. Kates, 1962). This assumption underpins much of our consideration of vulnerability reduction measures in the three adaptation measures discussed below.

D.5.1 Receptor Level Resilience Measures: Residential

a) Overview of role in FRM

Properties can be made more resilient or resistant to flooding (referred to here in the combined sense of Receptor Level Resilience, RLR). These measures can, if appropriately implemented, lessen the damage incurred during flood events and reduce reinstatement costs.

Several policy measures encourage individual property owners to protect themselves and their property from flooding. The Environment Agency's Flood & Coastal Erosion Risk Management Strategy (Environment Agency, 2011) and Defra's partnership funding (Defra, 2011) policies encourage local communities to contribute towards their risk reduction, not least by implementing RLR measures. Local authority enforced Building Regulations have been strengthened in recent years to promote RLR measures (e.g. Defra, 2007a; CIRIA, 2010), and subsides and grants are often made available for those in flood affected areas to install certain RLR measures. At the same time, the availability of these measures is increasing from a wide range of companies, including installing 'kitemarked' devices for preventing the ingress of flood waters into properties (Environment Agency, undated; National Flood Forum, 2012) and installing fixtures and fittings that are less susceptible to flood damage should a property be flooded (e.g. plastic kitchen fittings).

There are, however, counteracting tendencies to such trends. Property owners are often reluctant to implement risk-reducing measures which demonstrate to the wider public that their properties are at risk (such as external flood gates, see Harries, 2008; 2012) so the implementation of RLR measures is not 'plain sailing'. Furthermore, RLR measures are only likely be an efficient response where the frequency of flood events is high (Defra, 2014b), and are only likely to be effective when the external flood depth is less than 600mm (Defra, 2007a). They also often rely upon neighbourhoods acting to prevent flood waters propagating through party walls and shared roof spaces. At flood depths greater than this, or in the absence of the collective action that may be necessary, it is likely that resistance measure (i.e. external flood boards and similar products) will be overtopped, or will be of insufficient strength to withstand the loading of large depths of the flood water. Additionally, not all measures implemented will be successful. An evaluation of post-installation effectiveness commissioned by Defra concluded that (Defra, 2014b):

'Of the 11 Environment Agency responses received, 6 schemes had been tested and Property Level Protection measures deployed but only 4 provided further detail. The information provided showed that for 79 per cent of properties, Property Level Protection measures either prevented flood water ingress or served to reduce the impact and level of flooding experienced, whilst 21 per cent found that it made no difference at all.'

Nevertheless, under current planning policy all new properties built in the fluvial and coastal floodplain are likely to include resilience measures and there are there are low cost resilience measures that help people recover more quickly which are fairly cost neutral (and therefore potentially more likely to be approved by insurers (Rose *et al.,* 2016). Outside of the coast and fluvial floodplain it is unlikely that planning authorities will impose such conditions.

Retro-fitting resilience measures to existing properties (using various flood products and property modifications) is also gathering pace but progress is slow. The reasons for this are multiple and include issues of income and affordability, property tenure as well as a lack of access to suitably qualified professionals and a lack of consumer confidence in the value for money provided by such approaches (BRE, undated). This lack of penetration was also reflected in the Environment Agency's Long Term Investment Scenarios (LTIS) that assumed a present-day take up of between 3 per cent and 5 per cent for existing properties within the fluvial and coastal floodplain exposed to a high chance of flooding in England and Wales (Environment Agency, 2014, 2015). In Scotland take-up is greater, at 8 per cent (Scottish Government, 2015). Take-up in Northern Ireland is encouraged by the Homeowner Flood Protection Grant Scheme, whereby the government covers 90 per cent of RLR modifications up to £10,000 for properties that have previously been flooded (NI Direct, 2016).

In the most vulnerable neighbourhoods the evidence does suggest that the take-up by the most vulnerable in existing developments is likely to be lower than in the population as whole. There may be multiple reasons for this:

- *RLR measures can be expensive which may rule out installation for people on low incomes* (National Flood Forum, 2012). The conditions being imposed by planning authorities are likely to ensure such RLR measures are included for all new properties in areas prone to frequent flooding (greater than a 1:75 years return period). Research on nearly 1,000 respondents (from across a range of income levels) in England and Wales found that the majority of people overall were not willing to spend more than £500 on RLR measures and over a third would not pay anything. The evidence for this is largely anecdotal but with a strong supporting narrative from the National Flood Forum (2012) and the supporting case studies completed as part of this study (see Appendix E). A more specific insight into the rate of take-up and the type of measures installed is currently unavailable (although the on-going development to the national database of the take-up of RLR measures is likely to offer new insights in the short term (Defra, 2016)).
- *Grants may not be enough to encourage take-up by the most vulnerable.* Anecdotal evidence from the case studies (Appendix E) suggests that retrofitting a minimum number of flood products is likely to cost £8-10,000 and installing a full range of resilience measures may cost more than £30,000 per property. This is significantly greater than the available grant (typically £5,000, with top-up grants available in certain areas that have suffered recent flooding; for

example, the Cumbria Community Foundation offers an extra grant of up to £2,000[2] to affected properties in Carlisle following the flooding in 2015, although each case is considered individually so further funds may be granted on a means-tested basis).

- *Tenants in rented accommodation have a reduced ability and incentive to install property level measures.* In the context of private renting, there is also likely to be reliance among tenants on their landlords to undertake physical adaptation measures (as tenants are more constrained in making modifications to homes that they do not own, even if they can afford to take action, and are often frequent movers with insecure tenure with little incentive to make alternations).
- *Awareness of the flood risks faced.* Access to information is most often through the internet and provided only in English. The most vulnerable may have greater difficulty in access this information, especially if English is not their first language.
- *The process of applying for a grant is bureaucratic and cumbersome* (National Flood Forum, 2016). Evidence from the National Flood Forum indicates that the procedures for applying for grants are bureaucratic and overly complicated, and take-up has generally been poor for this reason. This is a disincentive to proactive action for all, but evidence from the case studies undertaken here suggests that the most vulnerable members of society will struggle more to overcome these difficulties and complete applications.

In combination, these barriers mean it is likely that retro-fitting of RLR in the most vulnerable neighbourhoods will be significantly less than elsewhere.

b) Representation of adaptation in the FFE

The FFE reflects *take-up* (how many assets/properties the method is applied to) and *effectiveness* (how much the measures reduce damage for each property). The FFE therefore uses two levers to represent RLP measures**:**

- Percentage take-up for new and existing properties (separately);
- For those properties that take-up the measures, some are successful and for those properties flood damages are reduced (through a reduction in the Weighted Average Annual Damage, WAAD value used).

c) Future change given a continuation of current levels of adaptation

Within the analysis presented here it is assumed that within the fluvial and coastal floodplains all new residential properties are built with appropriate RLR measures. Outside of fluvial and coastal floodplains, new properties continue to be built with limited (no) consideration of RLR measures. There is some limited take-up of RLR measures by existing homeowners in areas at a high chance of either coastal or fluvial flooding, with even less take-up in areas of high private tenancy (as discussed above).

[2] http://www.cumbriafoundation.org/fund/cumbria-flood-recovery-fund-2015-individuals/ Accessed June 2017

Of the properties that take-up property scale measures, ~80%are successful at reducing damage (Defra, 2014b). This is perhaps an overestimate but there is little evidence to contradict this estimate. When implemented, the reduction in damage is significant for lower flood depths (below 600mm – assumed to be associated with return periods of 10 years or less in coastal areas, 25 years or less in fluvial areas, 100 years or less in surface water areas) with progressively less impact as the severity of the event increases. RLR measures are assumed to be the least effective in coastal areas due to the potential for local wave action.

The quantified implementation of the influence of RLR measures within the FFE are summarised in the following tables.

% take-up of RLR measures

	All households				20% most vulnerable neighbourhoods (by NFVI)			
	Present day	2020s	2050s	2080s	Present day	2020s	2050s	2080s
Off floodplain fluvial / coastal floodplain								
% Take-up for new properties	0%	0%	0%	0%	0%	0%	0%	0%
% take-up for existing properties	0%	0%	0%	0%	0%	0%	0%	0%
On fluvial / coastal floodplain								
% Take-up for new developments (regardless of the probability of flooding)	0%	100%	100%	100%	0%	100%	100%	100%
% take-up for existing properties – **High** probability areas	0%	5%	7%	10%	0%	1%	1%	1%
% take-up for existing properties – **Moderate** and **Low** probability areas	0%	0%	0%	0%	0%	0%	0%	0%

Reduction in Residential WAAD value for those properties protected by RLR measures

SOP	All neighbourhoods			
	Reduction in WAAD (coastal)	Reduction in WAAD (fluvial)	Reduction in WAAD (surface water)	Reduction in WAAD (groundwater)
No protection	0%	0%	0%	0%
2	80%	100%	80%	80%
5	80%	100%	80%	80%
10	40%	100%	80%	80%
25	0%	40%	80%	40%
50	0%	25%	40%	25%
100	0%	0%	20%	0%
>200	0%	0%	0%	0%

D.5.2 Forecasting, warning and community response

a) Overview of role in FRM

Flood awareness is essential for reducing vulnerability of individuals and communities. Improving awareness can promote autonomous or planned behavioural responses by those concerned, and the forecasting of floods and providing warnings to communities is essential for enhancing this awareness (e.g. Parker *et al.,* 2009; Parker *et al.,* 2011).

Communities and individuals who receive these warnings are better able to prepare and respond by taking damage-reducing actions, better able to develop strategies to minimise the impact of the flood on their families and property, and thereby in a better position to hasten recovery, given that losses will be reduced, and injury and loss of life will hopefully be prevented (Parker *et al.,* 2009; Parker *et al.,* 2011).

This ability to respond is fundamentally affected by the timeliness of reliable warnings, the clarity of message and encouragement to act, and the ability of those involved to take action to help themselves or others (for example, older people with physical disabilities are less likely to be physically able to move valuable possessions to safety, but can be prioritised to receive assistance from voluntary services). Good forecasting and warning is therefore necessary to reduce the impacts of a flood, but it is not sufficient. Ultimately, it is the ability of people to respond to this information which makes the difference (Thrush *et al*., 2005) and therefore incidence management has an important role in complementing flood forecasting and warning activities.

Local authorities and agencies often have records of vulnerable people (such as older people with physical disabilities in receipt of care services) to help target assistance when a flood is imminent. Community networks (including informal and formal networks and "action groups") also play a significant role in improving the response and recovery of the community (Walker *et al.*, 2010; Geaves and Penning-Rowsell, 2014). It is, however, interesting to note that Green (1995) found that the extent and type of social support received by victims of flooding seemed to have no effect on the victims' level of stress or amount of disruption from a flood event.

In England, the Environment Agency allocates spending on flood warning based on a Flood Warning Investment Strategy (Ball *et al.,* 2012). They conduct a 'levels of service assessment' to allocate funding priorities for flood warning according to location, thereby establishing target standards of quality for the service in each flood warning area. This assessment reflects SOP and impact, without any specific consideration being given to vulnerability (Andryszewski *et al.,* 2005). In recent years there has been a significant expansion of 'Floodline Warnings Direct' (FWD), a centrally hosted warning and dissemination system that sends messages to the telephones of people in flood warning areas. SEPA provides a similar service in Scotland (although in Scotland current sign-up rates are significantly lower than those in England at around 16 per cent in coastal areas and 32 per cent in fluvial areas (as advised by SEPA during this study)). In Wales, Natural Resources Wales (NRW) have been responsible for flood warnings since April 2013 (Wales Audit Office, 2016). In Northern Ireland, the Rivers Agency have published maps of areas at high flood risk (Rivers Agency, undated) - as have other nations.

No consideration was given in the CCRA (Sayers *et al.,* 2015a) to a differential take-up or effectiveness of flood warnings in the most vulnerable neighbourhoods. There is however some evidence to suggest that vulnerability is significant and this is reflected in the development of the NFVI, and in particular the social indicators used to assess the 'ability to respond'. There are also systemic reasons way the most vulnerable may be disadvantaged by flood warning and forecasting processes. For example:

- *Barriers to receiving the warning:* Many low income household are no longer choosing to maintain a landline but instead rely upon mobile technologies. This creates complications in trying to contact households to convey flood warnings; for example, in Boston, the Environment Agency are able to contact many landline numbers in an emergency with flood warnings even if they are not signed up to Floodline. However, this service is not currently available for mobile phones but Lincolnshire Environment Agency are working on a deal with the mobile network provider EE to try and set up a similar scheme for mobile numbers registered in affected areas.

- *Accessing the content of warnings:* Minority ethnic groups for whom English or Welsh is not their first language may be less able to respond (Thrush *et al.,* 2005). This was certainly the case in Boston (see Appendix E), where there are a large number of migrants who are unfamiliar with the area, don't always speak sufficient English to understand flood warnings and remain largely segregated from the rest of the population of the town.
- *Awareness of the need to be 'flood aware':* One of the factors that has been shown to have the greatest impact on levels of "awareness" is lack of previous flooding experience. Clearly, if someone is new to the area they may not have experienced a flood event before and may not be aware that there is a risk, especially if living in rented accommodation as tenants tend to move more frequently (Thrush *et al*., 2005).

The inherent barriers to both response and recovery embedded in the NFVI and the systemic issues support a hypothesis that the take-up of individual damage-reducing actions in more vulnerable neighbourhoods is likely to be less than in less vulnerable areas.

b) Representation of adaptation in the FFE

Within the FFE both direct and indirect damages are assumed to reduce as forecasting and warning services improve (and increase as they degrade). Both take-up (the per cent of residential properties signing up to the service) and the effectiveness of that service (expressed through a per cent reduction in the standard damage values given within the WAAD tables) are considered.

In determining the values used within the FFE, the following assumptions are made (as in the CCRA, Sayers *et al.,* 2015a):

- *The take-up of warning services is greatest in coastal areas:* This reflects the heightened perception of risk (Parker, 1991 and Parker *et al.,* 2007) and the maturity of the flood warning system since it was implemented after the 1953 event. Numerous events have been tracked down the North Sea during this time, and warnings to the communities affected have become better publicised and more targeted because of this experience.
- *Surface water flood forecasting:* Effective forecasting and warning of surface water flooding (capable of reducing direct damages) remains out of reach.
- *The effectiveness, in terms of reduction in damage, increases with return period of the event:* This reflects the longer lead time, and hence greater opportunity to act, that is typically associated with more extreme events (Parker, 1991). Effectiveness of warnings in reducing damage during flash flood events (e.g. in Boscastle in 2004) is typically very low despite the rarity of the event, but in the majority of fluvial and coastal storm events a higher return period (often associated with longer lead times) increases the opportunity for people to take risk reducing actions, such as in Tewkesbury in 2007. This is recognised as a significant, but necessary, simplification.

In addition to these assumptions, consideration is also given to the differential influence in more vulnerable neighbourhoods. In particular:

- *The absence of community networks:* This can reduce the ability of an individual to respond effectively*;* for example, those with children of primary school age are likely to have good local networks (the "school gate" phenomenon) and be more informed and ready to respond. In the most vulnerable neighbourhoods (as defined by the NFVI) these informal networks are much reduced (RSPB, 2014).

- *Ability to respond:* An individual's ability to deploy flood protection measures at home, such as flood gates, in the case of rapid onset events like surface water flooding is likely to be limited where they have limited physical mobility (Defra*,* 2007b).

Although flood forecasting and warning is primarily targeted towards saving lives, the impact on people (and the ability for people to successfully evacuate etc.) is not included in the FFE. Only direct and indirect damages are considered. It is assumed that the impact on indirect damages is in direct proportion to the reduction in direct damages. The FFE applies a multiplier to the direct damages to account for these 'indirect' damages. In the absence of a forecasting or warning response this is set to 1.7. Where forecasting and warning systems are in place this multiplier is reduced by 50 per cent to 1.35. For example, if the direct damage to a property without any warning system were £100, then the direct plus indirect damages would be £170. With warning, the £100 is reduced to £95 (i.e. by 5 per cent), and £70 is reduced to £35. The total damages, direct and indirect, with the warning system becomes £130. This calculation process is used across all adaptation scenarios.

Note: It is recognised that this is a very approximate method of calculating in-direct losses and is unlikely to capture the full costs of a flood. Future research should be used to provide a more comprehensive assessment.

c) Future change given a continuation of current levels of adaptation

As in the CCRA (Sayers *et al*., 2015a) it is assumed here that flood forecasting and warning continues to be a significant component of the FRM effort and continues to improve (with up to 75 per cent of residential properties in coastal areas in England acting on warnings and slightly less in fluvial areas and amongst non-residential properties by the 2080s). Effectiveness also improves, reflecting the ability to forecast more frequent events with long lead times and continued increases in awareness amongst those at risk. As a result direct damages associated with storm events occurring more frequently (on average) than 1:75 years are reduced by 5 per cent by the 2080s.

Within the most vulnerable neighbourhoods take-up is less (reflecting the social context). In these neighbourhoods, given the absence of specific evidence, it is assumed that take-up is equivalent to the lower level of adaptation set out in the CCRA (Sayers *et al.,* 2015a). By the 2080s this equates to 25 per cent in coastal areas and 12 per cent in fluvial areas, compared to up to 75 per cent of people in coastal areas and 50 per cent in fluvial areas elsewhere. The reduction in direct damages is also reduced in the most vulnerable neighbourhoods reflecting the additional difficulties in deployment.

The quantified implementation of this adaptation measure is summarised in the following table.

% take-up and response (no. properties and businesses taking up and acting on warning)

Return period of flooding (years)	All other neighbourhoods			20% most vulnerable (by NFVI)		
	2020s	2050s	2080s	2020s	2050s	2080s
Coastal areas						
Residential	75%	75%	75%	50%	50%	50%
Fluvial areas						
Residential	50%	50%	50%	25%	25%	25%
Surface water areas						
Residential	0%	0%	0%	0%	0%	0%

% reduction in DIRECT damages (implemented as a % reduction in the estimated WAAD)

Return period of flooding (years)	All other neighbourhoods			20% most vulnerable (by NFVI)		
	2020s	2050s	2080s	2020s	2050s	2080s
<10	2%	3%	3%	1%	1%	1%
10-75	3%	5%	5%	2%	2%	2%
>75	5%	6%	7%	3%	3%	3%

% reduction in INDIRECT damages

The impact on indirect damages is assumed here to be in direct proportion to the reduction in direct damages. Therefore, no additional reduction is applied to the indirect damages (they simply reduce because the direct damages reduce).

D.5.3 Insurance and experience

a) Overview of role in FRM

Flood insurance is generally only compulsory in the UK for those purchasing their property with a mortgage. Other householders are free to purchase or not to purchase flood insurance, which is bundled in with domestic insurance against fire, theft, subsidence, etc. Flood insurance is universally made available in the UK for domestic properties and businesses through private insurance companies (Box 5-1) and aims to compensate victims for the flood damage that they incur, therefore enhancing recovery after flood events (and reducing vulnerability of residents). This has been the situation since the 1960s (Penning-Rowsell *et al.,* 2014a; Penning-Rowsell and Priest, 2015) and this insurance underpins all other FRM policies in the UK, relieving the government of the obligation to pay compensation for the damage caused by flooding. This is one of the few FRM activities that is applied across the UK although with varying associated conditions (National Flood Forum, 2012).

Penetration is also uneven. Based on the government's Household Expenditure Survey and evidence from its own members, the Association of British Insurers (ABI) estimate that the take-up of insurance in the UK is such that 93 per cent of all homeowners have buildings insurance that covers the structure of their home, but this falls to 85 per cent of the poorest 10 per cent of households purchasing their own property. Some 75 per cent of all households have home contents insurance, but half of the poorest 10 per cent of households do not have this protection. This prompted Watkiss *et al.* (2016) to note *"while most owner occupiers have building insurance, there are much lower levels of contents insurance among tenants, with many in the lowest income decile having no insurance at all"*.

Box 1 Flood insurance in the UK

Flood insurance is very common in the UK, for some internationally unique historical reasons (Penning-Rowsell *et al*., 2014b; Sayers *et al.,* 2013).

However, the situation is changing. Following the widespread autumn 2000 floods, in January 2001, the industry, through the ABI, agreed voluntarily that it would maintain flood cover for domestic properties and small businesses, but just for a period of two years. During the two years, the ABI was active in putting pressure on the Government to ensure that sufficient funds were made available to allow flood defences to be improved, thus reducing their potential liabilities.

More recently (2003-10), the Association of British Insurers (ABI), in its 'Statement of Principles on the provision of flooding insurance', indicated that flood cover would be maintained for domestic properties and small businesses where properties were currently protected to Defra's minimum indicative standard of 1 in 75 years, for urban areas, or better where improved defences to at least that standard were planned by 2007. In other locations, flood cover could not be guaranteed but would be considered on a case-by-case basis. The implementation of these principles was conditional upon specific actions from Government being carried out, on flood defence funding, development control and other matters (providing an informal cross-subsidy of reduce premiums).

We now have the third variant on the relationship between insurers and the government. Since April 2016 an arrangement termed Flood Re has created a pool into which all insurers contribute to subsidise the insurance premiums of those at greatest risk (Defra, 2014a). Householders purchasing flood insurance will not know whether they are in this pool or not, since they will deal with their conventional insurance company, but that company will cede the policy and the liability for claims to the Flood Re pool if the cost of insurance exceeds certain thresholds and certain eligibility criteria are met (including being build before 1st January 2009[3]).

The result is intended to make flood insurance affordable for those who otherwise would pay large premiums to be protected against current and future levels of flood risk, but the arrangement has a life of only twenty-five years after which the insurers and government have agreed that flood insurance becomes fully risk-reflective. Watkiss *et al*. (2016) discuss how this transition to market prices after Flood Re, noting that it is expected that, in the longer term, insurance premiums will rise substantially for those at risk, and those at most risk will pay much more than at present (in the shorter term, the proportion of people already paying a degree of risk-reflective pricing may see their premiums fall as price caps are imposed from April 2016). The transition to an actuarial accounting process could further discourage the most vulnerable for accessing insurance.

[3] Flood Re criteria: //www.floodre.co.uk/homeowner/eligibility/ Accessed May 2017

Insurance penetration levels used here are based on household expenditure survey.

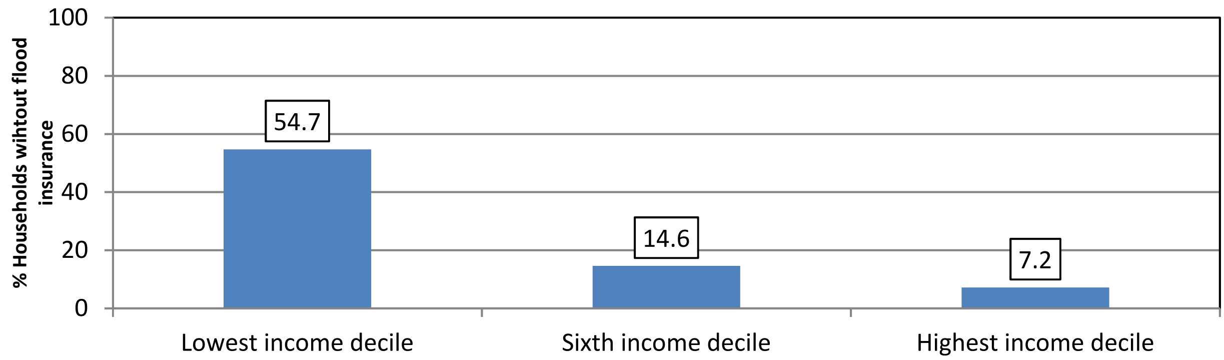
The difficulties in assigning penetration levels should also be noted:

Building cover: Using this generally means buildings cover penetration rates will be misunderstood, because the survey asks householders if they have purchased buildings cover. They may correctly answer no, because their cover should be provided elsewhere as they either rent or are a leasehold property owner. It is wrong to say therefore they do not have buildings cover for the property they are living in, they are just not responsible for purchasing it. Any renter will not be responsible for buildings insurance as this will fall to the landlord and contents insurance (with Alternative Accommodation cover) will be available for these renters, backed by Flood Re if required.

Contents cover: The relationship implied to the penetration of contents cover is probably reasonable (although without direct evidence this is difficult to determine). It is also the case that contents insurance is not tied to mortgages and Flood Re place no restriction on contents take-up (other than excluding properties build after 2009). It is recognised therefore that Flood Re encourage access for who previously have not purchased (but the evidence for this is not yet available).

Regarding the relationship between the most vulnerable communities and insurance, there are therefore several matters of concern:

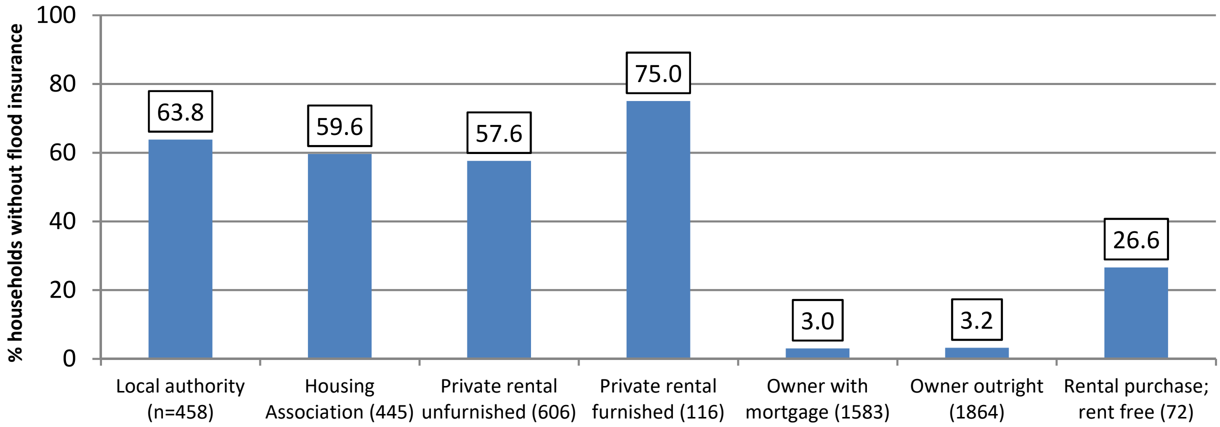
- *Insurance take-up is driven by levels of income:* The situation with regard to disadvantaged areas and flood insurance is driven by levels of income. Figure D-3 shows the marked difference in penetration levels with different levels of disposable income such that there is a 47.5 per cent difference between the lowest and highest income deciles. Disadvantaged areas are likely to be characterised by those who are on relatively lower incomes, and unable to afford insurance that will cover them against the damage that floods will bring. Within Floods Re premiums are linked the Council Tax banding as proxy for income thresholds, a link that is not without controversy.



Note: Figures are based on analysis pre-Flood Re. Source: (ONS, 2015)

Figure D-3 The relationship between household income and no flood insurance purchased (%) (income deciles 1, 6 and 10 only)

- *There are lower levels of penetration for households in rented accommodation:* Figure D-4 shows that households in rented accommodation have a far greater chance of not being insured at all, although local authorities and housing associations would be responsible for the repair of the structure of the buildings they own, if flooded, rather than the tenant, so the penetration figure here represents the penetration of contents insurance rather than domestic property insurance. Nevertheless, the difference between owner occupiers and tenants is striking, and is compounded by the fact that the private rented accommodation sector in the UK is growing quite rapidly, whereas owner occupation is declining proportionately (ONS, 2016). For structural repairs following a flood the occupants of those houses are dependent upon the landlord to fund and make any repairs. Therefore, the insurance position of the landlord is what is critical here rather than that of the tenant, and many local authorities self-insure rather than insure through the market.



Note: Figures are based on analysis Pre-Flood Re. Source: (ONS, 2015)

Figure D-4 The relationship between tenure and households with no flood insurance purchased

- *Under-insurance:* There is the question of whether this varies with different tenure types and household income levels (as take-up does, Figure D-4). In addition, excesses (deductibles) should be considered and any correlation again that there might be with tenure. However, at present, the available information here is sparse or virtually non-existent.

b) Representation of adaptation in the FFE

For those insured, flood insurance provides a mechanism for them to transfer part of their risk and reduce their vulnerability to flooding. When seen as part of a portfolio of measures to reduce or manage flood risk, flood insurance has four main roles:

- Reimbursing those who suffer damage, and thereby restoring them to their pre-flood financial situation;
- Spreading the costs of flooding across communities (and clients);
- Reducing the costs to the government of post-event recovery since the insured will receive insurance funds (note: where a private insurance sector exists only);
- Promoting a change of behaviour with regard to exposure to flood risk, by giving a signal of the hazard that people face and providing incentives for “good behaviour”.

It is only the first two of these that are of interest in this study.

Note: No quantified consideration was given to the influence of insurance with the CCRA, but its impact on reducing the loss of social well-being is significant, and the differential take-up by the most vulnerable when compared to the less vulnerable is pronounced, so it is included here.

c) Future change given a continuation of current levels of adaptation

Within the FFE, flood insurance acts to reduce the number households suffering an uninsured loss. Where flood insurance is in place it is assumed that households can cover the full economic loss caused by the flood (excesses or other constraints on what can and can not be claimed, and the difference between economic and financial losses are not considered). The insurance penetration, together with an understanding of income, is then used to estimate the "relative pain" metric that reflects the relationship between the uninsured loss and income.

To determine the extent of insurance penetration, consideration is given to:

- *Penetration of insurance:* evidence from the summer 2007 floods in England suggests that 76 per cent of household losses (building and contents) are covered by insurance (see Table 2.1, Chatterton *et al.,* 2010). We assume here that this is indicative of the penetration in all other neighbourhoods other than those that are the most vulnerable. In the most vulnerable neighbourhoods we assume there is a lower penetration of insurance (see table below).
- *Tenure of the property:* Evidence suggests that tenants are more likely than homeowners to have little or no flood insurance, and are often very significantly underinsured (ABI, 2010; ONS, 2015). Approximately 40 per cent of those in some form of rented accommodation take-up flood insurance (The Poverty Site, undated);
- *Low income:* Only one in three adults earning between £150-250 per week has home contents insurance compared with around 70 per cent of those on more than £600 per week (2015 Family Expenditure Survey, now called the Living Costs and Food Survey (ONS, 2015)). Around 55 per cent of households within the bottom 10 per cent by income have no flood insurance (ABI, 2010);
- *Direct experience of flooding:* It is unclear if direct experience of flooding affects the propensity to insure. Kates (1962) shows that direct experience triggers response, but that is not quite as direct as to say it triggers insurance. To reflect this relationship, it is assumed here that in areas prone to more frequent flooding the awareness of the risk faced is higher (and those living there are, on average, more likely to have been flooded previously. This translates to higher take-up rates in areas prone to more frequent flooding.
- *Surface water flood areas*: Insurance does not consider the source of flooding at all. It is all included, but awareness of surface water risks is much less than fluvial or coastal risks.
- *The move towards actuarial pricing after Flood Re*: The evidence presented above predates the introduction of Floods Re. Flood Re may have a positive impact on penetration but as yet this is unknown. Therefore, no adjustment is made to take account of Flood Re and no adjustment is made to reflect the loss of Flood Re in 2035.

In combination, these influences are translated into the specific changes within the FFE in accordance with the following table.

Note: WAAD represents both damage to the building and contents. Although it is recognised that penetration varies significantly between contents insurances and building insurance, and that building insurance is typically the responsibility of the owner rather than a tenant, this is not disaggregated in the assessment of relative pain here.

% penetration of insurance (residential properties)

Homeowners

Return period of flooding (years)	All other neighbourhoods			Low household income (20%ile) No history of flooding			Low household income (20%ile) Direct experience of flooding		
	Present Day - 2020	2050s	2080s	Present Day - 2020	2050s	2080s	Present Day - 2020	2050s	2080s
Coastal areas									
<75	76%	76%	76%	38%	38%	38%	45%	45%	45%
>=75-200	76%	76%	76%	34%	34%	34%	40%	40%	40%
>=200	76%	76%	76%	30%	30%	30%	35%	35%	35%
Fluvial areas									
<75	76%	76%	76%	34%	34%	34%	45%	45%	45%
>=75-200	76%	76%	76%	30%	30%	30%	40%	40%	40%
>=200	76%	76%	76%	26%	26%	26%	35%	35%	35%
Surface water areas									
<75	60%	60%	60%	40%	40%	40%	50%	50%	50%
>=75-200	60%	60%	60%	40%	40%	40%	50%	50%	50%
>=200	60%	60%	60%	40%	40%	40%	50%	50%	50%

Tenants

Return period of flooding (years)	All other neighbourhoods			Low household income (20%ile) No history of flooding			Low household income (20%ile) Direct experience of flooding		
	Present Day - 2020	2050s	2080s	Present Day - 2020	2050s	2080s	Present Day - 2020	2050s	2080s
Coastal areas									
<75	76%	76%	76%	20%	20%	20%	32%	32%	32%
>=75-200	76%	76%	76%	18%	18%	18%	28%	28%	28%
>=200	76%	76%	76%	16%	16%	16%	25%	25%	25%
Fluvial areas									
<75	76%	76%	76%	20%	20%	20%	32%	32%	32%
>=75-200	76%	76%	76%	18%	18%	18%	28%	28%	28%
>=200	76%	76%	76%	16%	16%	16%	25%	25%	25%
Surface water areas									
<75	50%	50%	50%	16%	16%	16%	20%	20%	20%
>=75-200	50%	50%	50%	14%	14%	14%	20%	20%	20%
>=200	50%	50%	50%	12%	12%	12%	20%	20%	20%

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