Department for Environment Food & Rural Affairs

Quick Scoping Review

Final Report FD2716

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Contents

Background

The concept of resilience is one that has become increasingly familiar across the flood and coastal erosion risk management cycle in particular, and the emergency planning literature in general: from "community resilience" (Cabinet Office, 2011), to "Property flood resilience" (Defra, 2016), "Infrastructure resilience" (National Infrastructure Commission, 2018) and "resilient places" (Environment Agency, 2019). As Samuels (2019) notes in relation to the Environment Agency (EA) draft National Flood and Coastal Erosion Risk Management Strategy (EA draft FCERM Strategy): "*it is clear than the concept of resilience is set to become a policy action*"(editorial, p 1). Across the academic literature "there *is no agreed definition of resilience*" (Ruszczyk, 2019), it is used in different ways for different contexts and coming from a range of disciplines. Given this, it is timely to consider the similarities and differences between those frameworks, to ensure that "*practitioners, policy-makers, and researchers have a shared vocabulary for and understanding of resilience and how it is assessed"* (Samuels, 2019, editorial, p.1).

This report is the literature review for the project FD2716. The primary aim of this project is to inform the development of Government flood resilience policies, including the 25 Year Environment Plan (25 YEP) and EA National FCERM Strategy.

This report provides an overview of definitions and measurement of resilience to natural hazards in general and flooding in particular with a view to developing a common framework that could be used across flood and coastal erosion risk management.

The literature review aims to answer three key research questions. These research questions were developed by the project team, in discussion with the Steering Group in the start up meeting, drawing on the questions outlined in the specification.

Research questions

1. How has resilience been defined and conceptualised in regard to natural hazards generally and flooding in particular?

- To what extent have different aspects (e.g. social, technical etc) of resilience to natural hazards generally, and flooding in particular been conceptualised or operationalised as one "overall resilience" concept? What challenges, advantages and disadvantages of bringing these aspects together, conceptually, methodologically and practically are considered in the literature?
- How have definitions and conceptualisations of resilience generally and flooding/natural hazards in particular been expressed or reflected across government in England and Wales and specifically with respect to flood and coastal erosion risk management policy?

2. What different metrics, indicators or standards have been used to describe, measure, assess or set targets for resilience to natural hazards, generally and flooding in particular?

- What are the challenges in developing metrics for different aspects of resilience to natural hazards generally and flooding in particular?

- What evidence is there around their implementability as tools for driving actions to support government policy?

3. How do the identified resilience frameworks (both concepts and metrics) perform in terms against the following flood and coastal erosion risk management (FCERM) criteria:

- addressing a range of risks and impacts
- capable of being tailored to geographical area and local variation
- level of ambition to drive action
- appropriate distribution of costs and benefits
- meaningful to a range of audiences
- enables identification of timescales for implementation of measures
- short- to long-term
- appropriate and feasible allocation of roles and responsibilities
- feasibility and affordability of data collection and verification.

This report presents the findings from the review of the literature in the following sections:

1. Approach to the literature review
2. Frameworks and definitions
3. Metrics and measurement
4. Assessing frameworks against FCERM criteria
5. Discussion and conclusions

Approach

In order to review the literature, we carried out a Quick Scoping Review using an expert driven approach to gather relevant documents from three types of sources:

1. Expertise within the team specifically (Prof. Dennis Parker, Jaap Flitverk, Dr. Clare Twigger-Ross and Paula Orr)
2. Papers provided by members of the Steering Group
3. Papers provided by the Call for Evidence[1]
4. Expert interviews

Initially, each expert in the team wrote a short piece drawing on their expertise and detailing some of the references (source 1). These documents were complimented by the references identified by the Steering Group (source 2). The papers from sources 1 and 2 were divided into two groups: those that the project team considered to be core to the questions and were most familiar with, and those which were deemed “new” in that they had not been reviewed before by the team. The initial number of papers provided through this route totalled 80 (67 new papers and 13 core papers). After an initial assessment of relevance to the research questions this was reduced to 67 (54 new papers and 13 core papers). The 54 new papers were then grouped according to author and prioritised prioritised according to their relevance to the research questions, giving a starting group of 28 papers for QSR analysis.

The papers from Source 3, the Call for Evidence, totalled 33, with eight duplicated documents from Sources 1 and 2. The remaining 25 documents were reviewed for relevance. 20 were considered not to present significantly different evidence from the papers already reviewed (over half were written by the same authors). The remaining five documents were included in this review.

Expert interviews (Source 4) were also conducted in order to reflect on or complement the literature being reviewed. Five experts were interviewed suggesting seven new sources, which have been considered in this QSR.

All the documents from all sources (1,2,3 and 4) were logged in an Excel spreadsheet, with basic information to identify the document: Author, Date, Title, Journal (if relevant), Access route (e.g. whether the document was provided by a Steering Group member, a team member or was identified through another route), along with additional information about relevance to the project, for example in relation to resilience concept, and research approach robustness, based on standard criteria (after Collins et al, 2015). A final column (‘Status’) was used to record decisions about which documents to include in the analysis for QSR.

[1] https://www.gov.uk/government/consultations/flood-and-coastal-erosion-call-for-evidence

The Excel spreadsheet facilitated clustering and comparison of the documents included in QSR analysis. The synthesis of the evidence is structured around the research questions and priority areas identified in the specification and referred to in the Background section of this report. Any additional key themes emerging from the evidence were drawn out and brought into the analysis.

1: Frameworks and definitions of resilience

This section discusses the frameworks and definitions of resilience under the first three research questions. Note that the last part of Research Question 1 (SRQ1.3) has been included in section 2, as it addresses the operationalisation as well as the concept of resilience.

RQ1: How has resilience been defined and conceptualised in regard to natural hazards generally and flooding in particular?

Overall, the field of resilience to natural hazards and flooding, its frameworks and definitions, is characterised by diversity. This suggests that it is not yet a mature science in the Kuhnian (Kuhn, 1962) sense. That is, it does not yet have a dominating and settled definitional, conceptual and theoretical basis which is widely accepted and adhered to.

The diversity is likely due to the need for different conceptualisations in different contexts. In addition, the multi-disciplinary approach to resilience can mean that:

> *"Owing to its application within numerous disciplines, an agreed definition is not possible…... Resilience is widely seen as a desirable system property in environmental management……giving it traction beyond the ecological field in complex human-related spheres. Resilience, if viewed holistically, can bring together different perspectives (economic, environmental, human, physical, and social)."* (Ruszczyk, 2019, p.2).

The different definitions and frameworks can be broadly divided into those that are more narrowly based e.g. resilience of materials, structures to disasters and those which move to a wider framework looking at resilience of communities or cities (covering physical and social structures) and tend therefore to take a more holistic perspective. For example, property flood resilience (Defra, 2016) is focussed on the resilience of the structural aspects of properties to flooding, whereas city resilience (The Rockefeller Foundation / Arup, 2015) covers health and wellbeing, infrastructure and ecosystems, economy and society, and leadership and strategy. Tanner et al (2016) in discussing the triple dividend of resilience provide further argument for a broad definition of resilience. Specifically, the triple dividend of resilience refers to three major benefits related to investing in resilience building:

1) Avoiding losses when disasters strike
2) Stimulating economic activity thanks to reduced disaster risk; having a reduced risk of flood for example protects and can lead to enhanced local economic activity and this is a key benefit highlighted in the draft EA FCERM strategy

3) Development co-benefits, or uses, of a specific disaster risk management (DRM) investment – for example, strengthened river embankments can act as pedestrian walkways, parks or roads.

Tanner et al (2016) argue that benefits 2 and 3 accrue regardless of whether or not there is a disaster. For example, developing a nature reserve around a natural flood management scheme provides environmental and social benefit that exist regardless of whether it floods or not. This proposition that there are wider benefits from building resilience beyond avoiding losses links to having a broader conception of resilience, as noted in the paragraph above. Work on the multiple benefits of flood and coastal erosion risk management schemes is a key area within FCERM in England and Wales although still lacking in robust evaluation (Twigger-Ross et al., 2017).

The move away from a purely protection-based approach to FCERM to a more holistic resilience-based approach is articulated within an engineering perspective by Pearson et al. (2018). They argue that there is a shift in practice from critical infrastructure protection (CIP) towards critical infrastructure resilience (CIR). The paper draws on the EU-RESILENS (2015–2018) project (Realising European Resilience for Critical Infrastructure) which frames CIR as:

> *"A transformative, cyclical process, building capacities in technical, social and organisational resources, so as to mitigate as far as possible impacts of disruptive events, and based upon new forms of risk management, adaptability and the assessment of potential trade-offs between parts of a system"*. (Pearson et al, 2018, p.324).

The RESILENS project proposes a transition from a narrow risk-led management approach to a more holistic resilience paradigm which integrates social and organisational factors as well as building capacity to change. The narrative of a move towards resilience is one that runs through many reviews and also strategies (e.g. EA draft FCERM Strategy, 2019) as the best way to approach climate change and its associated events. Linked to this, within definitions of resilience is the extent to which they are predominantly **reactive** or **proactive,** with the former emphasising a "bounce back" to an original state, and the latter emphasising a 'bounce forward', adaption or transformation to a new normal that enables a better recovery when the structure/community etc. is next faced with a shock or stress. Forrest et al. (2019) provide a useful distinction between the traditional engineering perspective which is "*more functionalist, focusing on resistance and a post-flood return to equilibrium (Liao, 2012; Matthews et al., 2014)"* (p.424) and a more ecological and evolutionary characterised as "*more dynamic, focusing on adaptability and transformability of a system, emphasising notions such as flood - ability and reorganisation (Liao, 2012; Matthews et al., 2014)"* (p.424).

McClymont et al. (2019) in a systematic review of flood resilience (excluding coastal erosion) represent these distinctions using a systems perspective and usefully summarise it in a diagram (see Figure 1) .

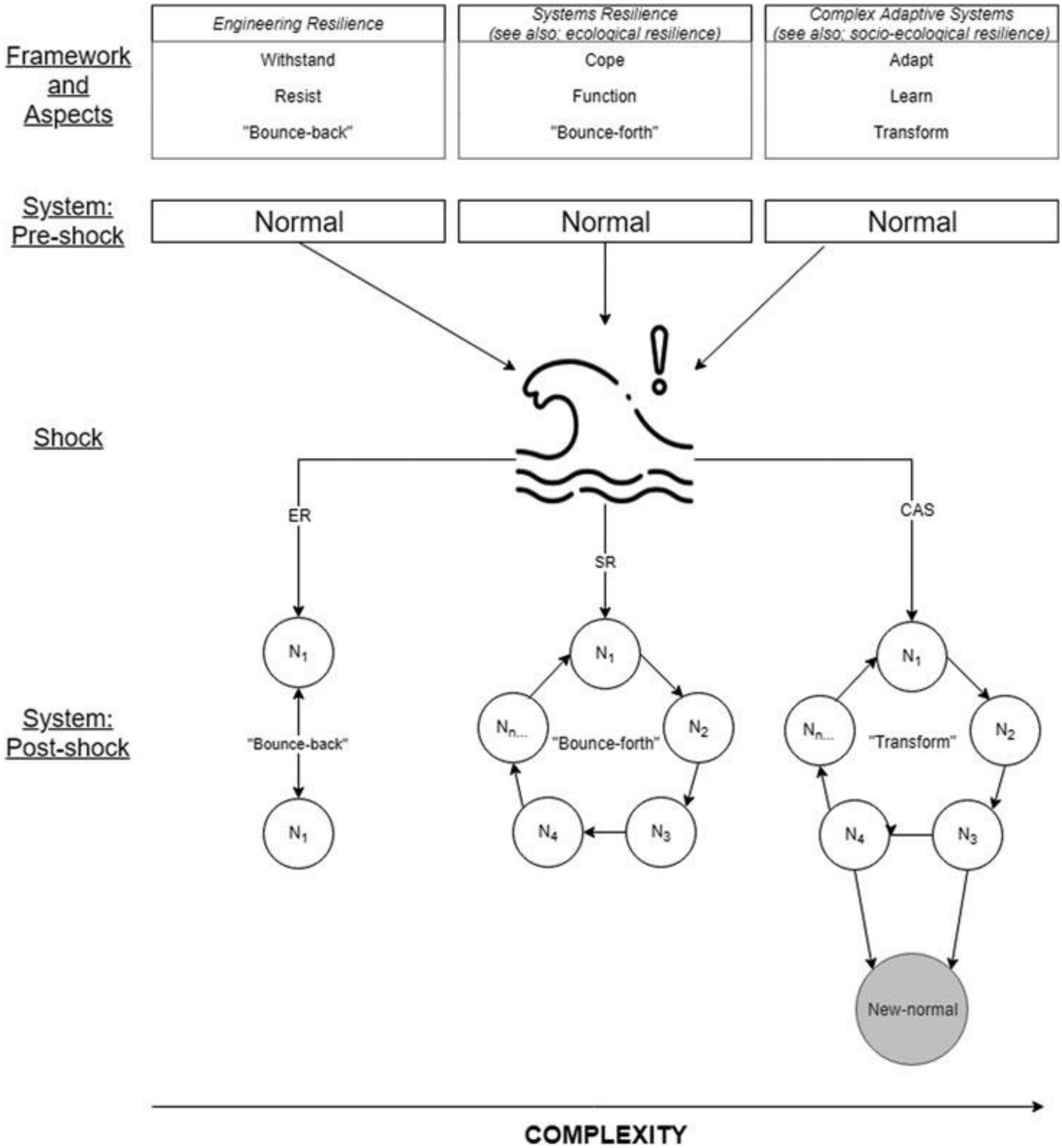

Figure 1 McClymont et al.'s (2019) conceptual model of resilience

Interestingly, in the 67 papers that were fully reviewed, McClymont et al. (2019) found that when the aspects of each definition were categorised into these three frameworks of resilience, the majority of the papers fell within engineering or systems frameworks.

Definitions vary in the extent to which they focus on these two aspects, for example, the UNISDR (2012, p.11) defines a city as resilient

"*by its capacity to withstand or absorb the impact of a hazard through resistance or adaptation, which enable it to maintain certain basic functions and structures during a crisis, and bounce back or recover from an event.*

The Department for International Development (DfID, 2011, p.6) definition adds in the notion of transformation:

> *"Disaster resilience is the ability of countries, communities and households to manage change, by maintaining or transforming living standards in the face of shocks or stresses - such as earthquakes, drought or violent conflict - without compromising their long-term prospects*."

Burton (2015) and IPCC (2014) further emphasise change and learning from events:

> *"resilience as the ability of social systems to prepare for, respond to, and recover from damaging hazard events (Cutter et al. 2008b). It includes conditions that are inherent and allow communities to absorb impacts and cope with an event. Resilience also encompasses post-event processes that allow communities to reorganize, change, and learn in response to an event (Cutter et al. 2008b)"* (Burton, 2015, p.69)

> *"The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation*" (IPCC, 2014, p.127).

From this it can be seen that resilience as a concept is neutral, it can be positive or negative (Palma-Oliveira and Trump, 2018). For example, "bouncing back" to a pre-flood state can easily reproduce vulnerabilities such that the next flood has the same negative impacts. Further, as the magnitude and frequency of floods change with climate change, responses need also to be dynamic, adaptive and learning. "*Frameworks of disaster resilience need to account for multiple entwined pressures, (e.g. development processes, DRR and climate change; see Kelman et al., 2015) to learn and adapt and to innovate existing risk management regimes on the community level" (*Kruse et al., 2017, p.2323). Given this, it is important that any definition of flood resilience focuses on the adaptive, transformative approaches to resilience. Dow et al. (2013) provide a useful discussion around the potential social limits to adaptation. They point out little is known about limits in social systems and "*whether there are social limits to adaptation, what influences their likelihood, where these might lie, who they would affect and what the consequences of reaching such limits might be*" (p.305). If the capacity to adapt is finite, then it will be extremely important for a resilience framework that includes adaptation measures within its components, to know what the limits are, how different social actors will be affected and the consequences of exceeding the limits. We would suggest that this is a key issue in relation to coastal erosion and areas of repeated flooding. Communities in some coastal locations are already facing limits to their capacity to adapt.

A further aspect to unpack with respect to the definitions and frameworks of resilience we have examined can be expressed in terms of resilience to "what?" and of "whom/what?" Some papers use the term "disaster resilience" (DFID, 2011; Bahadur et al., 2010) or "flood resilience" (Forrest et al., 2019; McClymont et al., 2019) emphasising what resilience building is **to** and that could be a general category of hazards such as “disasters” or to something more focussed such as “flood”. Others refer to “*resilient cities*” (The Rockefeller Foundation / Arup, 2015), “*community resilience*”(Kruse et al., 2017; Twigger-Ross et al, 2015), “*resilient places*”(EA, 2019a) and “*resilience of a system*” (IPCC, 2014) stressing **who** or **what** is becoming resilient. “Property flood resilience” includes both in its terminology. Characterising both of these aspects clearly is important for the operationalisation of any definition of resilience. Having these aspects clearly articulated enables the development of a common language (i.e. everyone knows what is being discussed) thereby avoiding confusion or misalignment of aims and outputs.

A further distinction can been made between those definitions that focus largely on the response and recovery to natural hazards, such as those detailed earlier in this section, and those that adopt what might be termed a “living with floods” position, focussing on enabling systems and communities to flourish in spite of disaster risk. Keating et al.’s (2017)’s definition is one of these:

> *the ability of a system, community, or society to pursue its social, ecological, and economic development and growth objectives, while managing its disaster risk over time in a mutually reinforcing way. Central to this conceptualization are the key community capitals……. This conceptualization is centred on **enhancing wellbeing** as the goal of resilience, rather than **disaster risk management**, which can be a means to resilience.”*(Keating et al., 2017, p.78) (bold emphases CEP’s own).

Similarly, The Rockefeller Foundation / Arup (2015) with their definition of city resilience stress it is about people being able to “*survive **and thrive***” (p.3).

A final key factor drawn out explicitly in The Rockefeller Foundation / Arup (2015) definition is a focus on those who are particularly vulnerable. This links back to the idea of resilience being about bouncing back better, so that those who are vulnerable to the specific shock or stress do not remain vulnerable in the future.

Overall, it is possible to summarise a set of common characteristics that run through the definitions we have looked at. Box 1 provides that summary.

Box 1 Common characteristics of resilience definitions

Resilience is characterised by….

- the ability or capacity to **prepare for, respond to, and recover** from damaging hazard events
- capacities to withstand or absorb the impact of a hazard and to **maintain functionality** or more positively to **enhance wellbeing** or **survive and thrive**
- being **reactive/stationary or proactive/dynamic**, with the former emphasising a “bounce back” to an original state, and the latter emphasising a “bounce forward”
- capacities to **adapt or transform** to a new normal that enables a better recovery when next faced with a shock or stress and does not **reproduce existing vulnerabilities**
- capacities to manage change **by learning and reorganising**
- a distinction between inherent and adaptive resilience. **Inherent resilience** is the pre-

existing or pre-event resilience within a community, whereas **adaptive resilience** is the ability of individuals, stakeholders, or communities **to learn** from and respond to changes precipitated by some hazard event

- **to what** e.g. natural hazards, flooding and **of whom/what** e.g. physical and social structures at different spatial scales: household, neighbourhood, city, region, country.

Within the documents for review, there were those which have reviewed resilience definitions and frameworks, specifically, Bahadur et al., 2010, Cai et al., 2018, Cutter, 2016, EA, 2019a, Koliou et al., 2018; Patel, et al, 2018; Twigger-Ross et al., 2014; Twigger-Ross et al., 2015. Rather than rehearsing the arguments covered in those reviews, we draw on their conclusions for our examination of key frameworks characterising resilience. There were 6 frameworks within the academic literature which were comprehensive enough (i.e. have definitions and theoretical underpinnings) to warrant inclusion here. **Error! Reference source not found.** provides an overview of those approaches and they are discussed more fully in the subsequent paragraphs.

Title of framework	Key components	Indicators/metrics (primary/secondary data collection)	Resilience to what of whom/what?	Key papers	Use
Disaster Resilience of Place model Baseline Resilience Indicators for Communities (BRIC)	Inherent and adaptive resilience 6 types of resilience: social, economic, housing/infrastructure, institutional, community, environmental	Indicators associated with each of the types of resilience Uses secondary data	Disasters – natural hazards Communities	Cutter et al. (2008) Cutter et al. (2010) Cutter et al. (2014)	Burton (2015) used post-Katrina Scherzer et al. (2019) used the BRIC in Norway Twigger-Ross et al. (2015) used in the FRCP evaluation
Flood Resilience Measurement Tool (FRMT)	5 capitals: human, social, physical, natural, financial 4 properties of resilience: robustness, resourcefulness, rapidity and redundancy 88 sources of resilience across the DRM cycle and 7 themes 29 ex-post outcome indicators	Uses both primary and secondary data	Flooding Communities	Keating et al. (2017) Campbell et al. (2019) From the Zurich Flood Resilience Alliance	The tool has been tested in 118 communities across 9 countries described in Campbell et al.

Disaster resilience framework	4 aspects: Context: resilience of what? Disturbance: resilience to shocks and stresses Capacity; exposure, sensitivity and adaptive capacities – key determinant of these are the resources that can be used. DFID use the 5 capitals from Sustainable Livelihoods Framework (SLF): social/human, physical, political, financial, environmental/naturale action: bounce back, bounce back better, recover but worse than before, collapse	Not clear if it has metrics associated with it	Disasters – shocks and stresses of System or process	DFID (2011)	
emBRACE community resilience framework	3 interrelated domains: A) Resources and capacities: (5 capitals informed by the SLF and its iterations (Kruse et al, 2017): natural, physical/place based, financial, socio-political and human B). Actions: civil protection and social protection C) Learnings: risk perception, problematising risk/loss, critical reflection, experimentation and innovation, dissemination, monitoring and review 2 extra-community	68 indicators 14 core indicators Uses mostly primary data with some secondary data	Natural hazards Communities	Kruse et al. (2017) emBRACE deliverables	Within the emBRACE project there were 5 case studies

	processes and structures: disaster risk governance and context, change, disturbance				
City Resilience Index	4 categories: the health and wellbeing of individuals (people); urban systems and services (place); economy and society (organisation); and, finally, leadership and strategy (knowledge), each with 3 goals 7 qualities of resilient cities: flexible, redundant, robust, resourceful, reflective, inclusive and integrated	56 indicators – 3 – 5 per 12 goals 156 prompt questions (1 – 7 per indicator) to collect both quantitative and qualitative (best and worst-case scenario) data Qualitative resilience profiles from qualitative data, no overall indices computed	Shocks and stresses Cities	The Rockefeller Foundation / Arup (2015)	Tested in 5 cities in the development, more details at www. cityresilienceindex.org
Australian Natural Disaster Index	8 themes of Coping capacity: social character; economic capital; infrastructure and planning; emergency services; community capital; information and engagement 2 aspects of adaptive capacities: governance, policy and leadership; social and community engagement These are set within a context of hazard type and occurrence and	Indicators for coping capacities and adaptive capacities Secondary data collection Aggregated measures of sub-indices and overall indices, mathematically	Natural hazards Communities	Parsons et al. (2016) Parsons et. al, (2017)	Used to map resilience to natural hazards across Australia

	external drivers and linkages	computed			

Table 1: Overview of disaster resilience frameworks

Disaster resilience of place (DROP) model and the baseline resilience indicators for communities (BRIC)

These two approaches have been developed by Cutter and colleagues. The DROP model (Cutter et al., 2008) proposes both inherent resilience which are the capacities within a community or system that can be drawn upon to help cope with an event or crisis, and adaptive resilience – that which is developed during or as result of the event or crisis. The capacities that Cutter uses, after considerable review of different approaches, are: social, economic, housing/infrastructure, institutional, community and environment/ecological. The work has been developed into a number of indicators for each capacity to enable the measurement of baseline resilience. This has been undertaken for areas of the US (Cutter et al., 2014) post-Katrina (Burton, 2015) and Norway (Scherzer et al., 2019).

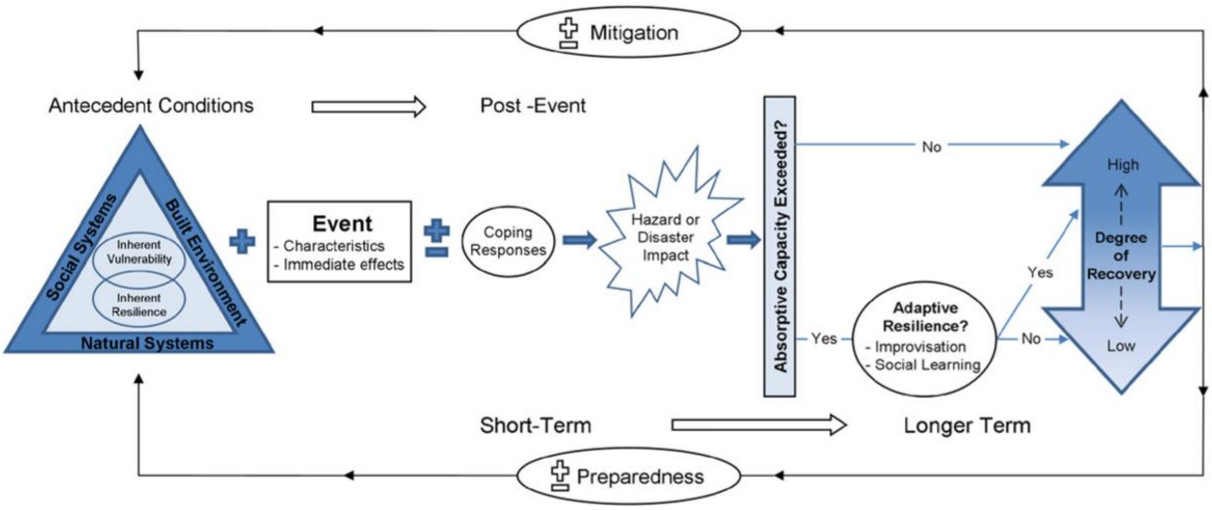

Figure 2 Disaster Resilience of Place model (Cutter et al., 2008)

For this baseline assessment work, data is collected from secondary sources. The benefit of using already existing data is that it has already been validated and a national dataset will be consistently available. The downside of using such data is that it is often at different scales and not always fine grained enough to enable differentiation of places' resilience. For example, in the UK Sayers et al. (2017) used data for the indicators in their Social Flood Vulnerability Index (SFVI) for England and Wales taken from the census (ONS) data which exists at the level of the Lower Layer Super Output Area (LSOA). The LSOA consist of groups of contiguous Output Areas[2] and have been automatically generated to be as consistent in population size as possible. The minimum population is

[2] Output Areas have an average population size of 125 households and around 300 residents, each clustered around a single mode, always above the confidentiality thresholds of at least 100 residents and 40 households. They generally fit exactly within the boundaries of parishes/communities and wards as at the reference date of 31 December 2002 and comprise where possible whole postcode units as at the time of the Census. The boundaries were created to enclose as compact an area as possible, although shapes may be attenuated by underlying patterns of settlement and postcodes. Where possible, OA boundaries were drawn to contain populations with homogenous characteristics, and around small, free-standing settlements.

1000 and the mean is 1500. Using this data does enable comparison across England and Wales but it means that because it is secondary data it is not collected with vulnerability in mind making some indicators harder to populate than others. The discussion of the SFVI further on in this section draws out some of the detail for this tool.

Twigger-Ross et al. (2015) used the framework of capacities as a tool for evaluation of the Defra flood resilience community pathfinders. They used it at the level of the areas of influence for each pathfinder, collecting baseline data for each capacity where it was available. What was challenging for their evaluation was that there was not data at the same level for all the indicators.

They also used the capacities framework to characterise the interventions and to frame the primary data collection from each of the pathfinders. This enabled a closer look at how each capacity might be developed or not through the various interventions. Orr et al. (2016) in examining the role of infrastructure improvements (specifically, community flood stores, rain gauges etc.) showed the way that these physical improvements could act as focal points for the engagement of local people in resilience building activities.

Flood Resilience Measurement Tool (Zurich Flood Resilience Alliance)

The Flood Resilience Measurement Tool comes from an alliance of NGOs, academics, and the private sector called the Zurich Flood Resilience Alliance. Their definition of disaster resilience is noted earlier in this section to be unusual in that it places enhancing wellbeing at the heart of its framework, making resilience more about creating conditions under which people can flourish even in the context of disaster risk. This tool has been created in the context of development work. The International Federation of Red Cross and Red Crescent (IFRC)'s conceptual framework (3) guided the development of the measurement method, especially the identification of resilience indicators.

Figure 3 IFRC framework for community resilience

88 sources of resilience were identified among the '5Cs' i.e. Human, Social, Natural, Physical and Financial capital. Between them they were chosen to represent the '4Rs' (i.e. the Robustness, Resourcefulness, Rapidity and Redundancy properties of resilience)

together with the different stages of the flood risk management cycle, defined as: Prospective risk reduction; Corrective risk reduction; Crisis preparedness; and Coping. Examples of sources of flood resilience within different capitals are given in Table 1 :

Capital	Source of resilience	Flood risk management cycle	Qualities
Human capital (assets and livelihoods)	Flood exposure perception	Prospective risk reduction	Robustness,
Human capital (life and health)	First aid knowledge	Crisis preparedness	Robustness, Preparedness
Financial capital (life and health)	Household financial savings that protect long term assets	Prospective risk reduction	Robustness
Financial capital (life and health)	Household flood insurance	Coping	Rapidity
Social capital (life and health	Access to external, formal flood-related services	Reconstruction	Resourcefulness
Social capital (life and health)	Social participation in flood management related activities	Coping	Resourcefulness
Physical capital (life and health)	Early warning systems	Crisis preparedness	Robustness

Table 1: Examples from the 88 sources of resilience from Keating et al. (2017, p.93)

As with other frameworks it uses a capitals approach together with properties of resilience. It is the only framework that is specifically focussed on flood resilience and the indicators are more precise and focussed on flood risk management, which should mean that their impact on overall resilience to flooding is clearer to track and intervene in. Further, Keating et al. (2017) are the only authors that have a set of 29 ex-post-flood outcome measures which provides some possibility of later developing targets for changes in resilience levels. Those outcome measures include:

- Death and injury due to flooding
- Building losses and damage
- Property losses and damage
- Flood learning
- Early warning system function
- Insurance Action
- Flood frequency and severity
- Number of people impacted

Disaster Resilience Framework (DFID, 2011)

The Department for International Development (DFID, 2011) reviewed many types of resilience and has a working definition in the context of disasters which is noted earlier in this section. As **Error! Reference source not found.** notes, there are four key elements of a resilience framework: the context, the nature of the disturbance, capacities to deal with this disturbance and reactions with different possible outcomes. Figure 4 shows how those four elements are conceptualised in DFID's framework. As with other frameworks it includes the capacity to deal with disturbance and uses the 5 assets from the sustainable livelihoods framework: social/human, physical, political, financial, environmental/natural. These five assets are used to map the range of interventions to enable examination of the portfolio of disaster resilience activities in a country or region.

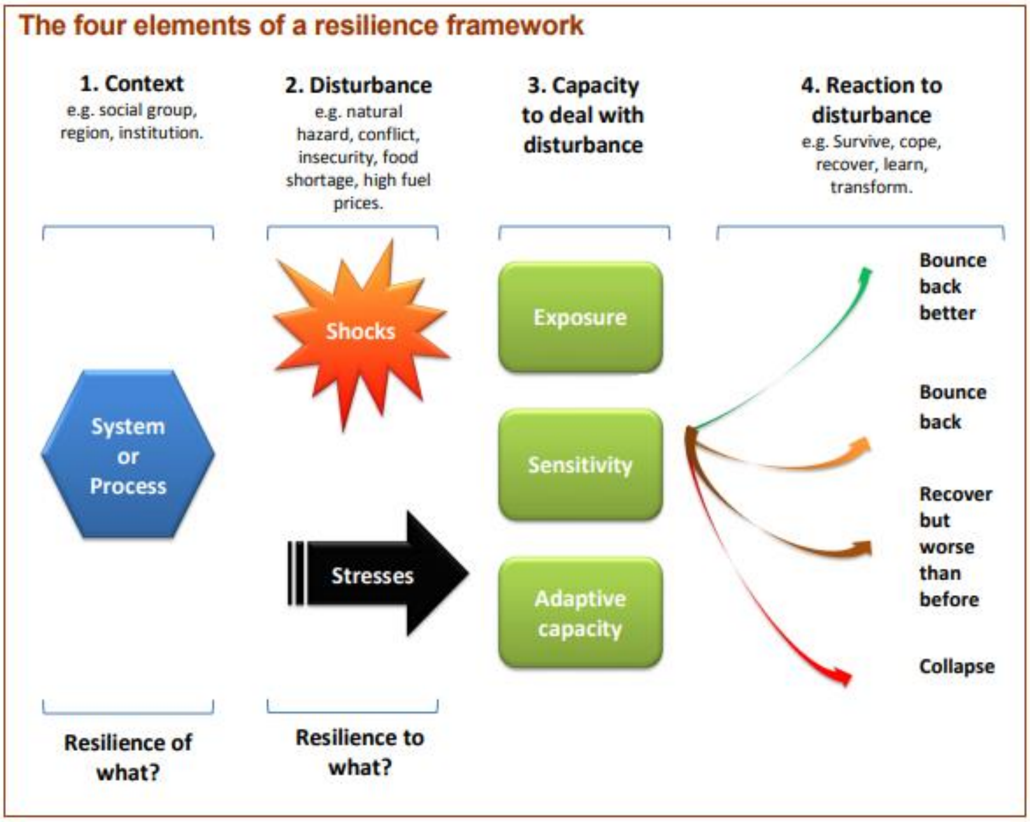

Figure 4: DfID model of resilience

emBRACE Community Resilience Framework (Kruse et al., 2017)

The emBRACE approach to community resilience was developed through a European research project. The project adopted the IPCC (2014) definition of resilience and developed the framework with three core areas. The emBRACE framework (Figure 5) shows community resilience as the central element of *"a knot surrounded by three loops that highlight intra-community interactions between various: resources and capacities, actions and learning elements*" (emBRACE, undated, p.6). It suggests that community resilience is influenced by extra-community forces comprising: context, disturbance and change over time. Further, the context for the framework includes a disaster risk governance domain, that is, the laws, policies and responsibilities that enable and support emergency management practices.

This framework was developed in order to explore the components of community disaster resilience across five European case studies. In terms of measurement, the project developed 68 indicators within the three areas across the case studies. The authors stress that the choice of indicators is dependent on the situation "*In other words, the proposed structure allows key indicators to be extracted, but does not necessitate that all key indicators must be extracted in every circumstance; those decisions remain context dependent*." (Becker et al., 2015, p.68). They prioritised the 68 further to produce 14 key indicators which cover the three areas; these are discussed in Section 2 on metrics. They are a mix of quantitative and qualitative measures but are largely bottom-up, collected at the community level.

Figure 5: The emBRACE framework of community resilience

City Resilience Index

The City Resilience Index (The Rockefeller Foundation / Arup, 2015) defines city resilience as:

> *"the capacity of cities to function, so that the people living and working in cities – particularly the poor and vulnerable – survive and thrive no matter what stresses or shocks they encounter."* (The Rockefeller Foundation / Arup, 2015, p.3).

It measures resilience at a city scale using 12 outcome goals across four areas: health and wellbeing, leadership and strategy, infrastructure and ecosystems, and economy and society. These goals are measured through 52 indicators which are assessed via 156 questions, which have quantitative and qualitative dimensions. The design of the framework means that it can be used at any city level location around the world (www.cityresilienceindex.org). The aim is to enable a city to measure and monitor the various components of resilience and to establish its strengths and weaknesses (The Rockefeller Foundation / Arup, 2015). Figure 6 represents those goals along with the qualities of resilience that cut across the goals. The qualities "*distinguish a resilient city from one that is simply liveable, sustainable or prosperous*" (The Rockefeller Foundation / Arup, 2015, p.8.). These qualities have similarities to the 4 "R"s in the Zurich Flood Resilience Alliance's FRMT. The measurement aspect is intended to be participative and part of a learning process. The qualitative dimension for each question consists of the user rating the indicator on a point between a described "best scenario" and "worst scenario" on a 1- 5 scale. This enables the development of CRI profiles, facilitating comparison across goals and cities. This approach overcomes the challenges of comparison across different metrics. By its nature the CRI focuses more generally on what makes the city flourish in the face of shocks and stresses and so could be seen as more focussed on building capacities in "peace time" on understanding the capacities to cope with recover from and adapt to emergencies.

Figure 6: Structure of City Resilience Framework (The Rockefeller Foundation / Arup, 2015, p. 9.).

Australian Natural Disaster Resilience Index (ANDRI)

The ANDRI was developed by Parsons et al. (2016) in the context of Australia's National Strategy for Disaster Resilience (Council of Australian Governments, 2011) which was adopted by all Australian States and Territories in 2011. The strategy recognises that disaster resilience is not just the domain of emergency service agencies but is conceived of as a shared responsibility among governments, individuals, communities and businesses. Parsons et al. (2016, p.5) are clear about the purpose of the ANDRI which is to "*audit the state of disaster resilience in Australia at one point in time".* They make a useful distinction between "top-down" and "bottom-up" assessments of resielince to natural disasters, with the former using secondary data to indirectly develop proxy indicators, and the latter focussed on community surveys and stakeholder interviews to directly derive indicators. The ANDRI is a top-down approach and was clearly developed to be practical and useable. It has two main components – coping capacities and adaptive capacities.

> *"**Coping capacities** are the means by which people or organizations use available resources, skills and opportunities to face adverse consequences that could lead to a disaster and **adaptive capacities** are the arrangements and processes that enable adjustment through learning, adaptation and transformation"* (Parsons et al., 2016, p.6, bold emphases CEP own).

Figure 7 shows how those capacities which make up the ANDRI sit within a context of natural hazards and external drivers. It is a relatively simple framework but in differentiating between coping and adaptation brings out the twin aspects of dealing with adverse consequences and learning to adapt and transform in order to adjust to a "new normal".

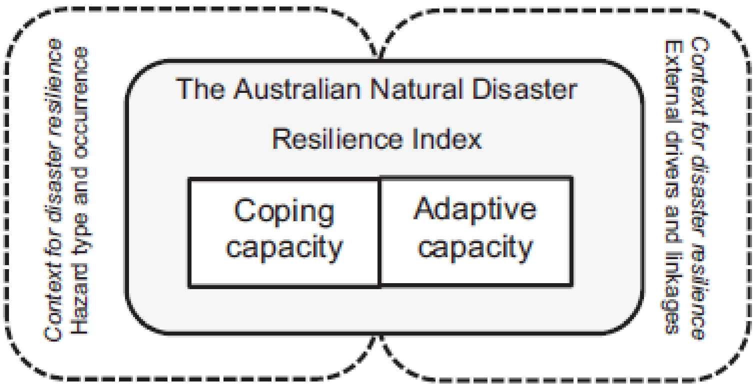

Figure 7: Conceptual elements of the Australian Natural Disaster Index (Parsons et al., 2016, p.6).

Parsons et al. (2016) provide a table showing the themes of coping and adaptive capacity within the Australian Natural Disaster Resilience Index which summarizes the relationships between the theme and natural hazard resilience. For example, **Error! Reference source not found.** shows two of the six themes within Coping Capacity together with a description of the sub-theme. What is important is that this shows where there is evidence for a relationship between a theme and resilience. This is important to ensure that indicators chosen are ones which if changed are likely to impact resilience levels. Over time, ideally, it may be that it is possible to draw out a reduced number of key indicators that are correlated with other indicators, such that, if that indicator changes it will have a significant impact on resilience.

Table 2: Examples of themes from Coping Capacity (adapted from Parsons et al., 2016, p.6).

Theme definition: Coping Capacity	Description of theme	Relationship of theme to natural hazard resilience
Social Character: the social characteristics of the community	Represents the social and demographic factors that influence the ability to prepare for and recover from a natural hazard event	Gender, age, disability, health, household size, and structure language literacy education and employment influence abilities to build disaster resilience (Morrow, 1999; Thomas et al., 2013)
Economic Capital: the economic characteristics of the community	Represents the economic factors that influence the ability to prepare for and recover from a natural hazard event.	Access to economic capital maybe a barrier to resilience (Bird et al., 2013). Losses from natural hazards may increase with greater wealth but increased potential for loss can also be a motivation for mitigation Economic capital often supports healthy social capital. (Thomas et al., 2013).

In terms of measurement the ANDRI does produce an aggregate score building up from the sub-theme, through the themes using statistical methods (see Section 2 for more information). This has enabled mapping of Australia in terms of the ANDRI and its sub-indices (Parsons et al., 2017).

Other related frameworks

It is important to note the work that has been carried out under the concept of vulnerability and social vulnerability in relation to flooding. Elsewhere (Twigger-Ross et al., 2014) we as others have argued that vulnerability is not simply the opposite of resilience, for example, someone may have mobility problems (a vulnerability) but because of good social networks can be alerted early before a flood and taken to a place of safety and so is resilient. Although the tradition of vulnerability and resilience assessment has come from different places, there are commonalities in assessment design (Parsons et al., 2016). A key index that has been developed within England for flooding is that of the Neighbourhood Flood Vulnerability Index (NFVI) (Sayers et al., 2018). "*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."*** (p.342). We can see a clear focus on the household level as shown by the variables in the model in 8. Many of these variables are also within some of the resilience indexes e.g. social character in the ANDRI (Parsons et al., 2016) model; social resilience in the BRIC model (Cutter et al., 2010), etc. Further, in relation to the other measures of resilience, the SFRI includes a measure of flood risk.

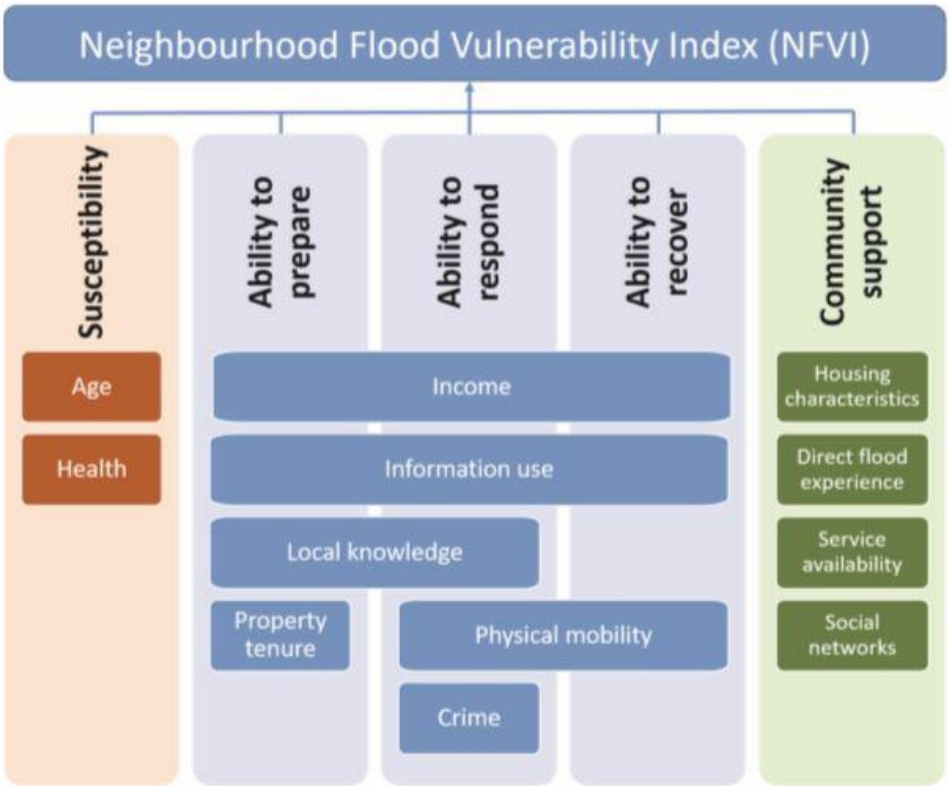

Figure 8: Components of the NFVI (Sayers et al., 2018)

In addition, to represent the relationship between vulnerability and flood risk, Sayers et al. (2018) developed the Social Flood Risk Index. This is used to identify those areas of the UK where the largest number of the most socially vulnerable people is most frequently flooded. It supports an understanding of geographic flood disadvantage. SFRI is calculated by the:

- Annual expectation of the number of people who will flood x the NFVI

This provides a combined expression of probability, exposure and vulnerability enabling flood risks in one neighbourhood to be compared with another in a way that explicitly accounts for social vulnerability. What is useful about this approach is that the mapping for the UK has been carried out linking vulnerability (NFVI) with flood exposure. It enables the mapping of locations where there are vulnerable populations exposed to flood risk. Because the NFVI is focussed on specific flood related vulnerability, it gives a better indication of those at flood risk in socially vulnerable areas than the metric currently used in FCERM by Defra/EA which is general measure of deprivation (the Index of Multiple Deprivation (IMD)). Sayers et al. (2016, p.349) say that "*This suggests that the IMD fails properly to identify those areas that are at greatest flood disadvantage.*"

A further theoretical framework of interest, social identity theory, was discussed by Drury et al. (2019) in the context of collective resilience in emergencies. The social identity approach provides a useful way of linking key aspects frequently observed within the community or social capital resilience capacity. The core aspect of the social identity approach is that each person has multiple social identities based on the different groups they belong to (e.g. choir members, women, consultants as well as personal identities (e.g. my personality).

Drury et al. (2019) focus on groups that develop or emerge to help after an event. They review the three key areas that are routinely mentioned as the community/group part of resilience: emergent disaster communities, social norms and existing relationships, showing how a social identity approach can account for the observations made around those concepts. An example is the coming together of people after a disaster (development of "therapeutic communities"). Drury et al. (2019) cite a qualitative study (Ntontis et al., 2018) that investigated residents who had been flooded in York in the 2015 floods. Drury et al. (2019) report that: *"Directly and indirectly affected residents stated that they came to see themselves as sharing a community identity with others affected by the flood due to the similar experience of an adverse event, due to suffering from similar problems that followed the event such as looting, and as a result of common struggles against the lack of the necessary infrastructure. The emergent sense of community became the basis for the provision of social support"* (Drury et al., 2019, p.5).

In relation to social norms, they argue that social norms are group norms. That is, whilst there are some overarching societal and cultural norms, groups with a shared identity have sets of norms that members adhere e.g. groups such as farmers where "self-reliance" is a group norm are more likely to be active within recovery rather than relying on the emergency services. They suggest that identification with a group mediates between the sharing of "common fate" and actions to help or support post-event. The value of using a social identity approach is that it has a firm theoretical and empirical base which can help unpack findings where seemingly similar contexts lead to differences in levels of community capital (as part of overall resilience). We would suggest that this is a useful addition to understanding the community capital resilience capacity.

The key similarities and differences between the frameworks are detailed in Box 2: Summary of similarities and differences between frameworks

Box 2: Summary of similarities and differences between frameworks

- Five of the six use a capitals/capacities approach, albeit in a slightly different way. This means that they are taking a multidimensional view of resilience, that includes structural resilience through to social and environmental resilience.

- There are overlaps in terms of the capitals/capacities approach e.g. social/human, economic/financial, environmental with some differences. Three frameworks (Flood Resilience Measurement Tool, emBRACE and DFID) draw on the sustainable livelihoods approach.
- Two (Flood Resilience Measurement Tool, City Resilience Index) draw on the idea of qualities or properties of resilience which comes from systems approaches to resilience i.e. robustness, resourcefulness, redundancy, flexibility etc.
- Only one (Flood Resilience Measurement Tool) framework is focussed solely on flood resilience. The others are focussed on disasters from natural hazards in general which means that their indicators are more general.
- In terms of scale, the frameworks are operationalised at the community (emBRACE; Flood Resilience Measurement Tool), city (City Resilience Index) and national level (ANDRI; BRIC).
- Clearly it makes sense to choose indicators that have been shown, empirically, to increase or decrease levels of coping and/or adaptation to a natural hazard in the object/community/city. Cutter et al. (2010) and Parsons et al. (2016) do show clearly where there is evidence for links between the variable and levels of resilience.
- Two approaches develop an index of resilience computationally: BRIC and ANDRI.

What is evident is that an accumulating, rather than an integrating, spectrum of practical resilience definitions and conceptualisations exists within the flood risk field. Drawing on the evidence in the preceding section, Figure 99 provides a possible way to conceptualise the different approaches linked to what that might mean in practice for FCERM.

Engineering resilience. At the narrow end is resilience as an engineering concept e.g. mechanical strength, hydraulic resistance, freeboard. Emphasises strength at a point in time; speed of recovery to pre-flood strength (i.e. bouncing back), maintenance of same structures over time but also sometimes increases in standards of protection over time as risk changes. Emergency responders and recovery entering early into spectrum around here, with communities conceived of as largely support in emergencies

Property-level resilience (consequence management) – again focused on physical strength/resistance measures but also on behavioural capacities of occupants in the case of warning-dependent resilience measures. Here we get the first ‘entry’ in the spectrum of people as actors in flood resilience. The aim is expressed as damage reduction.

Mitigation resilience (consequence management). Roughly at the same place on the spectrum are flood warnings which allow mobile engineering structures to be activated thereby increasing flood resistance and also provide a larger behavioural role for floodplain residents etc. The aim is expressed as damage reduction**.**

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Mitigation resilience through response (consequence management). Flood risk awareness raising, public education, flood preparedness measures focused on floodplain occupants becomes important roughly next on the spectrum as the approach to resilience becomes more targeted on those who occupy flood risk areas. Damage reduction again.

Resilience via vulnerability reduction. This now moves beyond consequence management and is based on a search for factors which lead to vulnerability in flood risk communities and ways of reducing it, subsequently translated into resilience enhancement possibilities. Social science approaches enter about here.

Social resilience representing capacity for adaption, learning and self-organisation (bouncing back better) and engagement of community resources. The spectrum here, near the far end, is what one might call a full blown 'social science' approach to understanding and measuring flood resilience among flood risk communities. The Zurich Flood Resilience Alliance conceptualisation and methodology is a good example of this approach although the context is an international development one. The EA Draft Stategy (2019) sets out this kind of approach .

Resilience through political (structural and institutional) change. At the very far, broad end of the spectrum is a 'political economy' approach to resilience which interprets vulnerability and resilience in terms of agency and power dynamics i.e. an approach which focuses on underlying structural and political (usually national and global) issues which may influence vulnerability and resilience. This might for example be shortcomings in nationally organised social welfare support in high unemployment, low income, poorly educated flood risk communities which might dominate and undermine any search for greater flood resilience targeting, for example, flood risk awareness raising, purchase of flood insurance etc.

Figure 9 Possible representation of spectrum of approaches to resilience

SRQ1.2 How have definitions and conceptualisations of resilience generally and flooding/natural hazards in particular been expressed or reflected across government in England and Wales and specifically with respect to flood and coastal erosion risk management policy?

This section focuses on SRQ1.2. To address this question our intention was to examine the definitions and conceptualisations available on webpages or in documents across a range of UK Government departments and government agencies. As the task progressed it became clear that there was considerable evidence focussed on flooding (e.g. Defra, Environment Agency (EA), Welsh Government, National Infrastructure Commission (NIC)) and emergency planning (e.g. Cabinet Office (CO)), so that forms the basis of our discussion.

In addition, we drew on existing work CEP had carried out for the Joseph Rowntree Foundation (JRF) project "Community resilience to climate change: an evidence review" (Twigger-Ross et al., 2015).

The use of the term "resilience" varies across these government departments/agencies from use of the term without a definition (National Flood Resilience Review, 2016), to loose frameworks (e.g. EA (2019)) to more defined frameworks (e.g. CO). It is used on its own as "resilience" to something e.g. flooding, climate change or of something e.g. communities, infrastructure as well as in conjunction with other terms e.g. "community resilience" (CO, Defra, Welsh Government Draft FCERM Strategy), "infrastructure resilience"(NIC) "flood resilience" (Defra) and "resilient places" (EA Draft FCERM Strategy).

In relation to flooding, resilience is used in relation to properties (Defra, 2016), communities (Defra, 2014); infrastructure (NIC, 2018) and more generally in relation to places (EA, 2019). For the Welsh Government, resilience is key to achieving national goals in many areas of the National Strategy (Prosperity for All), linking to many of the strategy's priority areas: Prosperous and Secure; United and Connected; Housing; and Mental Health (Welsh Government, 2019, pp.6-7).

These are aspects discussed in the following paragraphs.

The term "Property Level Resilience" (Defra, 2016) was formally introduced within the Property Flood Resilience Action Plan (Bonfield, 2016). The Action Plan provides a definition of Property Level Resilience (PLR) see Box 3.

Box 3 Definition of property level resilience

What do we mean by Property Level Resilience?

Property Level Resilience (PLR) aims to make people and their property less vulnerable to the physical and mental impacts of flooding. Actions that can be taken include installing flood doors, flood barriers, air brick covers, pointing or waterproofing brickwork, installing non-return valves, and moving vulnerable features such as sockets above floor level. Properties need a package of measures, some of which prevent water entering a house and others that minimise the impact should water enter the house, speeding up the recovery process. Sometimes the water should be let in. For floods over 60cm depth, or of prolonged duration, attempting to keep the water out can cause serious structural damage, owing to the unequal water pressures either side of the walls.

(Bonfield, 2016, p.8)

It is a clear definition, focussed on both resistance and adaptation to flooding in order to reduce the negative impacts. It is an area of both research (Lamond et al., 2017; Lamond et al. (forthcoming)) and practice (e.g. the Property Flood Resilience roundtable). Further, the EA (2019) has helped to establish three pathfinders to develop regional hubs to support the uptake of PLR. Finally, the Construction Industry Research and Information Association (CIRIA) and the Building Research Establishment (BRE) are managing a project to develop a Code of Practice and guidance for PLR.

What is clear is that within the area of flood and coastal erosion risk management, resilience is focussed on both resistance and adaptation and involves many of the key parties working to normalise PLR for those in at risk communities. It is also a key component within the EA draft FCERM strategy (EA, 2019) within Strategic Objective 2.4 which suggests that "*Either as a proactive step or in response to flooding, more should be done to encourage property owners to build back better and in better places"* (EA, 2019, p.38).

In relation to communities, although there have been Defra pathfinder projects that focussed on improving the resilience of communities to flooding (Twigger-Ross et al., 2015), the reference to community resilience within Defra documents is within the National Flood Emergency Framework (Defra, 2014) and firmly linked into emergency planning: "*The concept of a National Flood Emergency Framework was promoted by Sir Michael Pitt in his report on the summer 2007 floods. Its purpose is to provide a forward looking policy framework for flood emergency planning and response."* (p.3). There is no definition of community resilience, rather there is a short section which focuses on preparedness and the role of community flood groups. There is a similar use of community resilience in the Welsh Government's Draft FCERM Strategy: "*The resilience of a community to flooding is a measure of how it responds to and recovers from a flood event. A resilient community is well prepared for a flood and knows what action to take to reduce the potential impacts and damage caused. It is also able to minimise the disruption caused and recovers quickly from flood events.*" (Welsh Government, 2019, p.37).

Defra's understanding of community flood resilience is reflected in the specification for the Defra Flood Resilience Community Pathfinder programme (FRCP) (Defra, 2012) which focussed on "*innovative local initiatives that could be developed to complement the protection offered by flood defences at a property or community level, and to help people manage their level of risk and improve their financial resilience*." (p.2). The work of the pathfinders on resilience of communities to flooding, whilst still with a focus on engaging communities in emergency planning and preparedness went further into adaptation and mitigation. It also proposed a definition of community resilience (after Cutter et al., 2014) that went beyond emergency planning and management of residual risk (Twigger-Ross et al., 2015).

Three key documents that discuss resilience to flooding with a focus on infrastructure are the National Flood Resilience Review (HM Govt., 2016), the National Infrastructure Assessment (NIC, 2018) and the NIC Resilience Study Scoping Report (NIC, 2019).

The National Flood Resilience Review, in spite of using the term "resilience" throughout the document, does not provide a definition of it but does state it is resilience to flooding and resilience of infrastructure. Through the National Flood Resilience Review (HM Govt., 2016), "improving resilience" includes improving the protection of infrastructure with flood defences, improving incident response, improving resilience strategically and building resilience into the design of new urban developments:

"*With Sheffield as an example, we hope other urban areas will adopt the principles of building resilience into the design of their urban development and regeneration, creating additional social and economic value from flood defences*" (HM Govt, 2016 p.25).

However, overall, resilience is used interchangeably with flood protection, for example:

> *"For those assets within the Extreme Flood Outlines that are currently inadequately **or un-defended,** we have also collated information on planned resilience improvements. The results of our analysis show that some sectors are more **flood-resilient** at a local level than others*." (p.17).

The emphasis is centred on improvements to the physical capacity of places to reduce the negative impacts of flooding with relevant institutional improvements to support those changes. It is not clear how the use of the term "resilience" differs from the use of the term "risk". This distinction is also not clear within the definition of the NIC's resilience standard:

> "*The Commission's judgement is that all properties, wherever feasible, should be resilient to severe flooding, with a 0.5 per cent annual probability, by 2050. This is consistent with the advice provided to government by the Natural Capital Committee for the 25 year Environment Plan. Under this standard, someone living in a house at risk of flooding for 20 years would face less than a 1 in 10 residual chance of being flooded"* (NIC, 2018, p.90).

The metric used is a probability which is the usual way of expressing flood risk. Within the NIC (2018) assessment, resilience is defined in their glossary drawing on the UN definition:

> *"Resilience: The United Nations defines resilience as the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner".* (NIC, 2018, glossary).

NIC followed up the 2018 National Infrastructure Assessment with a scoping document for their study of resilience in autumn 2019. This provides more detail in terms of resilience, highlighting the range of definitions in relation to infrastructure systems, listing the following as some of them:

- *resist – the ability to withstand possible hazards*
- *absorb – the capacity of the system to limit the damage incurred during an event*
- *recover – the ability for the system to return to its original state following an event*
- *adapt – the system's ability to change to maintain its function in a new environment.*

They suggest that "*the Commission will continue to apply a broad understanding of resilience for this study, in order to look holistically at the resilience of infrastructure systems to understand problems and potential solutions*". (NIC, 2019, p.8).

From the discussion around the standard (NIC, 2018) however, it would seem that it does not differ in terminology from that of current descriptions of flood risk and it is unclear how the aspects of adaptation and transformation that are part of their definition could be incorporated into such a standard. Indeed, the NIC (2019) in their scoping report draw out the challenge of moving from a risk standard to a resilience standard recognising that "*Different frameworks for valuing resilience are used across sectors and it is perceived that, in practice, cost benefit analysis seldom adequately captures the value of resilience, as it does not fully quantify factors such as quality of life, societal or environmental benefits"* (p. 24).

In relation to infrastructure, it is helpful to look at Ofwat's (2017) definition of resilience which picks up on many of the themes reported so far:

> *"Resilience is the ability to cope with, and recover from, disruption and anticipate trends and variability in order to maintain services for people and protect the natural environment now and in the future."* (Ofwat, 2017, p.1).

This definition emphasises the functions of coping with, recovering from and maintaining an adequate level of performance. Ofwat talks about three types of resilience: corporate resilience (the capacity of a company's governance, accountability and assurance processes to help avoid, cope with and recover from, disruption of all types; and to anticipate trends and variability in its business operations), financial resilience and operational resilience (Ofwat, 2017). Systems thinking is central to Ofwat's conception of resilience. It is vital for companies to understand their interdependencies and interrelationships with the systems they are part of. These include the natural environment, social systems, the economy and agriculture. Among the benefits of taking a more holistic view are better planning based on knowledge of system pinch points and capacities as well as being able to implement more long-term and holistic solutions.

Moving on to the EA's (2019) definitions of "resilience for places" and "Resilient places":

> *"Through this draft strategy we introduce the concept of 'resilience for places' which refers to the ability for a community in a place to* ***cope with, and recover from****, all sources of flooding or coastal change"* (EA, 2019, p.18) (CEP's own emphasis).

This definition does not include the terms adapt or transform. However, there is a section in the strategy on "adaptive capacity" which seems to be separate from discussions of resilience. In addition, one of the objectives is that: "*places affected by flooding and coastal change will be 'built back better' and in better places*" (EA, 2019, p. 38), however the discussion within that section focuses on properties rather than any wider definition of places. In the glossary the term "Resilient places" is also defined with a focus on tools to reduce risk (probability x consequence).

> *"Resilient places*
>
> *Resilience in places should be made up of a combination of tools that reduce the likelihood and consequence of flooding. These tools include: asset resilience (delivering a standard of protection through construction of new defences and maintenance of existing defences), catchment solutions (e.g. natural flood management) and community or business resilience measures (e.g. property level resilience, warnings and recovery plans)."* (EA, 2019, p.62).

Within the draft strategy there is further discussion of tools to achieve place based resilience standards which are shown in Figure 10.

Figure 10: Tools used to achieve place based resilience

As part of the current research, the team conducted a review of asset resilience, to understand what metrics could be used to capture the role of flood defence assets in resilience. Box 4 summarises the approach used and the findings of the research.

Box 4 Asset resilience

The role of assets in resilience

As part of this study, Royal HaskoningDHV and CEP carried out a small related study to explore how the role of flood defence assets in overall flood resilience could be captured by resilience metrics. This aimed to support the Environment Agency's ongoing work to incorporate resilience into their asset management (goals and standards would be defined in terms of these metrics, see Section 2).

The Environment Agency already uses metrics to reflect the traditional, basic role of assets (i.e. prevent flooding up to a chosen event probability of exceedance).. This study however focused on five additional asset performance features that relate to elements of resilience other than 'Protection', and are not yet fully captured by the Environment Agency's existing metrics. These five features were identified in relation to existing resilience definitions from the Cabinet Office and the National Infrastructure Commission. They can be grouped into three 'asset life stages' as follows:

1. Behaviour under loading:
   - Chance of breach under the full range of loading conditions;
   - Breach / damage behaviour ('graceful' or catastrophic);
2. Behaviour after breach:
   - Continued partial performance after breach;
   - Recoverability – speed of repair or replacement;
3. Future:
   - Adaptive capacity - ability to change in order to maintain function in a new environment.

The literature review confirmed that there are no existing mature approaches for explicitly measuring the role of assets in flood resilience. There is a wide range of definitions and concepts, and it is noted that this hampers operationalisation. The existing resilience frameworks (ANDRI, CRI, ZFRA's Flood Resilience Measurement Tool) include infrastructure, mostly as a receptor but there is also some reference to their protective role.

The study has identified three levels (or tiers) of approaches for setting asset performance metrics:

1. Weighted scorecard / formula of basic asset characteristics (materials, structural principle, geometry) – relatively easy to develop and quantify, but poor proxy of actual resilience;
2. Performance indicators that take loading into account (e.g. adapted fragility curves, breach speed, residual performance, cost of future improvement) – medium effort to develop, will require modelling, good reflection of actual resilience;
3. Resilience indicators that take receptors into account (e.g. impact on risk to life, economic risk, health & social impacts) – high effort to develop and calculate, but with the strong benefit of enabling a direct link to overall flood resilience and its other 'capitals'.

If resilience metrics for assets need to relate directly to the metrics for overall flood resilience from the project, then this will require a 'level 3 approach': an approach that determines how the asset (system)'s resilience influences the impact of flooding on receptors, in all relevant dimensions.

The analysis shows that the role of assets in resilience contains multiple dimensions, and there is no single parameter that captures all of these adequately. If there were a need for a single metric for the role of assets in flood resilience, this would have to be a composite metric that combines those dimensions considered most important. This could include the potential for weighting to steer priorities (through an overarching weighted scorecard / formula, similar to the Partnership Funding calculator).

The study recommends further progressing thinking about this particular aspect of resilience.

This combination of definition and tools within the draft strategy are focussed, unsurprisingly, on what the EA can do to increase resilience of communities and infrastructure to flooding from all sources. Whilst there is not an explicit discussion of capacities within communities, institutions etc. in relation to resilience, there is a strong theme running through the strategy of the importance of context and places, that for resilience to be improved it needs to be understood in relation to local places, that one size doesn't fit all.

In the EA's response to Defra's call for evidence (2019), a set of resilience components with associated tools was presented as shown in Figure 11.

Figure 11: Resilience components and tools (EA response to Defra call for evidence, 2019)

What this adds, usefully, are different aspects of resilience, reflecting the components of other resilience definitions: prevention, protection, response, recovery and adaptation.

Continuing with infrastructure, albeit within the context of all hazards, the Cabinet Office (2019a) *Public Summary of Sector Security and Resilience Plans* focuses on Critical National Infrastructure (CNI). The SSRPs originated from the Pitt review (2008) of the 2007 floods and were originally intended to focus on resilience to flooding, but were expanded in 2015 to cover all hazards and security threats relevant to each sector. Consequently, they were renamed 'Sector *Security* and Resilience Plans (SSRPs). Within this document is an approach to resilience that focuses on Resistance, Reliability, Redundancy, and Response & Recovery. Figure 12 and Box 3 show the details of the framework. The Government's core objective includes

> "*reducing CNI's vulnerability to threats and hazards and improving resilience by strengthening the ability of CNI to withstand and recover from disruption"* (CO, 2019a, p.7*).*

It is not clear from the following summaries how this framework is used, there may be more clarity within the plans themselves.

Figure 12 Components of infrastructure resilience (CO, 2019a, p. 7)

Box 5 Details of infrastructure resilience

Resistance: Concerns direct physical protection (e.g. the erection of flood defences). Resistance is ensured by preventing damage or disruption through the protection of infrastructure against threats and hazards. This includes reducing vulnerability through physical, personnel and cyber security measures.

Reliability: The capability of infrastructure to maintain operations under a range of conditions to mitigate against damage from an event (e.g. by ensuring that electrical cabling is able to operate in extremes of heat and cold).

Redundancy: The adaptability of an asset or network to ensure the availability of backup installations, systems or processes or spare capacity (e.g. back-up data centres).

Response & Recovery: An organisation's ability to rapidly and effectively respond to, and recover from, disruptive events".

These four Rs again pick up on some aspects of definitions of resilience, and cross over with the components given in the EA response as noted above.

Moving away from flood resilience specifically, towards risks and emergencies more generally, the Cabinet Office work on community resilience was quite comprehensive following the Civil Contingencies Act 2004 which created Local Resilience Fora. It was boosted by the Pitt Review of the 2007 floods, and in 2011 the Strategic National Framework on Community Resilience (2011) was published. In that document resilience was defined as "*the capacity of an individual, community or system to adapt in order to sustain an acceptable level of function, structure, and identity"*, and community resilience as: "*Communities and individuals harnessing local resources and expertise to help themselves in an emergency, in a way that complements the response of the emergency services"*[3] (CO, 2011, p. 4). In reviewing it in 2015 Twigger-Ross et al. reported that "*it is the most widely recognised and adopted definition found on the websites and reports of*

[3] In the Civil Service Lexicon https://www.gov.uk/government/publications/emergency-responder-interoperability-lexicon

different government departments (Defra, DCLG and DECC)." (Twigger-Ross et al., 2015, p.22).

The promotion of community resilience is part of the government's national security strategy (HM Government, 2015) and the 2011 framework has been replaced by the Community Resilience Development Framework (CO, 2019b). It provides an overview of:

1. The strategic and policy context;
2. The roles and responsibilities of government, statutory partners and community networks;
3. The public's contribution to resilience;
4. Understanding and engaging community networks;
5. The steps for strategic approaches to developing community resilience; and
6. Examples of guidance, tools and programmes.

Interestingly, there is no comparable definition of community resilience to that of the 2011 publication, rather it talks about the aim of community resilience being "*a participatory approach to emergency management*" (CO, 2019b, p. 2) together with details of how community resilience is enabled by Local Resilience Fora:

> *"Community resilience is enabled when the public are empowered to harness local resources and expertise to help themselves and their communities to:*
>
> - *prepare, respond and recover from disruptive challenges, in a way that complements the activity of Category 1 and 2 emergency responders;*
> - *plan and adapt to long term social and environmental changes to ensure their future prosperity and resilience"* (CO, 2019b, p. 2).

As with other definitions within this section, there is an emphasis both on responding and recovering but also planning and adapting in the longer term. Further, the goal of that planning and adaptation is aspirational referencing future prosperity, more than just surviving the floods, and links with references in the previous section, e.g. to "survive and thrive" (The Rockefeller Foundation / Arup, 2015).

The framework summarises the aims, objectives, actions and outcomes that local emergency responders' strategies to support community resilience should consider. Table 3 shows that summary.

Table 3 Aspects for consideration in local responders' emergency strategies to support community resilience (CO, 2019b, p.4)

Aims	**A. Individuals, businesses, community networks and voluntary organisations** are empowered to prepare, respond and recover from emergencies and disasters. **B. Emergency responders & government** understand, enable and integrate the voluntary capabilities of the public into emergency planning, response and recovery activity.		
Objectives	**1. Enabling resilient behaviours** Informing and listening to the public about risk, appropriate preparedness and response actions, motivations and blockers to action. • Response communications and alerting • Education and awareness materials, programmes and campaigns	**2. Enabling community led social action** Supporting community networks to understand their capabilities, access resources, tools and responder partners and take collective resilience action with benefits for people and places. • Facilitating and advising community networks • Supporting community led emergency planning • Facilitating access to training and physical emergency resources	**3. Partnering with voluntary capabilities** Working with individuals, businesses, community networks, Community Emergency Volunteer Teams, spontaneous volunteers and voluntary organisations to co-produce, design and deliver support to the public. • Convening and consulting on plans • Agreeing roles and activation models dependent on need and appropriate to capabilities • Involving voluntary capabilities in exercises
Benefits	**Individuals behave in a resilient and prosocial way.**	**Community networks take action to support their members to be resilient.**	**Voluntary capabilities are integrated into emergency management.**
Outcomes	Increased: • understanding of needs and ability to target support those in acutest need • public confidence and motivation to act • collective capability to manage emergencies • trust and legitimacy of official emergency management activity • speed of recovery	Reduced: • social, financial and health impacts from emergencies • demand on emergency management resources • cost of response and recovery	

The focus is on community resilience as a process, with emphasis on responding and recovering from emergencies. The "public" are emphasised as partners in building community resilience with Section three titled "The public's contribution to resilience". Emphasis is here on community led social action and volunteering to complement the emergency responders, to help prepare, respond and recover from emergencies. A list of activities that could be undertaken by communities is provided. Box provides some examples from that list.

Box 6 Examples of activities communities could engage in (taken from CO, 2019, p.8)

Prepare:

- Identify their communities. vulnerabilities, capabilities and assets
- Alter the physical environment to mitigate risks
- Monitor local risk indicators and early warng signs

Respond:

- Trigger actions identified in community emergency plan
- Provide intelligence to emergency services
- Run or volunteer in reception centres providing information, physical and emotional support and coordination for the community and volunteers

Recover

- Identify community recovery needs and capacity, and match these to the available voluntary and statutory support
- Provide health and wellbeing services in the community
- Participate in long term recovery planning and implementation

These areas have some overlap with those of the EA, specifically in terms of response and recovery but are focussed on the management of a flood if it happens and specifically what members of the community can do to support local responders. The EA's five categories cover all aspects of the FCERM cycle.

Further sections of the framework discuss understanding and engaging community networks; and the steps for strategic approaches to developing community resilience. Community resilience is firmly within the frame of emergency planning and focusses on the relationship between local responders and local communities. It covers both reactive and proactive resilience with the emphasis on responding and recovering but also on planning to adapt.

Ntontis et al. (2019) discuss the differences between a bottom-up and top-down view of resilience. That is, bottom-up implies people's capacity to act adaptively during adversity and where agency and engagement of populations and engagement between people and other agencies is a prerequisite of resilience. A top-down view is where communities can appear as passive entities. Ntontis et al. (2019) suggest that there is a more top-down approach within the Civil Contingencies thinking, however, looking at this newer framework, it is clear that there is an expectation of engagement with members of the public in resilience building activities which is more bottom-up.

What is clear is that there is no single definition across these different, but related areas. However, there are some commonalities that run through them which echo aspects of the frameworks highlighted in the previous section.

- There is no overarching definition of resilience. A number of definitions highlight resistance, recovery and adaptation but these are more characterised as stages in the process, than qualities or principles, especially within the EA Draft FCERM Strategy.

- There is mention in the CO definition of what resilience is trying to achieve i.e. *future prosperity* beyond recovering from the disruptive event.
- In terms of focus there is an emphasis on infrastructure and emergency planning.
- There does not appear to be any quantitative measurement of resilience, apart from in terms of probabilities. Rather there are actions that can be carried out in order to promote resilience (EA, CO).
- The EA Draft Strategy and response to the call for evidence has a focus on how the EA can build its capacity to in turn build resilience to flooding and the CO framework focuses on how communities can build capacity in terms of response and recovery to help build resilience to flooding.
- Whilst there is an emphasis within the EA Draft Strategy on context and the differences between places, there is not a discussion of how that could be conceptualised or operationalised.

2: Metrics, indicators and standards

RQ2: What different metrics, indicators or standards have been used to describe, measure, assess or set targets for resilience to natural hazards, generally and flooding in particular? **What are the challenges in developing metrics for different aspects of resilience to natural hazards generally and flooding in particular?**

This chapter provides a review of metrics used to measure resilience including: Baseline Resilience Indicators for Communities (BRIC; Cutter et al., 2014) Community resilience index for Norway (Shertzer et al., 2019); Flood Resilience Measurement Tool (Keating et al., 2017; Campbell et al., 2019); emBRACE community resilience framework (Kruse et. al., 2017); City Resilience Index (The Rockefeller Foundation / Arup, 2015); Australian Natural Disaster Resilience Index (ANDRI; Parsons et al., 2016) and the flood hazard metrics for the UK (including Neighbourhood Flood Vulnerability Index (NFVI), Social Flood Risk Index (SFRI) and Relative Economic Pain (REP) as introduced by Sayers et al. (2016)).

While all the reviewed assessment frameworks/metrics are indicator based, some apply a top down assessment and mostly use secondary data (e.g. BRIC; Community resilience index for Norway; ANDRI; NFVI), and others at least to some extent apply bottom up evaluation approaches using mainly a mix of primary (interviews, questionnaires, workshops) as well as secondary data sources (FRMT; emBRACE; City Resilience Index). Mostly the assessment frameworks focus on community resilience, however some specifically address cities (e.g. City Resilience Index), or aim to provide for resilience evaluation for the whole country (Community resilience index for Norway; ANDRI; NFVI). Quite a few of the revised frameworks result in a numerical score presenting overall resilience, and/or performance against various elements of resilience (BRIC; Community resilience index for Norway; FRMT; City Resilience Index). Two of the assessment frameworks reviewed, which are both to some extent self-assessment evaluation tools are supported and enabled by on-line platforms (FRMT, and City Resilience Index).

This chapter also includes an overview of challenges for conceptualising, developing, and implementing indicator-based assessments of resilience.

Metrics and indicators of resilience

Baseline Resilience Indicators for Communities (BRIC)

Cutter et al. (2014) constructed a composite index of community resilience to disasters and its geographic variation when applied to specific places, i.e. community is understood here as place-based rather than relational. The BRIC developed by Cutter et al. (2014)

was adapted by Scherzer et al. (2019) and used to establish a baseline index for Norway of community resilience to natural hazards (e.g. storms, storm surges, floods, landslides, and avalanches). According to Cutter et al. (2014) a number of choices were made in constructing the US index:

- The spatial scale of analysis is the US county level, because 1) counties are the smallest level of physical aggregation for which a wide range of human and physical data are consistently collected and archived; 2) counties are the primary local management unit for emergency management; 3) there is relatively less change in boundaries compared to lower levels over time.

- Data sources: data were collected from 30 different sources: mainly from US federal agencies but including some from universities and NGOs such as the Red Cross and one commercial (paid for) source. Free and open data sources were preferred, so that it would be feasible to put the set of indicators together elsewhere or in future without high costs.

- Transformation and normalisation of data to allow comparison between different places, by transforming raw data into percentages and normalizing data so that all data have common reference points. The benefit of normalisation is that the resulting scores provide an indication of relative value of resilience, allowing (easily understood) comparison between different locations at a particular point in time which is useful for benchmarking and improving resilience over time and across places. However, the disadvantage of normalisation is that it does not give an absolute score for the resilience of individual places but a relative estimate of intrinsic resilience, which possibly over- or underestimates local resilience through the normalization process. This highlights the need to clearly define the objectives of measurement before selecting metrics.

- Adjustment of the orientation of each variable, so that higher values correspond theoretically to greater resilience.

The construction of an index of baseline resilience indicators for communities (BRIC) was based on a theoretical orientation combining the idea of distinct capitals and the concept of inherent resilience from the Disaster Resilience of Place (DROP) model (Cutter et al., 2008). This resulted in a set of 49 indicators:

- 10 social resilience indicators intended to: "*capture demographic qualities of a community's population that tend to associate with physical and mental wellness leading to increased comprehension, communication, and mobility*." (Cutter et al., 2014 p.68).

- 7 community capital indicators that; "*estimate the propensity for a community to call on the good will of local citizens to assist their neighbors and fellow citizens – a whole community approach to emergencies*."

- 8 economic resilience indicators reflecting economic vitality, diversity and equality in compensation.
- 9 housing and infrastructure indicators, focusing on the quality of housing construction and physical capacities to provide emergency shelter, medical care and other disaster-relevant infrastructural capacities.
- 10 institutional indicators to capture aspects related to programs, policies, and governance of disaster resilience.
- 5 environmental indicators.

The data for the indicators is used to provide a composite score for each of the six resilience sub-indexes. The BRIC was constructed by summing these composite scores.

When the BRIC indicators were applied at a national level, clear differences were found between geographical areas in terms of their performance against the resilience sub-indexes.

The information generated by the BRIC can be used in different ways:

- To monitor changes over time in overall resilience and in the contribution of different capacities
- By national decision makers to identify common issues that might be addressed by national policies, programmes or initiatives
- By local decision makers to compare their performance with that of other places and explore successful approaches taken in places with similar characteristics
- To target action and resources to address key weaknesses.

The authors make the point that for some indicators, the response to a low score will not be to seek to ‘improve’ the indicator as this may not be appropriate (e.g. % of the population without sensory, physical or mental disabilities) or feasible in the short term (e.g. % owner-occupied housing units) but to recognise the need for strategies or measures to address the issues associated with these indicators, such as ensuring that people with disabilities are able to respond quickly to flood warnings or flood events.

The BRIC developed by Cutter et al. (2014) was adapted by Scherzer et al. (2019) and used to establish a baseline, ”*an initial measure that can be used to compare communities and to track changes over time*” (abstract), community resilience index for Norway to natural hazards (e.g. storms, storm surges, floods, landslides, and avalanches). While the conceptual framework with its six resilience capitals or sub-domains (i.e. social, economic, housing/infrastructure, institutional, community and environment/ecological) and the hierarchical approach to index construction remain the same, the authors used the list of indicators proposed by Cutter et al. (2014) only as a guidance arguing that the community resilience index for Norway needs to be country-specific and indicators selected should be sensible and justifiable to the Norwegian context.

As explained by Scherzer et al. (2019), in the first step a wish list of 139 indicators (also called variables) was compiled based on the review of relevant literature and studies and assigned to a resilience subdomain (i.e. capital). The indicators were created using secondary data only. Based on the relevance and adequacy of indicators (indicators were discussed and selected in academic focus group with scholars involved in climate change and resilience research), their availability (aiming for equal distribution of all variables across all Norwegian municipalities) and reliability, normalization[4] using min-max transformation, and applied correlation analysis to identify potential problems arising from multicollinearity between variables, 52 initial indicators were selected. To create the index, the BRIC metric was applied, based on a hierarchical and average design statistical method using normalised values of indicators.

After the BRIC metric method was applied, five more indicators were excluded from the final resilience index, resulting in 47 indicators featuring six resilience capitals/sub-domains in the final resilience index for Norway which included:

- *social*: working age, internet subscriptions, number of doctors, etc.;
- *economic*: number of people employed, number of enterprises, etc.;
- *community*: proxy indicators for people's involvement in local organizations, such as youth clubs, sports clubs, or religious institutions, etc.;
- *institutional*: overall financial health of the community (municipality), the financial resources attributed to fire and accident prevention, etc.;
- *housing/infrastructure*: the majority of the indicators relate to qualities of infrastructural systems that will facilitate response and resupply during emergencies, such as proximity to the nearest airport, hospital, fire or police station, road safety, lengths of road, etc.;
- *environmental*: combines indicators capturing nature's absorptive capacities with indicators relating to a community's (non-)exposure to certain natural hazards as well as previous natural hazard experiences (Scherzer et al., 2019).

The resilience index makes it possible to calculate a resilience score (which is a number), in this case calculated at the national and municipal scale and for all six resilience capitals/subdomains.

Flood Resilience Measurement Tool

Another approach to using indicators to measure flood resilience is a tool developed by the Zurich Flood Resilience Alliance (ZFRA). ZFRA has developed an ”*holistic framework implemented in a web and mobile based tool for measuring community flood resilience in*

[4] Using min-max transformation (0–1 scaling). Normalization allows for the comparison and combination of otherwise very different variable constructs, such as percentages, per capita counts, or distance measures (Scherzer et al., 2019)

developing and developed countries (the Flood Resilience Measurement Tool, FRMT)“ (Campbell et al., 2019). The FRMT is based on the 5C-4R Flood Resilience Measurement Framework (FRMF) discussed in Section 1, consisting of 88 sources of resilience (i.e. indicators) providing at least one of the 4 properties of a resilient system (4R: Robustness, Redundancy, Resourcefulness and Rapidity) and, like Cutter et al. (2014), split across 5 capitals (5C: human, social, physical, natural, and financial).

As explained by Campbell et al. (2019), this 5C-4R conceptual framework is operationalized via the FRMT, an approach which ”*holistically measures a set of sources of community flood resilience and, when floods occur, it also measures resilient outcomes (level of loss and recovery time).“* By comparing pre-flood characteristics to post-flood outcomes, the approach aims to empirically verify sources of resilience, something which has never been done in this field (Keating et al., 2017).

The authors describe FRMT as an integrated, web-based and mobile device platform that collects data on the 88 sources of resilience (which are applied at the start and finish of a two-year period) through one or more of five data collection methods (including: household survey, community focus group discussion, key informant interviews, interest group discussion, and third-party data) selected by the users who are trained practitioners (largely international development NGO staff) working in developing countries.

The data collected is then used by designated community and NGO expert assessors to allocate a score from A to D (A being the best and D being the worst) for each of the 88 sources of resilience. Grade results (presented numerically) are displayed according to the 5Cs framework as well as other categories (dimensions) to inform a discussion on how to identify potential measures for building resilience (Figure 13). Campbell et al. (2019) report results from data collected in 118 communities across 9 countries using the FRMT. As noted in the previous section the goal of resilience is seen to be to enhance wellbeing rather than simply to manage disaster risks more effectively.

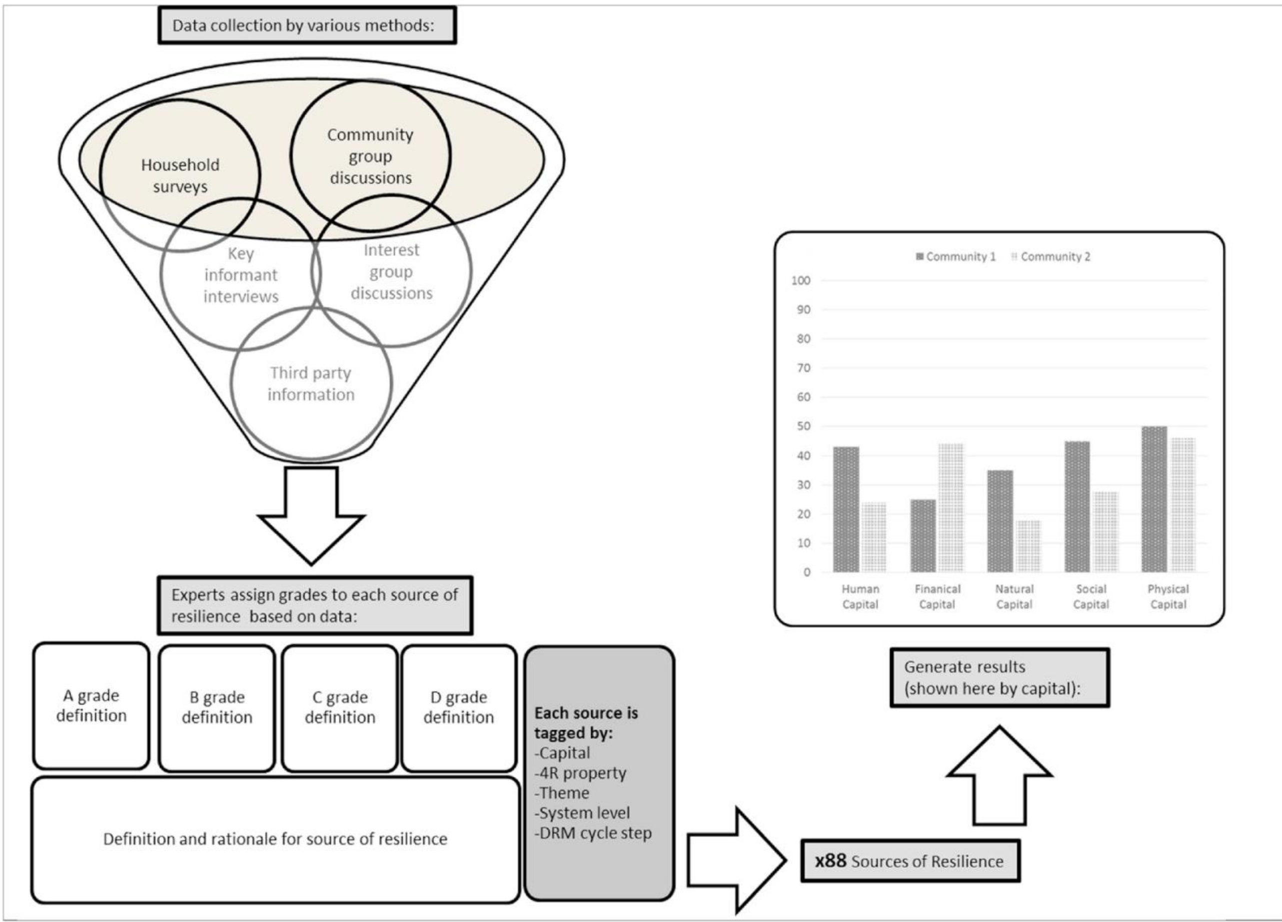


Figure 13 Zurich Flood Resilience Measurement Framework implementation process

The other benefits of developing and applying this kind of tool are identified by the authors as:

- deepening understanding of 'disaster resilience' in order to better target initiatives to enhance resilience
- benchmarking and measuring disaster resilience over time
- comparing how resilience changes as a result of different capacities, actions and hazards.

emBRACE community resilience framework

The emBRACE framework iteratively developed by Kruse et al. (2017), which is strongly supported by local research findings (i.e. empirical research of the specific local-level systems within the five case studies of emBRACE), was also developed for measuring resilience and as stated by the authors is *"a heuristic to be operationalized in the form of an indicator-based assessment"* (p.2329). It provides a possible, empirically legitimized way of selecting and conceptually locating indicators of community resilience. Unlike the BRIC (Cutter et al., 2014) and FRMT (Campbell et al., 2019) tools, which actually put a score to resilience, the application of this framework only goes as far as to some extent describing the process to identify the indicators that could be used to measure it.

The framework conceptualizes resilience across three core domains: (i) resources and capacities, (ii) actions and (iii) learning. The methods for the framework development included literature reviews, empirical case studies of community resilience related to hazards of different type and scale in five European countries, and participatory assessment workshops with stakeholders in case studies in Cumbria, England; Van, Turkey; and Saxony, Germany aiming to collect, validate and assess the local appropriateness and relevance of different dimensions of community resilience and indicators to measure them. For example, workshop participants in the case study in northern England considered that social-political and human capacities and resources are crucial for their community resilience; and indicators such as out-migration and in-migration, as well as willingness to stay in the region and engage in associational activities, were proposed to describe the degree of community spirit and solidarity (Kruse et. al., 2017).

The project derived study-specific community resilience indicators as well as a set of more general quantitative and qualitative indicators present across the case studies (e.g. the presence of an active third-sector emergency coordination body, the percentage of households in the community that subscribed to an early-warning system, social/mutual trust and the sense of belonging to a community) (Kruse et. al., 2017).

As noted in Section 1, 68 indicators were developed although with a stress on these being context specific. From that 68, 14 were drawn out as "key" indicators across the three areas. These are shown in Table 4, and Becker et al. (2015) provide questions and metrics for each of these indicators.

Area	Indicator
Resources and capacities	Presence of a (active) third sector emergency coordination body
	Social/Mutual trust
	Type of physical/infrastructural connection of community
	Sense of belonging
Actions	Existence of local tested community emergency plan
	% of households in the community subscribed to an early-warning system
	Belief in being well prepared for hazards & able to control the impacts
	% of persons with mandatory hazard insurance
	Collaboration and information exchange among actors involved in risk management
	Presence of cross-departmental municipality staff training

	programmes related to emergency management
	Integration in social networks
	Social support during/after event
Learning	Belief in effectiveness of self in coping with disaster related adversities
	Satisfaction with external financial support received

Table 4: List of key indicators from the emBRACE framework (Becker et al., 2016)

City Resilience Index

The City Resilience Framework developed by The Rockefeller Foundation and Arup (2015) provides the basis for the City Resilience Index, by defining its structure, categories, goals and indicators. The Index comprises 12 goals (elements most important in case of disastrous or catastrophic events) related to four dimensions of every city (health and wellbeing, economy and society, infrastructure and environment, and leadership and strategy), 52 indicators and 156 variables (i.e. qualitative questions and quantitative metrics). The aim of the Index is to ”*provide a common basis of measurement and assessment to better facilitate dialogue and knowledge-sharing between cities”* (The Rockefeller Foundation / Arup, undated). As stated by the authors, it ”*will provide cities with a comprehensive, credible, and technically-robust means to assess and monitor their resilience in order to inform urban planning and investment decisions*” (The Rockefeller Foundation / Arup, undated). The Index is intended to assess and measure relative performance of cities over time (i.e. the extent to which the city is achieving the 12 goals, based on 52 indicators), rather than comparing them to each other, so it will not deliver an overall score or provide a world ranking of the most resilient cities.

As a self-assessment tool, cities use the Index to identify and understand what they are already doing now (their strengths and weaknesses) to improve their resilience performance, and what is their trajectory. It is generally not possible to quantitatively measure future performance, therefore the Index gathers qualitative data to help indicate the city’s resilience path. This evaluation process involves the city planning its own performance (and actions) against each sub-indicator, using a series of qualitative questions. Cities assign a quantitative score on a linear scale 1 to 5 based on a definition of what worst (1) and best (5) performance could look like.

Where possible, cities can also measure their current performance using quantitative data based on proxy measurements within each sub-indicator which enables cities to establish a baseline, identify elements that might need attention to improve their resilience profile, compare performance between areas and monitor performance over time.

Like the FRMT (Campbell et al., 2019), the index application is enabled and supported by an online ‘self- assessment’ platform, used by city governments for collecting and analysing data, creating a city’s resilience profile.

Australian natural disasters resilience index

The Australian Natural Disaster Resilience Index (ANDRI) (Parsons et al., 2016), similarly to BRIC (Cutter et al., 2014) adopts a top-down approach applying indicators obtained from secondary data on a national scale. As described in the earlier section, the ANDRI is a hierarchical design based on coping and adaptive capacities divided into several themes (e.g. social character, economic capital, infrastructure and planning, engagement, governance, policy and leadership, etc.). Figure 14 shows that structure.

Figure 14: Hierarchical structure of ANDRI

The aim of the ANDRI is to assess the state of disaster resilience in Australia at one point in time and not to evaluate regulated performance criteria. The assessment outcomes will be 'nationally-standardised assessment of disaster resilience in Australia', reported as a State of Disaster Resilience Report.

The level of detail of the data used for the assessment is, where possible, the Statistical Area 2 (SA2) level of the Australian Bureau of Statistics as it is most illustrative of Australian neighbourhoods/suburbs and is the smallest level of the Australian Statistical Geographical Standard for which essential statistics (e.g. population, health, etc.) are all available.

There are two types of indicators:

- Quantitative indicators – indicators collected or compiled from exiting data sets such as census data, economic data, health data, telecommunications, infrastructure databases. These indicators are mostly continuous numbers.
- Semi-quantitative indicators – indicators derived from assessment of policies, plans, legislation, or other reports. These indicators may be partly composed of assessments of quantitative data, such as the State of the Public Service Survey. These indicators are mostly ordinal numbers and as such have a small number of integer values.

The process of creating an index is described in the flow diagram in Figure 15:

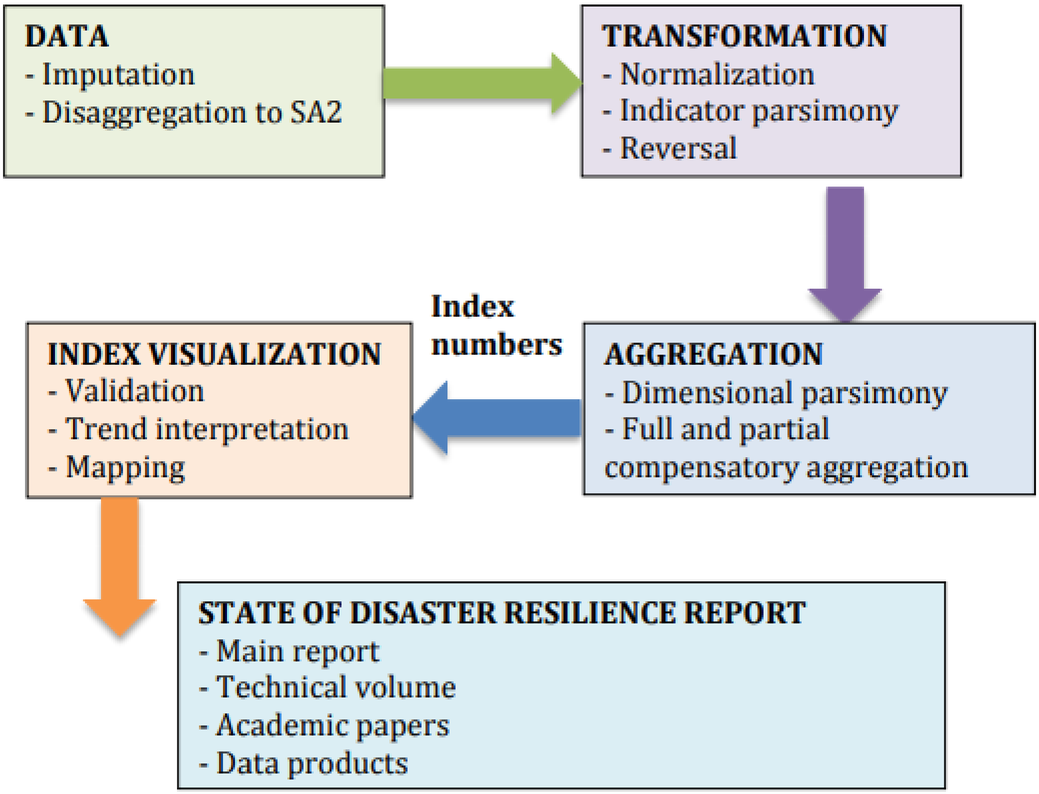


Figure 15: Flow diagram for creating the ANDRI (from Parsons et al., 2017)

90 indicators were collected across the 8 themes (coping and adaptive capacities) and transformed numerically to create indices for each sub-theme. From this Parsons (2019) has produces a “state of disaster resilience” map for Australia which uses the overall index.

Social Flood Risk Index

Although focused on vulnerability, as noted in the previous section, to provide better understanding of flood risk and flood risk management outcomes addressed, Sayers et al. (2016) suggest and introduce three new metrics that should be used alongside existing metrics as summarised here:

- Neighbourhood Flood Vulnerability Index (NFVI): The NFVI provides an improved expression of flood vulnerability and is put forward as an alternative/replacement to the Index of Multiple Deprivation in flood risk management decision-making and as an evolution of previous vulnerability metrics. It is a top-down approach and encompasses 12 indicators (e.g. age, health, income, social networks, services availability, etc.) derived from secondary data to support the assessment of five characteristics of flood vulnerability (susceptibility, ability of individual to prepare for a flood, ability of individual to recover from a flood, the ability of the community to support individuals). The NFVI is determined through a 3-stage process. Similarly to Cutter at al. (2014), in stage 1 the z-scores are determined for each indicator and normalised; in stage 2 the z-scores are calculated for each domain; and finally in stage 3 for each neighbourhood the z-scores derived for each indicator are summed with equal weighting to calculate the final z-scores (the NFVI).

- Social Flood Risk Index (SFRI): The SFRI is used to provide a combined expression of probability, exposure and vulnerability and is a means of directly comparing risk in one area with another in a way that explicitly accounts for vulnerability and the potential loss in well-being of residents.
- Relative Economic Pain (REP): The REP considers the influence of lower income levels and flood insurance penetration to better reflect the experience of a given economic loss in more and less vulnerable neighbourhoods. The REP highlights the systemic flood disadvantage experienced by those living in vulnerable neighbourhoods, when income and insurance take up (a function of tenure, income and history of flooding) are considered. This highlights the significant role that income, tenure and insurance play in systemically disadvantaging the most flood vulnerable communities (regardless of other characteristics that make communities flood vulnerable).

Sayers et al. (2017) created maps of the UK using these indices which provide a valuable resource for any resilience framework.

Challenges in developing metrics for different aspects of resilience to natural hazards generally and flooding in particular

Keating at al. (2017) recognise that measuring resilience is a challenging task for two reasons:

1. Resilience is a hidden quality that is not revealed until put to the test i.e. in a disaster or specifically a flood; and
2. It is often influenced by a complex set of holistic and qualitative characteristics.

However, such characteristics are not unique to resilience measurement, as gathering, synthesising and analysing often subjective and qualitative narratives is becoming a core part of modern development monitoring and evaluation (M&E) practice (Keating at al., 2017). Some common theoretical and practical challenges affecting indicator-based resilience measurement frameworks summarised from Keating et al. (2017) are:

- defining an appropriate scale of analysis both geographically and temporally, including specifying boundaries ("resilience of what and to what?")
- identifying the potential end users ("indicators for whom?") and potential purposes ("indicators for what?")
- balancing the need for specific indicators (of a particular hazard in a particular place for a particular institution) against the need for wide applicability.

A further issue is that "*resilience to one hazard does not necessarily translate into resilience to* another" (Keating et al., 2017), thus it is completely possible that measuring and enhancing resilience to one hazard may unintentionally decrease resilience to another (Schipper and Langston, 2015).

As argued by Tanner et al. (2017), who reviewed challenges for resilience policy and practice, as the interpretation and definition of resilience is so unclear (also see section 1 of this report), measurement becomes contested and a major challenge. Tanner et al. (2017) summarise 12 main challenges for monitoring, evaluation and learning around resilience as follows:

- Integration - Integrating resilience measurement into standard workflows of ongoing programmes, and not keeping them as separate M&E processes
- Spatial levels - Linking evidence and building processes from local to national levels that inform, advise and guide resilience-building investments
- Complexity - Addressing the issue of complex systems in M&E through connecting people who are working on innovative evaluation approaches and methods with a focus on resilience
- Common frameworks and tools - Lacking commonly accepted frameworks, tools and databases to systematically generate and store evidence on resilience
- Power and gender - Incorporating issues of vulnerability, power and gender effectively into resilience measurements
- Large-scale investments - Establishing M&E for programme-level, large-scale investments
- National capacity - Building capacity of M&E practitioners in the field, for building and strengthening the pipeline
- Measurement of transformation - Bringing in effective methods for measurement of transformative capacity at levels above community, making more of the data collected, and supporting more cross-fertilisation, maybe around common strategic goals
- Systems-level measures - Developing systems-level indicators that measure capacities (anticipatory, adaptive and transformative) at scales greater than the household (e.g. cities)
- Capacity to track large-scale changes - Applying capacities to larger scales and measuring capacities at levels higher than household scale to determine applicability and to track changes
- Systems-level resilience - Bringing in data and measurement techniques that can help capture systems-level resilience, rather than simple households (noting that ‘simple’ is a misnomer)
- Indicators of systems- level resilience - Defining common indicators of resilience capacity and resilience outcomes at system, rather than individual, levels

Although measurability of an unclear concept like resilience is questioned by many, there is also a growing notion among practitioners as well as academics about the usefulness of resilience measures in managing natural hazards (Burton, 2015; Cutter, 2016) emphasising that without a quantitative resilience assessment it is not possible to compare entities (e.g. areas, countries, etc.), to monitor performance, or to identify strengths and weaknesses in the system to improve the trajectory towards resilience (Scherzer et al., 2019).

Flood and coastal erosion risk management in England – current approach to metrics

In this section, the current approach to metrics, specifically in relation to FCERM investment decisions is considered in order to understand what any resilience framework would need to incorporate or replace.

The term resilience has become more prominent in the English flood and coastal erosion risk management community in recent years as discussed in previous sections. However, the concept of managing consequences and taking a 'whole portfolio' approach has been around for much longer, at least since the then Government's Making Space for Water document in 2004 (Defra, 2004). Various elements of the portfolio of approaches to managing consequences can be defined as different types of capacity for resilience (after Twigger-Ross et al., 2015), e.g.

- flood defences, property level protection (infrastructure)
- flood warnings (institutional)
- emergency planning (institutional)
- community flood groups (community capital)

They all clearly have a role in flood and coastal erosion risk management, but in practice when seeking Grant in Aid funding for measures, this rarely follows an integrated, truly portfolio-based approach but instead can be broadly characterised as following an approach that typically starts with consideration of flood protection:

- Invest in flood defence as far as justified (Treasury rules) and affordable (Grant in Aid plus third party funding).
- Maintain existing flood defences as far as affordable. Prioritisation based on economic risk (including households). (EA, 2010a; Middlesex Flood Hazard Research Centre, 2013; Environment Agency, 2019c).

With a decision to make an investment in flood protection there will still be residual risk. This is managed through two main processes: firstly, new development has to be considered in the light of that residual risk and it will set fixed floor levels (e.g. not lower than existing floor levels together with flood proofing depending on the proposed development). This follows from the National Planning Policy Framework. Secondly, further investment to manage residual risk that affects existing developments will cover PLR, flood warning, emergency planning, awareness raising, flood groups. Flood insurance also comes in here to cover residual risk.

There are mature, well-accepted and standardised metrics, calculation tools and processes for the investment in flood defences and managing residual risk through planning. For the former these ensure that Government's flood and coastal risk management budget is spent to maximise return on investment, in line with the Treasury's Green Book, and for the latter these aim to ensure that the chance of flooding for new homes is below a tolerable threshold. The residual risk, to be addressed by PLR, flood warning etc., is still significant (as shown by regular flood events), but often not enough to justify public investment. It is quite a mix of different measures and it was the focus of the Flood Resilience Community Pathfinders (Defra, 2015).

In theory, measures such as property level resilience or community flood groups could be assessed alongside flood defences to compete for government funding. This would need research to link the measures of improved resilience capacities (e.g. PLR, flood warning) to the reduction of damage, for example change the depth damage curves, since that is main measure that has currency within the current framework driving investment and other actions. Box 7 provides examples of approaches to calculating the benefits of these measures:

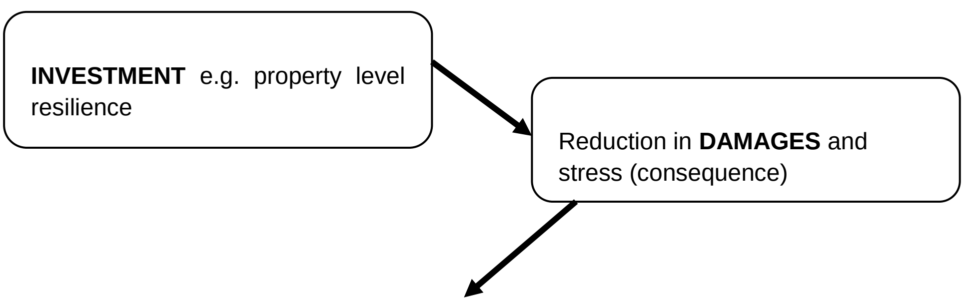
Box 7 Examples of approaches to calculating the benefits of non-structural measures

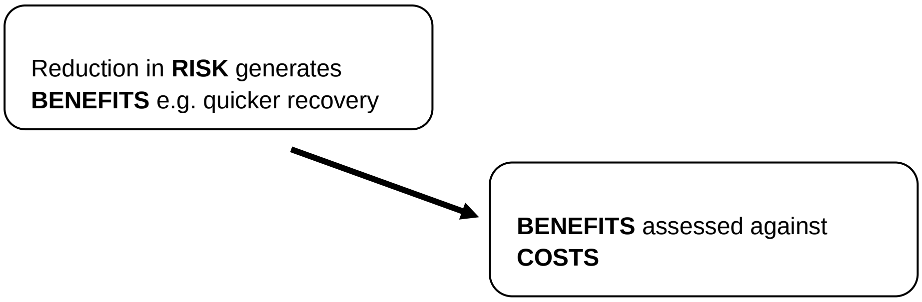
Within the FRCP evaluation (Twigger-Ross et al., 2015) a qualitative assessment was made linking the existence of a community group with the reduction in damages (the pathway was via provision of an earlier warning allowing people to move their furniture more quickly which reduced damages). In a similar vein there is debate around how much damage reduction could be attributed to a variety of property level resilience measures with a view to enabling lower premiums for people at risk of flooding who put in those measures The Joint Defra / EA R&D programme carried out work to explore methods for determining the economic benefits of non-structural FCERM actions (EA, 2015). This project developed an initial version of a tool that enables the calculation of the economic benefits of

- Forecasting and warning
- Emergency planning
- Working with communities
- Property level resistance and resilience

If these measures could compete alongside traditional flood protection measures this could shift the balance toward more investment in consequence reduction and in a wider concept of resilience. However, with limited budgets by definition this could mean accepting higher chances of flooding. Again in theory, measures such as PLR and flood warning could be assessed with the same risk-metrics of probability x consequence:

For example:





If that were possible, these measures e.g. PLR and flood groups could be compared and combined with e.g. flood defence (and even planning) measures in a true portfolio assessment. In practice this type of portfolio assessment doesn't really happen. One reason is that currently there are no equivalent mature calculation methods for measures such as PLR, flood warning and flood groups.

Practical examples from other countries on the measurement of resilience

The Netherlands

The Dutch language has no word for resilience. Yet, management of the consequences of flooding has become a more explicit element of overall flood and coastal erosion risk management in recent years. Historically the emphasis is very strongly on reducing the chance of flooding through flood defences. Since the 1960s there are legal flood defence standards, based on quantified assessment of probability and consequences. Until recently these standards were formulated as a hydraulic loading level that the defence needed to withstand. Since around 2015 they are defined as an acceptable overall chance of defence failure – and this is determined by two factors: economic optimisation and a tolerable chance of people dying (individual risk).

Since around 2010, the concept of Multi Layered Safety has been explored in the Netherlands, driven by rising awareness of climate change and events such as Hurricane Katrina. This is now being implemented in policy. This aims to move on from the traditional pure focus on managing the chance of flooding in order to achieve a tolerable risk level. Layer 1 remains flood defence, managed by the legal standards described above and secured politically by the Delta Commission. The other layers deal with the residual risk: Layer 2 concerns spatial adaptation, Layer 3 is incident management.

Layer 3 (incident management) has evolved significantly in recent years and is organised similarly as in the UK. Layer 2 (Spatial Adaptation) is currently being addressed through a national programme: 'Delta Programme Spatial Adaptation'. This involves a combined top-down (from government) and bottom-up (from local authorities and communities) process in order to bring together all relevant aspects, including the important connection with spatial planning, and adding other climate change factors (drought, heat stress etc.) into the equation.

In the context of the Netherlands, with its well-developed, funded and secured flood defence system that reduces the chance of flooding to very low levels, it makes sense that managing the chance of flooding and the consequences of flooding are treated as separate layers. There is no perceived need or appetite to consider them in an integrated way: no one would accept a higher chance of flooding in exchange for a reduction in the consequences.

This is also reflected in the absence of an insurance market related to coastal or major fluvial flooding in the Netherlands: the State sees itself as the 'Insurer of Last Resort', and for the State it is preferable to invest in reducing the chance to very low levels rather than to accept a higher chance.

U.S: New Orleans

Following Hurricane Katrina, the US Corps of Engineers introduced the concept of 'resiliency'. The defence system was designed to be reconstructed to a probability-based 1:100 year defence standard, but in addition, US Congress made funding available to reduce the chance of catastrophic failure during events exceeding the design standard. RHDHV was involved in conceptual study work to define formal metrics for this, in terms of benefits related to the reduction of economic risk and risk to life. This was deemed possible but complex and, importantly, difficult to explain. In practice, a pragmatic approach was chosen: the defences were first designed as normal to the fixed 1:100 year standard; and then the landward slopes were reinforced to ensure they would withstand overtopping in a 1:500 year event.

Australia

Since the 2010/11 floods, Australia (with Queensland as a particular example) focuses its flood risk management strongly on applying the full portfolio of approaches. This is for example illustrated in 'Brisbane's Floodsmart future strategy' (2011, updated in 2016).

In itself this message is not different from similar statements in Making Space for Water in England in 2004. However, there is a cultural / historical difference in that flood defences are traditionally and widely seen as unsustainable in principle, which then automatically puts more focus on reducing consequences: land use planning, awareness and emergency management, alongside focused flood mitigation infrastructure. Investments are prioritised based on 'value for the community' as part of Brisbane City Council's annual budget process. We have no detailed information but, considering normal approaches in Australia, we expect that value is expressed as economic benefits related to risk reduction (probability times consequence).

SRQ2.1: What evidence is there around the implementability of existing metrics as tools for driving actions to support government policy?

The papers reviewed in this QSR generally do not specifically address the metrics and tools for driving actions to support government policy. However, one could argue that the aim of all of the tools/metrics reviewed above is in one way or another to provide 'evidence on resilience' with the intention to support either national, regional, city or even community governance regarding flood and coastal erosion risk management as well as well as to inform governments on various scales (national, regional, local). Keating et al. (2017) state they hope that by sharing their process (FRMT), others (e.g. researchers, policymakers, and practitioners) entering the field of resilience measurement can learn from their experience.

Some governance challenges are reflected through the reviewed literature. Alexander et al. (2018) argue that in order to address fundamentally uncertain and complex problems such as flooding, the diversification of risk management strategies is essential for societal resilience, however, this also brings new challenges for legitimate governance. The shift towards risk management away from traditional patterns of defence (as also reflected in the metrics reviewed) raises questions about the distribution of roles and accountabilities across a differentiated spectrum of public and private actors, how to decide where and how risk management strategies will be applied and how to share the distribution of costs and benefits. Kruse et al. (2017) as well as Scherzer et al. (2019) recognise that context (e.g. cultural background, hazard types or the socio-political context) plays an important role when assessing community resilience and thus when applying the frameworks. In practice they will in most cases have to be adapted to the specific context. This might be a subject for further research.

Flood and coastal erosion risk management in England:

In principle 'consequence measures' can be measured and operationalised within the existing risk-based approach to flood and coastal erosion risk management. The impact of a measure would be reflected in a change to the damage curves used in standard modelling of flood economics, feeding into the normal business case process.

A key gap concerns the absence of mature and accepted methods for quantifying how measures reduce consequences / influence the damage curves. Methods do exist for PLP and are used in practice.

Project SC090039 in the FCERM R&D Programme developed initial methods. In combination with ongoing (and future) research into specific measures, this may be suitable for development into an operational tool.

A key challenge may be how to justify investing in consequence measures, given limited budgets, and within the rules of Treasury's Green Book. – it is possible that this will continue to drive investment in protection rather than consequence reduction.

In the literature we have reviewed authors who provide a definition of resilience which can be summarised as generally focussed on coping with a natural hazard in such a way as to be able to carry on normal daily living. This is coupled with more or less information on how that coping will be achieved: through reactive and/or proactive processes, within a series of capacities/resources, etc. This section provides a review of how far they have conceptualised and operationalised one "overall resilience" concept, together with a discussion of the challenges, advantages and disadvantages of bringing these aspects together.

Conceptualisation

As indicated by the previous section, the literature contains examples of different aspects (e.g. physical, social, economic, etc.) of resilience to natural hazards being brought together conceptually to generate an integrated resilience concept (e.g. UNISDR, 2012). Other examples are found in Cutter et al. (2014) and Parsons et al. (2017) who develop a composite index of community resilience to disasters. Some examples consider a wider range of risks (e.g. 'disturbances' of various kinds) than those posed just by natural hazards but nevertheless include the latter (e.g. The Rockefeller Foundation / Arup, 2015). This conceptualisation of resilience is based on system-based approaches and the long-standing notion of cities as 'systems of systems'.

A fairly common way of integrating different aspects of resilience to natural hazards in conceptual, as well as operational, terms is to use the 5Cs (i.e. Capitals) structure (these are occasionally also called 'domains' or 'sub-domains' and sometimes there are more than 5). For example, Scherzer et al. (2019) employ the BRIC (Baseline Resilience Index for Communities) conceptualisation of resilience (Cutter et al., 2008) which contains 6 'sub-domains': social, economic, community, institutional, housing/infrastructure and environmental. These are variously called capitals, capacities, resources or assets. A number of frameworks use the 5 assets from the sustainable livelihoods framework (e.g. DfID, 2011). Generally, these refer to what physical and social structures are available to help cope with, recover from and adapt to a shock or stress.

In addition to, and sometimes instead of the capitals/capacities approach is the employment of the '4Rs': usually robustness, rapidity, redundancy and resourcefulness (e.g. Cabinet Office, 2019; Keating et al., 2017; The Rockefeller Foundation / Arup, 2015). These are considered to be 'properties' or 'qualities' of resilience which can be considered as cross-cutting (i.e. cutting across the Capitals) aspects of resilience within an overall resilience conceptualisation. These tend to come out of a systems perspective, the idea being that systems with these properties are more likely to be able to cope with, recover from, or adapt to a shock or stress.

There are also some good examples of different aspects of resilience to floods being integrated conceptually to produce an overall concept of resilience. An outstanding example is the Flood Resilience Measurement Framework (Keating et al., 2017; Campbell et al., 2019). In this case Keating et al. (2017) define the 5 Capitals as: physical, natural, human, social and financial capitals. Although the general conceptualisation in this study is interesting and potentially useful, the international development context of the Zurich Flood Resilience Alliance's research is less applicable to the United Kingdom. In a study of the antecedent conditions for the recovery from Hurricane Katrina, Burton (2015), using Cutter et al.'s framework, integrates social, economic, institutional, infrastructural, community-based and environmental dimensions of resilience into a single resilience concept.

Operationalisation

Resilience to natural hazards as an overall concept is more limited at the operational than at the conceptual level - an indication of the challenges currently presented by this area of science. Potentially useful conceptualisations are often not yet followed through by effective operationalisation or the operationalisation only considers a narrow range of 'aspects'. However, there are some good examples of effective operationalisation in the literature. The Rockefeller Foundation / Arup's (2015) City Resilience Index is operationalised to produce various profiles of resilience rather than producing an overall resilience score. Even so, the combined resilience profiles might well be regarded as an overall resilience assessment. Cutter et al.'s (2014) composite index of community resilience to disasters is another operationalisation example. The final step of the operationalisation is the construction of the BRIC and this is achieved by summing the composites of the six resilience sub-indexes. Potential scores range from zero to six, with higher scores corresponding to more resilience, and lower scores, less resilience. BRIC values can then be compared over time (e.g. 2000, 2005, 2010, etc.) as a means for charting progress in enhancing resilience to disasters. Scherzer et al. (2019) also employ the BRIC methodology in Norway to bring different aspects of resilience together in an overall resilience score which can be broken down into sub-indices for domains (e.g. social, economic) and spatial units (regions and counties).

Cutter (2016) assesses a range of resilience measurement methodologies. All attempt to bring the different aspects of resilience together into an overall resilience concept. All also attempt to operationalise the measurement methods. Disaster resilience assessment approaches are of three types: indices, scorecards and tools; the most prominent being indicators and scorecards. Indicators are quantifiable variables that represent a selected characteristic of resilience and are combined to generate an overall resilience index. Indices are a statistical approach that summarizes observations or measurements by aggregating multiple indicators into a single value. The index is used to illustrate the multi-dimensional nature of the resilience and ultimately combines the complexity into a single numeric value. Scorecards are given numerical values (1–10), letter ''grades'' such as (A–F), or descriptors such as ''excellent to poor'' and are normally based on qualitative assessments and then converted to scores, while indices mostly use quantitative data to derive the index value.

Good examples of operationalisation of different aspects of resilience applied to floods are fairly limited. For example, de Bruijn's (2004) attempt to integrate physical, social and economic aspects into an overall resilience perspective is limited, not only by the definition of resilience as returning to normal but also by the limited scope of the indicators employed. The key one examined here is the FRMT (Keating et al. (2017) and Campbell et al. (2019)) together with Burton (2015), a real-world application using Hurricane Katrina and the recovery of the Mississippi Gulf Coast in the United States as a case study. The methodology employs 98 resilience indicators/metrics across the 'capitals' as well as combinations of indicators, mathematically combined to arrive at an index of resilience.

Challenges, advantages and disadvantages: conceptually, methodologically and practically

The principal challenges, advantages and disadvantages in pulling together different aspects of resilience in an overall measure of flood resilience are set out in Table 6 below. The difference between some of the categories in the table sometimes becomes unavoidably blurred.

	Conceptual	Methodological	Practical
Challenges	Deciding how far along the spectrum of conceptualisation (from narrow to broad) of resilience is desirable. Which sectors, domains or capitals to employ (they vary in the literature). Should the 4Rs be employed and in what ways?	There is no systematic and consistent representation of community resilience in measurement methods at the moment. Which of the more common and tested methodologies to employ? Is it sensible to identify sources of resilience? Which indicators/metrics to employ? How should flood resilience at different stages of the flood event cycle be represented in the methodology? Should different aspects of resilience as measured by indicators/metrics be weighted? What balance should be struck between quantitative and qualitative measures of resilience? What kind of resilience index is required – a profile of sub-indices; an overall scorecard or index? Verification or validation of resilience measures (currently an area presenting some difficulties/gaps). Integrating physical infrastructure resilience metrics with social and economic systems	Deciding how far along the spectrum of conceptualisation of resilience is practical. How to define community on the ground. What scale for example? How best to identify these sources of resilience – which stakeholders are best involved? Which indicators/metrics are practical in terms of data availability and/or acquisition? How should different aspects of resilience be weighted in the construction of a resilience index? (This is currently an area of difficulty/gap). What is the process for calculating an overall resilience score, index or profile? Verification and improvement of resilience over time is necessary to make progress (i.e. ex ante and ex-post assessments) – how is this to be achieved? What system needs to be established to ensure that this is achieved? Estimating the costs and benefits of resilience measures and increments of improvements. Currently the MCM offers a limited approach (mainly to warnings and Property Level Protection). However a programme to update the MCM to take on board resilience is scheduled for 2019-20.

		and metrics (often a weak area/gap). Is resilience to be compared across space as well as time? What factors could affect spatial comparisons? How should they be allowed for? How can sensitivity and uncertainty analysis be used to reduce the subjective biases that are intrinsic to the index construction process?	
Advantages	While resilience is a contested concept, it becomes much less so when considered in a particular context (i.e. it is a flexible concept). Common frameworks use well-recognised 5C, 4R frameworks and thereby integrate different aspects of resilience and different properties of resilience. Different stages of the flood event cycle can be factored in.	Bringing as many aspects together in an overall index of resilience should provide the best way of getting at resilience on the ground in real terms and so should be a basis for successful FCERM. To do otherwise runs a risk of missing significant sources of resilience or barriers to resilience. Constructs including the Cs and Rs (if used) can and should be customised to suit circumstances (i.e. there is methodological flexibility).	Employing secondary source data avoids time-consuming fieldwork data collection.
Disadvantages	Resilience remains a contested concept.	A full-blown, multi-faceted methodology is quite complex to construct and to apply. As indicated above, a number of challenges will need to be overcome for success in terms of actually improving flood resilience on the ground over time. Resilience to floods may well be affected by systems/policies beyond the control or	Indicators may or may not reflect actual resilience/vulnerability well and may well focus on more "general" resilience that FCERM cannot influence. How to isolate those indicators which do reflect resilience well? More research is needed to understand which interventions affect which

		influence of FCERM agencies and policy. How are underlying resilience factors to be taken into account or factored into the methodology or are they to be excluded?	indicators and why. There may be relatively resource demanding approaches to gathering evidence to score indicators. If used, grading systems are qualitative and judgemental but may have underlying quantitative inputs to qualitative scores (NB many indicators may defy quantitative measurement and/or may be better measured qualitatively).

Table 6: Summary of challenges, advantages and disadvantages of using an overall measure of resilience)

3: Assessing frameworks against FCERM criteria

RQ3: How do the identified resilience frameworks (both concepts and metrics) perform against flood and coastal erosion risk management (FCERM) criteria, as set out in the specification?

In order to explore how some of the resilience frameworks described above perform against the criteria identified in the project specification, we have reviewed three models that have been used internationally and considered their performance. The models reviewed are:

- Zurich Flood Resilience Alliance’s FRMT
- The emBRACE project’s Community Resilience Framework
- Australian Natural Disaster Resilience Index (ANDRI)

These three frameworks were chosen as they fulfilled the following criteria:

- Clear definition of adaptive, transformative resilience
- Multi-dimensional approach to resilience: physical, social etc.
- Well defined indicators
- Empirically tested
- Metrics
- Focussed on flood or disaster resilience

presents the frameworks against the FCERM characteristics. It focuses on the operationalisation of resilience frameworks, it does not assess the effectiveness of the frameworks in achieving their own purposes or in contributing the enhance resilience more widely.

1. We have used a simple High - Medium - Low (H-M-L) scale, to reflect the high-level nature of these scores, based on the literature examined rather than an extensive examination of each of the frameworks.
2. Notes on individual criteria:
   - Feasibility and affordability of data collection and verification: we have made an assumption that any data collection and verification system will have to cover a range of characteristics, qualities and outcomes. Judgement about feasibility and affordability are based on the kinds of data to be collected (does it already exist, if not, can it be collected easily by non-specialists? Can indicators be selected to reflect differences in context?)

Table 7: Comparing frameworks against FCERM criteria

Criteria	Frameworks		
	Zurich Flood Resilience Alliance: Flood Resilience Measurement Tool (Keating et al., 2017; Campbell et al., 2019)	**emBRACE Community Resilience Framework (Kruse et al., 2017)**	**Australian Natural Disaster Resilience Index (Parsons et al., 2016, 2017)**
Range of risks and impacts: can be tailored to geographical area/local variation	**H** Multidimensional framework covering 5 capitals - 4 resilience capacities. Tested in 118 communities across 9 countries.	**M** Interdisciplinary, multi-level and multi-hazard framework. Covers three dimensions: resources (5 capitals), actions (physical protection and social protection) and learning. The framework was developed in a European context; in developing it, the research team drew upon wider research knowledge and experience, but the framework has not been tested outside Europe.	**M** Set of indicators used to map resilience to natural hazards across Australia at one time. Based on indicators for coping capacities and adaptive capacities. Units of measurement are large (population range from 3000 - 25000). Where data is not available at that scale it is disaggregated from higher scales.
Level of ambition to drive action	**H** Provides a resilience measurement verification methodology which can incentivise and drive forward resilience improvement. The tool provides an overall score for resilience which allows comparison of communities (Campbell et al., 2019) The tool includes a set of 29 ex-post-flood outcome measures which creates the possibility of developing targets for changes in	**N/A** No information available	**M** Goes some way to providing a practical resilience decision-support tool for managing how societies live within changing and uncertain environments.

	resilience levels.		
Distribution of costs and benefits	**N/A** Application of results in selection of measures or resource allocation is unclear	**N/A** Application of results in selection of measures or resource allocation is unclear	**N/A** Application of results in selection of measures or resource allocation is unclear
Communication: meaningful to a range of audiences	**H** Developed with national and international organisations working on flood planning, response and recovery. Local communities are involved in defining the indicators and collecting data, therefore the evidence is meaningful to them. [*Note: no evidence found about the involvement of local and national flood management institutions and how relevant the evidence is to them]*	**M** Developed with participants in five case study locations in Europe: The framework was considered meaningful by these participants.	**N/A** Government and emergency service agencies involved in developing the tool (Parsons et al., 2016). Not clear to what extent it is used or understood by members of the community.
Timescales: enables identification of timescale for implementation (short- to long-term)	**N/A** Application of results in selection of measures or resource allocation is unclear.	**N/A** No information available	**N/A** Application of results in selection of measures or resource allocation is unclear.
Appropriate and feasible allocation of roles and responsibilities	**H** Communities involved in collecting data. Working with NGOs.	**N/A** No information available	**L** Top-down method. No local involvement.
Feasibility and affordability of data collection and verification	**M** Relatively resource demanding as the approach involves gathering evidence on 88 indicators. Uses both primary and secondary data: the use of secondary data will reduce cost/effort. Data	**H** 68 indicators (14 of which are seen as priority indicators) within the three areas (resources, action, learning).: "*the proposed structure allows key indicators to be extracted, but does*	**H** Top-down secondary data collection facilitates data collection and verification.

	is collected and assessed via a web- and mobile-based measurement tool which makes it accessible for use in different places and at low cost.	*not necessitate that all key indicators must be extracted in every circumstance; those decisions remain context dependent*." (Becker et al., 2015, p. 68).	

4. Main findings

The key points from the QSR that are relevant to the development of policy on flood and coastal erosion resilience are:

1. Experience of developing and applying resilience frameworks in different international context (including considering resilience solely in relation to floods or in relation to all natural hazards) suggests a comprehensive framework should contain:
    - A clear definition that underlines proactive, adaptive resilience
    - A description of the capacities/resources that need to be developed in order to improve resilience
    - A set of qualities/principles that pertain to the resources e.g. robustness, rapidity, resourcefulness and redundancy
    - A set of indicators and metrics.

2. Several of the frameworks reviewed e.g. FRMT (Keating et al., 2017); ANDRI (Parsons et al., 2016); BRIC (Cutter et al., 2014) could be further considered to see how well they might work within the current FCERM context in England, in relation to the four elements listed above.

3. Consideration should be made of how the work of Sayers et al. (2017) in describing flood vulnerability, risk and disadvantage and providing metrics for their measurement could be included as part of any resilience framework for England, given the extent and detail of the work. In particular, the Neighbourhood Flood Vulnerability Index (NFVI) provides an improved expression of flood vulnerability and could be examined as an alternative that could be used in place of the Index of Multiple Deprivation in FCERM decision-making and as an evolution of previous vulnerability metrics.

4. Understanding of the limits to adaptation to coastal erosion and repeated flooding. If a national definition and approach to resilience is to be relevant to these contexts, it will be essential to review the evidence as to what the limits to adaptation are, how different social actors will be affected and the consequences of exceeding the limits.

5. A resilience framework can be used for different objectives and its design will need to reflect these objectives. Further consideration should be given to what the purposes of a flood and coastal erosion resilience framework should be. The possible purposes or uses of a resilience framework are likely to include:
    - Investment decisions
    - Supporting communities to improve their resilience
    - Comparing resilience across regions/countries to work out where to focus resources
    - Monitoring changes in resilience to better understand the factors that enhance or reduce resilience

6. A number of key gaps have been identified in the evidence on approaches to resilience in general and to flood and coastal erosion resilience in particular:

- The interrelationships between resilience capacities: are there capacities that are more important for resilience to flooding or the resilience of people and places? If so, what are the implications for the practical application of flood resilience approaches?
- To what extent and how do changes to in resilience capacities change resilience outcomes? What are the effects in terms of reducing physical damage, reducing psychological and social impacts and reducing negative effects on livelihoods?
- What further evidence is there of the development of metrics to value all aspects of resilience, to build on the approaches explored, e.g. FRMT (Keating et al., 2017); ANDRI (Parsons et al., 2016), City Resilience Index (The Rockefeller Foundation / Arup, 2015)?

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