Present and future flood vulnerability, risk and disadvantage

A UK assessment

Assessment Methodology

Prepared for Joseph Rowntree Foundation, Climate Change and Communities Programme

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1.0 ANALYSIS APPROACH

1.1 Overview

The analysis provides an estimate of present-day flood risk across the UK based on an assessment of the flood hazard, exposure and vulnerability. Estimates of future risks, through to the 2080s, then account for the influences of both endogenous and exogenous drivers on these three issues (Figure 1).

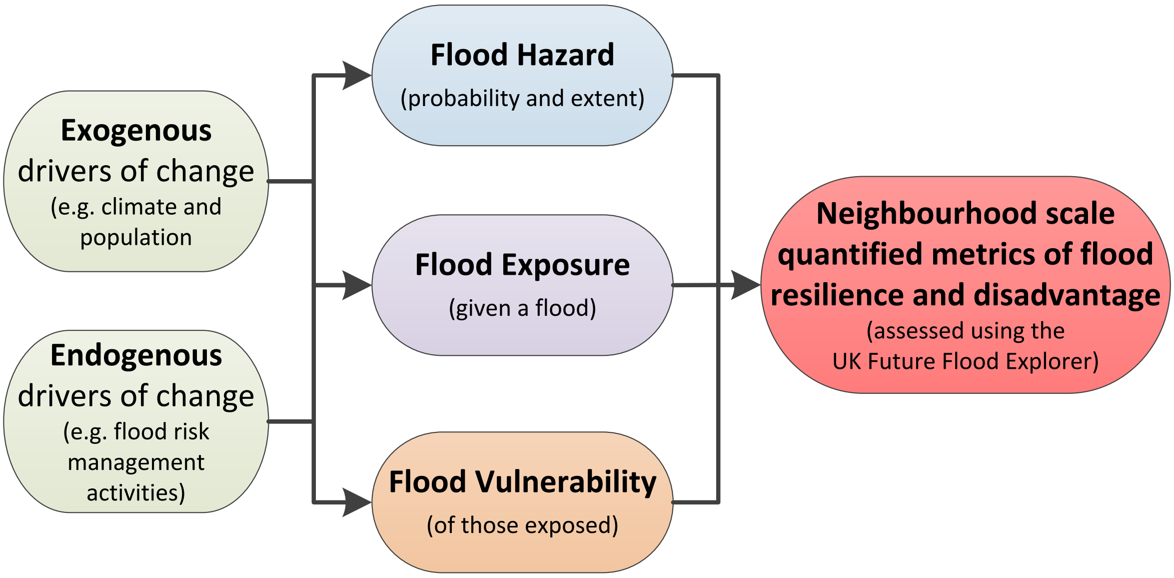

Figure 1 Framework of analysis

The scope of each aspect of the analysis is outlined below with additional information provided in the following section and, where appropriate, supporting appendices.

Flood hazard

Two aspects of the flood hazard, probability and spatial extent, are considered in the context of three sources of flooding; **fluvial** (river), **coastal** and **surface water** (pluvial) flooding.

Two aspects of the flood hazard are considered for each source as follows:

- **Probability** is defined here as the annual exceedance probability of a flood to any depth. The lead authorities in England, Wales and Scotland all assess the flood probability using slightly different bandings and make varying assumptions regarding the performance of flood defences. The Future Flood Explorer interprets this information to provide a coherent assessment of probability that reflects the performance of defences where they are known to exist (as described in detail in Sayers *et al*., 2015a, 2016).
- **Spatial** resolution of the probability reflects the native resolution of the national flood hazard data used in the development of the Future Flood Explorer. This data varies in resolution as follows:
    - *Fluvial flooding* – the resolution used is 50m in England and Wales and 5-20m for Scotland.

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- *Coastal flooding* – the resolution used is 50m in England and Wales and 5m for Scotland.
- *Surface water flooding* – the resolution used is 2m in England and Wales and 5m for Scotland.

Note: No consideration is given to groundwater flooding. This is because of the relatively low importance of groundwater flooding at a national scale when compared with fluvial, coastal and surface water (see Sayers *et al.,* 2015) and the difficulty of providing a credible assessment. Given the context of the study no consideration is given to the joint probability of flood sources – this is however a potential further extension although care will be needed to avoid adding unnecessary complexity to the analysis.

Flood Exposure

Residential property data (based upon national point datasets) together with locally representative household occupancy rates (from census data) are used to quantify the number of people that may be flooded during a given flood event and subject to a potential loss of well-being.

The location of a single residential property is taken from national receptor datasets, namely:

- England and Wales: National Receptor Dataset (NRD) – Dated 29/10/14.
- Scotland: Scottish Property Dataset (SPD) – Dated 29/01/2015.

These supporting datasets identify individual residential property footprints and provide information on the likely number of households at ground floor within a given footprint (Figure 2). Information on the percentage of properties with a basement within a given neighbourhood is taken from the 2001 Census.

Note: There are known errors associated with these datasets (see Sayers et al., 2015c – Appendix G) but they are assumed here to be fit for purpose in the context of residential property locations.

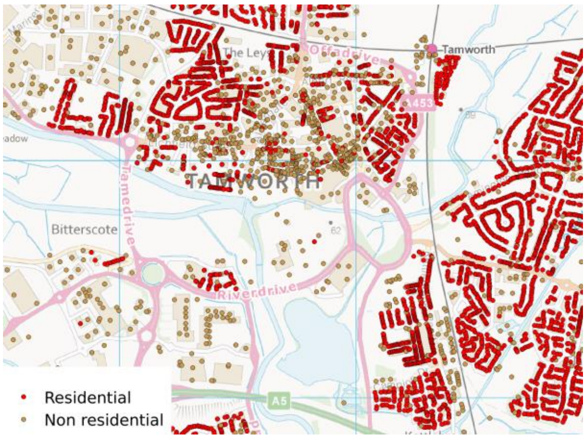


Figure 2 National receptor datasets are used to identify the location of residential properties.

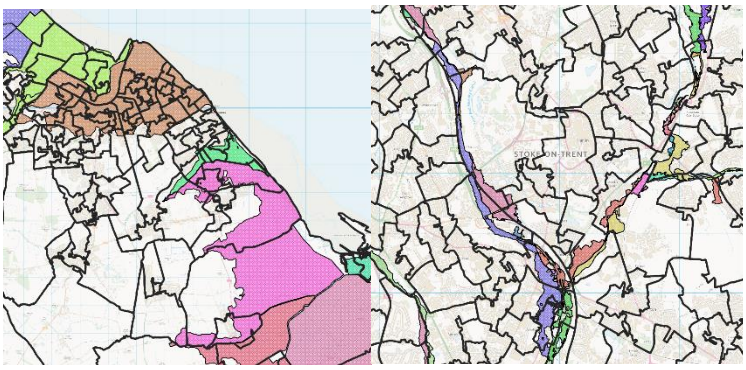
Flood Vulnerability

Census data for 2011 is used to assess the susceptibility of individuals to experience a loss in well-being when exposed to a flood as well as their ability to prepare, respond and recover from a flood (without significant emergency support from the authorities).

Social vulnerability can be extremely localised, to a specific street, household or individual. Analysis at such a localised scale is not practical in the context of this study (although possible in principle). The concept of the 'neighbourhood' is therefore used as a small, but aggregated, spatial unit for assessing socio-economic factors. A neighbourhood is defined by census geographies (i.e. Lower Super Outputs Areas (LSOAs) in England and Wales and Data Zones (DZs) in Scotland.

Using these as the basis for the analysis of neighborhoods, provides several advantages over previous studies:

- ***Improved homogeneity of socio-economic indicators*****:** Using a smaller scale improves our ability to identify areas of disadvantage.
- ***Improved resolution of the risk analysis that provides a balance between resolution and practicality***: The FFE has been reconfigured based on so-called Census Calculation Areas (CCAs); created using census geographies but attributed with the flood defence characteristics of the Calculation Areas (the spatial resolution of the FFE used in support of the CCRA, Sayers *et al*., 2015a, 2016). This enables the FFE to operate at CCA level, and produce information on flood risk at a more refined spatial scale that is directly linked to census data. There are approximately 500,000 CAs in the UK (covering coastal, fluvial and surface water floodplains); introducing the neighbourhood scale increases this to approximately 800,000 CCAs. This is a feasible number for use in the FFE. Using any smaller units (e.g. census output areas) may lead to too great a computational burden and may convey a false sense of precision.



Left: Coastal Calculation Areas (coloured) overlain with LSOA boundaries (bold black lines)

Right: Fluvial Calculation Areas (coloured) overlain with LSOA boundaries (bold black lines)

Figure 3 Census Calculation Areas (used here) and Calculation Areas (used in CCRA, Sayers et al., 2015b)

- ***Normalising neighbourhood size:*** The scale of a 'neighbourhood', based on the census area definitions, provides a balance between resolution and practicality. The three census-based definitions of 'neighbourhood' however vary in size and population count across the UK, with DZs in Scotland covering, in general, a smaller area and population than LSOAs (see below). To overcome the bias this introduces, metrics are either aggregated to larger areas that represent geographic lenses of interest, or normalised to be risks 'per person on the floodplain'.

Table 1 Comparison of Census areas used to describe 'neighbourhoods'

Area (ha)	10%ile	50%ile	90%ile	Average
England and Wales – LSOA	18	47	1,000	430
Scotland – DZ	9.7	23	1,900	1,200
Population	10%ile	50%ile	90%ile	Average
England and Wales – LSOA	1,300	1,600	2,000	1,600
Scotland – DZ	540	750	980	760

Note: A more detailed breakdown of the census datasets and sources used to support this provided in the discussion on Neighbourhood Flood Vulnerability Index (NFVI) and its supporting variables.

Exogenous future change

Two drivers of change, outside of FRM policy, are considered to influence future flood risk:

Climate change

Two climate projections are considered, a 2^{o}C and 4^{o}C rise in Global Mean Temperature (GMT) by 2080s (from the 1961-90 baseline as used in UKCP09). These are the same as those used for the UK Climate Change Risk Assessment (CCRA, as set out in Sayers *et al*., 2015b). For each projection, consideration is given to changes in mean sea level, peak fluvial flows and short duration rainfall, all of which act to change the probability of flooding.

Note: No consideration is given here to the growth of the floodplain that may result from climate change. Only the probability of flooding within the present day, undefended, 1:1000 year return period floodplain is considered. Notwithstanding the potential expansion of the floodplain under more extreme assumptions of sea level rise (as explored in Sayers *et al.*, 2015a and subsequent discussion in Edwards, 2017) this static, but broad, definition of the floodplain is considered a reasonable assumption in the context of this study.

More detail on the projections used can be found here: Sayers, P. B., Horritt, M. S., Penning-Rowsell, E. and Mckenzie, A. (2015). **Climate Change Risk Assessment 2017: Projections of future flood risk in the UK** – **Appendix C: Climate change projections**. Sayers and Partners LLP report for the Committee on Climate Change.

Population growth

The Office for National Statistics (ONS) produce population projections for England, Wales, Scotland and Northern Ireland to 2100, with sub-national population projections to 2037 (ONS, 2014). The Adaptation Sub-Committee (ASC) extrapolated this data to provide population projections to 2100 for Low, Principal and High population growth variants at a local authority level (Sayers *et al.,* 2015c).

The Low and High variants used here generally indicate a growth in population (particularly London and the south-east of England). The only exceptions to this are in Northern Ireland (where, under the low growth variant, population decreases slightly by 2080s) and in Wales (where, under the low growth variant, population decreases slightly between the 2050s and 2080s).

Locally applicable property occupancy rates (derived at neighbourhood scale based on property and census data) are used to translate the population projections to the construction of new residential properties on the floodplain (after taking appropriate account of spatial planning).

Note: No consideration is given to economic growth. Exploring the influence of differential economic growth across social characteristics of flood disadvantage is beyond the scope of this study. It is therefore assumed that economic differentials remain unchanged in the future and monetary losses are expressed at present day values (without discounting).

No consideration is given to the potential expansion of the undefended floodplain in response to climate change, only the probability of flood changes.

More detail on the projections used can be found here: Sayers, P. B., Horritt, M. S., Penning-Rowsell, E. and Mckenzie, A. (2015). **Climate Change Risk Assessment 2017: Projections of future flood risk in the UK – Appendix B: Population growth projections.** Sayers and Partners LLP report for the Committee on Climate Change.

Demographic change (Age profile)

Between 2014 and 2025 the numbers aged over 75 are expected to increase by 37% (2.2 million). This compares to an expected growth of 8% in population as whole (ONS 2014 principal projection). Growing numbers of elderly people, and the increasing number of under 5 year olds projected to occur from around the 2040s, could have a significant influence on overall vulnerability. However, given that the ONS 2014 principal projections for the Under 5s and Over 75s provide no information on change in the spatial distribution of age this has no impact on the NFVI or SFRI z score ranking. The age projection does however impact the number of elderly and very young people that may be at risk.

Endogenous future change

Purposeful actions taken to directly control or strongly influence future flood risk increasingly include a broad range of responses. This 'whole system' approach is reflected here through eight individual adaptation measures (Figure 4). To determine the effectiveness of each adaptation measure in managing future risk it is assumed that current **FRM policies continue to be implemented as effectively as they are today**. In the context of a national analysis, the effectiveness of individual adaptation measures is often considered to be independent of social vulnerability (as for example within the CCRA, Sayers *et al.,* 2015a). To overcome this short-coming, the analysis presented here differentiates the effectiveness of individual adaptation measures based on vulnerability (where there is some evidence to do so).

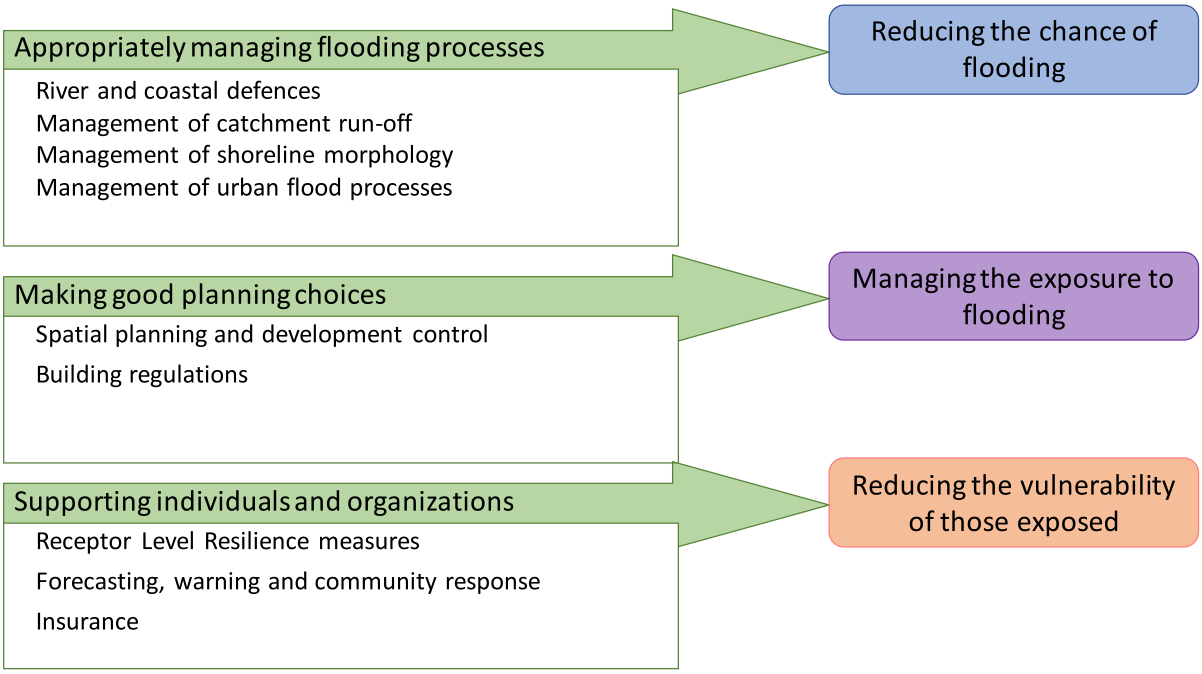


Figure 4 Endogenous change: Adaptation measures considered as part of a continuation of current levels of adaptation

Note: It is recognised that across the UK FRM takes place as a continuous process. Planned schemes and activities for specific locations, not yet completed, are not included here. Further detail on the forward plan can be obtained from the FRM leads for each part of the UK.

Important caveats

There are some important caveats that relate to representation of all adaptation measures within the analysis and the variation in national policies between England, Wales and Scotland as well as also the local context within which risks are managed. These are summarised in Box 1-1.

Box 1-1 Individual adaptation measures: Important caveats

National policies and implementation vary: The contrasting FRM legislation and the approaches adopted across England, Wales, Scotland and Northern Ireland mean that the emphasis of past adaptations and the mix of future adaptation measures that may be used will differ (and perhaps markedly) across the UK. In developing the individual adaptation measures it has been necessary to develop a single UK wide assessment of their effectiveness. In some instances, achieving this single view is difficult. For example, Scotland has a stronger policy focus on natural flood management than elsewhere in the UK. In England, however, take up of flood warning services is much more widespread. These, and many other differences (as set out in Sayers et al., 2017 Appendix D), have been considered in developing a representative description of the effectiveness of each adaptation measure. In most cases a greater emphasis has been placed on policies that have the potential to influence risk the most. Any future development of the FFE could consider adaptation measure variations for each country (whilst continuing to analyse risk in a consistent way across the UK).

Actions outside of FRM: Although an increase in residential properties is assumed to occur alongside population growth, no consideration is given to broader developments that would be needed to reflect or support that growth (*i.e.* new schools, hospitals etc.) nor the actions taken by those providers to safeguard their services during a flood.

Local context is important: The applicability and effectiveness of a given mix of adaptations will reflect the local context within which they are applied. This local context is in part embedded within the description of the individual adaptation measures. For example, the degree to which climate change reduces the Standard of Protection provided to an area reflects the present-day standard in that area. This means that parts of the floodplain protected to a higher standard today continue to have more effort devoted to them in the future. The consideration of specific local constraints and opportunities that will determine the feasibility of specific adaptation measures at a local level is, however, not considered.

Continuous process of adaptation: It is recognised that across the UK FRM takes place as a continuous process. Planned schemes and activities for specific locations, not yet completed, are not included here. Further detail on the forward plan can be obtained from the FRM leads for each part of the UK.

Sayers, P.B., Horritt, M., Penning Rowsell, E., and Fieth, J. (2017).

2.0 Analysis method: The future flood explorer (UK-FFE)

A development of the UK Future Flood Explorer (FFE) - the same modelling framework used in the UK Climate Change Risk Assessment, CCRA (Sayers *et al.,* 2015a, 2016) – is used to behaviour of the UK flood risk system that can then be used to assess present day flood risks (for a range of metrics) and the change in risk given a range of influences (such as climate change, population growth and adaptation), including actions to manage the probability of flooding as well as those that influence exposure and vulnerability).

The high computational efficiency of the FFE allows a consistent assessment of flood risk across England, Wales, Scotland and Northern Ireland under the multiple scenarios of interest here (*e.g.* two climate change projections, +2°C and +4°C rise in Global Mean Temperature, low and high population projections and taking accounting of future adaptation).

Building upon the analysis completed for the CCRA, the FFE has been revised and enhanced in three areas for application here: the spatial resolution of the analysis, the characterisation of flood vulnerability, and adaptation to flood risk differentiated by the vulnerability of the communities affected. The importance of these advances is discussed below.

Spatial resolution of the analysis

The underlying spatial resolution of the flood hazard data varies across the UK and ranges from 2m-50m (depending upon flood source and location). Exposure data used is based on residential point datasets (and hence has the resolution of a single property). This does not however imply the results are credible at these scales. The concept of the 'neighbourhood' is therefore used as a small, but appropriately aggregated, spatial unit for aggregation of flood hazard and exposure with census based vulnerability data. Neighbourhoods correspond to Lower-level Super Output Areas (LSOAs) for England and Wales, Super Output Areas (SOAs) for Northern Ireland, and Data Zones (DZs) for Scotland. There are 42,619 neighbourhoods in the UK. The average population in each of these areas varies by country: 1600 in England, 760 in Scotland, 1600 in Wales and 2000 in Northern Ireland. This represents an evolution of the previous assessments of flood disadvantage for England and Wales (Lindley *et al.,* 2011, based upon Middle Layer Super Output Areas, MSOAs) and maintains the resolution of previous studies in Scotland (Kazmierczak *et al.,* 2015).

Neighbourhoods are used in aggregation and reporting of FFE outputs, and are also the basic unit at which census based vulnerability is calculated.

Characterisation of flood vulnerability

FRM policy typically considers vulnerability through the lens of deprivation (as indicated by the Index of Multiple Deprivation) and this view provided the basis of the analysis presented in the CCRA (Sayers *et al.,* 2015a). A focus on deprivation however does not necessarily reflect a community's vulnerability to a flood should it occur (although vulnerability is influenced by income deprivation, as clearly demonstrated by Tapsell *et al.,* 2002). To overcome this short-coming, and build on the characterisation of flood vulnerability advanced by Lindley *et al.,* (2011) and more recently by Kazmierczak *et al.,* (2015), a new measure is introduced here: the **Neighbourhood Flood Vulnerability Index** (NFVI). The FFE has been extended to include the representation of the NFVI.

More detail on NFVI and the indicators used to calculate it are provide in main report and Appendix B (Sayers et al., 2017) and summarised in **'Sayers at el 2017 - Present and future flood vulnerability risk and disadvantage - NFVI and Vulnerability Indicators'.**

Differential capacity to adapt

In the context of a national analysis, the effectiveness of individual adaptation measures (Figure 4) is often considered to be independent of social vulnerability (as for example within the CCRA, Sayers *et al.,* 2015). To overcome this short-coming, the analysis presented here differentiates the effectiveness of individual adaptation measures based on vulnerability (where there is some evidence to do so).

More detail on each individual adaptation measure, how it effectiveness has been differentiated between more and less socially vulnerable communities and the supporting evidence, is provided in main report and Appendix D (Sayers *et al.,* 2017).

3.0 Metrics of flood exposure, vulnerability and risk

The degree of social flood resilience and disadvantage is therefore interpreted through a series of quantified expressions of exposure, vulnerability and risk (Table 2).

Table 2 Vulnerability and risk metrics used to determine the degree of social flood resilience

Metric	Insight provided
Exposure metrics	
Floodplain population (FP)	The scale of the potential exposure within a neighbourhood in the absence of defences.
Expected Annual Probability of flooding: Individual (EAI)	An individual's annual 'average' exposure to flooding, taking account of defences. Athough not representative of any specific individual this provides a means of comparing the 'average' exposure between neighbourhoods.
Number of People Exposed to Frequent Flooding (PEFf)	The number of people exposed to flooding more frequently than 1:75 years, on average.
Vulnerability metrics	
Neighbourhood Flood Vulnerability Index (NFVI)	The propensity of those living in a neighbourhood to suffer a loss of well-being should a flood occur.
Risk metrics	
Expected Annual Damages (EAD) - Residential only	The annual 'average' direct economic damages, in monetary terms, taking account of defences.
Expected Annual Damage: Individual (EADi)	The average (economic) risk faced by an individual living within the floodplain. Although not representative of the risk faced by any specific individual this provides a means of comparing risks between neighbourhoods.
Relative Economic Pain (REP)	The 'relative pain' of the economic risks faced by those exposed to flooding (expressed as the ratio between uninsured economic damages and household income).
Social Flood Risk Index (SFRI)	The level of social flood risk (a combination of exposure, vulnerability and probability of flooding), at a neighbourhood scale (SFRI) and as an individual 'average' (iSFRI).

These headline metrics include a combination of traditional risk metrics and new metrics developed here. Each metric is discussed in turn below.

Metrics of exposure

Floodplain population (FP): This is an estimate of the number of people living (not working) within the floodplain within a given neighbourhood. The estimate is made by combining the average occupancy rate of a household within a given neighbourhood and the number of residential properties that would be exposed to flooding with a return period of 1:1000 years or more frequent (in the absence of defences, where they exist). This metric also considers the number of people in areas exposed to surface water flooding with a return period of 1:1000 years or more frequent, even though these areas are not in what are traditionally thought of as floodplains.

Note: This metric does not change with climate change. This is because the floodplain extent, defined by the present day 1:1000-year return period flood, is assumed to remain unchanged in the future (although flood probability within the floodplain does change). This is not a true representation, as floodplains are likely to extend further (in the absence of defences) with climate change, but is considered reasonable given the most significant impact of climate change on surface water and fluvial floods is likely to be the change in probability of flooding. At the coast this assumption is more challengeable under more extreme sea level rise assumptions (beyond those considered here) and was explored in the CCRA (Sayers *et al.,* 2015a). This metric does, however, change with population growth.

Expected annual probability of flooding: Individual (EAI): The expected annual probability of an individual experiencing flooding is calculated by combining the spatial variation in the annual probability of flooding to any depth with the location of individual residential properties and neighbourhood average occupancy rate. In doing so, the EAI is used to provide a people-focused annual 'average' exposure to flooding.

Note: EAI is calculated at a neighbourhood level and is an average value for those living within the 1:1000-year floodplain (or surface water equivalent) within that neighbourhood and is not associated with a specific individual.

Number of People Exposed to Frequent Flooding (PEFf): A focus on expected values alone (*e.g.* EAI above) can mask important differences in the profile of the risk faced between neighbourhoods. For example, an area with many people exposed to very infrequent flooding would yield the same estimate of EAI as an area where only a few people are exposed to frequent flooding. This metric (PEFf) therefore focuses on the number of people exposed to flooding more frequently than 1:75 years (on average). To enable a valid comparison between areas the PEFf is expressed as an average value per head of those living within areas exposed to a probability of flooding of 1:1000 or greater (and within the aggregation area of interest).

Note: To quantify exposure to flooding, only those living on ground floor or basement properties are considered in England and Wales; for Scotland, all properties are included; for Northern Ireland ground floor properties only are included, and additional multiple properties within the same building footprint are not counted. These differences in the treatment of properties stem from the different data sets used in each country. No distinction is made between those living in a basement flat and those living on the ground in terms of exposure. It is however assumed that basement properties suffer more economic damage (by a factor of 1.5 owing to likely greater impact of a flood on household inventory items stored there: personal communication with Edmund Penning-Rowsell) compared to an equivalent ground floor property experiencing the same return period flood (see risk metrics).

In some texts, the term 'exposure' incorporates the chance that a person will be present when a flood occurs (*e.g.* Hartford and Baecher, 2004). Under this more nuanced interpretation fewer people may be exposed in a predominantly residential floodplain during the day because they are away at work, or because they have successfully evacuated the area in response to a warning. This is not done here.

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Metrics of vulnerability

Neighbourhood Flood Vulnerability Index (NFVI): A new index, Neighbourhood Flood Vulnerability Index (NFVI), is used to provide insight into the social vulnerability of a neighbourhood should a flood occur. The NFVI combines the five domains of vulnerability based upon a subset of twelve 'vulnerability indicators'. These are summarised in Figure 5 and discussed in detail in the Climate Just technical document together with the associated process of weighting.

More detail on NFVI and the indicators used to calculate it are provide in main report and Appendix B (Sayers et al., 2017) and summarised in **'Sayers at el 2017 - Present and future flood vulnerability risk and disadvantage - NFVI and Vulnerability Indicators'.**

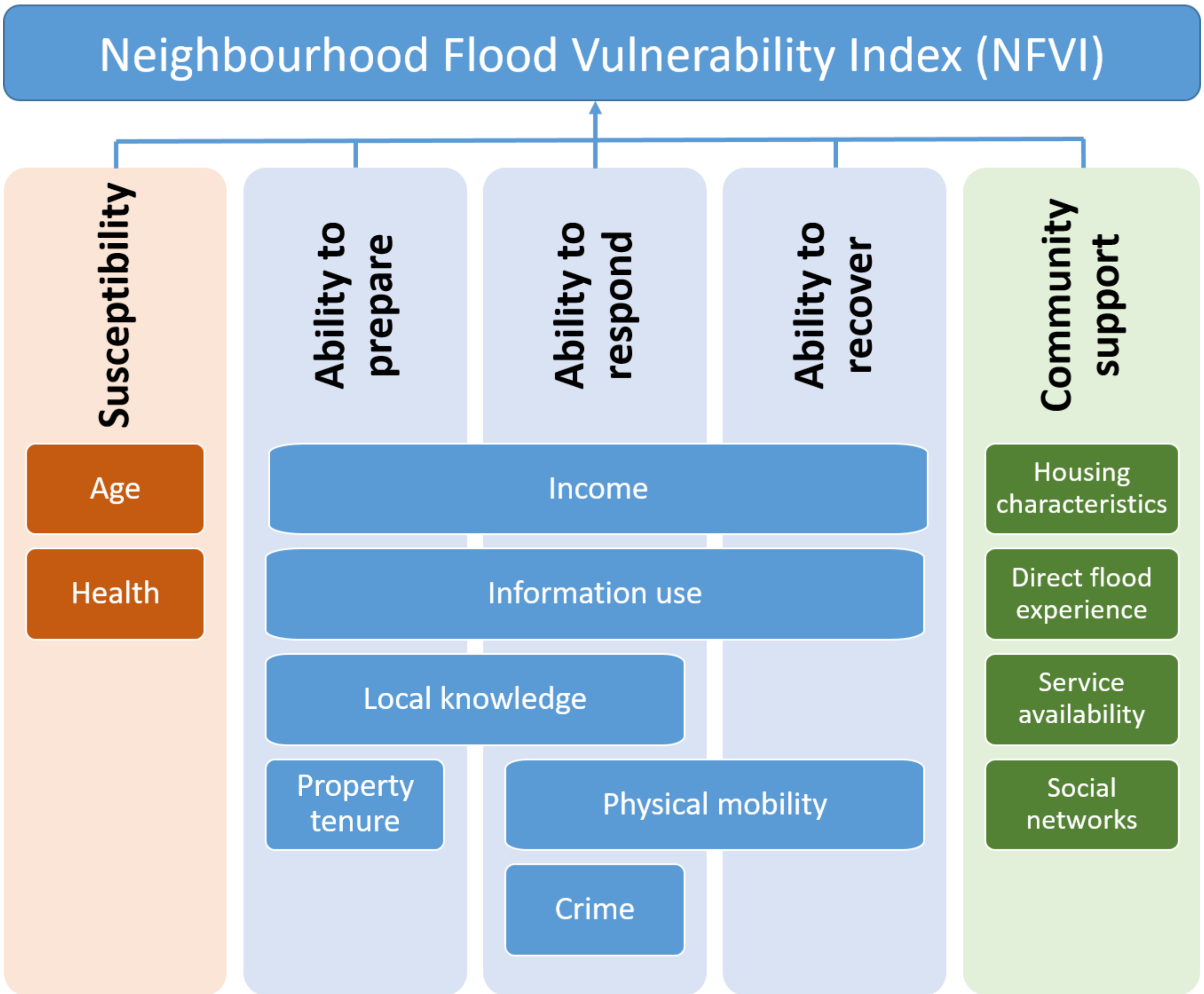

Figure 5 Neighbourhood Flood Vulnerability Index: Influential domains and indicators

Metrics of flood risk

Expected Annual Damages (EAD): This provides the conventional view of risk that estimates the Expected Annual Damages in national economic terms. The assessment of EAD used here combines the annual probability of a residential property being flooded and the associated direct economic damages. It uses the Weighted Annual Average Damage (WAAD) methodology (Penning-Rowsell *et* *al.,* 2013; Sayers *et al.,* 2015a) to estimate the direct economic damage to residential properties with an uplift of 1.5 applied to the proportion of properties with basements (as determined through the 2005 census data).

Note: The focus is on economic loss to the UK and not the financial loss that may be incurred by an individual. Wider social impacts (such as monetisation of mental health impacts) are also excluded. No consideration is given here to indirect damages (such as the consequential costs on the public purse of supporting short- and long-term recovery) or wider impacts, such as the valuation of the health impacts (physical and mental).

Expected Annual Damage: Individual (EADi): This provides an estimate of the average (economic) risk faced by an individual living within the floodplain with a given neighbourhood. Although not representative of the risk faced by any specific individual, this provides a valid means of comparing risks between areas.

Relative Economic Pain (REP): In recognition of the varying coping capacity between more affluent and lower income households, this metric captures the relationship between uninsured economic damages and household income. The REP is used to express the 'relative pain' of a risk and is defined here as:

REP = (1- insurance penetration) x Expected Annual Damages (direct residential) per household within the floodplain / Average income per household within the neighbourhood.

Note: As previously noted (see EAD), the damages calculated here are economic losses, whereas the impact of flooding on uninsured households is related to the financial losses. The *REP* metric should therefore not be viewed as directly representing the impact on household finances, but is nevertheless a useful metric relating losses to income and insurance take-up. No consideration is given to issues of excess, deductibles or exclusions (including uninsured impacts, such as long-term physical or mental health that may be associated with a flood).

In assessing the REP, household income is taken from the appropriate census data sources for each constituent county. These are generally available at a larger spatial scale than the census areas used in this study (*e.g.* MSOA for England and Wales rather than LSOA), and are therefore sampled down to the appropriate scale. Values for Northern Ireland are only available at Local Government District level, and therefore do not, for example, differentiate between richer and poorer areas of Belfast.

Social Flood Risk Index (SFRI): A third new risk metric, the SFRI, is used to identify those areas where the largest number of the most vulnerable people are exposed to frequent flooding. The SFRI therefore directly supports an understanding of Geographic Flood Disadvantage and is estimated at both a neighbourhood scale and as an individual 'average' as follows:

- SFRI helps identify those areas where many vulnerable people, as defined by the NFVI, are exposed to flooding and is calculated as follows:

  SFRI = Expected Annual Probability of Flooding: Individual (EAI) x Number of people within the floodplain (FP) x Neighbourhood Flood Vulnerability Index (NFVI).

- *Social flood risk index: Individual* (iSFRI) helps identify those neighbourhoods where the vulnerability of those exposed is high (even when only a few people may be exposed) and is calculated simply by dividing the SFRI by the floodplain population, to give:

  SFRI Individual = Expected Annual Probability of Flooding: Individual (EAI) x Neighbourhood Flood Vulnerability Index (NFVI).

Note: The SFRI is a relative index and has no units; the greater the value, the higher the level of social flood risk.

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