Flood vulnerability, risk and social disadvantage: Current and future patterns in the UK

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Abstract

Present day and future social vulnerability, flood risk and disadvantage across the UK are explored using the UK Future Flood Explorer. In doing so, new indices of neighbourhood flood vulnerability and social flood risk are introduced and used to provide a quantitative comparison of the flood risks faced by more and less socially vulnerable neighbourhoods. The results show the concentrated nature of geographic flood disadvantage. For example, ten local authorities account for fifty percent of the most socially vulnerable people that live in flood prone areas. The results also highlight the systematic nature of flood disadvantage. For example, flood risks are higher in socially vulnerable communities than elsewhere; this is shown to be particularly the case in coastal areas, economically struggling cities and dispersed rural communities. Results from a re-analysis of the Environment Agency's Long-Term Investment Scenarios (for England) suggests a long-term economic case for improving the protection afforded to the most socially vulnerable communities; a finding that reinforces the need to develop a better understanding of flood risk in socially vulnerable communities if flood risk management efforts are to deliver fair outcomes. In response to these findings the paper advocates an approach to flood risk management that emphasizes Rawlsian principles of preferentially targeting risk reduction for the most socially vulnerable and avoids a process of prioritisation based upon strict utilitarian or purely egalitarian principles.

Keywords: Flood, risk, social vulnerability, disadvantage, social justice, climate change, climate justice

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Introduction

Developing a better understanding of flood vulnerability in disadvantaged communities is a prerequisite for delivering a socially just (i.e. fair) approach to prioritising flood risk management (FRM) efforts. Such an approach emphasises Rawlsian principles of preferentially targeting risk reduction for the most socially vulnerable, and avoids a process of prioritisation based upon strict utilitarian or purely egalitarian principles (Johnson *et al.,* 2007), and is recognised as a central component of a strategic approach to flood risk management (Sayers *et al,* 2014).

Social vulnerability in the context of floods relates to how flooding impacts on, and creates losses in, people's wellbeing (Tapsell *et al.,* 2004, Lindley *et al.,* 2011, England and Knox, 2015). Delivering socially just FRM thus requires two central research questions to be addressed. The first relates to the geographic nature of flood disadvantage and the ability to identify those communities where high levels of social vulnerability combine with a large number of people exposed to flooding. The second relates to the systemic nature of flood disadvantage and the ability to assess the degree to which FRM policy (and its implementation in practice) can be consider successful in delivering socially just outcomes (as expressed by the comparative risks faced by the most socially vulnerable communities when compared to the average).

Following a short discussion of the concept of 'fairness', the analysis presented here explores the geographic and systemic aspects of flood disadvantage today and how these may change in the future. In doing so, the influences of changes exogenous to FRM (*e.g.* climate change and population change) and influences that are largely endogenous to FRM (*e.g.* FRM policy and its broader impacts on issues such as insurance) are considered. Both present-day and future flood disadvantage are explored through a quantified analysis at a UK scale (using the UK-Future Flood Explorer, UK FFE, Sayers *et al.*, 2015, 2016). Based on this evidence, a series of policy recommendations are made with the aim of promoting social justice and improving resilience in the most socially vulnerable communities across the UK.

What is meant by a 'fair' approach to FRM

Notions of social justice have long been debated by philosophers and theologians. The purpose of this paper is not to provide new philosophical debate but rather to consider how these concepts inform (or not) FRM and how they can be used to frame a quantitative national assessment of 'fairness'. Interpreting social justice in the context of FRM is not however straightforward. This is because the nature of 'justice' is disputed, and can be seen from many perspectives (*e.g*. Vojinović and Abbott, 2012). Three broad theories are however generally accepted as central to these discussions (Johnson *et al.,* 2007, Penning-Rowsell *et al.,* 2016, Sayers *et al.,* 2017).

First utilitarianism, as introduced by Jeremy Bentham, 1748-1832 and John Stuart Mill 1806-1873, provides the underpinning advocacy for a benefit cost approach to determine the worthwhileness of an investment in a single intervention measure (or portfolio of measures). In FRM practice however utilitarianism often defaults to a rather narrowly defined cost benefit approach that tends to consider only those benefits and costs that can be readily monetised and often fails to take account of complex externalities, such as the impact on ecosystem health (e.g. Sayers, 2017) and the wider social impacts of flooding (*e.g.* the significant costs of mental health impacts from floods may still fall on the public purse but to other government departments than those financing FRM, Waite *et al.*, 2017). The implementation of FRM measures is often criticized because of this narrow focus and its tendency to suggest that it is preferable to maximise the collective outcome for the many to the detriment of the few; thereby prioritising efficiency over all other considerations.

Secondly, egalitarianism, or rights based theories of justice, recognise that the framework of society (its laws, institutions, policies, *etc.*) give rise to variations in the distribution of benefits and burdens across the members of that society (*e.g.* Sen, 1992). Egalitarianism is concerned with this distribution (distributive justice) and seeks to ensure that all citizens have equal opportunity to have their risk managed and have equal voice in decision-making processes and governance (procedural justice). Both of these general propositions influence FRM. In some countries, such as the Netherlands, the principle of 'solidarity' seeks to provide a high level of flood safety for all individuals (*e.g.* van Alphen, 2014) despite the implications for resource efficiency. In UK, the combination of the significant spatial heterogeneity in the flooding process, the long history of urbanisation and the associated significant sunk investment in flood defences means that such an approach, even if achievable, would be either grossly inefficient (diverting resources from more beneficial activities) or not meaningful for those affected (*e.g.* if the minimum level of safety would need to be set very low, to be practical everywhere (Defra, 2004)). This does not mean however that no effort is made to maximise the number of people that have their risk managed. The incremental Benefit:Cost Ratio (iBCR) test applied in England, for example, examines the marginal increase in benefits compared with the marginal increase in costs associated with delivering a progressively higher standard of protection (Defra, 2014b). This approach attempts to support utilitarian efficiency and distributive equality by directing limited national investment towards maximising the number of properties and their occupants provided with a minimum degree of protection, and away from providing higher standards in a few locations (despite the latter achieving a greater economic return).

Finally, a Rawlsian perspective promotes a theory of justice in which 'fairness' plays a central role (Rawls, 1971). Rawls argues that a 'fair' approach seeks to maximise the minimum outcomes by making the choice that produces the greatest return for the least advantaged (the so-called *'maximin rule'*). This is a powerful concept that suggests even if considerations of efficiency indicate differently, it may be 'fair(er)' to spend taxpayers' money unevenly if it maximises the benefits for those who have little welfare resource. The delivery of forecast and warning services is often implicitly Rawlsian, for example, typically providing information in multiple languages and prioritising the physically disabled (Environment Agency, 2009). The only direct expression of Rawlsian principles within the FRM investment decision-making process however is in the formula used to determine the maximum contribution to a specific FRM scheme from general taxation. Through the Flood Defence Grant-in-Aid (FDGiA) formula (Defra, 2011) preferential weighting is given to schemes that reduce flood risk to deprived households (as defined by the Index of Multiple

Deprivation)[b]. The outcomes from investment in FRM for the 20% most deprived households are also explicitly monitored at a national level (*i.e.* Outcome Measures 2a[c]). No consideration, however, is currently given to degree to which this outcome is proportionally fair. It is also the case that HM Treasury guidance (that sets out the governing principles of economic appraisal to be used by UK central government, HM Treasury, 2003) is based on the concept of welfare economics and provides an opportunity to incorporate equity weightings, noting that the distributional implications of alternative options must be 'c*onsidered during an appraisal and promotes the use of distributional weights to adjust explicitly for distributional impacts in the benefit cost analysis'*. Such adjustments are however seldom made in FRM practice.

Although these theories have been explored in a number of projects (e.g. Johnson *et al.*, 2007; Nada-Rajah, 2010, Kind *et al.*, 2017), and 'fairness' has been recognised as part of 'good' strategic FRM (Defra, 2013; Sayers *et al.*, 2014), there has been little quantification of the degree to which FRM delivers 'fair' outcomes for socially vulnerable communities and how climate change and current adaptation efforts may influence these outcomes. The need to address this latter topic is increasingly recognised at a global scale (*e.g.* Hallegatte *et al.,* 2016) as well as within the UK and is the motivation for the analysis presented here.

Why assess 'fairness' of flood risk management at a national scale

National assessments of flood risk are widely recognised as providing important evidence to inform policy decisions (*e.g.* Penning-Rowsell, 2015). Such assessments have been pursued actively by the Environment Agency since 2002 (covering England and Wales, *e.g.* Sayers *et al.,* 2002, Hall *et al.*, 2003) and their predecessors since 1998 (Burgess *et al.*, 2000), and more recently by Scottish Environment Protection Agency (SEPA) since 2011. This importance arises because of the role of a national level determination of risk in setting the pace of adaptation and shaping the policy response and resource inputs (*e.g.* Environment Agency, 2009; Defra, 2011). Their importance has been further strengthened through the Climate Change Act 2008 that requires a UK-wide *Climate Change Risk Assessment* (CCRA) to be undertaken on a five-yearly cycle that is independent of national FRM authorities but which influences the scale and focus of adaptation measures (Committee on Climate Change, 2016). The assessment of flood risk at a national scale is consequentially the fundamental basis for policy making and the directing of risk reducing investment.

The *Climate Change Risk Assessment - Future Flooding Studies* (Sayers *et al.,* 2015), for example, suggests that in a +4^{o}C climate future (an extreme but plausible assumption) flood risk is likely to increase despite on-going efforts to adapt and encourage the adoption of an 'enhanced whole systems' approach to adaptation. The evidence provided to national policy makers has, to date, however included very limited insight into either geographic or systemic flood disadvantage and the CCRA says little about future flood disadvantage or the policy responses that may be needed to specifically target socially vulnerable communities. The absence of a social justice lens also permeates the Environment Agency's programme of

[b] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/297377/LIT_9142_dd8bbe.pdf Accessed June 2016

[c] http://webarchive.nationalarchives.gov.uk/20140328084622/http://www.environment-agency.gov.uk/research/planning/122070.aspx Accessed January 2017

flood and coastal erosion risk management for England. This plan sets out a six-year investment plan (2015-2021) for capital spending on FRM, which includes £2.3 billion of public expenditure (Defra, 2014a) yet there is limited alignment between planned investment and areas where high levels of vulnerability and exposure combine (England and Knox, 2015).

The changing context of flood risk management and its potential implications for social justice

The focus of FRM is changing, away from a narrow economic risk focus to one that seeks to deliver broader social and ecosystem resilience (*e.g.* Sayers *et al.*, 2014, 2017) based on an understanding of the risks, uncertainties and vulnerabilities (Sayers *et al.*, 2016 – Supplementary Figure S1). The national Flood Resilience Community Pathfinders Scheme (2013-15), for example, sought to stimulate approaches to community FRM that better enable communities to move towards greater resilience to flooding (Defra, 2013). An early review of this programme however highlighted some of the difficulties in understanding what is meant by resilience and how this understanding shapes the nature of the solutions proposed, noting *'the way resilience is framed will lead to different actions and emphases'* (Twigger-Ross *et al.,* 2014). The relationship between social vulnerability and resilience also emerged as a central message from this review, with the suggestion that community networks (between individuals and more formal organisations) play a central role in both.

The political framework within which FRM is delivered is also changing. The ongoing process of devolution (*i.e.* to Scotland and to Wales but also to cities, such as Manchester) has the potential to alter the powers and competencies at a local and national scale and hence the way issues of social justice are embedded in FRM investment decisions.

Method of assessment

To explore the degree to which FRM in the UK can be considered social just, the analysis here seeks to understand both the geographic and systemic nature of flood disadvantage and identify those neighbourhoods at greatest flood disadvantage now and in the future (through to the 2020s, 2050s and 2080s) across the UK. In doing so, the analysis differentiates the results by country (England, Wales, Scotland and Northern Ireland), flood source (coastal, fluvial and surface water flooding), urban and rural settings and city regions in decline.

The large spatial scale of the analysis, the multiple future scenarios (Supplementary Figure S2) and the portfolio of FRM adaptation measures to be considered (Supplementary Figure S3) mean it is difficult to explore all the relevant combinations using conventional numerical modelling approaches (a challenge recognised in Kwakkel *et al*., 2013). Instead, the approach used here builds upon lessons from past national scale studies undertaken in the UK (e.g. Evans *et al.,* 2004a&b, Sayers *et al.,* 2015) and insights from international research (e.g. Klijn *et al.,* 2004 and 2014, Bouwer *et al.,* 2010) to allow a rapid evaluation of the effects of climate and population change and adaptation using the UK Future Flood Explorer (FFE) – Supplementary Figure S4.

The UK FFE uses available data on flood hazard, exposure and vulnerability to develop a credible representation of the behaviour of the UK flood risk system (that takes account of the flood defences where they exist). This approach was shown to support credible policy insights as part of the UK CCRA (Sayers *et al.,* 2015, 2016) and has been revised and enhanced in three areas for application here: the spatial resolution of the analysis, the characterisation of flood social vulnerability, and adaptation to flood risk differentiated by the vulnerability of the communities affected. These advances are briefly discussed below.

Spatial resolution of the analysis: the 'neighbourhood' unit and adaptations

The underlying spatial resolution of the flood hazard data used within the UK FFE varies from 2m-50m (depending upon flood source – coastal, fluvial or surface water (pluvial) and location). The data on exposure is based on residential point datasets (and hence has the resolution of a single property). The results however are not necessarily credible at these scales because of localised issues that may or may not be well reflected in the supporting data. The concept of the 'neighbourhood' is therefore used as a small, but locally aggregated, spatial unit to bring together flood hazard and exposure with census based social vulnerability data. The spatial scale of a 'neighbourhoods' varies across the UK and is based upon census Lower Layer Super Output Areas (LSOAs) in England and Wales, Super Output Areas (SOAs) in Northern Ireland and the Data Zones (DZs) in Scotland (as defined in the 2011 Census). This definition yields a total of 42,619 neighbourhoods with the average population in each varying slightly by country: 1600 in England, 760 in Scotland, 1600 in Wales and 2000 in Northern Ireland.

For each neighbourhood, an Impact Curve is generated relating the return period of a current or future flood event to the magnitude of the impact (*i.e.* a loss of well-being as defined by one of several metrics, Supplementary Figure S5). Each Impact Curve is then manipulated within the FFE to represent the influence of climate and population change as well as adaptations to flood risk within a given neighbourhood (Supplementary Figure S6). For example, to represent climate change the Impact Curve is moved to the left along the return period axis. The raising of flood defences, however, would act to reduce risk and is represented by shifting the Impact Curve in the opposite direction.

This approach provides a significant increase in resolution from the analysis undertaken as part of the CCRA (based there upon the much larger Calculation Areas, defined using coastline and river boundaries to subdivide the floodplain, and 1km squares elsewhere) and represents an evolution of the previous present day assessments of flood disadvantage (in England, based upon Middle Layer Super Output Areas, MSOAs (Lindley *et al.*, 2011), and in Scotland based upon Data Zones (Kazmierczak *et al.,* 2015)).

The characterisation of flood vulnerability

UK FRM policy typically considers social vulnerability through the lens of deprivation (as indicated by the Index of Multiple Deprivation, DCLG, 2015) and this view provides the basis of the analysis presented in the CCRA (Sayers *et al.,* 2015). A focus on deprivation however does not necessarily reflect a community's vulnerability to a flood (although flood vulnerability is significantly influenced by income deprivation, as clearly demonstrated by

Tapsell *et al*., (2002)). To overcome this shortcoming, 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 NFVI expresses the neighbourhood's characteristics that influence the potential to experience a loss of well-being when exposed to a flood and over which flood management policy has limited or no control. In doing so, the NFVI builds upon previous studies (Tapsell *et al.,* 2002; Lindley *et al.,* 2011; Twigger-Ross *et al.,* 2014; Kazmierczak *et al.,* 2015) and requires consideration of five characteristics to provide a single vulnerability index at a neighbourhood scale (Figure 1).

The assessment of each characteristic is based upon one or more indicators (*e.g.* age, health *etc.*) that are, in turn, based upon one or more supporting variables (Table 1). Each indicator is normalised to a z score (derived by subtracting the mean value and dividing by the standard deviation). If a variable is already in the form of a rank (*e.g.* as is the Index of Multiple Deprivation), the equivalent z score is determined by assuming the rank is drawn from a normal distribution and calculating the number of standard deviations from the mean associated with that rank. The resulting z scores are then equally weighted to estimate each of the five characteristics (Susceptibility; Ability to Prepare; etc.). The only exceptions to this are the supporting variables associate with 'direct flood experience' and 'primary school aged children' (Table 1; e1 and n3). These variables act to reduce social vulnerability (*e.g.* those with experience know how to cope better than those without; families with schoolchildren tend to have more local contacts (Tapsell *et al.,* 2002; Twigger-Ross *et al.,* 2014)), and hence a negative weighting is applied (to reduce rather than increase the relative vulnerability of one neighbourhood compared to another). The resulting values for each characteristic or indicator are then themselves transformed into a z score, and summed, with equal weighting. The final z score is calculated based on these results and used as the NFVI (Supplementary Figure S7).

The differential capacity to adapt

Good FRM adopts a portfolio of responses (Evans *et al.,* 2004a&b; Sayers *et al.,* 2014) to provide a 'whole system' management response (an approach that includes actions to manage the source, pathways and receptors of risk, Sayers *et al.,* 2002). In the context of a national analysis the effectiveness of individual adaptation measures is however often considered to be independent of the vulnerability of those at risk (as for example within the CCRA, Sayers *et al.,* 2015). To overcome this deficiency, the analysis presented here differentiates the effectiveness of individual FRM adaptation measures based on neighbourhood vulnerability (where there is evidence to do so). For example, 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 across the UK, there is some evidence to suggest that the most vulnerable neighbourhoods are less well protected than others (England and Knox, 2015), with investment focused in urban areas (and away from rural areas) and towards more affluent areas (and away from deprived areas). This is reflected here in the assumed future adaptation of defence measures. There is also anecdotal evidence to suggest that in innercity areas (where urban flooding and drainage is significant) a differential in the retrofitting of Sustainable Urban Drainage (SUDS) measures may exist. This is reflected in the analysis here by assuming no retrofitting takes place in more vulnerable communities (compared to 10% elsewhere, ASC, 2014).

Spatial planning and development control are also important FRM measures and population growth and associated development are important drivers of future risk. Analysis of new residential developments (in England only) in the period 2008-2014 undertaken here suggests that the percentage of new properties built within the fluvial and coastal floodplain is around 14 per cent in the most vulnerable areas (defined by the top 20 per cent of neighbourhoods by NFVI) and 11 per cent in less vulnerable areas (Sayers *et al.,* 2017). This differential in current planning outcomes is assumed to persist into the future and is therefore carried forward into the analysis.

Property level protection measures (PLP), warning services and insurance also all provide important FRM contributions, but all three can be difficult for the most vulnerable to access. Regarding property level measures, evidence suggests that the uptake by the most vulnerable in existing developments is likely to be significantly lower than in the population as whole (National Flood Forum, 2012). There may be multiple reasons for this including:

- property level measures can be expensive which may rule out installation for people on low incomes (National Flood Forum, 2012);
- the process of applying for a grant is bureaucratic and cumbersome (National Flood Forum, 2016);
- grants may be insufficient to encourage take up by the most vulnerable (based on evidence from the case studies undertaken in this research);
- tenants in rented accommodation have a reduced ability and incentive to install property levels measures; and
- developing an awareness of flood risk within transient communities maybe more difficult.

In combination, these barriers mean it is likely that retro-fitting of PLP measures in the most vulnerable neighbourhoods will be significantly less than elsewhere, and this differential is carried forward into our analysis. There is however little existing evidence that would suggest the uptake of such measures within new developments is any different in more and less vulnerable neighbourhoods.

There is also some evidence to suggest that social vulnerability influences a community's ability to respond to a warning (Thrush *et al.,* 2005). In part, this is already reflected in the NFVI (Table 1: f1, f2, k1) but social vulnerability can also influence the effectiveness of such measures due to, for example:

- *Barriers to receiving the warning:* many households (particularly low-income households) are no longer choosing to maintain a telephone landline but instead rely upon mobile technologies (see Money.co.uk (2017). This can create complications in trying to contact households to convey flood warnings, largely because there is no published list of mobile phone numbers as there is for landlines. Loss of power during a flood can also prevent communication, as mobile telephones (and cordless landlines) require power to charge batteries (Pitt, 2007). Transient and travelling communities may also be difficult to reach.

- *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).
- *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 (Thrush *et al.,* 2005).

In combination, these challenges are assumed to lead to lower rates of uptake of warning services and the action taken in response to the warnings to be less effective at reducing economic damage in the most vulnerable neighbourhoods when compared to less vulnerable neighbourhoods.

Private insurance underpins FRM policies in the UK. This is one of the few FRM policies whose measures are universally applied across the UK (National Flood Forum, 2012). Penetration is, however, uneven. Based on the government's Household Expenditure Survey and evidence from its own members, the Association of British Insurers (ABI) estimate that the uptake 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. The differential in contents insurance is much greater. Some 75 per cent of all households have contents insurance, but less than half of the poorest 10 per cent of households and even fewer who are tenants have this protection. This prompted Watkiss *et al.,* 2016 to note that *"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".*

Since April 2016 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 excluding properties built after 1st January 2009). The result is intended to make flood insurance affordable, including for example capped premiums linked to Council Tax bandings[d]. However, in high risk areas, it is unclear whether Flood Re has been successful in improving insurance uptake in the most vulnerable neighbourhoods and it does nothing to assist the uninsured. It is also the case that Flood Re has a life of only twenty-five years after which flood insurance will become fully risk-reflective. Watkiss *et al.,* 2016 discusses how this transition to market prices will, in the longer term, lead to substantially higher premiums for those at risk, and those at most risk will pay much more than at present. This transition to an actuarial accounting process could further discourage the most vulnerable from accessing insurance.

[d] http://www.floodre.co.uk/industry/how-it-works/eligibility/

To establish a credible representation of the role of insurance within the analysis, and how it may be more or less effective in the most vulnerable neighbourhoods, several issues have necessarily been considered and partially modelled. First, regarding uptake by income, there is a 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 (ONS, 2015). Secondly, insurance has lower levels of penetration across households in rented accommodation (ONS, 2015) – although local authorities and housing associations would typically be responsible for any structural repairs following a flood, and in the private rented sector the landlord will be responsible for structural repairs. Therefore, the insurance position of the landlord is what is critical in terms of structural repair. This however is not considered further here.

Risk and vulnerability metrics

As Cutter *et al* (2010) in the USA and Walker and Burningham (2011) in the UK have shown, the way in which flood risk, vulnerability and resilience are measured is crucial to the way they are understood and managed. Several new risk metrics are used here to unpack flood disadvantage. The first, used at the neighbourhood scale, is the Social Flood Risk Index (SFRI). This is used to identify those areas where the largest number of the most socially vulnerable people are most frequently flooded (*i.e.* return period, on average, of 1 in 75 years or more frequent). The SFRI therefore directly supports an understanding of geographic flood disadvantage (defined earlier) and is estimated at both a neighbourhood scale and as an individual 'average' as follows:

- *Social flood risk index* (SFRI) helps identify those areas where many vulnerable people, as defined by the NFVI, are exposed to flooding and is calculated as the product of the NFVI and the annual expected number of people flooded as follows:

$$SFRI = \langle Annual\ expectation\ of\ the\ number\ of\ people\ flooding \rangle \times NFVI$$

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

Secondly a metric of *Relative Economic Pain* (REP) is introduced in recognition of the varying coping capacity between more affluent and low income families. This metric captures the relationship between uninsured damages and household income: the larger the former in relation to the latter, the greater the REP. The REP builds upon previous research touching on issues of outrage (Evans *et al.,* 2004a,b; Sayers *et al.,* 2014) to express the 'relative pain' of a risk and is defined here as the uninsured loss (represented by one minus the insurance penetration) times the EAD on the floodplain, divided by total income on the floodplain:

$$REP = \frac{(1 - I) \times EAD}{Income}$$

Where *I* = percentage of the loss covered by insurance, *EAD* = Expected Annual Damages, and *Income* = household annual income.

The validity of approach

The validation of any analysis of risk is difficult to determine, in part because flood events are rare and flood systems are non-stationary (Sayers *et al.,* 2016). The validity of any analysis therefore relies upon acknowledging assumptions and limitations and gaining confidence that the analysis is credible at the scales of interest and in the context of the objectives.

To provide appropriate confidence in the analysis presented here, three important aspects are discussed below. First, it is assumed that the input data used by the FFE (including, but not limited to, flood hazard, defence standards and conditions, property counts, census data) is credible at the scales of interest and in the context of the project objectives. This is reasonable given all the datasets are routinely used by various national and local organisations (Defra; the EA; SEPA), despite recognised controversy regarding the absolute values of some of the datasets (such as data based upon the National Flood Risk Assessment in England (Penning-Rowsell, 2014, 2015, 2016)).

Secondly, to provide valid estimates of risk the FFE must provide a faithful reproduction of the underlying data. To provide confidence that this is the case the results of the FFE have been previously compared to standalone estimates of the number of properties nationally at significant risk and the resultant expected annual damages (as produced by Environment Agency's National Flood Risk Assessment, and the Scottish Environmental Protection Agency (SEPA). Such comparisons have confirmed the ability of the FFE to produce known results (Sayers *et al.,* 2015).

Thirdly, to provide confidence that the extension of the analysis to represent neighbourhood vulnerability and using social flood risk indices is justified, three additional activities have been undertaken (Sayers *et al.,* 2017):

- *Engagement with an Advisory Group*: The analysis has been scrutinised as they have emerged by an extensive Joseph Rowntree Foundation convened Advisory Group.
- *Engagement with national policy leads:* Policy leads from England, Wales, Scotland and Northern Ireland have each been engaged to discuss the role of social justice in current policy approaches to FRM and the anticipated direction of travel.
- *Local case studies and review:* Four local case studies (in Boston, Cumbria, Blaenau and in York, the last undertaken in association with Robotham, 2016) have been used to ground-truth the estimates of social vulnerability and social flood risk. These discussions provided confidence that the relative distribution of social vulnerability was indeed locally representative (Sayers *et al.,* 2017).

To develop a UK wide view of adaptation to flood risk, the individual measures have been chosen to be a reasonable representation of current approaches across England, Wales, Scotland and Northern Ireland. For example, it is assumed that analysis of recent development in England (2008-14) is indicative of the effectiveness of spatial planning across the UK. This is of course a simplification and fails to reflect the full variation in national policies between England, Wales, Scotland and Northern Ireland as well as the local context within which risks are managed, but nonetheless is considered reasonable in the context of the national level analysis presented here.

Discussion of results

To understand the multiple and important messages that emerge from this analysis four aspects are considered:

(i) The relationship between social vulnerability, floodplain population and exposure to frequent flooding.
(ii) The economic risks faced by the socially vulnerable and the influence of differentials in income and insurance penetration.
(iii) The relationship between cities in relative economic decline, deprivation and flood disadvantage.
(iv) The evidence of greater investment in socially vulnerable neighbourhoods

Floodplain population, vulnerability and exposure to frequent flooding

The situation today[e]

Today, approximately 6.4m people in the UK live in areas prone to fluvial, coastal and surface water flooding, with around 1.5 million of these (23.4%) living in the 20% most vulnerable neighbourhoods (as defined by the NFVI – Supplementary Table S1). Of the 1.8 million people living in the coastal floodplain, 33% are within the 20% most vulnerable neighbourhoods and 10% in the 5% most vulnerable neighbourhoods (by NFVI). Of those exposed to frequent flooding, the majority (67%; 1.3m) live in the most socially vulnerable neighbourhoods (top 20% by NFVI) (Supplementary Table S2).

The proportion of socially vulnerable neighbourhoods exposed to flooding varies across the four nations. In Northern Ireland, 55% of the population exposed to flooding live in the top 20% of neighbourhoods by NFVI and 25% of the total population exposed to frequent flooding are in most vulnerable communities (the top 5% by NFVI). This represents a significant systemic flood disadvantage. The disproportionality is less elsewhere (in Scotland 9% of the floodplain population live in the top 5% communities by NFVI; in England 5%; and in Wales 3%).

Seventy-five local authorities (approximately one fifth of the UK total) account for 50% of those living in flood prone areas. The concentration becomes more marked when the most vulnerable neighbourhoods (top 5% by NFVI) are considered, with over 50% of the population exposed to flooding in the most vulnerable neighbourhoods located in just ten local authorities (Hull, Boston, Belfast, Birmingham, East Lindsey, Glasgow, Leicester, North East Lincolnshire, Swale District, and Tower Hamlets). Figure 2 illustrates this clustering and highlights concentrations of people in vulnerable neighbourhoods on the floodplain in Scotland's central belt, Belfast, the Humber, Lincolnshire, Birmingham, South Wales, and the Severn and Thames Estuaries.

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[e] Dateline Autumn 2016.

The drivers of social vulnerability (as in Table 1) are, in general, similar across all sources of flooding. In coastal settings, however limited *service availability* (Table 1: s1 to s4) plays an enhanced role and is a key contributor to the high levels of vulnerability observed, along with *physical mobility* (m1 to m3) and *information use* (f1 and f2) (Supplementary Figure S8).

In the future

The number of people living in flood prone areas is set to rise (by 45% to 10.8m people by the 2080s, assuming a high population growth, Supplementary Figure S9). By the 2080s 6.4m people will be exposed to frequent flooding, up from 2m today (assuming a +4^{o}C climate future and a continuation of the current level of adaptation). In socially vulnerable neighbourhoods the increase is equally dramatic, increasing from 451,000 today to 1.4m by the 2080s and disproportional exposure to flooding of those living in socially vulnerable neighbourhoods that exists today continues (Supplementary Figure S10). Those living in the most socially vulnerable neighbourhoods exposed to fluvial flooding see their risk increase at a faster rate (increasing from 24,000 to 63,000; +263%).

Expected annual damages and the influence of income and insurance

The situation today

Expected Annual (economic) Damages (EAD) across the UK is an estimated £351 million (residential property only), with the majority generated in England (79%, £277 million). The contribution from elsewhere in the UK is however more significant when considered in the context of the most socially vulnerable neighbourhoods (Supplementary Figure S11). This is most significant in Northern Ireland where the 20% most vulnerable neighbourhoods account for 67% of the EAD (in Scotland the equivalent figure is 22%, in England 22% and in Wales 26%). Therefore, although Northern Ireland accounts for only 2% of the UK EAD when all neighbourhoods are included, when considered from the perspective of the most vulnerable neighbourhoods (*i.e.* the top 5% by NFVI) the contribution from Northern Ireland increases substantially to 10% of UK EAD.

These headline figures however mask the risks faced by individuals. When normalised by population across the four countries, those living in flood prone areas in Scotland are set to experience the highest EAD per person (on average, £113 per person) and over double that of England (on average, £50 per person) - Supplementary Figure S12. When considered by flood source, the highest EADs are experienced in fluvial (£97 per person) and coastal (£76 per person) floodplains (in areas prone to surface water flooding we found the value to be much less at £16 per person). In many cases, these estimates change little between more and less socially vulnerable neighbourhoods, except in Wales where the most vulnerable neighbourhoods (5% by NFVI) are exposed to significantly lower risk (on average, £40 per person) compared to the average in Wales (£60 per person).

Lower incomes (~£7,500 per head in socially vulnerable neighbourhoods compared to~£10,500 on average) and low levels of contents insurance penetration (~40% of homeowners and 25% of tenants compared to the national average of ~75%) mean the relative impact of a flood is higher in socially vulnerable neighbourhoods that elsewhere.

This is reflected in the substantial increase in *'relative economic pain'* (introduced above) with socially vulnerability. In areas prone to coastal/tidal flooding, for example, the most socially vulnerable neighbourhoods (5% by NFVI) experience over twice the average *'relative economic pain'* (Sayers et al, 2017). In fluvial floodplains, the *'relative economic pain'* is three times higher than the average.

In the future

The EADs associated with flooding are set to rise (from £351 million today, residential direct damages only, to £1.1 billion by the 2080s, assuming *a* +4^{o}C climate future, high population growth and a continuation of current levels of adaptation). At a UK scale the increase in EAD in socially vulnerable neighbourhoods (defined by top 20% by NFVI) is, in general, in line with this overall increase; rising from £81 million today to £250 million by the 2080s (slightly greater than 20%). This is not the case in Scotland however, where the analysis suggests the contribution to EAD from the 20% most vulnerable neighbourhoods increases from 22% today to 29% by the 2080s.

The disproportionality in the risks faced by socially vulnerable neighbourhoods in coastal areas experienced today persists into the future (with substantial increases in risks experienced across all neighbourhoods). With fluvial and surface water flood risk the pattern of disproportionality in EAD also remains largely as today. When income and insurance are considered, the increase in EAD translates to significant increases in the REP across the UK and for all sources of flooding, particularly for the most vulnerable neighbourhoods.

City regions in economic decline, deprivation and flood disadvantage

The situation today

At a UK scale, urban settings dominate flood risk, accounting for £264 million (75%) of present day EAD and 5.2 million (82%) of the people exposed to flooding. When considered from the perspective of socially vulnerable neighbourhoods (the top 20% by NFVI) the flood risks in rural neighbourhoods are however more significant, accounting for 45% of the total £47 million EAD and 30% of the people exposed to flooding (Supplementary Figure S13).

The relationship between deprivation and flood disadvantage is also striking. Sixteen of the 24 city regions classed as in relative economic decline by Pike *et al.* (2016) experience levels of flood disadvantage above the UK average. This reflects a combination of influences but from the perspective of the analysis here is driven by higher than average levels of social vulnerability (as shown by the NFVI in those cities) and a greater than average number of people exposed to a frequent flood (in Glasgow, for example, those living in the floodplain are almost twice as likely to experience frequent flooding than the UK average). When income and insurance penetration are considered, the REP associated with flooding is significantly higher in these sixteen cities, reflecting the lower levels of income (on average) and lower levels of insurance (Figure 3).

This connection is, in part, recognised within government policy. The UK government, for example, collects data on deprivation across a range of domains (including income, health, housing quality, availability of services). These are combined into an Index of Multiple

Deprivation (the IMD – introduced earlier) and used across government to understand the distribution of social inequalities associated with a neighbourhood and to inform resources allocation. Although IMD is not however a measure of 'flood social vulnerability' *per se*, flood vulnerability (as defined by the NFVI) is much higher in deprived areas (as defined by the Index of Multiple Deprivation, IMD) and increases in line with the IMD (Supplementary Figure S14). This, of course, is to be expected as the NFVI and the IMD seek to express similar characteristics of a neighbourhood (although the NFVI is focused on those characteristics that make a neighbourhood 'flood vulnerable' rather than the more general expression of deprivation provided by the IMD). This distinction between the general measure of deprivation, given by the IMD, and the more specific expression of social vulnerability to flooding, as expressed by the NFVI, is important as flood risk in socially vulnerable areas (defined by the NFVI) is consistently greater than that in deprived areas (defined by the IMD). This suggests that the IMD fails properly to identify those areas that are at greatest flood disadvantage. The underlying reasons for this are difficult to determine without further research (and have not be explored further here); however, given the role of the IMD in FRM policy across the UK (including supporting the identification of investment priorities in England through the FDGiA) these differences may be significant and question if IMD is an appropriate measure for use in the FRM context.

Future risks

In deprived neighbourhoods (as defined by the IMD) flood risk tends to increase in line with increases shown elsewhere. The focus on 'deprivation' however highlights the importance of income, and its influence in insurance penetration, in increasing the relative economic pain experienced by those flooded and is reflected in significant increases in REP into the future in the most deprived areas.

The greatest increases are seen in major and minor conurbations (experiencing an increase in EAD of 200% and 350% under a +2^{o}C and +4^{o}C climate future respectively) and rural towns and fringes in a sparse setting (increasing by 200% and 400%). In these settings, the most socially vulnerable neighbourhoods experience slightly higher percentage increases in risk when compared to less vulnerable neighbourhoods. This suggests that most vulnerable neighbourhoods in more dispersed settings (both urban and rural) may be particularly difficult to address within the current approach to adaptation and investment frameworks.

Long-term investment in England: Evidence for greater investment in vulnerable neighbourhoods

The Long-term Investment Scenarios (LTIS) published by the Environment Agency (2014a) explore the long-term investment case for reducing flood risk (in England) based on optimising the Net Present Value of the different investment choices, using a simplified set of policy options from 'do nothing' to 'improve +' with a time horizon stretching through to 2100 (Supplementary Table S3). In doing so, LTIS considers costs and benefits but without any consideration of either who pays or the FDGiA rules that seek to positively discriminate in favour of the protection of deprived households (Defra, 2011). In this context, the LTIS investment analysis is based on the principle of 'utility', and although it does not attempt to set out priority short-term investments, the LTIS does set the long-term direction of travel.

The investment scenario which maximises the Net Present Value over the 100-year period is referred to as the "optimised investment scenario" (Environment Agency 2014). The analysis presented in the CCRA of the LTIS policy choices (Sayers et al., 2015) is extended here to explore the impact on risk in socially vulnerable neighbourhoods.

The results suggest that there is a strong case for improving the protection afforded to socially vulnerable neighbourhoods (with nearly 55% of properties assigned an *Improve* or *Improve+* policy option in the most vulnerable neighbourhoods, defined by the top by 5% NFVI, compared to c.35% on average; as illustrated by Supplementary Figure S15 that shows the percentage of residential property exposed to frequent flooding (*i.e.* a return period of 1:75 years or less) that, under the optimised investment scenario, are assigned to each LTIS policy option). Residential properties in socially vulnerable neighbourhoods are also less likely to be assigned a '*do nothing'* or a '*maintain crest*' policy choice - indicating possible deteriorating or no change in protection standards - when compared to residential properties on average (c.48% compared to 61%). These results suggest that there is a direct long-term economic case for greater investment in FRM in vulnerable neighbourhoods, although this is an inference that which will need to be explored further in future research.

Conclusions

The research reported here reinforces the inability of existing metrics to properly capture the differential nature of the risks faced in more and less socially vulnerable communities. To overcome these deficiencies three new metrics are introduced to be used alongside existing metrics. Firstly, a *Neighbourhood Flood Vulnerability Index* (NFVI) is shown to provide an improved expression of flood social vulnerability and is put forward as a replacement for the Index of Multiple Deprivation in FRM decision making. Secondly, the *Social Flood Risk Index* (SFRI) provides a combined expression of probability, exposure and vulnerability that enables flood risks in one neighbourhood to be compared with another in a way that explicitly accounts for social vulnerability. The thirdly, *Relative Economic Pain* (REP) index: by accounting for the influence of lower income levels and lowers levels of flood insurance the REP better reflects the experience of a given economic flood loss in more and less vulnerable neighbourhoods.

Based on these new metrics, and exploring our two research questions, the results highlight clusters of *geographic flood disadvantage* across the UK, with 50% of most socially vulnerable people exposed to flooding living in just ten local authorities. The results also highlight the *systemic flood disadvantage* experienced by those living in socially vulnerable neighbourhoods. For example, in economically struggling cities, coastal floodplains and dispersed rural communities the most socially vulnerable often experience levels of Expected Annual Damages above the average. When income and insurance penetration are considered (as represented by the REP index) the disproportionality in the risks faced is even more stark. This highlights the central role that lower incomes and lower levels of insurance penetration play in systemically disadvantaging the most socially vulnerable communities. Yet these communities contain people and households that are the least likely to be able to help themselves when flooded.

The spatial patterns of geographic disadvantage continue into the future with flood risks increasing for many neighbourhoods as a function of their geography (for example, assuming a continuation of current levels of adaptation the majority of communities at the coast experience significant increases in risk due to sea level rise). There is however a disproportional increase in flood risk faced by the most socially vulnerable. This acts to increase the systemic flood disadvantage and reflects the legacy of past investment and planning decisions, but is primarily influenced by the constraints on adaptation experienced by the socially vulnerable at both an individual and community level (including the limited capacity to make local contributions to the costs of FRM interventions, if such contributions are necessary).

Through re-examination of the optimised investment scenario in England within the Long-Term Investment Scenarios (Environment Agency, 2014) the research presented here reveals a strong long term economic case for improving the protection afforded to socially vulnerable communities (although the reasons for this future investment bias towards deprived areas are as yet unclear). Whatever the reason, it would appear there is a utilitarian argument for reducing the risk in the most vulnerable communities as well as a Rawlsian one. It is also clear that income (and consequently health, as in our NFVI but not in the IMD) are central drivers in flood vulnerability and are directly influenced by broader planning and economic development policy. Flood risk management investment should be geared up by supporting multiple parallel government and private sector funding streams. In England for example, the FDGiA process could be reconfigured to better support economic regeneration, for example in economically struggling city regions (highlighted here as centres of geographic flood disadvantage).

Many uncertainties remain and the results presented here will need continued research to better understand the root causes of flood vulnerability and disadvantage and how best to address them. This paper presents only a first step towards quantifying social justice dimensions in FRM, but already clearly highlights the systemic flood disadvantage that exists and the need to prioritise the most socially vulnerably if FRM is to deliver fair outcomes in the future (not least in response to climate change). To do so will require a greater emphasis to be placed on Rawlsian approaches alongside issues of utility and equality. Significant further research however will be needed to evaluate the ability of FRM policy, and broader spatial and economic policies, to deliver such outcomes.

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Figures

Figure 1 The Neighbourhood Flood Vulnerability Index (NFVI): Influential characteristics and indicators

Figure 2 Present day: Concentration of people living in flood prone areas

Figure 3 City regions in Relative Decline: Relative Economic Pain of flooding

Tables

Table 1 Neighbourhood Flood Vulnerability Index: Indicators and supporting variables

Supplementary Figures

Supplementary Figure S1 An understanding of vulnerability, risk, and uncertainty is needed to make informed choices (Sayers et al., 2016).

Supplementary Figure S2 Exogenous change: Climate change and population growth

Supplementary Figure S3 Endogenous change: A portfolio of adaptation measures are considered (after Evans et al, 2004a&b; Sayers et al, 2014).

Supplementary Figure S4 The basic framework of the analysis of risk and flood disadvantage

Supplementary Figure S5 Indicators of social flood resilience and disadvantage

Supplementary Figure S6 Neighbourhood Impact Curve: Example relationship return period v impact used within the FFE (after Sayers *et al.,* 2015)

Supplementary Figure S7 Calculation of the Neighbourhood Flood Vulnerability Index (NFVI)

Supplementary Figure S8 Present day: Drivers of neighbourhood vulnerability at the coast (see Table 1)

Supplementary Figure S9 Future change: Floodplain population: By country

Supplementary Figure S10 Future change: Exposure to frequent flooding: By source

Supplementary Figure S11 Present day: Contribution to Expected Annual Damages (By country)

Supplementary Figure S12 Present day: Expected Annual Damages: Individual (By country)

Supplementary Figure S13 Present day: A comparison of flood risk in rural and urban settings

Supplementary Figure S14 Present day: A comparison of risks in deprived and vulnerable neighbourhoods

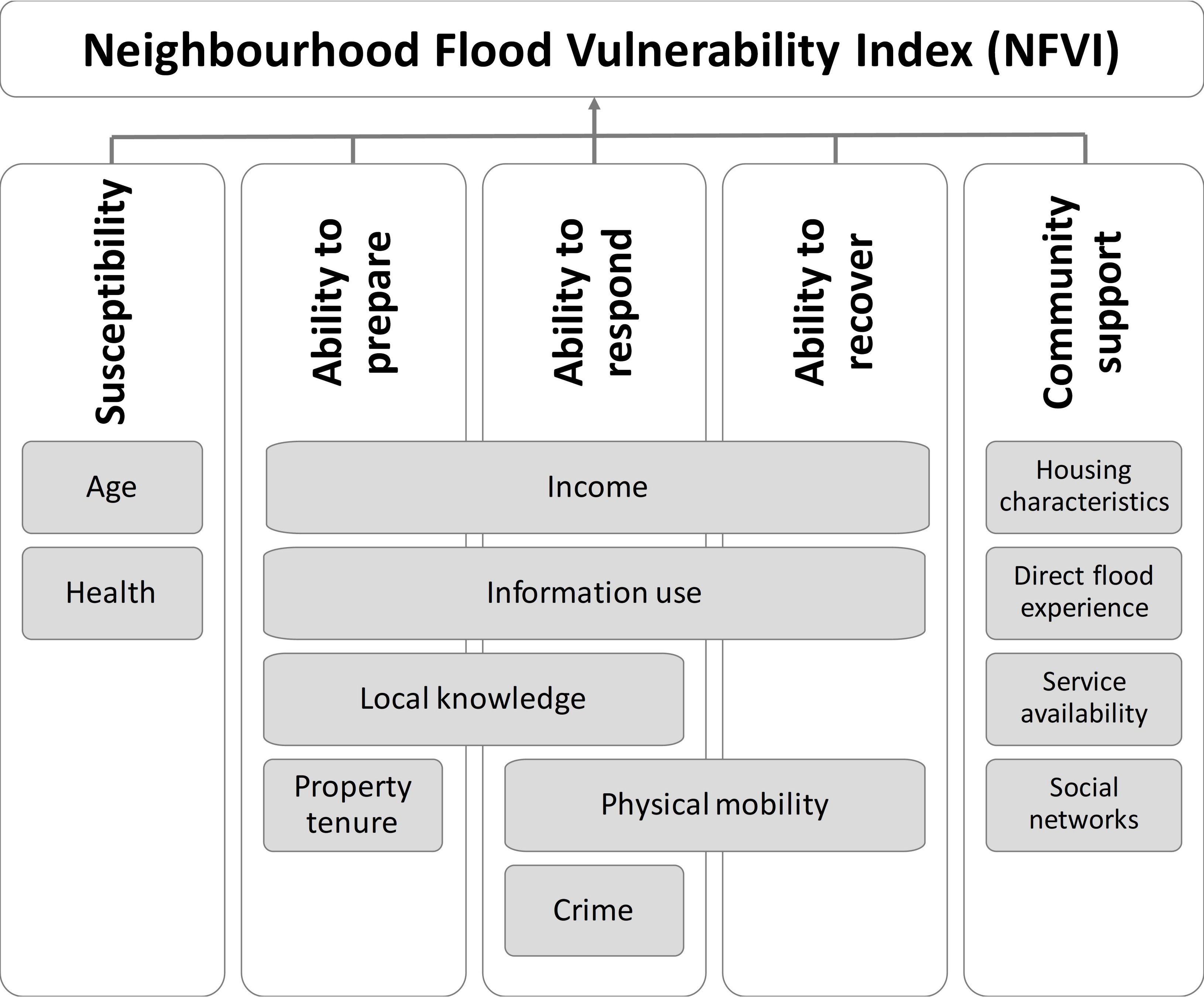
Supplementary Figure S15 Percentage of residential properties in areas receiving a particular policy choice

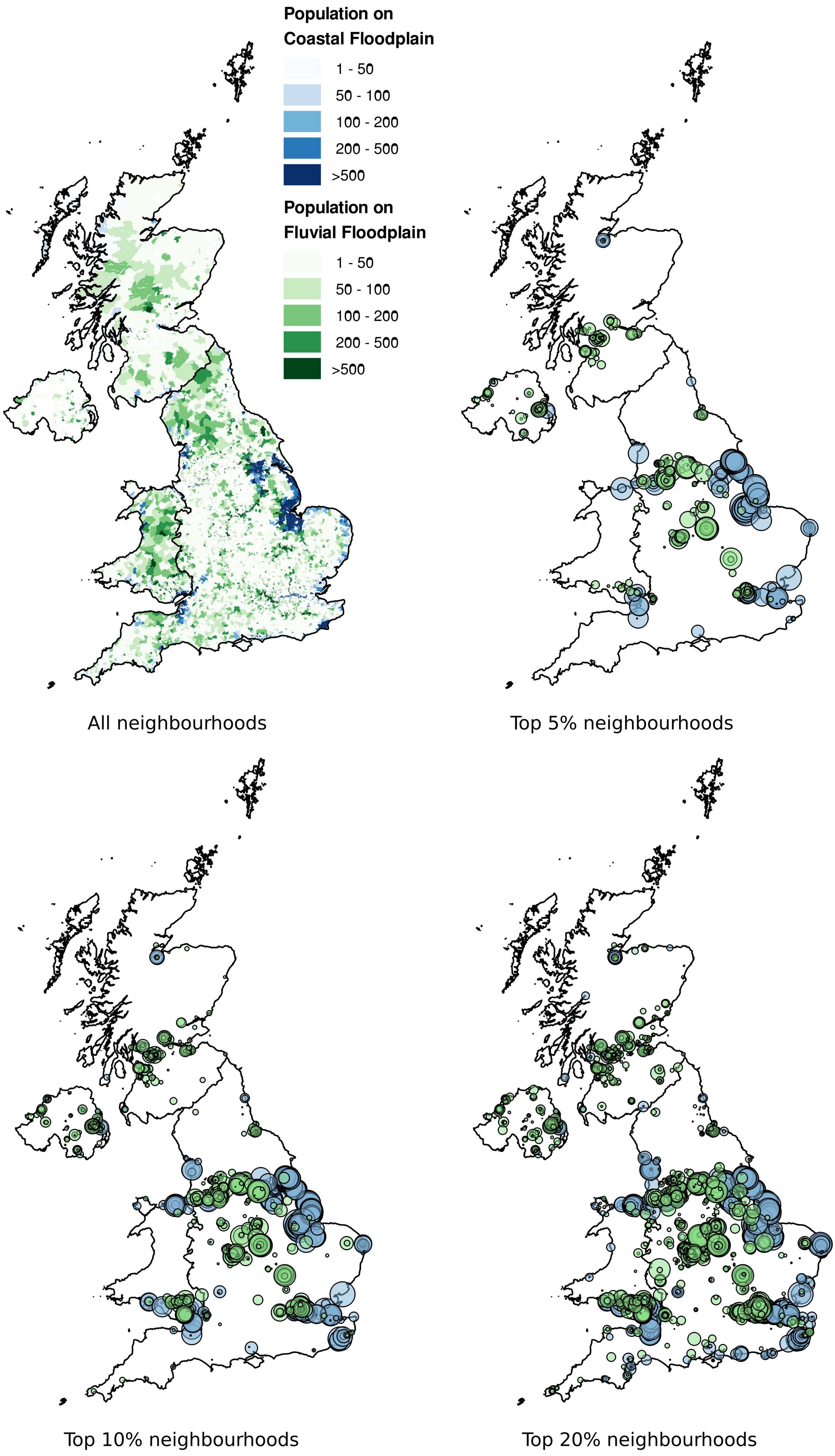
Supplementary tables

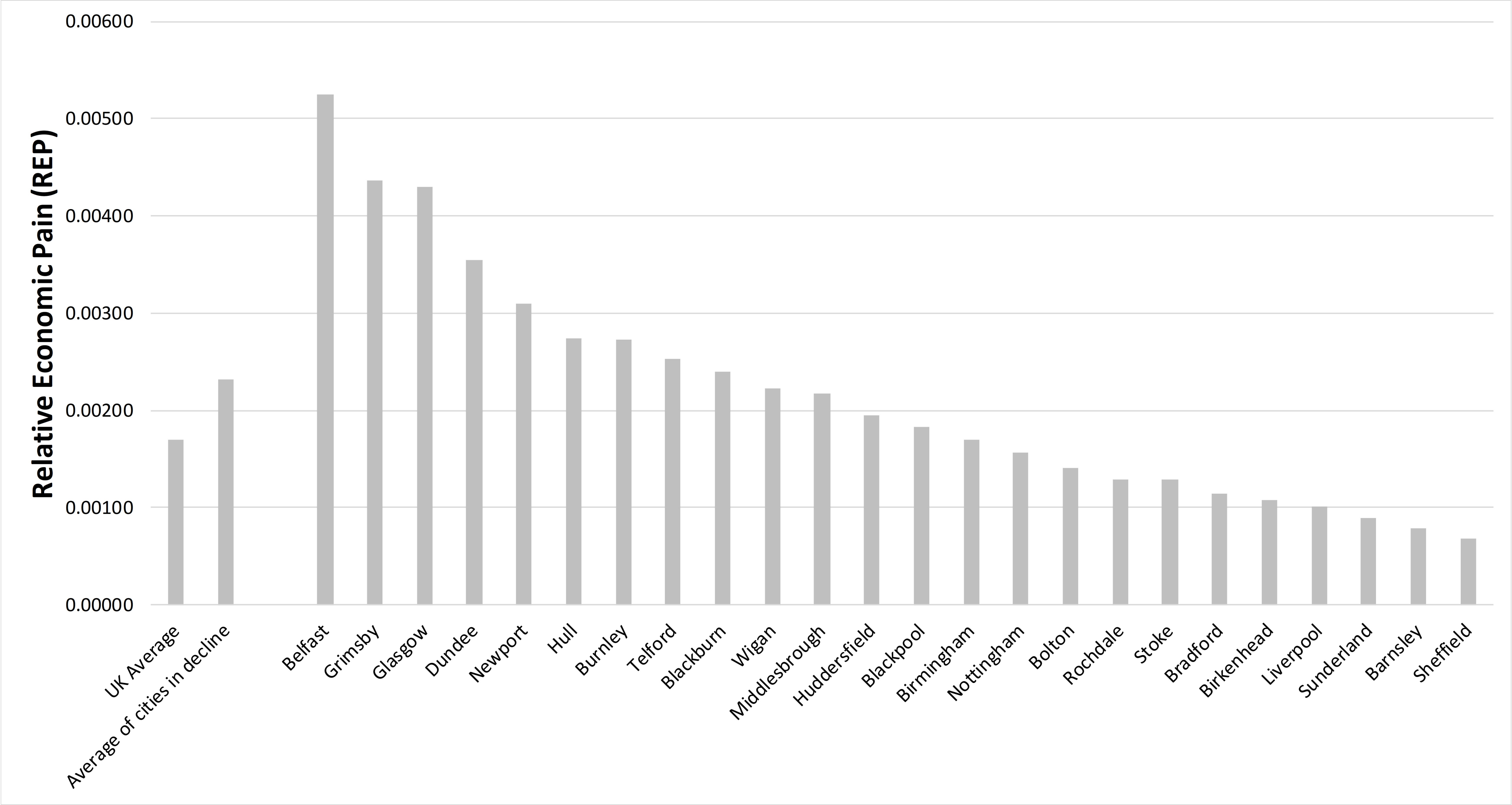
Supplementary Table S1 Present day: Population of flood prone areas

Supplementary Table S2 Present day: People exposed to frequent flooding (1:75 years or more frequent)

Supplementary Table S3 The LTIS policy options (from Long Term Investment Strategy (LTIS) Improvements – Part 1 Technical Documentation, June 2014, Environment Agency (2014))


Neighbourhood Flood Vulnerability Index (NFVI)
Susceptibility
Ability to prepare
Ability to respond
Ability to recover
Community support
Age
Health
Income
Information use
Local knowledge
Property tenure
Physical mobility
Crime
Housing characteristics
Direct flood experience
Service availability
Social networks

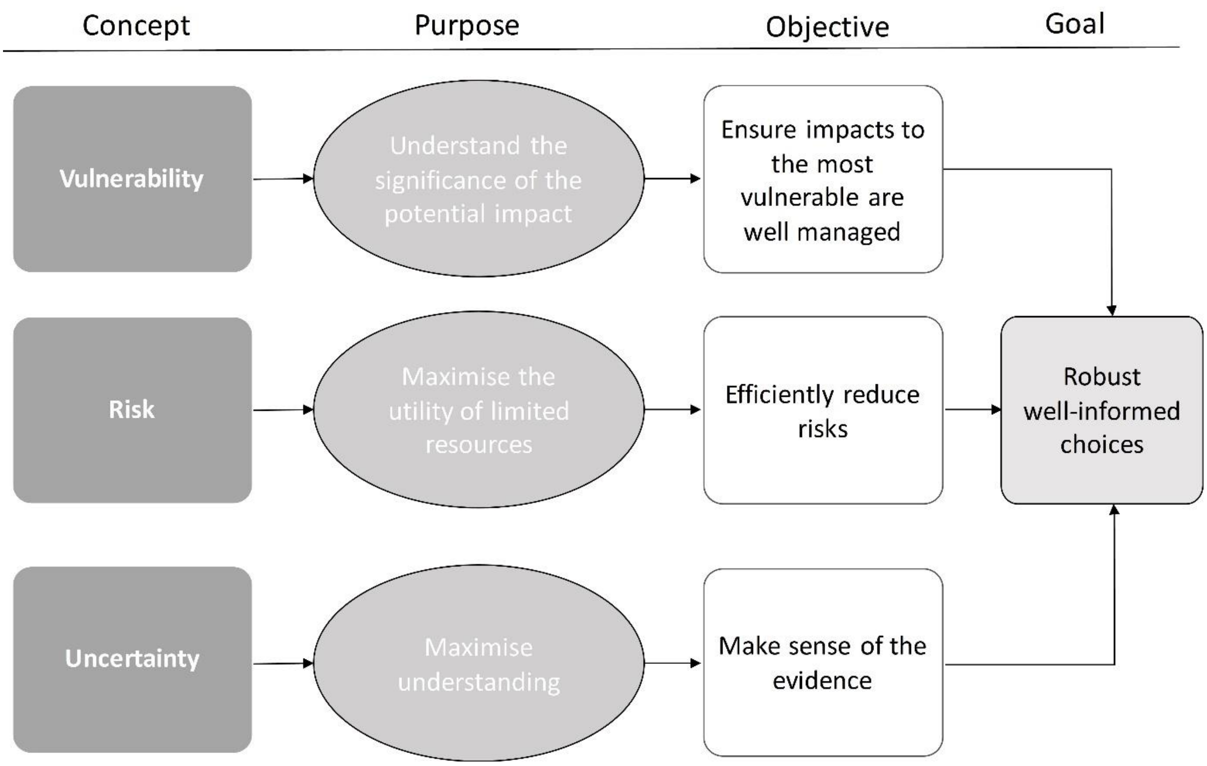

Population on
Coastal Floodplain
1 - 50
50 - 100
100 - 200
200 - 500
>500
Population on
Fluvial Floodplain
1 - 50
50 - 100
100 - 200
200 - 500
>500
All neighbourhoods
Top 5% neighbourhoods
Top 10% neighbourhoods
Top 20% neighbourhoods



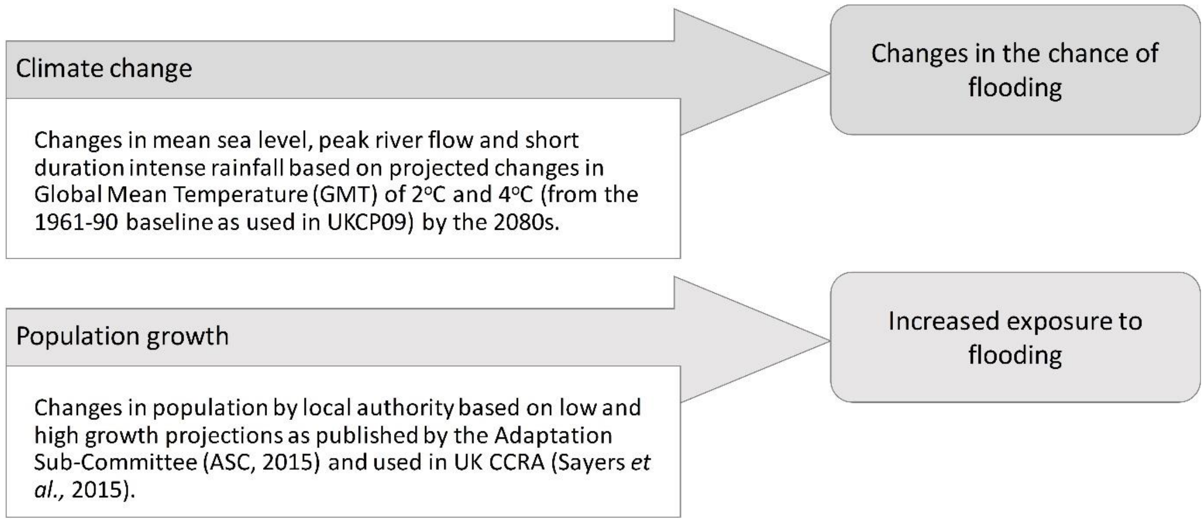
Relative Economic Pain (REP)
0.00600
0.00500
0.00400
0.00300
0.00200
0.00100
0.00000
UK Average
Average of cities in decline
Belfast
Grimsby
Glasgow
Dundee
Newport
Hull
Burnley
Telford
Blackburn
Wigan
Middlesbrough
Huddersfield
Blackpool
Birmingham
Nottingham
Bolton
Rochdale
Stoke
Bradford
Birkenhead
Liverpool
Sunderland
Barnsley
Sheffield

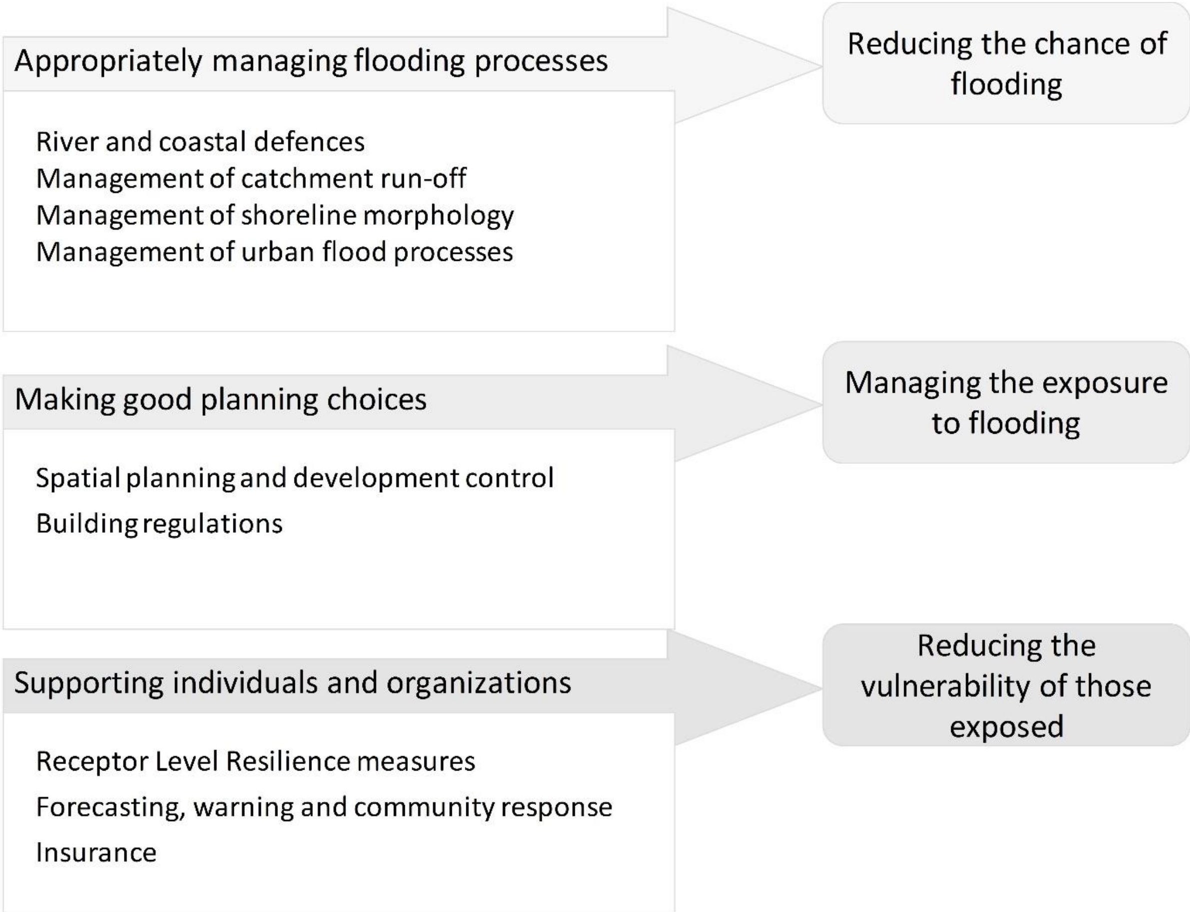
Table 1 Neighbourhood Flood Vulnerability Index: Indicators and supporting variables

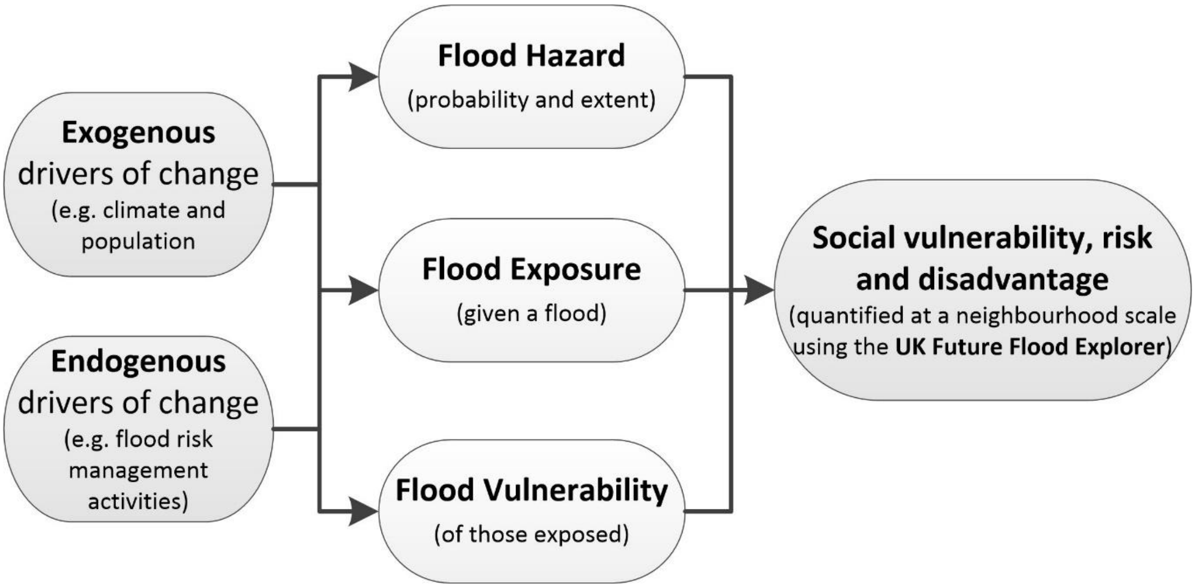
Indicator	Supporting variables	
Age	a1	Young children (% people under 5 years)
	a2	Older people (% people over 75 years)
Health	h1	Disability / people in ill-health (% people whose day- to-day activities are limited)
	h2	Households with at least one person with long-term limiting illness (%)
Income	i1	Unemployed (% unemployed)
	i2	Long-term unemployed (% who are long-term unemployed or who have never worked)
	i3	Low income occupations (% in routine or semi-routine occupations)
	i4	Households with dependent children and no adults in employment (%)
	i5	People income deprived (%)
Information use	f1	Recent arrivals to UK (% people with <1-year residency coming from outside UK)
	f2	Level of proficiency in English
Local knowledge	k1	New migrants from outside the local area (%)
Tenure	t1	Private renters (% Households)
	t2	Social renters (% households renting from social landlords)
Physical mobility	m1	High levels of disability (% disabled)
	m2	People living in medical and care establishments (%)
	m3	Lack of private transport (% households with no car or van)
Crime	c1	High levels of crime
Housing characteristics	hc1	Caravan or other mobile or temporary structures in all households (%)
Direct flood experience	e1	No. of properties exposed to significant flood risk (%) (acts to reduce social vulnerability)
Service availability	s1	Emergency services exposed to flooding (%)
	s2	Care homes exposed to flooding (%)
	s3	GP surgeries exposed to flooding (%)
	s4	Schools exposed to flooding (%)
Social networks (non-flood)	n1	Single-pensioner households (%)
	n2	Lone-parent households with dependent children (%)
	n3	Children of primary school age (4-11) in the population (%) (acts to reduce social vulnerability)

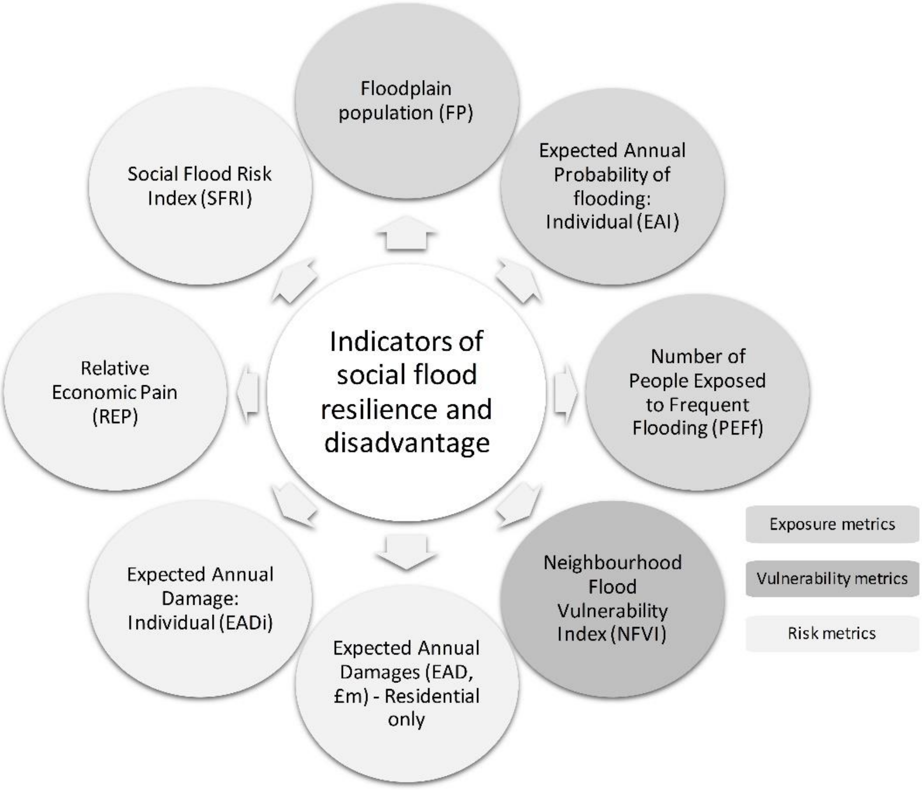


Concept
Purpose
Objective
Goal
Vulnerability
Understand the significance of the potential impact
Ensure impacts to the most vulnerable are well managed
Risk
Maximise the utility of limited resources
Efficiently reduce risks
Robust well-informed choices
Uncertainty
Maximise understanding
Make sense of the evidence

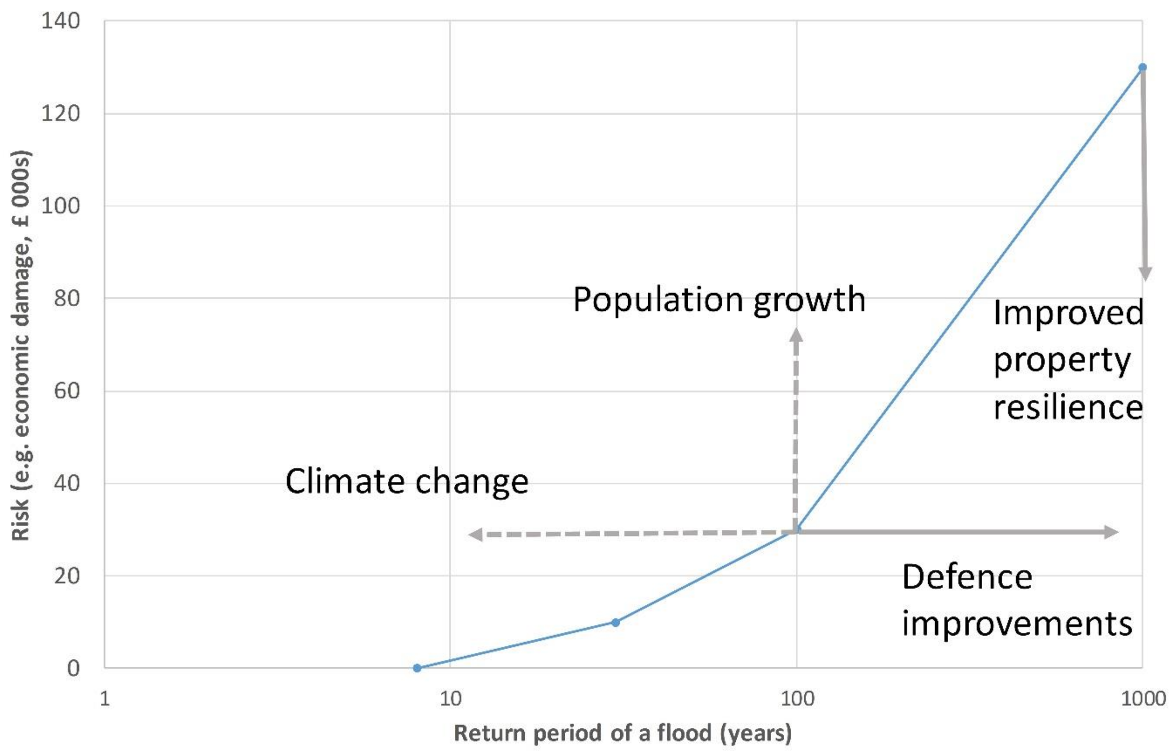

Climate change
Changes in mean sea level, peak river flow and short duration intense rainfall based on projected changes in Global Mean Temperature (GMT) of 2°C and 4°C (from the 1961-90 baseline as used in UKCP09) by the 2080s.
Changes in the chance of flooding
Population growth
Changes in population by local authority based on low and high growth projections as published by the Adaptation Sub-Committee (ASC, 2015) and used in UK CCRA (Sayers et al., 2015).
Increased exposure to flooding


Appropriately managing flooding processes
River and coastal defences
Management of catchment run-off
Management of shoreline morphology
Management of urban flood processes
Reducing the chance of flooding
Making good planning choices
Spatial planning and development control
Building regulations
Managing the exposure to flooding
Supporting individuals and organizations
Receptor Level Resilience measures
Forecasting, warning and community response
Insurance
Reducing the vulnerability of those exposed

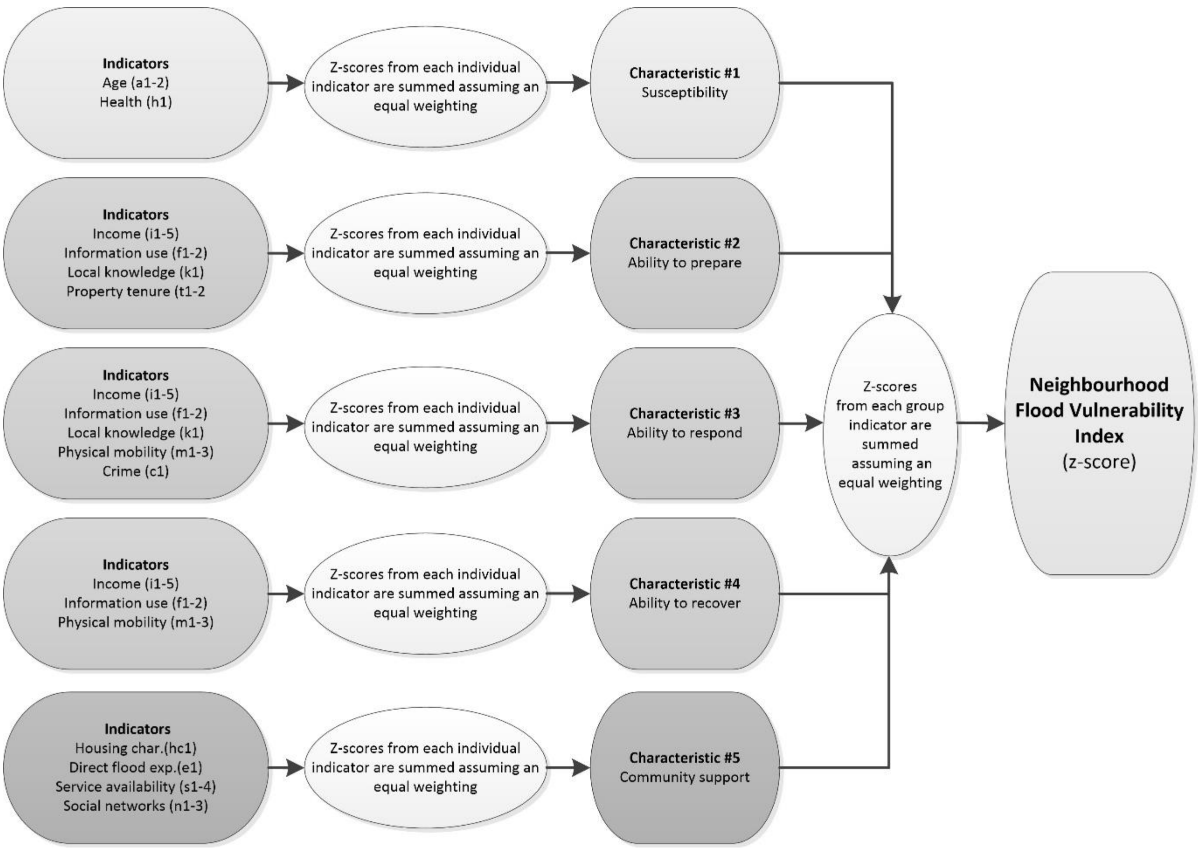

Exogenous drivers of change (e.g. climate and population
Endogenous drivers of change (e.g. flood risk management activities)
Flood Hazard (probability and extent)
Flood Exposure (given a flood)
Flood Vulnerability (of those exposed)
Social vulnerability, risk and disadvantage (quantified at a neighbourhood scale using the UK Future Flood Explorer)

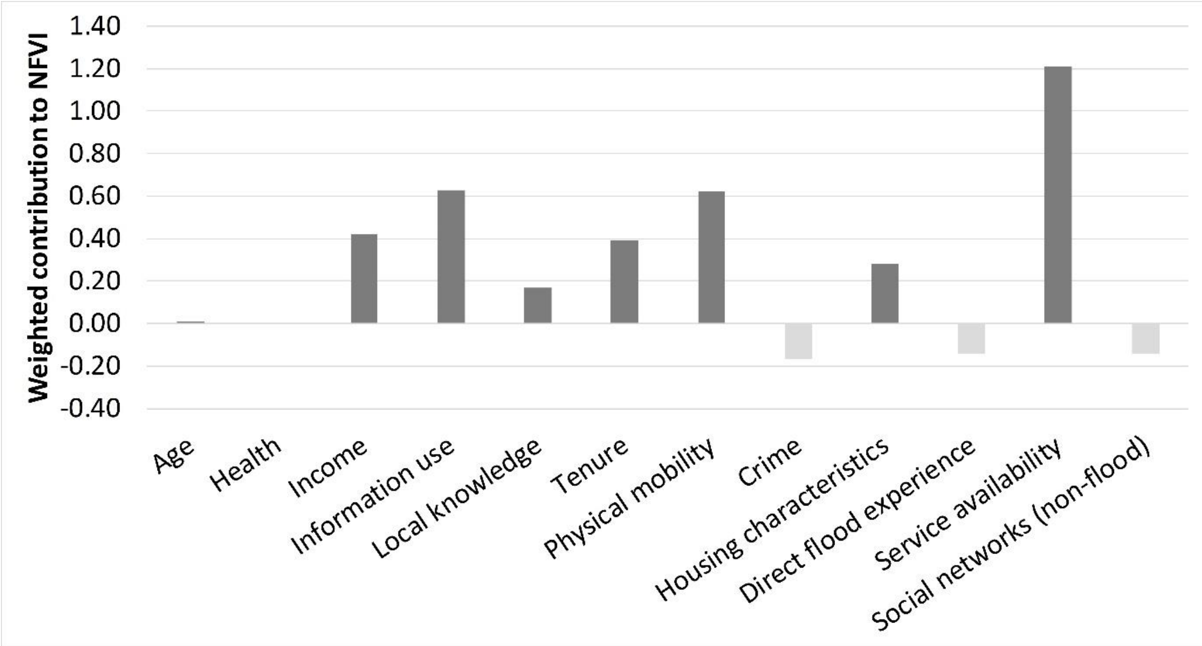


Floodplain population (FP)
Expected Annual Probability of flooding: Individual (EAI)
Number of People Exposed to Frequent Flooding (PEFf)
Neighbourhood Flood Vulnerability Index (NFVI)
Expected Annual Damages (EAD, £m) - Residential only
Expected Annual Damage: Individual (EADi)
Relative Economic Pain (REP)
Social Flood Risk Index (SFRI)
Indicators of social flood resilience and disadvantage
Exposure metrics
Vulnerability metrics
Risk metrics

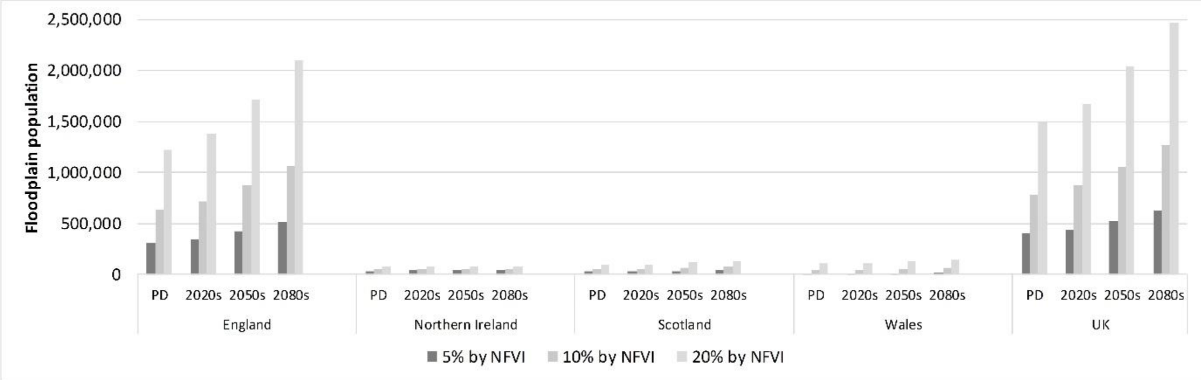


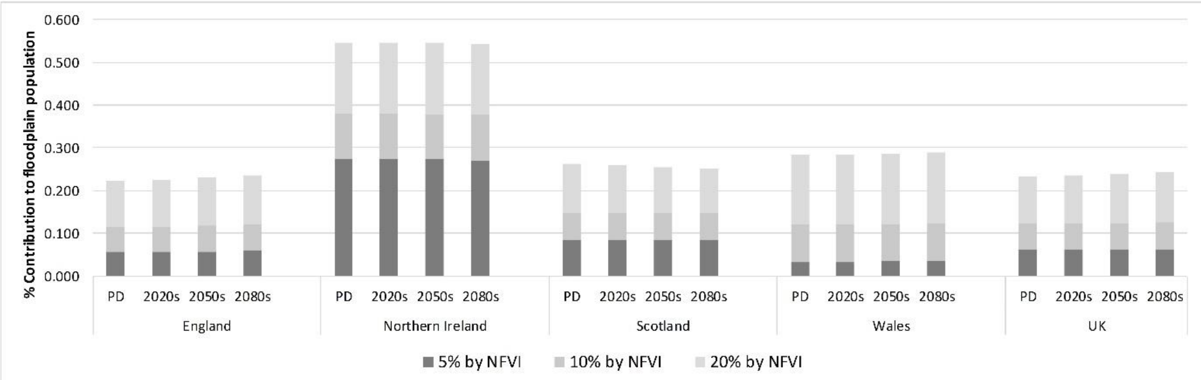
140
120
100
80
60
40
20
0
1
10
100
1000
Risk (e.g. economic damage, £ 000s)
Return period of a flood (years)
Population growth
Improved property resilience
Climate change
Defence improvements

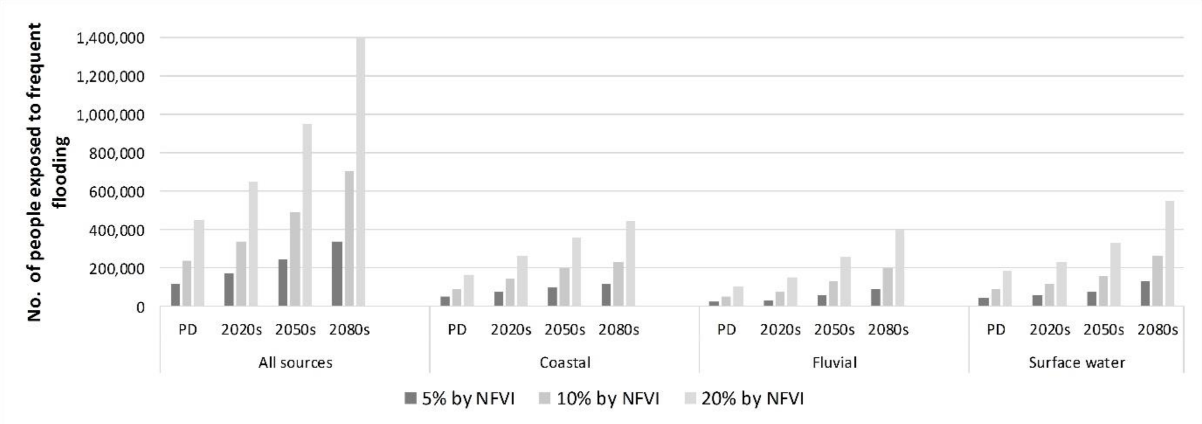

Indicators
Age (a1-2)
Health (h1)
Z-scores from each individual indicator are summed assuming an equal weighting
Characteristic #1
Susceptibility
Indicators
Income (i1-5)
Information use (f1-2)
Local knowledge (k1)
Property tenure (t1-2
Z-scores from each individual indicator are summed assuming an equal weighting
Characteristic #2
Ability to prepare
Indicators
Income (i1-5)
Information use (f1-2)
Local knowledge (k1)
Physical mobility (m1-3)
Crime (c1)
Z-scores from each individual indicator are summed assuming an equal weighting
Characteristic #3
Ability to respond
Indicators
Income (i1-5)
Information use (f1-2)
Physical mobility (m1-3)
Z-scores from each individual indicator are summed assuming an equal weighting
Characteristic #4
Ability to recover
Indicators
Housing char.(hc1)
Direct flood exp.(e1)
Service availability (s1-4)
Social networks (n1-3)
Z-scores from each individual indicator are summed assuming an equal weighting
Characteristic #5
Community support
Z-scores from each group indicator are summed assuming an equal weighting
Neighbourhood Flood Vulnerability Index
(z-score)

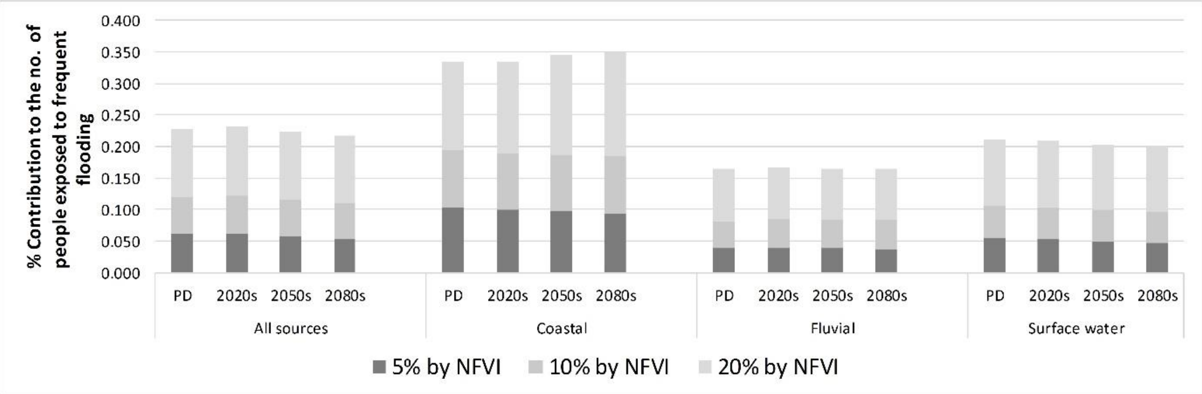


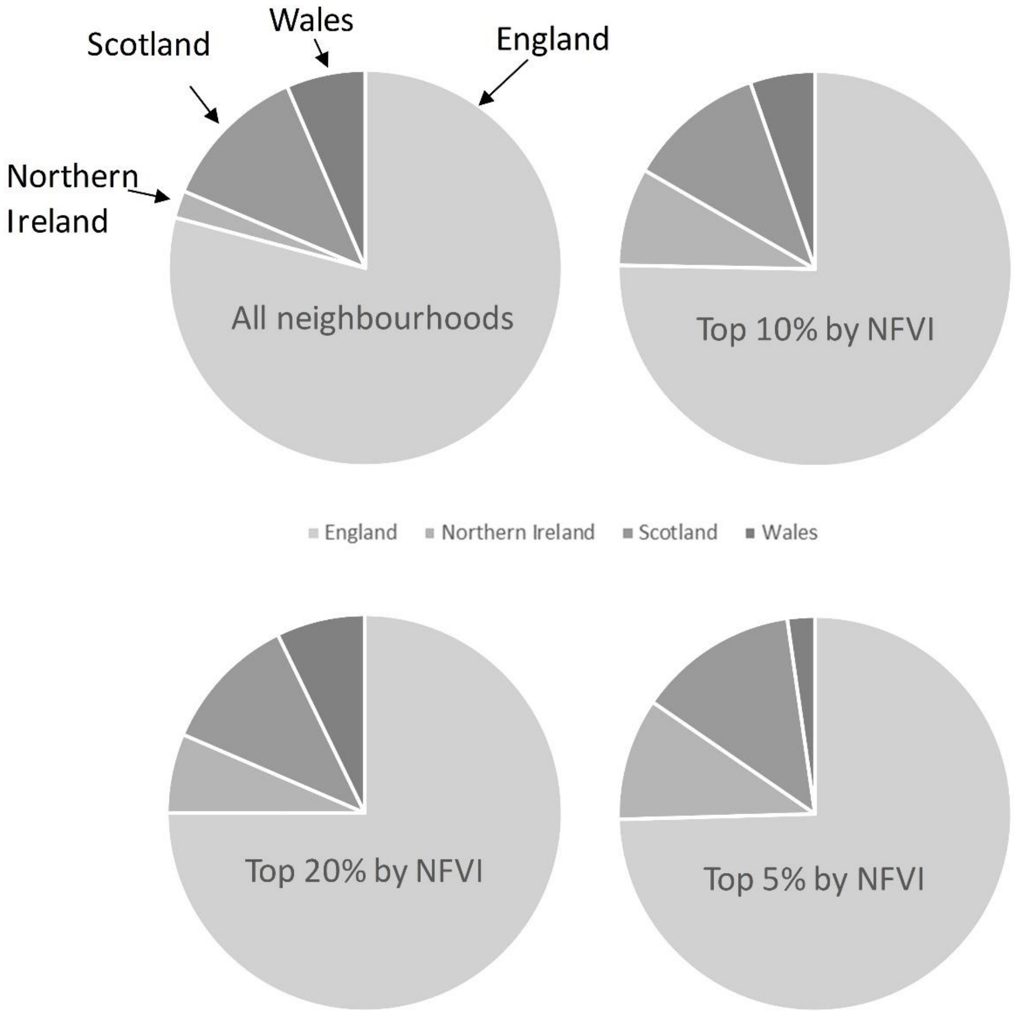
Weighted contribution to NFVI
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
Age
Health
Income
Information use
Local knowledge
Tenure
Physical mobility
Crime
Housing characteristics
Direct flood experience
Service availability
Social networks (non-flood)

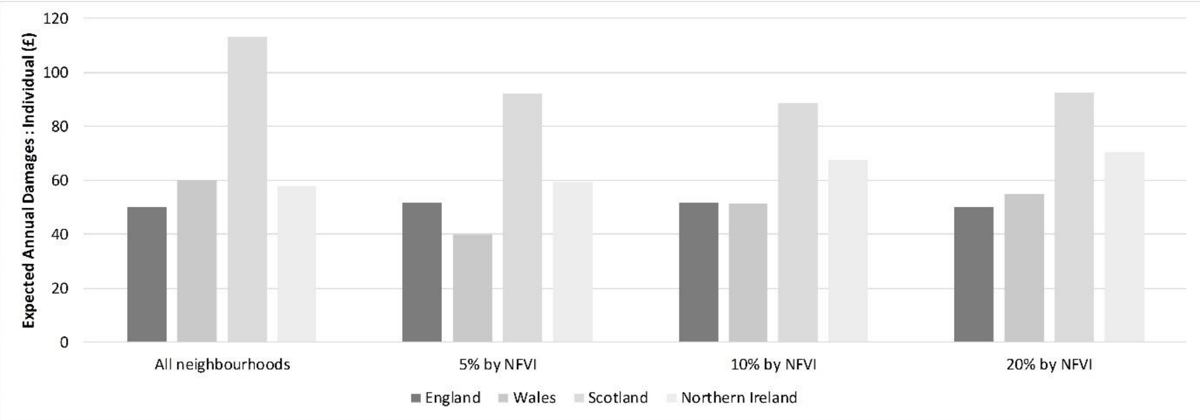

2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Floodplain population
PD
2020s
2050s
2080s
England
Northern Ireland
Scotland
Wales
UK
5% by NFVI
10% by NFVI
20% by NFVI

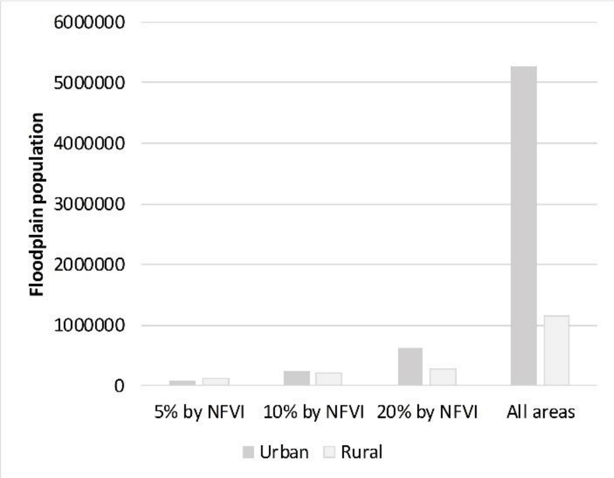

0.600
0.500
0.400
0.300
0.200
0.100
0.000
% Contribution to floodplain population
PD
2020s
2050s
2080s
England
Northern Ireland
Scotland
Wales
UK
5% by NFVI
10% by NFVI
20% by NFVI

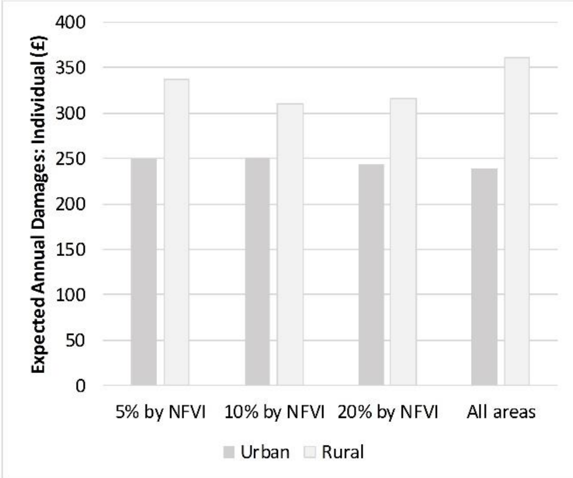

No. of people exposed to frequent flooding
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
PD
2020s
2050s
2080s
All sources
Coastal
Fluvial
Surface water
5% by NFVI
10% by NFVI
20% by NFVI

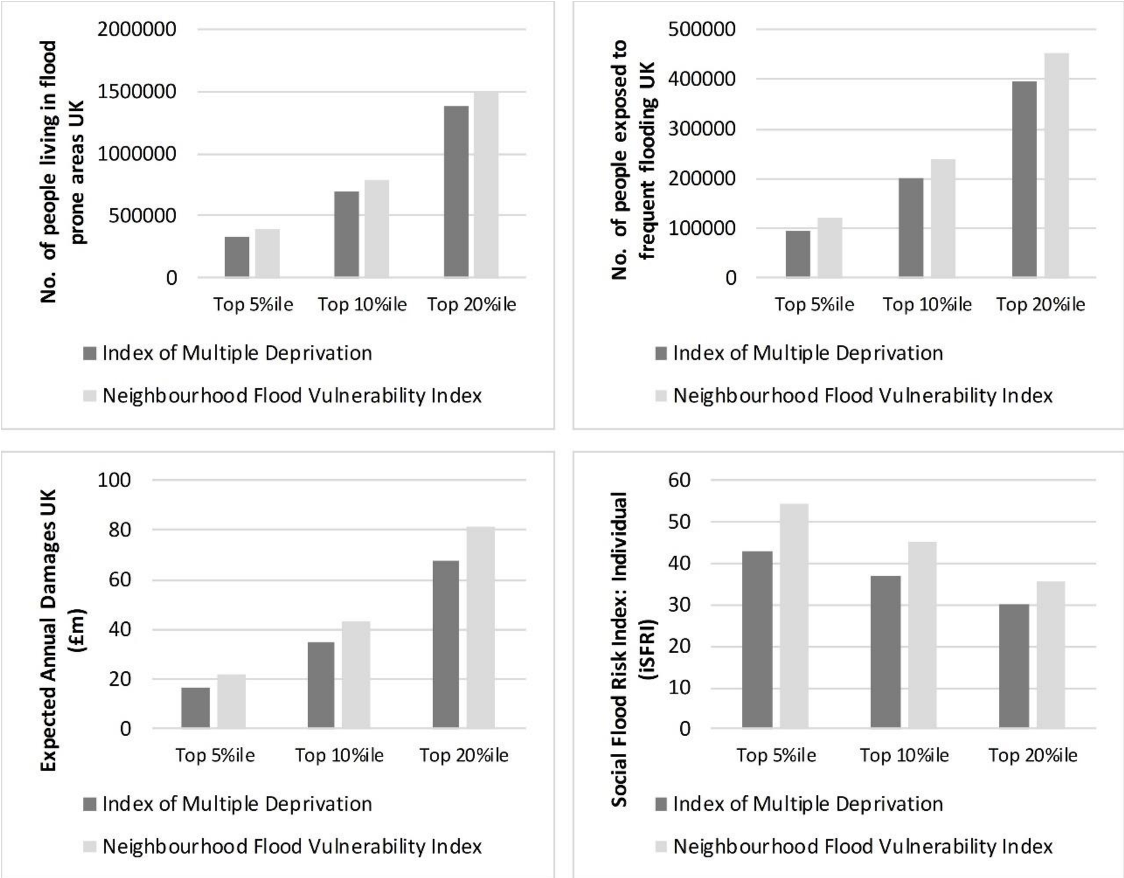

% Contribution to the no. of people exposed to frequent flooding
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
PD
2020s
2050s
2080s
All sources
Coastal
Fluvial
Surface water
5% by NFVI
10% by NFVI
20% by NFVI


Wales
Scotland
England
Northern Ireland
All neighbourhoods
Top 10% by NFVI
England
Northern Ireland
Scotland
Wales
Top 20% by NFVI
Top 5% by NFVI

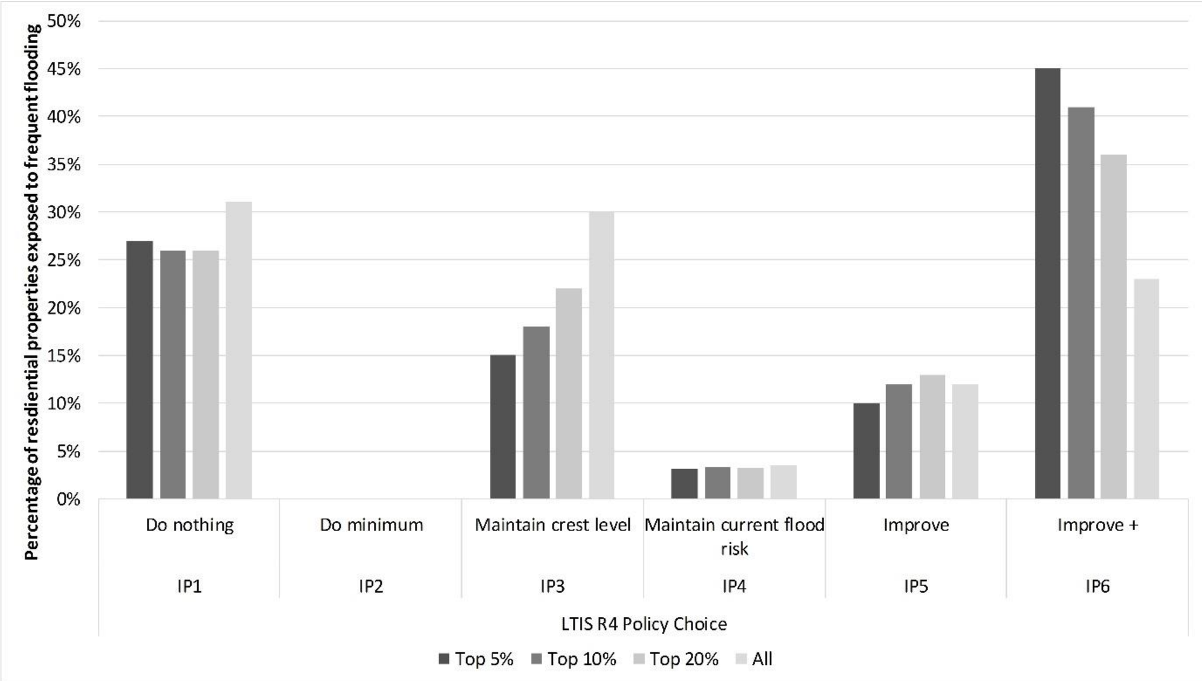

Expected Annual Damages : Individual (£)
120
100
80
60
40
20
0
All neighbourhoods
5% by NFVI
10% by NFVI
20% by NFVI
England
Wales
Scotland
Northern Ireland


6000000
5000000
4000000
3000000
2000000
1000000
0
Floodplain population
5% by NFVI
10% by NFVI
20% by NFVI
All areas
Urban
Rural


400
350
300
250
200
150
100
50
0
Expected Annual Damages: Individual (£)
5% by NFVI
10% by NFVI
20% by NFVI
All areas
Urban
Rural



No. of people living in flood prone areas UK
2000000
1500000
1000000
500000
0
Top 5%ile
Top 10%ile
Top 20%ile
Index of Multiple Deprivation
Neighbourhood Flood Vulnerability Index
No. of people exposed to frequent flooding UK
500000
400000
300000
200000
100000
0
Top 5%ile
Top 10%ile
Top 20%ile
Index of Multiple Deprivation
Neighbourhood Flood Vulnerability Index
Expected Annual Damages UK (£m)
100
80
60
40
20
0
Top 5%ile
Top 10%ile
Top 20%ile
Index of Multiple Deprivation
Neighbourhood Flood Vulnerability Index
Social Flood Risk Index: Individual (iSFRI)
60
50
40
30
20
10
0
Top 5%ile
Top 10%ile
Top 20%ile
Index of Multiple Deprivation
Neighbourhood Flood Vulnerability Index



Percentage of resdiential properties exposed to frequent flooding
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Do nothing
Do minimum
Maintain crest level
Maintain current flood risk
Improve
Improve +
IP1
IP2
IP3
IP4
IP5
IP6
LTIS R4 Policy Choice
Top 5%
Top 10%
Top 20%
All

Supplementary Table S1 Present day: Population of flood prone areas

	All neighbourhoods (000s)	Vulnerable neighbourhoods (000s)					
		Top 20% by NFVI		Top 10% by NFVI		Top 5% by NFVI	
By country							
UK	6,398	1,497	23%	802	13%	419	7%
England	5,508	1,216	22%	635	12%	316	6%
Wales	378	107	28%	45	12%	13	3%
Scotland	376	74	20%	56	15%	32	8%
Northern Ireland	136	74	55%	52	38%	37	27%
By flood source							
All sources	6,398	1,497	23%	802	13%	419	7%
Coastal (and tidal)	1,809	604	33%	340	19%	179	10%
Surface water	2,869	594	21%	293	10%	148	5%
Fluvial	1,720	299	17%	155	9%	71	4%

Supplementary Table S2 Present day: People exposed to frequent flooding (1:75 years or more frequent)

	All neighbourhoods (000s)	Vulnerable neighbourhoods (000s)					
		Top 20% by NFVI		Top 10% by NFVI		Top 5% by NFVI	
By country							
UK	1,985	1,333	67%	239	12%	122	6%
England	1,612	1,216	75%	174	11%	88	5%
Wales	117	36	30%	15	13%	4	3%
Scotland	200	51	26%	29	15%	17	9%
Northern Ireland	55	29	53%	20	35%	14	25%
By flood source							
All sources	1,985	451	23%	239	12%	122	6%
Coastal (and tidal)	489	164	33%	95	19%	50	10%
Surface water	870	103	12%	52	6%	24	3%
Fluvial	626	184	29%	92	15%	48	8%

Supplementary Table S3 The LTIS policy options (from Long Term Investment Strategy (LTIS) Improvements – Part 1 Technical Documentation, June 2014, Environment Agency (2014))

Policy Option	Change to expenditure	Change to risk
Do Nothing	Passive assets[1]: no expenditure on maintenance or replacement of passive flood risk management assets Active assets: not included in expenditure	Passive assets degrade and fail over a short period of time. The level of flood risk will increase quickly over time as assets fail. Non-operation of active assets increases risk on the very short term
Maintain crest level	Maintain and replace current flood risk management assets to their existing crest levels	The level of flood risk will increase over time due to climate change.
Maintain current flood risk	Maintain current flood risk management assets, replace with larger/longer/more robust structures. Build new assets	The level of flood risk will remain static as the size of defences keeps pace with climate change
Improve	Maintain and replace current flood risk management assets. Assets to be replaced with larger/longer/more robust structures. Build new assets	The level of flood risk reduces as assets are replaced with ones that offer a better standard of protection
Improve+	Maintain and replace current assets. Assets to be replaced with larger/longer/more robust structures. Build new assets	The level of flood risk reduces as assets are replaced with ones that offer a better standard of protection

[1] The term "asset" here refers to any structure or other intervention that influences flood probability. They are seen as assets as they have this valuable role (Sayers et al, 2015b).