SHIFTING FLOOD RISK MANAGAMENT (FRM) IN ENGLAND AND THE NETHERLANDS: PUBLIC FLOOD RISK PERCEPTIONS AND RESPONSES

by

LUCINDA KAYE CAPEWELL

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School of Geography, Earth and Environmental Sciences

University of Birmingham

United Kingdom

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ABSTRACT

Floods are one of the most damaging global events faced by society. Recent, significant flood events have also occurred despite suggestions that improved disaster risk reduction in the years prior have counteracted increasing socio-economic exposure and vulnerability. Shifting management, from traditional hazard-focused and engineered measures to integrated Flood Risk Management (FRM), is one way of tackling this 'wicked' water and flood problem. Yet, by applying a risk-based approach, and more emphasis being given to other aspects of the safety cycle such as preparation and recovery, it is important to understand how flood risk perceptions influence personal behaviours to risks. However, a feedback loop has been identified between flood risk perceptions and FRM, with only one side of this relationship included in literature. Recent socio-hydrology theories and concepts are contributing to this gap, but this work remains predominately theoretical.

Applying an interdisciplinary approach, this thesis first reviews the evolution of FRM directions in England and the Netherlands, two countries described as similar in some cases of managing flood risk. It then draws upon case studies of different FRM approaches in both countries to investigate the often-missed influence of varying FRM upon flood risk perceptions. Finally, this thesis analyses public preferences towards FRM and socio-hydrological response assumptions to flood events.

The results indicate that although both countries have progressed to a well-developed state of FRM, dominant and county-specific factors have both hindered and progressed developments. The level to which FRM measures are applied, and whether these are reactive or proactive, also differs between countries due to varying combinations of policy

change drivers. When investigating flood risk perceptions in the case studies across England and the Netherlands, FRM may play a part in influencing these, particularly when considering future likelihood of flooding, but a combination of other influential factors such as political involvement, community participation and frequent flooding also play a role in driving flood risk perceptions. Finally, socio-hydrology response assumptions and FRM preferences were tested with respondents that had been directly, indirectly, and never impacted by flooding. The results found that while prevention may be preferred to protection overall for FRM, flooding responses depend on the influence of previous flood events.

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TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

ABBREVIATIONS

ABI – Association of British Insurers

AEP – Annual Exceedance Probability

AHP – Analytical Hierarchy Process

CaR – Communities at Risk

CBA – Cost-Benefit Approach

DCE – Discrete Choice Experiment

DEFRA – Department of Environment, Food and Rural Affairs

DEM – Digital Elevation Model DRR – Disaster Risk Reduction

EA – Environment Agency

EM-DAT – Emergency Events Database

EU – European Union

FAG – Flood Action Group

FAHP – Fuzzy Analytical Hierarchy Process

FCERM – Flood and Coastal Erosion Risk Management

FCRIP – Flood and Coastal Resilience Innovation Programme

FD – Floods Directive

FFA – Frequently Flood Allowance

FloodRe – Flood Reinsurance

FPP – Flood Protection Programme

FFFP – Foresight Future Flooding Project

FRM – Flood Risk Management

GIS – Geographical Information Systems

HANZE – Historical Analysis of Natural Hazards in Europe

IAHS – International Association of Hydrological Sciences

ICE – Institute of Civil Engineers

IDBs – Internal Drainage Boards

IPCC – Intergovernmental Panel on Climate Change

IWM – Integrated Water Management

I&W – Ministry of Infrastructure and Environment (Ministerie van Infrastructuur en Waterstaat)

KNMI – Royal Netherlands Meteorological Institute (Koninklijk Nederlands Meterlogisch Instituut)

LLFAs – Lead Local Flood Authorities

MAF – Ministry of Agriculture and Fishers

MAFF – Ministry of Agriculture, Fisheries and Food

MCDM - Multi-Criteria Decision Making

NFM – Natural Flood Management

MLS – Multi-Layered Safety (Meerlaagsveiligheid)

MSfW – Making Space for Water

NBS – Nature Based Solutions

NRA – National Rivers Authority

NRD – National Receptors Database

NPPF – National Planning Policy Framework

NWP – National Water Plan

OMs – Outcome Measures

ONS – Office of National Statistics

PFR – Property Flood Resilience

PPG25 – Planning Policy Guidance

PMT – Protection Motivation Theory

PPS25 – Planning Policy Statement

RBMPs – River Basin Management Plans

RftR – Room for the River (Ruimite voor de Rivier)

RMAs – Risk Management Authorities

SDG – Sustainable Development Goals

SoP – Statement of Principles

SPN – Selly Park North

SPS – Selly Park South

STAR-FLOOD – STrengthening And Redesigning European FLOOD risk practices Towards appropriate and resilient flood risk governance arrangements project

SUDs – Sustainable Urban Drainage Systems

SVDS – Storm Tide Warning Service (Stormvloedwaarschuwings)

UN – United Nations

UNDRR – United Nations Office for Disaster Risk Reduction

VNK – Security in the Netherlands (Veiligheid Nederland in Kaart)

VROM – Ministry of Housing, Spatial Planning and Environment (Ministeries van Volkshuisvesting, Ruimlelijke Ordening en Milieu)

V&W – Ministry of Transport, Public Works and Water Management (Ministerie van Verkeer en Waterstaat)

WFD – Water Framework Directive

WBs – Water Boards

CHAPTER 1:

INTRODUCTION

CHAPTER 1: INTRODUCTION

'Every year, new record-breaking hydrological extremes affect our society' (Alfieri et al., 2015, p. 2247). Flooding, whether fluvial, coastal, pluvial or groundwater, is one of the most frequent and damaging hazards affecting societies globally (Jongman et al., 2015). Rising socio-economic exposure increasing local flood risks (high confidence) and intensifying hydrological cycles and events (medium confidence) are further increasing associated flood damages (IPCC, 2014a; Wiering et al., 2018). In the period between 1990 and 2018, globally insured economic flood losses equalled $926 billion (Munich RE, 2019), of which $175 billion of insured losses occurred in Europe, with $96 billion of this proportion attributed to 21 events (Munich RE, 2019).

Since 2018, catastrophic flood events include the 2021 Western Europe flood events across the Netherlands, Germany, Belgium, Romania, Italy, and Austria that resulted in 242 fatalities, with estimated insured losses of >$11.8 billion (The Insurer, 2021), and damage to properties, roads and other critical infrastructure and supplies (Kreienkamp et al., 2021). Flooding regarded as remarkable in hydrological terms also impacted the UK during the winter of 2019-2020 and resulted in >4200 properties flooded and insured flood losses totalling £214 million (Parry et al., 2020, p. 1; Sefton et al., 2021). These events and associated impacts occurred despite suggestions that improved management and Disaster Risk Reduction (DRR) have counteracted increasing exposure and reduced vulnerabilities and fatalities (Winsemius et al., 2016; Paprotny et al., 2018; Formetta & Feyen, 2019).

Increases in flood frequency, severity and damages are anticipated in the future (Winsemius et al., 2016; Blöschl et al., 2017), with these problems further compounded by the multi-faceted nature of flooding and heightened by societal complexities that have no clear or simple solution. This often results in water problems being referred to as 'wicked problems' that are complex, unstable issues with no singular solution (Rittel & Webber, 1973). Any implemented 'solutions' leave additional marks in the system (Rittel & Webber, 1973). Managing problems of flooding, both now and in the future, is therefore a critical challenge and key debate among policy makers, Risk Management Authorities (RMAs) and the public.

Continuous interactions, or co-development, between people and floods over centuries have shaped societies, institutions, and flood risk and protection systems (Barendrecht et al., 2017). Flood risk, encompassing hazard, vulnerability, and exposure is non-stationary and can be influenced by hydrological and socio-economic processes including risk management (Merz et al., 2010; Kreibich et al., 2022). Changing factors in the flood risk system also influence other elements due to feedback mechanisms, occasionally resulting in unexpected system changes (Barendrecht et al., 2017). The dynamic nature of flood risk therefore contributes to the status of flood management as being in state of constant flux (Bubeck et al., 2017). Further, flood risk perceptions and awareness interact with both flood risk and its management. Risk perceptions affect the risk-management system by influencing management paradigms and associated strategies, as well as individual actions towards flooding that may have reciprocal impacts from feedbacks within the system. This extended system is illustrated in **Figure 1-1**, in which elements continuously interact and evolve with each other.

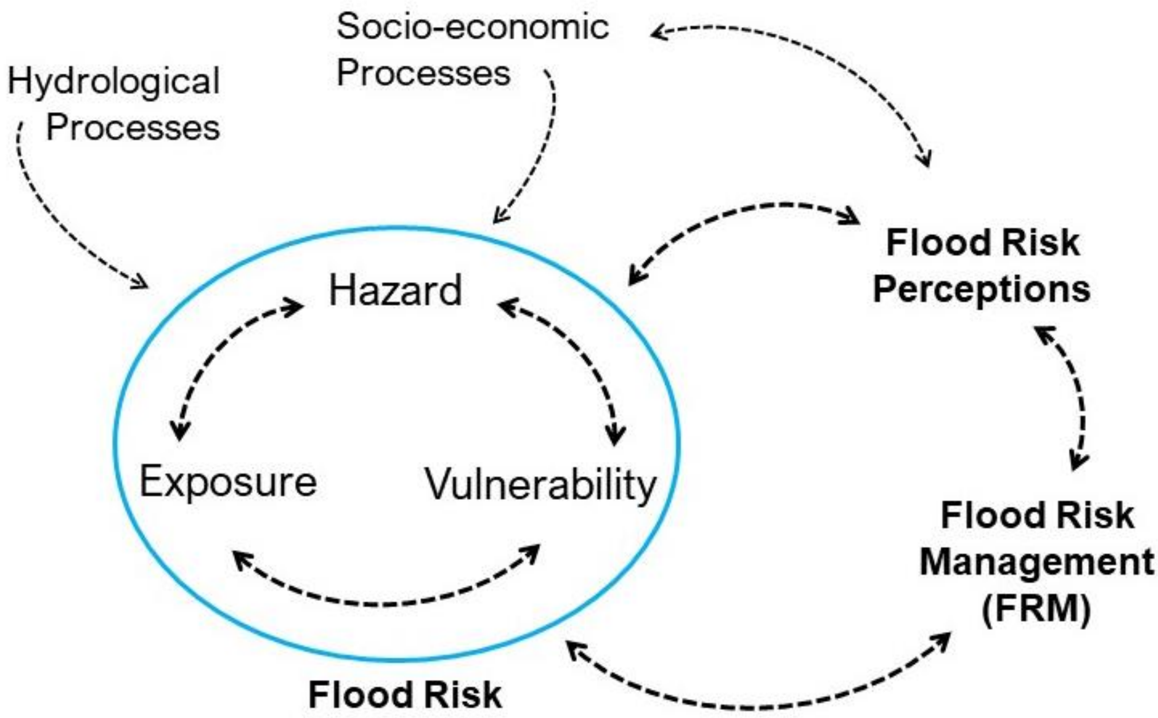

Figure 1-1: Schematic illustration of the co-evolvement of the elements of flood risk and its interaction with flood management and flood risk perceptions in an extended feedback loop.

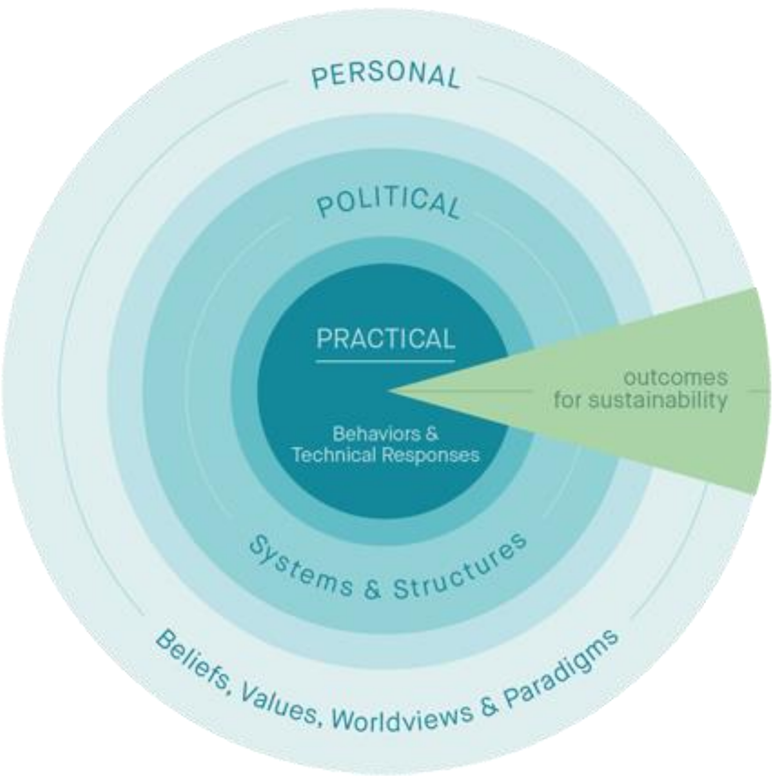

Figure 1-2: The Spheres of Change framework schematic. Source: O'Brien & Sygna (2013).

These interconnections have been identified by the 'Spheres of Change' theory and framework (**Figure 1-2**) that highlights linkages between three spheres: practical, political, and personal for transformations to address multifaceted environmental issues such as climate change (O'Brien & Sygna, 2013; O'Brien, 2018). The practical sphere refers to management outcomes such as DRR practices, policies, strategies, and technological responses; the political sphere includes economic, political, social, and cultural systems that shape and support policy changes in the practical sphere; and the personal sphere refers to all individual and collective beliefs, values, and perceptions that in turn influence the political and practical spheres. Transformations undertaken in the personal sphere are considered the most powerful, with perceptions, values, beliefs, and assumptions driving changes in the subsequent spheres and influencing actions, in this case DRR actions and strategies, as well as larger systems and paradigms that steer these (O'Brien & Sygna, 2013). This transformations model can be applied to flood risk and its management and provides useful insight in linking together important themes examined in this thesis: policy, practice, and perceptions.

Flood management developments have been well documented globally, with historical advances focusing on flood protection that sought to overcome, hold back, and defend against rising floodwaters (Sayers et al., 2015a). However, questions have been raised over the effectiveness of these measures when used in isolation, given changing flood risk (Grabs, 2016). This has led to a progressive shift towards managing flood events using a Flood Risk Management (FRM) approach. FRM is a holistic, risk-informed approach that considers all elements of flood risk (hazard, exposure, and vulnerability) equally, that may have been previously overlooked by engineered and structural protection, to encourage the inclusion of non-structural measures to reduce catchment-scale flood risks and address social aspects of this risk (Merz et al., 2014; Ward et al., 2020). FRM strategies to increase and improve flood resilience have grown in popularity in recent years, largely to counteract the uncertainties associated with climate change (McClymont et al., 2020). Although this FRM shift has been globally implemented (and aided by catalyst flood events), location-specific, contextual, and historical factors, as well as differing policy actors, beliefs and chosen solutions have resulted in FRM actions and portfolios varying between individual countries (Sayers et al., 2015a; Wesselink et al., 2015). For example, England and The Netherlands are two countries that have developed from strengthened flood protection to integrated FRM. Their comparable progression reflects, in part, a shared need to comply with European Union (EU) water directives (Matczak et al., 2016), as well as similar, long-standing government roles in flood management (van Buuren et al., 2015), common experience of managing large floods including the 1953 North Sea storm surge, and projected increasing flood impacts from socio-economic and climatic changes (van Buuren et al., 2018). Yet different national priorities, catchment geographies, socio-economic conditions and historic management choices have led to varying FRM practices, policies, timings, and associated flood risk perceptions and responses of individuals in both countries.

Traditional flood protection measures have enabled socio-economic development behind infrastructure in at-risk areas (Di Baldassarre et al., 2018), resulting in increased, and often hidden, vulnerability to flood risk and losses that drives rising damages (IPCC, 2014a). Current predictions estimate that by 2060, an excess of 80% of the global population will reside in flood-prone locations (De Wrachien et al., 2011). This greater exposure to flooding may uncover further vulnerabilities that increase the susceptibility of communities and individuals to be greatly impacted by flood events (Cardona et al., 2012). This includes those living behind flood protection whose residual risk is increasing, as well as in areas that were not previously at risk. However, uncertainties remain because social vulnerability can only be coarsely accounted for (Bouwer, 2011), if included at all. There is therefore a key need to include social vulnerability in future risk assessments (Bouwer, 2011; Koks et al., 2015).

The move to FRM, and need to consider the societal aspects of flood risk whilst including the public and stakeholders in FRM to increase social resilience to flooding, has highlighted that differing levels of flood awareness and risk perceptions can have an important impact on changing societal vulnerability (Bubeck et al., 2012a). The way flood risks are perceived is fundamental to how communities and individuals prepare for, respond to, and behave towards flood hazards (O'Neill et al., 2016). These risk perceptions are controlled by an individual's conceptual understanding of risk (O'Neill et al., 2016), and are continually influenced by other internal and external elements. Flood risk perceptions can therefore provide insights for FRM strategies (Bubeck et al., 2012b), particularly influencing perception characteristics and motivations of individuals to "take action" against flood risk. However, research often misses the reciprocal links between flooding and society (Sivapalan et al., 2011) and only analyse one side of the interplay between flooding, societies, and human adjustments that connect both systems (Di Baldassarre et al., 2013a). This includes the influence of FRM strategies on flood risk perceptions. More recently, with the aim of addressing this gap, emerging socio-hydrology concepts have highlighted the other side of this dynamic relationship between society and hydrological systems that is poorly represented in current literature, as well as the important interactions and feedback within this system (Sivapalan et al., 2011; Di Baldassarre et al., 2013b). This includes links between floods and societal behaviour to protect against and adapt to flooding, and the importance of flood frequency and social memory motivating these behaviours (Gober & Wheater, 2015; Ciullo et al., 2017; Fuchs et al., 2017). However, a large amount of this work remains theoretical and focuses on modelling behaviours to represent societal influences and behaviours.

1.1 Research Rationale

Increasing and changing flood risk is a major concern globally. Flood losses, damages and impacts including fatalities are generally less severe in developed countries (Tanoue et al., 2016). However, European countries are experiencing rising flood risks from increasing socio-economic development in flood risk areas that increase exposure and damages, as well as potential hydrological changes from climate change (Hegger et al., 2016a). To account for this changing risk, in addition to other influencing environmental (Sayers et al., 2015a), social (Di Baldassarre et al., 2018), and economic (Nye et al., 2011) factors, flood management has developed from a focus on solely "traditional" engineered structures and assets to FRM. This shift has been well documented with several studies describing differing FRM and governance strategies for individual countries or catchments (e.g. Bergsma (2019) for the US; Puzyreva & de Vries (2021) for Berkshire, England; Esmaiel et al. (2022) for Egypt; Jia et al. (2022) for Yangtze Basin, China) and in national comparisons (Wesselink et al., 2015; Matczak et al., 2016; Chan et al., 2022). However, these studies tend to focus on specific FRM strategy aspects or summarise approaches in general. Few studies consider influencing location-specific, contextual and historical factors to explore ***why*** countries adopt specific FRM directions and strategy portfolios in response to flood risk (Wiering et al., 2017, 2018). To truly understand current FRM approaches and consider future development, previous flood management strategy progression, physical country characteristics, and socio-political culture need to be considered. The effectiveness of chosen FRM measures is also an important research benchmark for these to be successful to manage rising flood risks (Hudson et al., 2014) although this effectiveness is highly variable (Priest et al., 2016). Managing flood risk is a complex problem, and measures should be continually revised in line with the development and improvements of technology, awareness, and expertise that shape overall FRM strategies (Tariq et al., 2020). To do this, empirical data is continually needed on the implementation, progress, and performance of measures that are necessary to design and improve FRM policies in future (Poussin et al., 2015). To some extent, this research also seeks to identify the effectiveness of some specific measures in each country's FRM portfolio.

Within the shift to flood risk and resilience-based FRM strategies, it is increasingly important to understand societal vulnerability. Yet, the consequences of social vulnerability for global flood risk are still not fully understood and remain difficult to address (Jongman et al., 2015; Koks et al., 2015). In many cases social vulnerability is not included in flood risk assessments and analyses (Jongman et al., 2015), which commonly focus on 'economic vulnerability' monetised in loss functions and defined as the predisposition to incur losses (Mechler & Bouwer, 2015) rather than societal factors. Moreover, the role of risk perceptions and their impact on vulnerability, and the implications for flood risk, have grown in importance in recent years. The influencing factors of risk perceptions have been widely studied in DRR literature, including the situational and cognitive elements that control risk severity judgements (O'Neill et al., 2016). More recently, investigations have focused on the role risk perceptions play towards triggering behavioural changes that increase preparedness, willingness to act, and overall community resilience, although this connection is sometimes unclear (Wachinger et al., 2013; Genovese & Thaler, 2020).

However, few studies have investigated the opposing counter-effect of how FRM strategies have altered flood risk perceptions, either positively or negatively, that may impact future flood risks due to system feedbacks. The rare studies that investigate the impact of FRM measures on risk perceptions focus on one measure in one area (Ludy & Kondolf, 2012), the role of trust in RMAs and DRR in general, or perceived responsibilities for management of flooding (Bichard & Kazmierczak, 2012). However, the evaluation of strategies to improve flood perceptions, awareness and understanding (Sayers et al., 2015a), as well as the influence of varying structural and non-structural FRM strategies on altering flood risk perceptions and thus overall flood risk, should also be considered.

Emerging socio-hydrology concepts have begun to indicate the influence of general flood strategies, that focus on protection or adaptation for societies, as well as making several advances towards conceptualising the responses of communities following flood events (Ciullo et al., 2017). However, these models use theoretical flood situations in hypothetical areas, which are accompanied by assumptions of public flood response and therefore may not accurately represent realistic societal responses. While some studies have applied socio-hydrological models to real-life flood prone settlement areas (Ciullo et al., 2017), the public response assumptions remain untested.

By focusing on England and the Netherlands, and flood risk from primarily fluvial (with consideration towards pluvial) events, this thesis seeks to contribute to the understanding and debate on the nature of evolving FRM policy and practices in Europe. Further, this research aims to improve understanding of the links and system feedbacks between flood risk, management, and public flood risk perceptions and responses in both countries. More generally, this research offers an opportunity to add to the emerging literature on FRM and resilience, specifically for England and the Netherlands. Finally, the research contributes to the current ‘Panta Rhei’ scientific decade of the International Association of Hydrological Sciences (IAHS) which is dedicated to research activities on change in hydrology and society and calls for more paired catchment studies (Kreibich et al., 2017), as well as the recognised need for comparable community based DRR studies (Laurien et al., 2020).

1.2 Research Aims and Objectives

Focusing on the research gaps identified, this thesis aims to investigate the evolution of flood management practices and policies towards diversified FRM strategies, that focus on addressing all flood risk elements (hazard, exposure and vulnerability), and the influence these approaches have on flood risk perceptions, while testing public preferences and socio-hydrological response assumptions in England and the Netherlands. To achieve this aim, four research objectives have been identified:

1. To evaluate the development of flood management policies and practices in England and the Netherlands from 1945 and compare the diversified FRM approaches and internal and external policy drivers that have applied in both countries;

2. To discern the level to which current social vulnerability data can be incorporated alongside hazard and exposure data to produce an effective flood risk map;

3. To determine whether the flood risk perceptions of individuals are influenced by the dominant FRM strategy present to address their flood risk;

4. To test public preferences to FRM measures and theoretical socio-hydrological response assumptions that are perceived to occur following a flood event.

1.3 Thesis Structure

This thesis comprises 8 chapters. Following this introduction chapter, Chapter 2 synthesises the academic literature across the main research themes as well as beginning to address the first objective with a document review of FRM developments in England and the Netherlands. Chapter 3 details the varying and inter-disciplinary methodology used to address each research objective that are applied in Chapter 4, 5, 6 and 7, respectively. This is illustrated in **Figure 1-3** that highlights the linkages between these research objectives and research themes in this thesis. Finally, Chapter 8 summarises and concludes the main research findings, while providing discussion points on the implications for future FRM and recommendations for future avenues of research from this thesis.

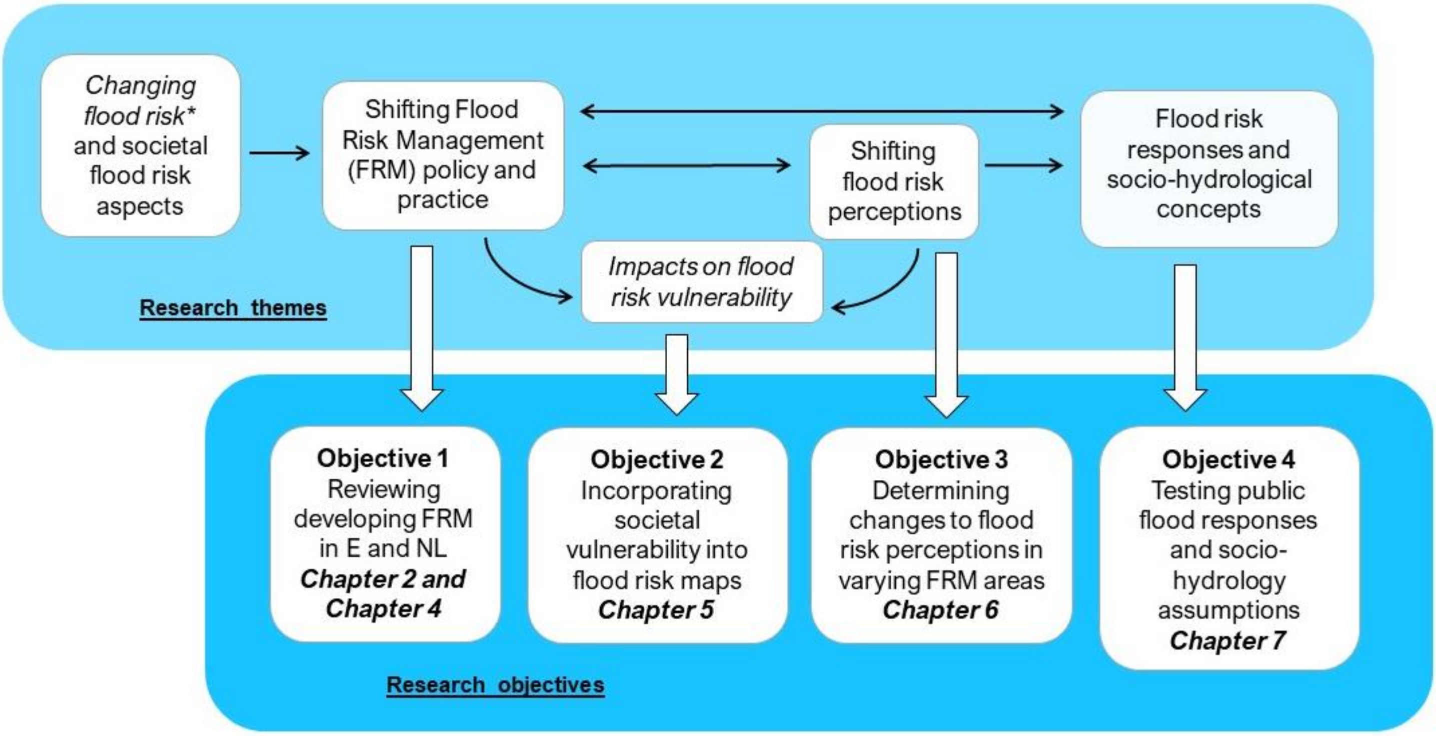

Figure 1-3: Linkages of interconnecting research themes with research objectives and their corresponding research chapters. Themes with * are key fields for the research themes focused on in this thesis, but not specifically included in research objectives.

CHAPTER 2:

LITERATURE REVIEW

Some concepts in this chapter that focus on unintended and negative consequences of flood reduction measures were used in discussion for Ward et al. (2020). This particularly includes the ‘levee effect concept’ and flooding from failures of dikes and levees that have shaped sections of this literature review and thesis, rather than textual sections The paper also introduces the ‘paired events’ study that is highlighted in Chapter 6.

Ward, P.J., de Ruiter, M.C., Mard, J., Schroter, K., Van Loon, A., Veldkamp, T., von Uexkull, N., Wanders, N., AghaKouchak, A., Arnbjerg-Nielsen, K., **Capewell, L.**, Carmen Llasat, M., Day, R., Dewals, B., Di Baldassarre, G., Huning, L.S., Kreibich, H., Mazzoleni, M., Savelli, E., Teutschbien, C., van den Berg, H., van der Heijden, A., Vincken., J.M.R., Waterloo, M.J., and Wens, M. (2020). The need to integrate flood and drought disaster risk reduction strategies. *Water Security*, 100070 https://doi.org/10.1016/j.wasec.2020.100070

CHAPTER 2: LITERATURE REVIEW

2.1 Scope of Chapter

This chapter provides an overview of the academic literature on the main research themes addressed in this thesis, specially: changing flood risk and flood management, flood risk perceptions and socio-hydrology. Shifting and developing flood risk and FRM that includes emerging resilience concepts have been identified, and the chapter highlights important reciprocal links to flood risk perceptions. Finally emerging socio-hydrology research concepts are considered that further identify important connections between water and society.

2.2 Flood Risk and Changing Flood Risk

The Intergovernmental Panel on Climate Change (IPCC) defines a flood as when waterbodies overflow their normal confines or water accumulates over areas that are not normally submerged. This includes fluvial river flooding, flash flooding, urban flooding, pluvial rainfall flooding, sewer flooding, coastal flooding, and glacial lake outburst floods (IPCC, 2019). This is similar to several definitions in the literature (e.g. Blöschl et al., 2015), although some have separate definitions for floods (once events have occurred) and flooding (active impact during the event) (De Wrachien et al., 2011), or focus on the varying severity of the event that can range from 'water outside its normal confines' to 'inundation which causes damage' (Samuels et al., 2006, p. S142).

Alongside the definition of a flood, the IPCC defines a "hazard" as the 'potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources' (IPCC, 2019, p. 814). This definition has evolved since its first inclusion (IPCC, 2014a), in which it no longer refers to the physical impact of the event but focuses entirely on the physical hazard. Further IPCC reports combine the terms "flood" and "hazard" to define "flood hazards" as the physical event of flooding, taking into account the frequency and magnitude of flooding (IPCC, 2020) that can be applied to all flood mechanisms and types. For the research presented in this thesis, this joint definition of a flood hazard will be used as it enables the physical hazard of a flood to be separated from other risk elements that will be discussed shortly. This thesis also focuses predominately on fluvial flood events that have a temporal scale ranging from a few hours to several days (Kreibich et al., 2019), with considerations of pluvial surface water flooding where necessary as the two often occur together.

The probability and intensity of fluvial flood hazards are dependent on the physical flood generation processes (Merz et al., 2010), in which key drivers of high river flows from prolonged and severe rainfall and snowmelt (Arnell, 2015) are exacerbated by catchment properties and land use characteristics affecting runoff and infiltration rates (De Wrachien et al., 2011; Blöschl et al., 2015). Yet, while there is a consistent possibility of a physical flood event occurring from changing climate and weather patterns, it is commonly recognised that flood hazards only become damaging when interacting with human society (Merz et al., 2010). This is central to the more recent debate surrounding the term "*natural hazards"* and the notion that there is no such thing as a natural disaster but rather hazards develop into disasters by interacting with society (UNDRR, 2021). Flood risk thus emerges from the combination of a physical hazard and the societal processes of exposure and vulnerability, referred to as the risk triangle (Chrichton, 1999) or the functions of risk (De

Wrachien et al., 2011). Thus, referring to hazards as natural disasters ignores the complex social construction of disaster risk and the diverse disaster drivers (Chmutina & von Meding, 2019).

Exposure represents all at-risk assets within the built and natural environment that could be affected by a hazard (Merz et al., 2010; Cardona et al., 2012; Kreibich et al., 2017). Vulnerability has several definitions that have developed over time. In this thesis, vulnerability is defined as the propensity and susceptibility of exposed at-risk areas, including human beings and livelihoods, to be adversely impacted by the occurrence of a hazard (Cardona et al., 2012; Kreibich et al., 2017). This focuses specifically on social vulnerability and does not include the vulnerability of physical or economic assets that could be grouped under exposure. Fundamental socio-economic and political circumstances can increase susceptibility to the impact, losses and disruption caused by hazards (Cardona et al., 2012) while reducing the capacity to cope with, resist, and/or recover from these events (De Wrachien et al., 2011). These circumstances can include economic conditions such as the amount or availability of monetary resources, social conditions of social relationships, networks and inclusion, and/or demographic factors such as differing levels of education and age (Merz et al., 2010).

While this definition and focus on social vulnerability has been adopted in this thesis, definitions vary throughout the disaster risk literature due to the evolving and uncertain nature of the term. Cardona et al. (2012) provides an early view of vulnerability concepts that relate to the physical resistance of engineered structures. Developments in the understanding of climate change identified the need for studies that investigate the range of adaptive responses that substantially alter the impacts and consequences of a changing climate (Burton, 1997; Smithers & Smit, 1997). Consequently, definitions at this time varied to include the inability to cope with stresses (Watts & Bohle, 1993), or the inability to respond, cope and adapt (Adger & Kelly, 1999). Many recent definitions consider vulnerability the degree of susceptibility to be damaged, that includes the capacity to respond, recover (Merz et al., 2010) or react to stresses (De Wrachien et al., 2011).

Some flood risk definitions focus only on hazard and exposure and ignore vulnerability altogether or combine vulnerability aspects within exposure (Merz et al., 2007). For instance, acknowledging flood risk as a combination of hazard probability and resulting negative consequences (Raaijmakers et al., 2008). This often tends to focus on tangible vulnerability determined by socio-economic structures and property weaknesses (Blaikie et al., 1994). However, by focusing on 'economic vulnerability' monetised in loss functions and defined as the predisposition to incur losses (Mechler & Bouwer, 2015), this can miss important vulnerability conditions determined by combinations of physical, social, economic and environmental factors and processes that can increase the susceptibility to impacts (UNISDR, 2009).

The definition in the 2007 EU Floods Directive (FD; 2007/60/EC) similarly follows this classification but considers societal impacts, defining flood risk as a 'combination of the probability of a flood event and the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event' (European Union Commission, 2007, p. 28). Klijn et al. (2015), however, considers that by combining these elements, exposure can be 'swallowed by the definition of vulnerability' (p. 852). Cardona et al. (2012) also highlights key issues surrounding elements or communities being exposed to hazards but not vulnerable due to increased capacities.

Although there have been questions over varying elements of flood risk, floods are recognised to be increasing. Several flood event databases, such as the Flood Phenomena dataset from the European Environment Agency (2018), the EM-DAT (Emergency Events Database) by the Centre for Research on the Epidemiology of Disasters (Jones et al., 2022; CRED, 2022), the Global Active Archive of Large Flood Events by the Dartmouth Flood Observatory (Brakenridge, 2016), and the NatCatService by Munich Re (Munich RE, 2019) provide reasonable estimates of flood events since the 1980s and have identified increasing trends. Further, Paprotny et al. (2018) compiled European flood data from a new HANZE (Historical Analysis of Natural Hazards in Europe) database, and identified an increasing trend of observed flood events, classified into severity quantiles (**Figure 2-1**). In addition to the overall increasing trend, smaller floods recorded in the database have a steeper annual increase of 2% per year, compared to the largest floods that increase by 0.3% annually (Paprotny et al., 2018). This increase in smaller events may reflect the increased reporting of less severe floods (Paprotny et al., 2018) in addition to changing flood risk.

The nature of risk is extremely dynamic and subject to change from shifting climate and socio-economic processes and elements (**Figure 2-2**) (IPCC, 2020). One changing element of flood risk can influence others in the system due to feedback mechanisms that can sometimes have unexpected results (Barendrecht et al., 2017). This includes "solutions" to, or management of, the flood problem that can create new issues while aiming to solve one aspect of a complex, wicked water problem (Khan et al., 2010). Flood assessments have developed alongside this recognition of expanding flood risk aspects (de Moel et al., 2015). However, uncertainties remain applicable to all elements (hazard, exposure and vulnerability) in current and future risk analyses, especially those that only focus on one changing element (IPCC, 2020).

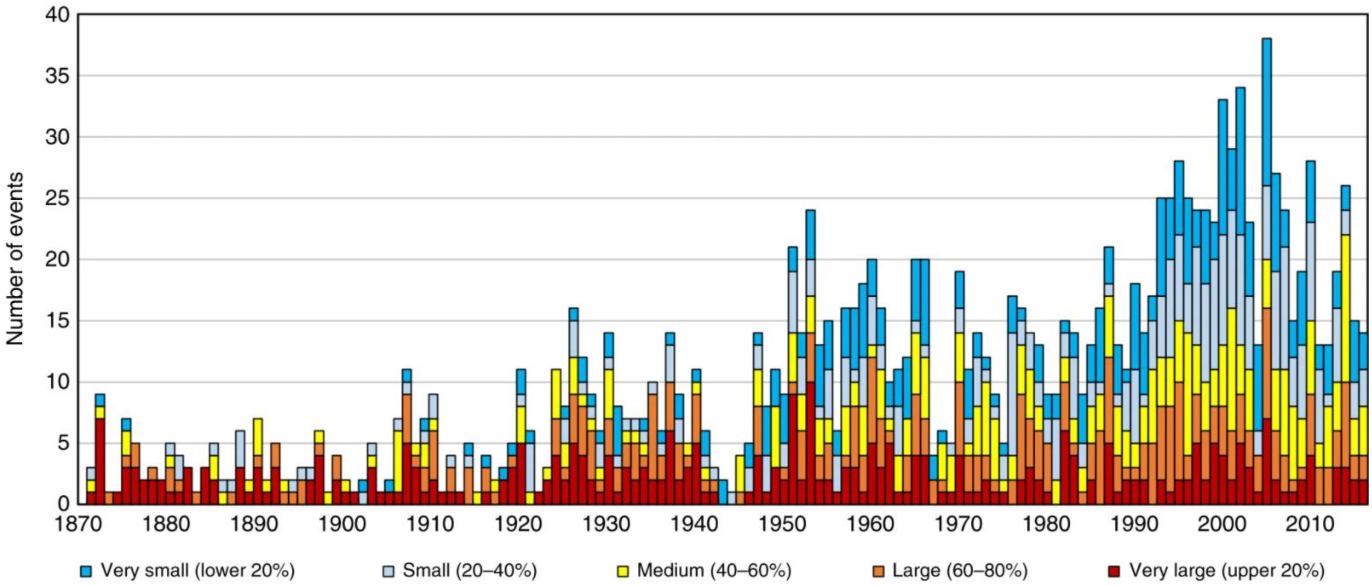

Figure 2-1: Observed increasing frequency of flood events across Europe from 1870 to 2018 by. Events are categorised into severity quantiles based on reposted event impacts. Source: Paprotny et al. (2018).

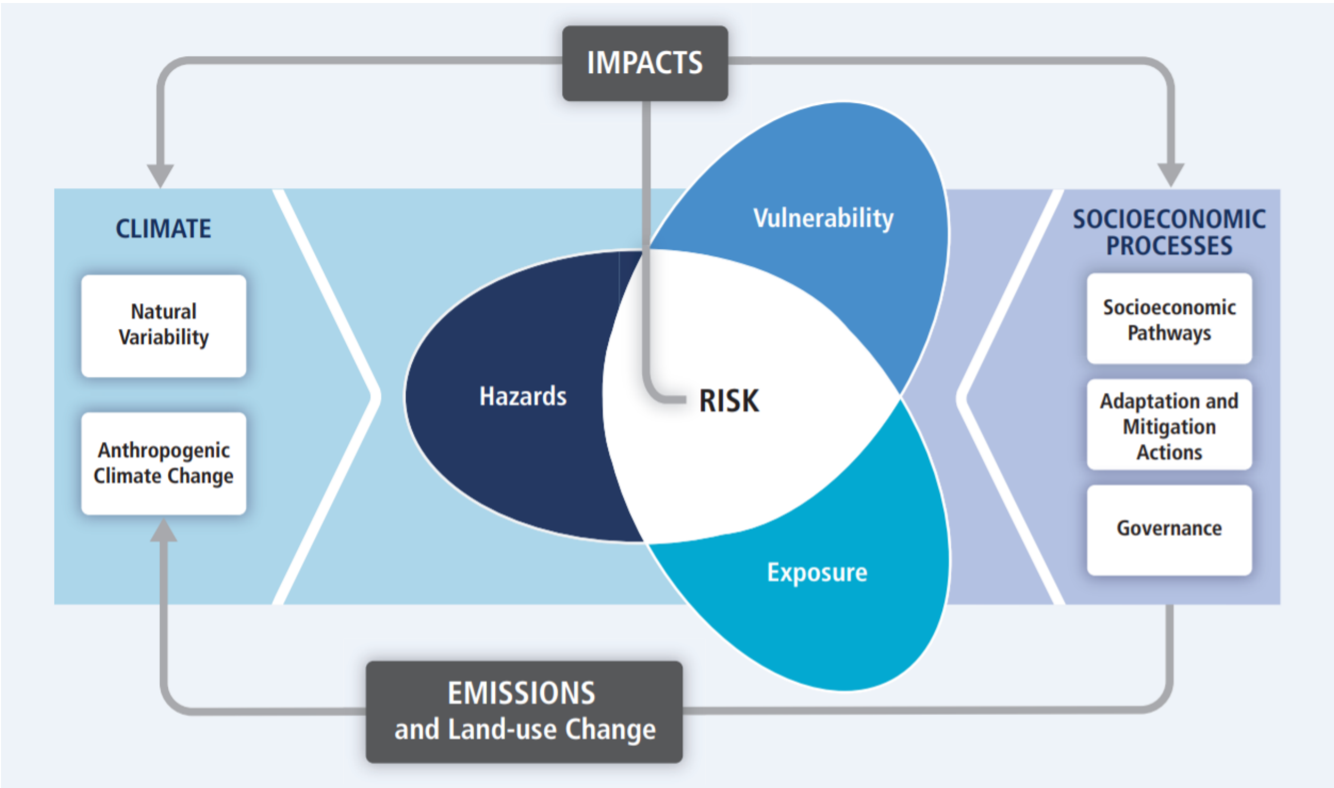

Figure 2-2: Graphical representation of interactions between flood risk elements (hazard, exposure, and vulnerability) and their ability to be influenced by climate and socio-economic processes, as well as a combination of the two (land use and emission changes). This driving processes can in turn be altered by impacts from flood risk and feedbacks within the system. Source: IPCC (2014b).

Flood hazard physical generation processes have already been considered (i.e. rainfall, snowmelt, high river flows, situational catchment and drainage properties) (Merz et al., 2010; De Wrachien et al., 2011; Arnell, 2015; Blöschl et al., 2015). However, recent anthropogenic climate changes are intensifying processes in the hydrological cycle by increasing the frequency, intensity and duration of rainfall events and energy available for snowmelt (Kundzewicz et al., 2013; Blöschl et al., 2015). Several studies have investigated these impacts on flood conditions and changing flood regimes across multiple catchments and scales. For instance, Seneviratne et al. (2012) found that globally more catchments have increased rates of precipitation rather than decreased. Hall et al. (2014) compiled studies on flood frequency trends, and although not all were directly comparable, the dominant pattern across Europe was one of decreasing trends in Northern and Eastern Europe, increasing observed flood changes in Western Europe, including England and The Netherlands, and mixed signals in Central Europe. Although increasing flood frequencies from intense hydrological events are difficult to assess at a global scale, there is medium confidence that these are increasing at regional and local scales (IPCC, 2014). Additionally, Blöschl et al. (2017) identified changes in European river flood timing between 1960 and 2010 of –65 and +45 days from changes in seasonal precipitation, soil moisture and snow fall/melt processes. This concept of changing hazard trends, both increasing and decreasing, has led to an increase of the term 'climatic impact driver' rather than hazard that has predominately negative connotations (IPCC, 2020).

While climate change impacts on hydrological regimes may differ by scale and confidence level, there is growing consensus that rising socio-economic exposure from increasing development, exposed assets, and population growth in at-risk areas is the primary driver in escalating flood damages (Blöschl et al., 2015; Bouwer, 2011; Jongman et al., 2015; Viglione et al., 2016; Wiering et al., 2018) and significantly increased urban flood risks (high confidence) (IPCC, 2014a). Greater exposure to flood hazards can also uncover previously hidden vulnerabilities (Cardona et al., 2012). Further, socio-economic developments, and anthropogenic, river and catchment-scale interventions, can impact hydrological regimes. Urban interventions and land use changes (e.g. non-permeable areas) can significantly increase run-off and infiltration rates, while control measures and river channel alterations can reduce available floodplain storage areas, and increase in-channel river levels and water conveyance rates through catchments (Blöschl et al., 2015; Skublics et al., 2016; Munoz et al., 2018). Responses to, or a mismanagement of, flood risk can at times increase flood risks both directly in the affected area, or elsewhere in the catchment (IPCC, 2019).

2.3 Flood Management

While flood risk results from complex interactions between hazard events and human societies, it can also depend on human behaviour in response to, and the capacity to manage, this risk (Gober & Wheater, 2015). Typically, early settlers adapted to flood events by building or migrating to settlements on higher land (Fanta et al., 2019; Wang & Gao, 2020), for example in the early Holocene around 4500 BP in China (Zeng et al., 2016), 4300 BP (4.3 ka) in Norway (Balbo et al., 2010), and during the middle-ages across Europe (Pinke et al., 2016). A good review of the literature investigating relocation to higher ground during flood events with supporting theories is provided by McLeman & Smit (2006). Early adaptation strategies were also observed, including flood sensitive land-use planning that was widely practiced by the Romans, while issuing flood warnings that was common practice in ancient Egypt (Sayers et al., 2015a). This was generally coupled with a belief that floods were "acts of god" (Samuels et al., 2006).

Increasing trade, navigation, and the need for water supply alongside socio-economic growth and accelerating urbanization has expanded settlements sizes, which subsequently developed into towns, cities, and "*megacities*" (Kummu et al., 2011; Di Baldassarre et al., 2013a; Ceola et al., 2014; Fang et al., 2018). This increasing exposure in floodplains and at-risk areas led to advancing engineering technologies to provide, and increase the reliance upon, structural flood protection for flood management (Sayers et al., 2015a; Mees et al., 2016; Bubeck et al., 2017). Structural protection or defences, often referred to as "traditional" engineered or resistance measures, concentrate on reducing the probability and occurrence of physical flood hazards and are widely discussed, both positively and negatively, across the literature (Park & Miller, 1982; Samuels et al., 2006; Nye et al., 2011; Birkholz et al., 2014; Merz et al., 2014; Di Baldassarre et al., 2018; Mård et al., 2018).

The problems associated with structural flood protection include the difficulty and economical impracticality of defending all at-risk areas against all size flood events (Johnson et al., 2007; Nye et al., 2011; Thaler & Hartmann, 2016). Ward et al. (2017) further clarifies this point, by estimating that the protection standard (design level) required to optimise the use of solely structural protection against increasing flood risks in some countries would be so high that it would be financially unfeasible. Considerable environmental impacts (Sayers et al., 2015a) and societal problems related to flood exposure and vulnerability as a result of flood hazards (Merz et al., 2010; Birkholz et al., 2014) are also recognised. The latter include the unintended consequences of enabling socio-economic development behind protection infrastructure (Di Baldassarre et al., 2018) (Ward et al., 2020) and the impact of increasing assets and population growth in at-risk areas (Park & Miller, 1982; Mård et al., 2018). Not including or assuming these social elements remain stationary ignores key factors surrounding highly dynamic functions, that may change quicker than the hazard itself (Merz et al., 2010, 2014; Kreibich et al., 2017) and all elements of flood risk (hazard, exposure, vulnerability) need to be addressed to reduce impacts from future events (Kreibich et al., 2022). This includes issues surrounding the illusion of complete safety from failure to communicate remaining residual risk (Burby, 2006; Birkholz et al., 2014). Tobin (1995) titled this the 'Levee Love Affair' where structural defences provide total protection until design levels are reached or compromised, resulting in widespread flooding in unprepared and unaware communities (Tobin, 1995; Di Baldassarre et al., 2018). Several strategies that attempt to address flooding are also suggested to not cope well with uncertainty, and a lack of consideration of changing, and particularly increasing, trends may result in large fatality and damage impacts in the future (Morrison et al., 2018).

The combination of these issues and advances in non-structural strategies that incorporate potential uncertainties, have encouraged a shift to integrated FRM that intends to apply a holistic approach to reduce flood risk elements (hazard, exposure, vulnerability) equally for all size flood events by considering societal, sustainability and resilience building factors to "*live with water*" (Klijn et al., 2008; Merz et al., 2010; Nye et al., 2011; Grabs, 2016; Morrison et al., 2018). This shift to FRM is well documented by Merz et al. (2010) and Klijn et al., (2008) who describe the key FRM elements and essential requirements. Both refer to managing flood risk holistically by replacing fragmented management approaches for sole events with an integrated systems approach that combines structural and non-structural regulatory, financial, and communicative measures (Klijn et al., 2008; Merz et al., 2010). This includes implementing a wider portfolio of measures across all aspects of the safety cycle: prevention, protection, mitigation, preparation and recovery (Matczak et al., 2016; Wesselink et al., 2015; Wiering et al., 2018) to address whole catchment flood risks (Johnson et al., 2007; Sayers et al., 2015). This aims to provide a 'safe-fail' system, that may occasionally fail but in a safe way with a greater capacity to recover quickly (Kundzewicz et al., 2018). Thus, integrating a combination of measures supports suggestions that solutions to wicked water problems are not simply true or false, but better or worse in a socio-economic context (Khan et al., 2010).

Hegger et al. (2016a) provides a good summary of each safety cycle component. These are highlighted in **Table 2-1**, with examples of specific measures that fall under each category. Some scholars describe "mitigation" as all flood hazard prevention activities undertaken before and during an event, covering all aspects of the safety cycle except recovery (Genovese & Thaler, 2020). However, this research considers mitigation measures separately, and distinguishes between strategies that improve flood risk protection, prevention, mitigation, and preparation under the FRM umbrella. Flood protection remains important and necessary for different socio-economic and climate scenarios (Winsemius et al., 2016) but should be used in combination with other preparatory, prevention and mitigation strategies such as Sustainable Urban Drainage Systems (SUDs) or Nature Based Solutions (NBS) (de Bruijn et al., 2015; Matczak et al., 2016).

This recognition of a diversified approach is not new as early researchers such as White (1945) identified varying "adjustments" to flooding that include protection, abatement and structural arrangements which could be considered mitigation, land-use changes for prevention, and emergency measures, public relief and insurance for preparation and recovery.

Table 2-1: Aspects of the safety cycle with their focus, aim and example measures. Adapted from Hegger et al. (2016a).

FRM/safety cycle strategy type	Focus of strategy	Aim of strategy and example measures
Flood risk prevention	To keep people away from floods	To decrease the exposure of people and property to flood risks by discouraging development in at-risk and flood prone areas through spatial and land-use planning
Flood risk protection	To keep floods away from people	To decrease the probability and frequency of, and defend against, flood events using structural protection measures and infrastructure such as flood walls, dikes, and embankments, as well as dams and weirs. These measures are generally referred to as structural or traditional measures
Flood risk mitigation	To reduce the impacts of floods on people	To decrease the consequences of flood events when they occur using smart and innovative planning approaches in flood prone areas. This includes flood proofing properties and new buildings with Property Flood Resilience (PFR) measures (formerly recognised as Property Level Protection), and storing and retaining water within environmental systems before it impacts societal structures (people and property) such as Sustainable Urban Systems (SUDs), Nature Based Solutions (NBS) or Natural Flood Management (NFM) and Integrated Water Management (IWM)
Flood risk preparation	To prepare people for floods	To increase preparation for flood events through the development and implementation of early warning systems and disaster and contingency planning, as well improving awareness and education of flood risk in at-risk areas
Flood risk recovery	To help people recover from floods	To increase the potential for recovery after a flood event by recovery and reconstruction plans, as well as risk transfer insurance or flood damage compensation system

The inclusion of softer, non-structural mechanisms and measures within FRM also play an important role in decreasing flood vulnerability that may counteract increasing flood risks from climate changes (Kreibich et al., 2019). This includes key advances in stakeholder engagement to address perceptions and behaviours to flood risk and subsequent governance, and how these influence FRM strategies, their acceptability, effectiveness and supporting policies (Morrison et al., 2018).

For effective FRM, Merz et al. (2010) suggests proactive behaviour that supports adaptative strategies is more beneficial than reactive behaviour. Kreibich et al. (2017) compared eight case studies of 'paired' flood events (two events occurring in the same area) that implemented risk reduction strategies, such as individual precautionary and preparedness measures (e.g. Property Flood Resilience; PFR), improved awareness, early warning systems, and emergency management, after the first event. The study concluded that damages were reduced, even if the second event was larger, and identified a medium to large reduction in vulnerability in all case studies with some reducing exposure (Kreibich et al., 2017). Increasing public participation (Wehn et al., 2015) and improving flood risk communication with increased flood awareness and knowledge (Sayers et al., 2015a) are also suggested as necessary, and are increasingly used (Morrison et al., 2018), to deliver effective FRM strategies (Cologna et al., 2017). Individual flood risk elements, such as vulnerability, can therefore be equally positively and negatively influenced by certain types of risk management (Kreibich et al., 2019).

More recently, emerging resilience-based strategies have begun to focus on building the capacity of societies exposed or vulnerable to deal with flooding, and enable decision-makers and practitioners to manage the uncertainties that accompany future flood risk and climate change projections (Reynard et al., 2017). Typically, resilience refers to the ability of a system to recover and resume functionality after a disaster (Kuang & Liao, 2020; McClymont et al., 2020). McClymont et al. (2020) provides a good review of the developments of resilience concepts, starting from the introduction of the term in ecology (Holling, 1973). However, developments in other areas has expanded the term to now include three distinctions: engineering resilience, socio-ecological or systems resilience, and complex adaptive systems or evolutionary resilience (Martin-Breen & Anderies, 2011; Hegger et al., 2016a; McClymont et al., 2020). Engineering resilience is defined as a systems ability to withstand disturbances and "resist and return" or "bounce-back" quickly (Holling, 1996; Hegger et al., 2016a; McClymont et al., 2020). Systems resilience is conceptualised as systems maintaining functionality by absorbing disturbances to "bounce-forward" and retain system functionality, structure and feedbacks for securing long-term stability (Hegger et al., 2016a; McClymont et al., 2020). Finally, evolutionary system resilience includes adaptability and transformability of systems (Folke et al., 2010; Hegger et al., 2016a) that recognises reorganising and transforming through adaptive governance and learning rather than simply withstanding and recovering (McClymont et al., 2020).

These distinctions of resilience can equal capacities for action as (1) the capacity to resist, (2) the capacity to absorb and recover, and (3) the capacity to transform and adapt (Hegger et al., 2016a). There are, however, some inconsistencies with adaptive resilience and whether it refers to coping with, recovering from, and/or adapting to expected and unexpected changes (Morrison et al., 2018), or whether it should focus on institutionalised mechanisms for learning and improving the capability of adopting new approaches by actors, institutions, and the public (Hegger et al., 2016a). There is also little consensus on the roles of flood protection for resilience (Restemeyer et al., 2015; Hegger et al., 2016a;

Morrison et al., 2018; Kuang & Liao, 2020). Some studies recognise the importance of protection in making areas more resilient (Restemeyer et al., 2015) whilst others focus on resilience from social, financial, and natural mechanisms (Laurien et al., 2020) with protection measures seen as detrimental to these (Liao, 2012). Although there are suggestions that resilience is only marginally and supplementarily applied in FRM (Disse et al., 2020), a balanced portfolio of FRM measures that include resilience strategies, alongside all other safety cycle aspects, is necessary to cope with and adapt to flood risks and provide effective FRM (Hegger et al., 2016a; Disse et al., 2020) that is itself constantly in a state of flux given the dynamic nature of flood risk (Bubeck et al., 2017).

Whilst there may be discrepancies in the theory, several global frameworks are encouraging FRM. This includes the DRR focused 2005-2015 United Nations (UN) Hyogo Framework for Action and its 2015-2030 successor agreement, the United Nations Office for Disaster Risk Reduction (UNDRR) Sendai Framework, implemented in 163 countries across Asia and the Pacific, Latin America, the Caribbean, Africa, Arab States, Europe, and the Commonwealth of Independent States. These concentrate on understanding risk and vulnerabilities, strengthening DRR through appropriate mechanisms (legislative, institutional and financial), governance and resilience, and enhancing preparedness and post-disaster strategies and assessments for effective recovery, rehabilitation, and reconstruction that "builds back better" (UNDP, 2015; United Nations, 2015). The frameworks have encouraged integrated FRM across the globe including applications of NBS and Natural Flood Management (NFM) in Africa (Aly et al., 2022). Further, the Paris Agreement on Climate Change and the UN Sustainable Development Goals (SDG) highlight the need to achieve sustainable FRM and resilient cities for the future (United Nations, 2021).

Shifting FRM is also underlain by policy and legislative changes that alter the direction of management attention, effort and investment (Penning-Rowsell et al., 2017). Across Europe, the 2000 EU Water Framework Directive (WFD) and previously mentioned 2007 FD daughter directive are key legislation for Integrated Water Management (IWM) and FRM. The WFD commits to achieve 'good' water quality status for waterbodies, reduce the impact from flood protection, and encourages IWM to 'work with nature, rather than against it' in River Basin Management Plans (RBMPs) (European Commission, 2011; Matczak et al., 2016). The FD, initiated by the Netherlands for national cooperation (Jong & Brink, 2017), acknowledges that flooding is unpreventable and seeks to reduce consequences with improved preparation, coping and adaptation capacities from flood risk assessments, hazard mapping and long-term FRM plans (Matczak et al., 2016; Priest et al., 2016; Morrison et al., 2018).

However both directives only set targets, and FRM strategies and implementation timescales vary in EU member states (Johnson et al., 2007; Priest et al., 2016). For instance, Poland remains reliant on structural protection; Belgium is increasing river space alongside flood protection (Matczak et al., 2016); Germany and Hungary have developed ecosystem-based IWM (Becker, 2009; Huitema & Meijerink, 2010; Werners et al., 2010); Sweden focuses on flood preparation crisis-planning and education (Nohrstedt & Nyberg, 2015); and France is emphasising preventative spatial planning, building regulations and flood recovery insurance (Matczak et al., 2016). Globally, the US emphasises flood-zoning, floodplain management and non-structural measures for prevention and preparedness alongside traditional protection and insurance (Samuels et al., 2006; Galloway, 2008; Bubeck et al., 2017); and Japan and China are increasing ecosystem-based IWM (Johnson et al., 2007; te Boekhorst et al., 2010).

As FRM strategies differ between countries, their effectiveness may also vary (Priest et al., 2016). Frameworks must therefore recognise failings from existing FRM approaches (Priest et al., 2016) and continually review their performance (Poussin et al., 2015) in line with knowledge, technology, and expertise improvements (Tariq et al., 2020). These FRM strategy divergences also reflect how management responses are tailored to location-specific flood risk situations, including constraints, politics, and historical contexts that include cultural processes, backgrounds and historical choices (Sayers et al., 2015a; Wesselink et al., 2015; Matczak et al., 2016; Priest et al., 2016; Wiering et al., 2017). However, investigating FRM in EU Member States is interesting due to the shared implementation of the FD, but the considerable differences between countries in physical conditions, actual flood experience, FRM strategies and governance, and economic, social, administrative, and legal contexts present (Hegger et al., 2016a). European FRM comparison studies are therefore widely apparent (Klijn et al., 2008; Thaler & Hartmann, 2016), as well comparisons with countries outside the EU such as the US (Samuels et al., 2006), New Zealand (van Buuren et al., 2018) and Japan (Chan et al., 2022).

A large proportion of studies that compare FRM in Europe are research outputs from the 2012 to 2016 STAR-FLOOD (STrengthening And Redesigning European FLOOD risk practices towards appropriate and resilient flood risk governance arrangements) project that investigated FRM strategies in 18 regions across 6 countries for improved flood risk resilience in Europe (European Commission, 2016). Under the STAR-FLOOD umbrella, Hegger et al. (2016b) compared FRM in Belgium, France, the Netherlands, Poland, Sweden, and the UK, while Matczak et al., (2016) investigated FRM and governance strategies, dynamics and arrangements in the same countries. Dieperink et al. (2013) identified governance challenges across Europe, and Hegger et al. (2016a) investigated how to enhance the resilience of governance structures. Other STAR-FLOOD research outputs include investigating shifting flood defence strategies (Goytia et al., 2016; Gralepois et al., 2016), varieties of flood risk governance strategies (Wiering et al., 2017), strategies to improve flood resilience (Driessen et al., 2016; Hegger et al., 2016a; Suykens et al., 2016), citizen involvement in FRM (Mees et al., 2016), and the impact of the FD (Priest et al., 2016).

2.4 Developments Towards FRM in England and the Netherlands

England and the Netherlands have previously been described individually and in national comparisons (e.g. Klijn et al., 2008; van Buuren et al., 2015, 2018; Wesselink et al., 2015; Wiering et al., 2015; Bubeck et al., 2017) including STAR-FLOOD outputs (Dieperink et al., 2013; Hegger et al., 2016a; Kaufmann et al., 2016c; Matczak et al., 2016). However, FRM developments and the introduction of resilience concepts have occurred since its conclusion in 2016. The comparisons between both countries often describe similar evolutions of management strategies. This comparable progression also reflects, in part, a shared need to comply with EU water directives (Matczak et al., 2016). Although this now differs for England, several FRM changes between 2007 and 2020 adhere to these frameworks. Other FRM similarities include long-standing governmental roles in flood management (van Buuren et al., 2015), experience of managing large floods including the 1953 North Sea storm surge, and projected increasing flood impact from socio-economic and climatic changes (van Buuren et al., 2018).

In England, the first legislation for flood and land drainage works was introduced in the 13th Century (English Nature, 2006), with developments from 1945 to the FRM strategies currently present illustrated in **Figure 2-3**, including key policies, legislation and strategies, and major flood events. More information for each policy, legislative, and strategy document within this development are provided in Table **2-2** with an indication of the management strategy focus at the time of introduction.

The RMAs and government bodies that implement policies and practices for flood management in England have also developed overtime with changing priorities. Policies in this review were first introduced by the former Ministry of Agriculture and Fisheries (MAF) governmental department, originally the Ministry of Agriculture from its introduction in 1889, that was retitled the Ministry of Agriculture, Fisheries and Food (MAFF) in 1955, before finally becoming the Department of Environment, Food and Rural Affairs (DEFRA) in 1995. DEFRA now guides current FRM policies (Tunstall et al., 2004; Wiering et al., 2015). Internal Drainage Boards (IDBs), still active today in 9.4% of England (ADA, 2017), originated in 1215 but were granted powers from land drainage policies in 1930 alongside Catchment Boards, retitled River Boards in 1948, River Authorities in 1965, and Regional Water Authorities in 1973, until water companies were privatised for wastewater in 1989 and the National Rivers Authority (NRA), created in 1988 to take over responsibility for flood management in England (Scrase & Sheate, 2005). The Environment Agency (EA) assumed responsibility in 1995 (Tunstall et al., 2004; Wiering et al., 2015). The EA still manages fluvial flood risks in England, with Lead Local Flood Authorities (LLFAs) Local Authorities and IDBs managing ordinary (smaller) watercourses and pluvial flood risks. These are supported by Regional Flood and Coastal Committees (RFCCs) of appointed RMA members. However, powers for flood management have always been permissive, with no legal or statutory duties to provide FRM (Wiering et al., 2015). Works are carried out at public expense to reduce wider economic and social factors related to flooding, but there is no general right to be protected from flood risk (EA, 2020d).

13th Century

13th Century: First legislation for flood and drainage works, with maintenance and repairs included from the 15th Century (English Nature, 2005).

17th Century: Contribution from Dutch engineers increased land drainage and river channel modifications and flood protection (Klijn et al., 2008).

1920

1920s: Flood insurance policies from 1922 and total loss cover from 1929 but take up was low from low awareness and few significant floods (Penning-Rowsell et al., 2014; Matczak et al., 2016).

1930: Land Drainage Act

1940

1947: Town Planning Act

March 1947 Floods: Rapid snowmelt and heavy rainfall caused widespread flooding in England that exceeded drainage capacities and inundated ~270,250 ha of agricultural land with estimated damages of ~12 million (in 1947; £473 million in 2019 prices) impacting agricultural production (Johnson et al., 2005; Penning-Rowsell et al., 2006; EA, 2018c).

Post-flood legislation

1947: Policy Circular by MAF, IDBs and Planning Authorities

1948: River Boards Act

January 1953 Storm Surge Floods: Product of a meteorological depression coinciding with anticyclone system and high spring tides caused wave heights that exceeded Meteorological Office estimates by 2.4m (Hall, 2011). Coastal flooding along England's East Coast caused protection failures at 1200 locations and estimated damages of £50 million (in 1953; £1.4 billion in 2019 prices), >24,000 properties inundated, 47,000 livestock lost, 307 fatalities and 32,000 people evacuated (Hall, 2011; Penning-Rowsell; Wadey et al., 2015).

Post-flood actions

1953: Establishment of the Departmental Committee on Coastal Flooding and publication of interim and final reports that instituted the Storm Tide Flood Warning System (Waverley Committee, 1953) and coastal protection standards based on a financial CBA of probability and consequences to the estimated 1953 event flood-return period as a maximum standard of protection (Waverley Committee, 1954; Penning-Rowsell et al., 2006; Hall, 2011). Local Authorities urged to using Town and Planning Act Powers to avoid ill-considered development (Penning-Rowsell et al., 2006; Hall, 2011).

Post-flood legislation

1953: Coastal Flood Emergency Provisions Bill

1960

1972: Thames Barrier and Flood Prevention Act

1960s Fluvial Floods: Fluvial flooding in 1960 and 1968 highlighted the need for fluvial flood warning systems but land drainage policies continued to progress as late as 1977 (Penning-Rowsell, 2015a; Scrase & Sheate, 2005).

1963: Water Resources Act

1980

1973: Water Act

1989: Water Act

1991: Water Resources Act

1993: Strategy for Flood and Coastal Defence in England and Wales by MAFF

1995: Environment Act

April 1998 'Easter Floods': The product of extreme and prolonged rainfall, the Easter Floods caused >£300 million in damages (in 1998; >£530 million in 2019 prices), five fatalities and inundated 4500 properties, 500 businesses and 2000 caravans despite large investments in structural protection in the years prior (Johnson et al., 2005; Penning-Rowsell et al., 2006; EA, 2018b).

Post-flood actions

1998: Independent Bye and Horner (1998) report suggested improvements to flood warnings (that were unsatisfactorily issued), public awareness, emergency response and overall FRM effectiveness rather than increasing flood protection (that was largely sufficient). The National Flood Warning Centre and FloodLine information and warning service were established (Johnson et al., 2005; Nye et al., 2011).

2000

October 2000 Floods: Widespread flooding across England and Wales that inundated 10,000 properties across 700 locations with estimated damages of >£1 billion (in 2000; £1.6 billion in 2019 prices) (EA, 2001; Johnson et al., 2005; EA, 2018c).

2001

Post-flood actions

2001: Institute of Civil Engineers (ICE) Learning to Live with Rivers report advocated for the use of comprehensive FRM options (Fleming, 2002). Yet, investments increased for existing and new flood protection assets, and improvements to flood warnings, awareness campaigns and emergency planning (EA, 2001).

Post-flood legislation

2001: Planning Policy Guidance (PPG25)

2002: Statement of Principles (SoP)

2004: Foresight Future Flood Project (FFFP)

2004: Civil Contingencies Act

2005: Making Space for Water (MSfW) Policy

July 2007 Summer Floods: Widespread flooding in July 2007 from heavy rainfall and high river flows, groundwater and soil levels during the wettest recorded UK summer period. Impacts include 13 associated fatalities, >55,000 inundated properties, thousands of people evacuated, and disruptions to water and power supplies and transport infrastructure (EA, 2007; Marsh & Hannahford, 2007; Pitt, 2008; Chatterton et al., 2010). Estimated damages equal ~£3.2 billion (in 2007; >£4.4 billion in 2019), 76% of which was insured but 24% incurred significant losses (Chatterton et al., 2010). 9% (1,016km) of structural protection in England and Wales was tested, with 4.5% overtopped and a small number failing physically (Pitt, 2008).

Post-flood actions

2007: Independent Pitt (2008) Review made 92 recommendations to improve flood prediction, prevention, emergency management, resilience and recovery for FRM, spatial planning and climate adaption, and encouraged the update of PFR and NFM.

2008: New Outcome Measures (OMs) replaced the previous priority scoring system to direct FRM investments to reduce household and deprived (e.g. smaller rural or dispersed) community flood risk, provide economic and biodiversity benefits, improve flood warnings and contingency planning, avoid inappropriate development and undertake long-term FRM plans (Johnson & Penning-Rowsell, 2010).

2007: Flood Risk Regulations

2008: Climate Change Act

2010

2009: River Basin Management Plans (RBMPs)

2010: Flood and Water Management Act

2010: National Flood Emergency Framework

2011: National Flood and Coastal Erosion Risk Management (FCERM) Strategy

2012: National Planning Policy Framework (NPPF)

Winter 2013/2014 Floods: Winter flooding caused estimated damages of £1.2 million (in 2014; almost £1.3 million in 2019) (Chatterton et al., 2010).

2014: Water Act

2015: RBMPs 2015-2021 and Flood Risk Management Plans (FRMPs) 2015-2021

Winter 2015/2016 Floods: Winter flooding inundated >20,000 properties with ~£1.6 billion in damages (in 2016; >£1.7 billion in 2019) (EA, 2018b).

Post-flood legislation

2016: National Flood Resilience Review to assess at-risk critical infrastructure and promoted increasing country-wide resilience to flood risks and the use of temporary and demountable defences (HM Government, 2016).

2018: 25-Year Plan to Improve the Environment

2020

Winter 2019/2020 Floods: Heavy rainfall in winter resulted in several flood events across England, including floods in November in Northern England, floods in December in Southern England, and floods in February across the Midlands from two storm events (Finlay, 2020). Initial estimates of flood damages from November 2019 were ~£110 million, and from February were ~£214 million (ABI, 2020).

2020: National FCERM Strategy

2021: Adaptation Action Coalition founded

2021: RBMPs 2021-2027 and FRMPs 2021-2027

2022: Management Strategy 1-Year Plan and Roadmap to 2026 by the EA

Figure 2-3: A review of flood management developments in England from 1945 to 2022. Blue full triangles indicate flood events that had an impact on policy and practice.

Table 2-2: Policy, legislative and strategy changes in flood management in England from 1945 to present, including the EU WFD and FD. The Focus of Management Approach column indicates whether the policy, legislation or strategy document have promoted (↑) or demoted (↓) implementation of integrated FRM based on four categories – the use of structural flood protection for agriculture and urban areas (**FP**); IWM and sustainable NBS including SUDs (**E**); preventative measures that include spatial and land-use planning (**SP**); and risk approaches for mitigation, preparation and recovery such as PFR, flood insurance, awareness raising and emergency and contingency planning (**R**). Size of arrow is indicative of impact size, with lines (—) representing no change or no inclusion in document. References are included for documents where available.

Year	Policy, Legislation or Strategy	Important points	Focus of Management Approach				Phase
			FP	E	SP	R	
1930	Land Drainage Act	Powers to IDBs and Catchment Boards to streamline and improve river channel management (referred to as arterial drains) to increase water conveyance (e.g. dredging), land drainage and flood defence works in agricultural areas with (Cubley, 1952; Johnson, 1954; Scrase & Sheate, 2005).	↑	↓	—	—	Priority for agricultural land drainage and structural flood protection
1947	Policy Circular	Policy Circular by MAF, IDBs and Planning Authorities emphasised the need for structural flood defence for agricultural areas and spatial planning procedures to avoid development impacting drainage and reservoir areas (Hopkins, 1991; Parker, 1995; Penning-Rowsell et al., 2006; Stevens et al., 2016).	↑	—	↑	—	
1947	Town and Country Planning Act *Town and Country Planning Act 1947*	Suggested limiting development in at-risk and floodplain areas but priorities for housing pressures reduced the impact of implementation (Tunstall et al., 2004; van Buuren et al., 2015; Matczek et al., 2016).	—	—	↑	—	
1948	River Boards Act	Transferred powers for flood protection and agricultural drainage to newly established River Boards (Cubley, 1952; Scrase & Sheate, 2005; Johnson & Priest, 2008).	—	—	—	—	
1953	Coastal Flood Emergency Provisions Bill	Circumvented existing spatial planning policies for coastal repairs to damages occurring during the 1953 storm surge damages and defences (Hall, 2011)	↑	—	↓	—	
1963	Water Resources Act *Water Resources Act 1963*	River Boards replaced with River Authorities that undertook powers for flood protection, land drainage, prevention of river pollution with additional powers on water quality and water resource conservation (Ineson, 1963).	—	↑	—	—	Urban priority for structural flood protection
1972	Thames Barrier and Flood Protection Act	Construction of the Thames barrier, previously initiated by the 1978 Thames Flood Act, that applied a standard of protection of a 1 in 1000-year event (1 in 100-year standard elsewhere in the country) (Penning-Rowsell et al., 2006).	↑	—	—	—	
1973	Water Act *Water Act 1973*	River Authorities replaced with larger Regional Water Authorities for water conservation, water supply, sewage works and treatment, pollution prevention, land drainage and flood protection (Ofwat & DEFRA, 2015).	—	—	—	—	

1989	Water Act *Water Act 1989*	Re-divided functions of water management with privatisation of water companies for sewage and wastewater duties and the NRA for management of rivers, land drainage and pollution (Ofwat & DEFRA, 2015).	–	–	–	–	
1991	Water Resources Act *Water Resources Act 1991*	Granted powers for constructing and maintaining flood protection, flood forecasting and flood warnings (Scrase & Sheate, 2005).	⇧	–	–	↑	
1993	Strategy for Flood and Coastal Defence in England and Wales (MAFF/WO, 1993)	Strategy by MAFF focused on flood protection measures but encouraged technically and environmentally sustainable measures to reduce flood *risks* to people, the natural and developed environment (using a CBA), predominately in urban areas, for the first time (DEFRA, 2004; Scrase & Sheate, 2005; Ash, 2008).	⇧	↑	–	–	
1995	Environment Act *Environment Act 1995*	EA assumed responsibility and powers for flood risk reduction and other environmental management with the merger of the NRA and pollution management bodies (Tunstall et al., 2004; Wiering et al., 2015).	–	–	–	–	
2000	European Union Water Framework Directive 2000/60/EC (EU, 2000)	Improving water management for water protection, maintaining aquatic environments/ecosystems and a good status of water quality, based on a river basin scale. Required for all member states (EU, 2000).	–	↑	–	–	
2001	Planning Policy Guidance 25 (PPG25): Development and Flood Risk	Introduced a 'sequential test' and 'exception rest' to limit and avoid non-essential development in flood zones, with suggestions to avoid and reduce unsustainable structural defence (Penning-Rowsell et al., 2006).	↓	–	⇧	–	
2002	Association of British Insurers (ABI) Statement of Principles (SoP)	An insurance industry agreement, that replaced an informal 'Gentleman's Agreement', to ensure household flood insurance by ABI in medium at-risk areas where flood protection was planned or present (Penning-Rowsell, 2015b; Surminski & Eldridge, 2017).	↑	–	–	↑	
2005	Making Space for Water (MSfW) (DEFRA, 2005)	First policy to promote sustainable, catchment-wide, participatory FRM measures (e.g. land use planning, resilience building and nature conservation) and holistic flood risk reduction across whole catchments for all risk (local and national risks, urban and rural areas, and all flood types) (DEFRA, 2004; 2005; Johnson & Priest, 2008; Nye et al., 2011). Managed realignment of defence lines to improve sustainability and environmental benefits was included but not acted on and assets were maintained (DEFRA, 2005). Evidence base includes the UK FFFP.	↓	↑	↑	↑	**Diversified and intergrated FRM**
2004	Civil Contingencies Act *Civil Contingences Act 2004*	Enhanced community resilience procures and building with improved flood forums and emergency contingency planning (coordination, preparation, response and recovery) between RMAs to reduce flood risk impacts (Wiering et al., 2015).	–	–	↑	↑	
2006	Planning Policy Statement 25 (PPS25): Development and Flood Risk Revised in 2010 (Department for Communities and Local Government, 2010)	Replaced the 2001 PPG25 and continued to improve and strengthen spatial planning procedures and practices (van Buuren et al., 2015).	–	–	↑	↑	

2007	European Union Floods Directive 2007/60/EC – shared directive (EU, 2007)	Requires member states to implement preliminary FRAs, flood hazard and risk mapping and FRM plans but no specific targets (EU, 2007).	–	↑	↑	↑	
2008	Climate Change Act *Climate Change Act 2008*	Assesses climate change risk every 5 years with national adaptation programme and incorporated Pitt (2008) recommendations.	–	–	–	↑	
2009	Flood Risk Regulations *The Flood Risk Regulations 2009*	Formally transposed the 2007 EU Floods Directive (and used of FRA, flood risk maps and FRM plans into English law (Priest et al., 2016).	–	–	–	↑	
2009	River Basin Management Plans (RBMPs) Revised in 2015 and 2022 (DEFRA/EA, 2015)	Plans to improve and protect water environments based on WFD requirements. Revised every 6-years and intregrated into the FRMPs with the 2015 update (DEFRA & EA, 2015.	–	↑	–	–	
2010	Flood and Water Management Act *Flood and Water Management Act 2010*	The Act improved flood event investigations and reporting with newly introduced LLFAs and established RFCCs (DEFRA & EA, 2011), and was the formal Act of the implementation of the 2011 National FCERM strategy necessary by the FD.	–	⬆	↑	↑	
2010	National Flood Emergency Framework Revised in 2014 (DEFRA, 2014b)	Framework that incorporated Pitt (2008) recommendations to improve flood emergency understanding, planning, preparation, and recovery.	–	–	–	↑	
2011	National Flood and Coastal Erosion Risk Management (FCERM) Strategy for England (DEFRA/EA, 2011)	National FCERM Strategy that incorporated regularly updated Oms and Pitt (2008) recommendations to improve management authority coordination (with new LLFAs), flood risk understanding, preparedness (e.g. forecasting, warning, and awareness), recovery, present and future management infrastructure (e.g. protection and other systems like SUDs), spatial planning and risk reduction planning procedures while achieving wider environment benefits (DEFRA & EA, 2011).	↑	↑	↑	⬆	
2012	National Planning Policy Framework (NPPF) Revised in 2018 and 2019 (Ministry of Housing, Communities and Local Government, 2014)	Government planning policies for achieving sustainable development with future considerations of climate change, flooding, and coastal change challenges. The Framework includes the sequential and exception tests, suggests the use of SUDs for development and highlights the need to stop flood risks being moved or increasing elsewhere (DEFRA, 2012). Revised in 2018 and 2019.	–	–	↑	–	
2014	Water Act *Water Act 2014*	Introduced a Flood ReInsurance (FloodRE) scheme to ensure affordable flood insurance for high-risk areas, replacing the insurance industry SoP agreement (DEFRA, 2014a; Surminski & Eldridge, 2017; Flood Re, 2018).	–	–	–	↑	
2015	RBMPs and Flood Risk Management plans (FRMPs): 2015 to 2021 (EA, 2015b)	FRM plans realising the 2011 FCERM Strategy and objectives by addressing catchment flood risks for 7 river basin districts in England and 3 crossing boundaries with Wales and Scotland, in line with FD requirements. Plans include flood types and characteristics, existing FRM, and roles, responsibilities, objectives and measures for future FRM (EA, 2016).	–	–	–	↑	

2018	A Green Future: 25 Year Plan to Improve the Environment (HM Government, 2018)	A 25-year environment plan for climate adaptation and environment improvements that emphasises the need for resilience from sustainable NBS and NFM, SUDs and PFR to reduce national flood risks (HM Government, 2018).	—	⬆	—	↑	
2020	National Flood and Coastal Erosion Risk Management (FCERM) Strategy for England (EA, 2020b)	Updated FCERM strategy to increase country-wide flood resilience and incorporate more measures to avoid, prevent, protect, respond, and recover from flooding (EA, 2019c). This includes creating local and national resilient places supported by a £200 million Flood and Coastal Resilience Innovation Programme (FCRIP), upgrading flood protection assets with a £5.2 billion defence programme to protect 336,000 properties by 2027, increasing the use of NBS, NFM and IWM with SUDs and more emphasis on flood risk responsibilities and understanding for preparedness and response (EA, 2020c). A Frequently Flooded Allowance (FFA) was subsequently announced to improve the eligibility of smaller, dispersed communities receiving FCERM funding for FRM and resilient measures (DEFRA, 2022).	↑	↑	↑	⬆	
2021	RBMPs and FRMPs: 2021 to 2027 (EA, 2022c)	Draft FRMPs focus on strategic flood risk planning and work to achieve the goals of the 2020 FCERM strategy and 25 Year Environmental Plan with highlighted roles and responsibilities of RMAs. Flood risks assessments for rivers and seas and local sources should be provided for River Basin Districts	—	—	—	↑	
2021/ 2022	EA Management Strategy 1-Year Plan and Roadmap to 2026	Plans to realise the three main FCERM Strategy objectives (climate resilient places, increased and resilient infrastructure, and improved public response and adaption to flood risks) that align with other publications such as the 25-Year Environment Plan and FRMPs (EA, 2022).	↑	↑	↑	↑	

In the Netherlands, historic, regular flooding prompted settlement on artificially raised land ('terps') in some parts of the country (Wesselink et al., 2007; van den Brink et al., 2011). Land subsidence from continuous drainage led to community-action to enclose settlements in early 'polders' (Hoeksema, 2006; Wesselink et al., 2007; van den Brink et al., 2011). This collective action evolved into institutionalising water management in the 12th Century (Olsthoorn & Tol, 2001), with FRM developments from 1945 to the present illustrated in **Figure 2-4**. This includes key policies, legislation and strategies, and major flood events. More information for each policy, legislative, or strategy in this development is provided in **Table 2-3** with an indication of the management focus of each strategy.

The RMAs and government bodies that implement flood management in The Netherlands include central government (*Rijksoverheid*) and Rijkswaterstaat, the operational government department (established as the *Bureau voor den Waterstaat* in 1798) for management of primary defences. The Ministry of Water Management (*Ministerie van Waterstaat*) was founded in 1809 and became the Ministry of Transport, Public Works and Water Management (*Ministerie van Verkeer en Waterstaat*; V&W) in 1908. V&W merged with the Ministry of Housing, Spatial Planning and the Environment (*Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieu*; VROM) to form the Ministry of Infrastructure and Environment (*Ministerie van Infrastructuur en Milieu*; IenM) in 2010, retitled the Ministry of Infrastructure and Water Management (*Ministerie van Infrastructuur en Waterstaat*; I&W) in 2017. These bodies alongside the 23 Water Boards (WBs; *Waterschappen*), initiated in the 12th Century, that conduct water management duties and maintenance, and the provinces that implement national water management frameworks (Olsthoorn & Tol, 2001). Flood safety is a legal and statutory duty in The Netherlands, with costs directly funded by €6.5 billion annual taxes (Wiering et al., 2015).

12th Century

12th Century: Water management institutionalised with dikes and drainage enabling land reclamation (Olsthoorn & Tol, 2001; Cultural Heritage Agency, 2014).

15th – 16th Century: All major river dikes connected into uninterrupted systems to maximum water levels (Vis et al., 2003; Gerritsen, 2005; Cultural Heritage Agency, 2014) that were breached or overtopped by major flood events, including the 1421 flood and 1570 flood (Tol & Langen, 2000; van Stokkom & Smits, 2002; Wesselink et al., 2015).

1900

1908: River Act originated in 1806 (*Rivierenwet*)

1940

1939: Rijkwaterstaat and Flood Tide Committee reports

January 1953 Storm Surge Floods: High spring tides, high wind velocities and an 18-hour storm duration breached 800km of dikes at 900 locations. Coastal flood warnings were issues by the Royal Netherlands Meteorological Institute's (*Koninklijk Nederlands Meterologisch Instituut*; KNMI) Storm Tide Warning Services (*Stormvloedwaarschuwings*; SVDS) but these were inefficient. The impacts greatly exceeded those in England and inundated 136,500 ha of land, destroyed 3000 properties, damaged a further 43,000, and caused the loss of tens of thousands of livestock, over 1800 fatalities and required 100,000 people to be evacuated (Gerrisen, 2005; Hoeksema, 2006; Wesselink et al., 2007).

Post-flood actions

The newly-established Delta Committee initiated the 'Delta Plan' for increased protection with its legal framework provided by the 1958 Delta Act (Gerritsen, 2005; Jorissen et al., 2016), and recommended improved SVDS and disaster planning (Gerritsen, 2005). Rijkwaterstaat assumed responsibility for primary dike control and newly-merged WBs assumed responsibility for dike safety maintenance (Gerritsen, 2005).

Post-flood legislation

1953: Flood Damage Act (*Wet op de Watersnoodschade*)
1958: Delta Act (*Deltawet*)
1971: Delta Damage Compensation Act (*Deltaschadewet*)
1985: Disaster Act (*Rampenwet*)

1960

1980

1985: Dealing with Water (*Omgaan met Water*) Report

1986: National River Management Competition winning entry – Plan Stork (*Plan Ooievaar*)

1989: Water Management Act (*Wet op de waterhuishounding*)

1989: Third National Water Management Memorandum (*Derde Nota Waterhuishouding*)

1991: Water Boards Act (*Waterschapswet*)

1993: Dutch World Wildlife Fund Living Rivers (*Levende Rivieren*) Plan

1993: Environmental Management Act (*Wet milieubeheer*)

December 1993 Floods: High flows in the River Meuse inundated ~17,000 ha outside of dike rings with estimated damages of >€100 million (2019 prices; 253 million Dutch Guilders in 1995) and 8000 people were evacuated (Wind et al., 1999; Jak & Kok, 2000; Slomp, 2012).

Post-flood actions

Dikes were subsequently strengthened and improvement studies for reducing floods from the River Meuse were established (Wesselink et al., 2013).

Post-flood legislation

1995: Flood Defence Act (*Wet op de Waterkering*)

January 1995 Floods: A second, longer duration flood occurred along the River Meuse with lower peak discharges and damages, but dike stability concerns along the Nederrijn-Lek and Waal River Rhine branches resulted in 250,000 people evacuated in anticipation of flooding. This increased estimated financtial damages from €74 million to €400 million (2019 prices; 165 million Dutch Guilders in 1995) (Wind et al, 1999; Jak & Kok, 2000; Slomp, 2012).

Post-flood actions

Structural protection was strengthened but concerns around solely applying dike protection led to a new 'Room for the River (RftR; *Ruimite voor de Rivier*) strategy (Rijke et al., 2012; Kaufmann et al., 2016a). The 2005 Works in the River Meuse (*Maaswerken*) Programme, similar to RftR, also improved river capacity and constructed dikes (Slomp, 2012; Wesselink et al., 2013).

Post-flood legislation

1995: Flood Defence Act (*Wet op de Waterkering*)
1995: Delta Plan Large Rivers (*Deltawet Grote Rivieren*)
1996: Policy Room for the River (*Beleidslijn rumite voor de rivier*)
1997: Disaster Act (*Rampenwet*)
1998: Calamities Damage Compensation Act (*Wet tegemoetkoming schade bij rampen*)
1998: Fourth National Memorandum on Water Management (*Vierde nota Waterhuishounding*)

1998

1998 Floods: Intense precipitation and flooding in September and October 1998 in the North and West of the Netherlands inundated agricultural assets and properties with >€40 million in estimated flood damages (2019 prices; 90 million guilders in 1998) (Jak & Kok, 2000).

Post-flood actions

Newly-established Water Management for the 21st Century (Water beleid voor de 21e eeuw) committee.

Post-flood legislation

2000

2000: 21st Century Water Management: Dealing Differently with Water (Water beleid voor de 21e eeuw: Ander omgaan met water) Policy

2001: Flood Protection Programme (FPP)

2001 & 2002 Near-flooding: Near flooding along the River Meuse in 2001 and 2002 (van der Brugge et al., 2005).

Post-flood actions

Flood protection tested every 6 years in the Flood Protection Programme (FPP) that found 15% of dikes below safety standards in 2011 and 24% below standards in 2006 (Deltacommissie, 2008; PBL Netherlands Environmental Assessment Agency, 2014; Kaufmann et al., 2016c).

2003 Regional Flooding: A regional dike failure under drought conditions caused localised flooding in Wilnis (western province) (van der Brugge et al., 2005).

Post-flood actions

2006: Security in the Netherlands (*Veiligheid Nederland in Kaart*; VNK) Study
2008: Working with Water - Second Delta Committee Report

2003: Amendement Decree Decree on Spatial Planning 1985 (Water Assessment) (*Wijzigingsbesluit Besluit op de ruimtelijke ordening 1985; watertoets*)

2006: Policy Rules for Major Rivers (*Beleidslijn Grote Riveren*)

2008: Spatial Planning Act (Wet Ruimtelijke Ordening)

2009: Policy Document on Water Safety (Beleidsnota Waterveiligheid)

2009: Water Act (*Waterwet*)

2009: National Water Plan 2009-2015 (*Nationaal Waterplan*; NWP)

2009: River Basin Management Plans (RBMPs)

2009: Water Decree

2010

2010: National Water Test Planning Procedures

2012: Delta Act on Water Safety and Freshwater Supply (*Deltawet waterveilingheid en zoetwatervoorziening*)

2012 Flood Threat: Concerns of potential coastal flooding and dike failure from prolonged high water levels that resulted in 800 people being evacuated from Groningen (northern province) (Cultural Heritage Agency, 2014).

Post-flood actions

A second Security in the Netherlands (VNK) study in 2012 that estimated dike-ring flood risks and potential failures foe the Delta Programme (Rijkswatersaat VNK Project Office, 2012).

2014: Delta Programme (yearly from 2012) but included the Delta Decisions in 2014

2016: National Water Plan 2016-2021

2017: Water Act (*Waterwet*)

2020

2021: Environment and Planning Act (*Omgevingswet*)

2021: Adaptation Action Coalition founded for climate-resilience by 2030

2021 July Floods: Flooding in Europe in 2021 that affected Germany and Belgium, as well as countries such as the southern province of Limburg in the Netherlands, resulted in 242 fatalities and significant damages and insured losses to properties and critical infrastructure of >$11.8 billion across EU (Kreienkamp et al., 2021; The Insurer, 2021). River levels in the Meuse and many tributaries reaches the highest recorded levels, with the event probability calculated at 1/200-year in the Meuse and between 1/100 and 1/1000-years for its tributaries (Task Force Fact Finding Hoogwater 2021, 2021). Two local dikes breached that inundated >2,500 properties with estimated damages of €350- €600 million but no primary dikes breached, and no fatalities occurred in the Netherlands (Task Force Fact Finding Hoogwater 2021, 2021). Approximately 50,000 people were evacuated, but evacuation messages and response were successful with few residents rescued by emergency services (Task Force Fact Finding Hoogwater 2021, 2021).

2022: National Water Plan 2022-2027

Figure 2-4: A review of flood management developments in the Netherlands from 1945 to 2022. Blue full triangles indicate flood events, with blue outline triangles indicating threats of flood events that had an impact on policy and practice.

Table 2-2: Policy and legislative changes in the Netherlands for evolving FRM from 1945 to present, including EU Directives. Focus of Management Approach refers to how the policies/legislation have either promoted (up arrow) or demoted (down arrow) implementation of integrated FRM based on four categories – the use of structural flood protection for agriculture and urban areas (**FP**); IWM and nature-based sustainable measures including SUDs (**E**); preventative measures that include spatial and land-use planning (**SP**); and risk approaches for mitigation, preparation and recovery such as PFR, flood insurance, awareness raising and emergency and contingency planning (**R**). Size of arrow is indicative of size of impact, with circles representing no change or no inclusion of strategy in policy/legislation. References are included where available.

Year	Policy/Legislation	Important Points	Focus of Management Approach				Phase
			FP	E	SP	R	
1908	River Act (revised from 1808) *Rivierenwet 1908*	Clarified legal roles and state powers of V&W, Rijkswaterstaat and the WBs to provide drainage and defence works for flood safety, and public funding for large scale flood defence and drainage works (van Stokkom & Smits, 2002; Nienhuis, 2008; Van Doorn-Hoekveld, 2014).	↑	↓	−	−	**Traditional structural flood protection for urban and agricultural areas**
1953	Flood Damage Act *Wet op de Watersnoodschade 1953*	Provided government compensation for 1953 storm surge flood damages (Gerritsen, 2005; Jorissen et al., 2016).	−	−	−	−	
1958	Delta Act *Deltawet 1958*	Legal framework for the 'Delta Plan', implemented by the newly-established Delta Committee using 1939 Rijkwaterstaat and Flood Tide Committee reports, to protect against flood risks with protection standards that balance CBA hazard probabilities and socio-economic consequences (Gerritsen, 2005; Jorissen et al., 2016). The west coast was protected to a 1/100,000-year flood standard, south-west and north coasts were protected to 1/4000-year standard and river areas with lower socio-economic consequences and longer evacuation times were protected to 1/2000 or 1/1200-yeard standards (Klijn et al., 2008; Wiering & Winnubst, 2017). The Delta Act also initiated the Delta Works storm surge barriers to close vulnerable estuaries (European Commission, 2018).	↑	−	−	−	
1971	Delta Damage Compensation Act *Deltaschadewet 1971*	Government compensation for damages occurring from closing estuaries with the Delta Works	−	−	−	−	
1985	Disaster Act (*Rampenwet)* Revised in 1997 *Wijzigingswet Rampenwet 1997*	Improved disaster planning recommended by the Delta Committee (Gerritsen, 2005). The Act requires contingency plans by provinces that specify hazards, emergency management and organisational structure from responsible RMAs or agencies (emergency services) (Olsthoorn & Tol, 2001).	−	−	−	↑	
1989	Water Management Act *Wet op de waterhuishouding (WWH) 1987*	Management structure changes for flood safety and dike defence responsibilities, and spatial planning procedures by outlining the legal basis for the water management planning system (Olsthoorn & Tol, 2001).	↑	−	↑	−	
1989	Third National Memorandum on Water Management *Derde nota Waterhuishounding* (Rijkswaterstaat, 1989)	Integrated IWM and spatial planning by connecting water management with environmental, nature and spatial planning policies, emphasising sustainable development, while continuing dike improvement (Rijkswaterstaat, 1989; van der Brugge et al., 2005)	↑	⬆	↑	−	

1991	Water Boards Act *Waterschapswet 1991*	Organised Provinces roles over Water Boards, Water Board central role in regional and local water management and their arrangements (abolishing, establishing, and regulating) as they continued to be merged	–	–	–	–	
1993	Environment Management Act Revised in 2005, 2007 and 2011 *Wet milieubeheer 2011*	Legal framework to protect the environment with plans and programs, and sets standards for desired environmental quality and identified impacting factors (e.g. physical measures). 2011 Revision improved alignment with WFD	–	↑	–	–	
1995	Flood Defences Act *Wet op de Waterkering 1995*	Legally formalised the higher standards of flood protection for dike rings based on exceedance probabilities (1/100,000; 1/4000; 1/2000; 1/1200-years) implemented after the 1953 storm surge	⇧	–	–	–	
1995	Delta Plan Large Rivers *Deltawet Grote Rivieren 1995*	Improved fluvial flood defence dikes and suspended environmental procedures (EIAs) to reinforce 1000km existing and 150km new sikes along the River Meuse (Slomp, 2012; Wesselink et al., 2013; Kaufmann, 2018).	↑	↓	↑	–	
1996	Policy Room for the River *Beleidslijn rumite voor de rivier 1996*	Formalised the Room for the River (RftR) policy and strategy to improve riverine flood safety and spatial quality by increasing river space to prevent future events (Rijke et al., 2012; Wesselink et al., 2015; Kaufmann, 2018). Measures included relocating dikes inland, constructing bypass channels, removing obstacles, and lowering floodplain surfaces but strengthening dikes remained important (Busscher et al., 2019). Calamity polders that designated potential area for controlled flooding (Rijke et al., 2012).	–	⇧	↑	–	IWM
1997	Disaster Act (Rampenwet) *Wijzigingswet Rampenwet 1997*	Revised Disaster Act					
1998	Calamities Damage Compensation Act *Wet tegemoetkoming schade bij rampen 1998*	Up to 60% of flood damages compensated for the 1993 and 1995 flood events and for future natural disasters events (Van Doorn-Hoekveld, 2014).	–	–	–	–	
1998	Fourth National Memorandum on Water Management (*Vierde nota Waterhuishounding)* (Rijkswaterstaat, 1998)	Supported the Room for the River policy by stating a preference for sustainable engineering methods instead of continually dike raising (Rijkswaterstaat, 1998; Kaufmann et al., 2016a).	–	↑	–	–	
2000	Dealing Differently with Water: Water Management for the 21st Century *Anders omgaan met water: Waterbeleid voor de 21e euw* (Ministerie V&W (CW21), 2000)	Policy by the newly-established Water Management for the 21st Century Committee that advised on reducing possible future water impacts and challenges with a necessary mix of spatial and technical measures (Ministeries V&W (CW21), 2000; WB21, 2000). The Policy included a three-step controlled water drainage (*drietrapsstrategie*) approach to retain, store and drain water with increasing public flood risk awareness and emergency planning communication for the first time (Ministeries V&W (CW21), 2000).	↑	↑	↑	↑	
2000	European Union Water Framework Directive 2000/60/EC – shared directive (EU, 2000)	Improving water management for water protection, maintaining aquatic environments/ecosystems and a good status of water quality, based on a river basin scale. Required for all member states (EU, 2000).	–	↑	–	–	

2003	Amendment Decree Decree on Spatial Planning 1985 (Water Assessment) *Wijzigingsbesluit Besluit op de ruimtelijke ordening 1985 (watertoets), 2003*	Amended to the Spatial Planning Decree to implemented the Water Assessment *(Watertoets)* spatial planning procedure, that aims to avoid development reducing available river space, in law for all regional, master and zoning plans	–	–	↑	↑	
2006	Policy rules Major Rivers (*Beleidslijn Grote Riveren)* (Ministerie V&W and Ministerie VROM, 2006)	Improved spatial zoning and planning regulations to reduce and avoid development that hinders the possibility of river widening schemes (Ward et al., 2013a).	↑	↑	↑	–	
2007	European Union Floods Directive 2007/60/EC – shared directive (EU, 2007)	Requires member states to implement preliminary FRAs, flood hazard and risk mapping and FRM plans but no specific targets (EU, 2007).	↓	↑	↑	↑	**FRM**
2008	Spatial Planning Act *Wet ruimtelijke ordening 2008*	New Spatial Planning Act implemented through five laws including Spatial Planning Act, Spatial Planning Decree and Implementation Act Spatial Planning Act. Provides the legal basis for the 2009 National Water Plan (NWP).	–	–	↑	–	
2009	Policy Document on Water Safety (*Beleidsnota Waterveiligheid)* (Rijksoverheid, 2009)	Policy Note to improve other 'safety chain' aspects and sets out the policy strategy for the 2009 National Water Plan. This formally introduces the flood risk approach that focuses on environment sustainability and water safety and covers all aspects of the safety cycle such as PFR for vulnerable and vital infrastructure, flood awareness, warning systems, and contingency planning and co-ordination (Rijksoverheid, 2009). Also introduces the Multi-Layered Safety (MLS; *Meerlaagsveiligheid*) strategy that integrates three-layers: (1) dike protection; (2) flood prevention spatial planning; and (3) disaster and emergency planning (Kaufmann et al., 2016b; Jong and Brink, 2017).	↑	–	↑	⬆	
2009	Water Act *(Water Wet)* (Ministerie V&W, 2010)	The integrated Water Act combines eight existing Acts, including the Water Management Act, Groundwater Act and Flood Defence Act (Ministry of Transport Public Works and Water Management, 2009). Introduced the second Delta Programme and Delta Fund, updated flood protection legal standards, changed flood defence monitoring cycle from 6 to 12 years. The Act also provides the legal basis for the 2009 NWP, and formally transposed the WFD and FD into Dutch law (Priest et al., 2016).	↑	–	–	↑	
2009	National Water Plan (*Nationaal* Waterplan) 2009-2015 (Ministerie V&W, 2009)	The NWP for 2009-2015 replaced the 1998 Fourth National Memorandum Policy and includes an initial elaboration of the Delta Programme (to protect against future flooding and secure sufficient supplies of freshwater) and implemented the MLS strategy alongside existing measures (e.g. the Water Assessment) (Minsteries V&W, 2009; Van Alphen, 2016). Flood protection remains the cornerstone of flood safety policy, with the inclusion of Delta Dikes, recommended by the 2008 Working with Water report that have such a high construction strength a sudden flood is ruled out (Deltacommissie, 2008), and continuing dike strengthening (e.g. FFP) (Ministeries V&W, 2009). Also includes FRMPs for Dutch sections of the Then, Meuse, Schelde and Ems river basins (Ministerie V&W, 2009).	↑	↑	↑	↑	
2009	River Basin Management Plans (RBMPs) Revised in 2016 and 2022 (Rijksoverheid, 2016)	River Basin Management Plans for the four river basin districts: Rhine, Scheldt, Meuse, and Ems. Plans define ecological potential and mitigation methods for heavily modified waterbodies	–	↑	–	–	

2009	Water Decree *Waterbesluit 2009*	Institutionalised the Water Assessment, and formally transposed the WFD and FD into Dutch law alongside the 2009 Water Act (Priest et al., 2016).	—	—	↑	—	
2012	Delta Act on Water Safety and Freshwater Supply *Deltawet waterveilingheid en zoetwatervoorziening 2011*	The legal basis of the yearly Delta Programme and annual €1 billion Delta Fund for flood safety, with plans to protect the country from high water and changes to the FPP cycle from 6 years to 12 years (Priest et al., 2016; Van Alphen, 2016).	↑	—	↑	—	
2016	National Water Plan 2016-2021 (Ministerie I&W and Ministerie EZ, 2015)	The updated 2016-2021 NWP implements the revised Water Act and Delta Decisions (included in the Water Act), and includes strategies that include dike improvements and river widening schemes where possible, particularly in the Meuse, and improvements to campaigns to increase public flood awareness (e.g. OW Water), information sharing (e.g. 'Am I being flooded?', *Overstroom Ik?* And National Information System Water and Floods, *Landelijk Informatresysteem Water en Overstroming*) and emergency and contingency planning (e.g. Water and Evacuation Project) (Ministerie I&W & Ministerie EZ, 2015; Delta Programme 2021). The NWP also includes updated FRMPs for four river basins.	↑	↑	↑	↑	
2017	Water Act *Waterwet 2017*	The legal basis for the updated 2016-2021 NWP and included the five 2014 Delta Programme Delta Decisions for FRM, spatial adaptation, freshwater supply, and overall strategies for Lake IJssel and the Rhine-Meuse estuaries. The FRM Delta Decision focused on six new flood protection standards between 1/300 and 1/100,000-years across new dike stretches with increased protection in areas of higher socio-economic impacts, and an individual minimum mortality probability of 1/100,000-years for every individual (0.001%) for every individual. The spatial adaptation decision proposed climate and water-proof regulations and procedures for new and existing developments (Dutch Ministry of Infrastructure and the Environment & Ministry of Economic Affairs, 2014; Van Alphen, 2016).	↑	—	↑	↑	
2022	National Water Plan 2022 – 2027 (Government of the Netherlands, 2021a, 2021b)	The updated 2022-2027 NWP highlights a greater recognition of accepting residual risk with the controlled water drainage strategy (Government of the Netherlands, 2021b). Water-resiience strategies have been grouped under climate-proof and adaptation measures for future water risks (floods and droughts) that applies the flood-risk approach, MLS, and flood protection through the FPP to create a climate proof and water robust spatial design across the Netherlands (Government of the Netherlands, 2021b). The NWP also updates the FRM plans for the Rhine, Meuse, Ems and Scheldt, an extension of the NWP, that includes preparation and recovery strategies for FRM and crisis DRR (Government of the Netherlands, 2021a).	↑	—	↑	↑	

2.5 Flood Risk Perceptions

With the shift to FRM, the importance of flood risk perceptions and behaviours (IPCC, 2014a) have been increasingly recognised. From a behavioural or sociology perspective, risk can be considered a product of decisions undertaken towards a hazard (Birkmann, 2013). The way risk is perceived is fundamental to how individuals and collectives respond to, behave towards, and undertake preparedness for hazards (O'Neill et al., 2016). Increased perceptions motivate individuals to prepare for risks whereas low or false risk perceptions can reduce motivation to act or lead to the hazard being ignored altogether (Cardona et al., 2012; Wachinger et al., 2013). Risk related decisions undertaken can therefore alter vulnerability levels, and potentially increase losses or harm during events (Birkmann, 2013).

O'Neill et al. (2016) describes an individual's conceptual understanding of risk as the highest controlling factor of risk perceptions, that can subsequently be defined by: awareness, worry, and preparedness (Raaijmakers et al., 2008). Lechowska (2018), Bubeck et al. (2012) and Kellens et al. (2013) provide good reviews of these determining, and constantly evolving, factors identified from empirical research. These include independent risk characteristics and social contexts, individual dependent factors such as socio-economic demographics, cognitive, emotional, and personal responses driven by feelings of dread and worry (Botzen et al., 2009a; Bradford et al., 2012; Wachinger et al., 2013; O'Neill et al., 2016), and any cultural-historical, religious, and political contexts of the hazard (Lechowska, 2018). Wachinger et al. (2013) also suggest that cognitive factors are moderated by external information processes, including communication by media, peer, governmental and authority sources (Cottle, 2014; Feldman et al., 2016; Cologna et al., 2017; Mehring et al., 2018), social networks (Haer et al., 2016). The impact of trust in managing RMAs (Terpstra, 2011), as well as varying stakeholder groups ranging from government authorities to flood volunteers (Seebauer & Babcicky, 2018), and perceived responsibility and ownership of risks (Bradford et al., 2012) are also considered in the literature.

Direct experience and proximity to hazards can also alter risk perceptions and capacities to prepare and respond (Siegrist & Gutscher, 2008; Ten Brinke et al., 2008; Aldunce et al., 2015; Shao et al., 2017). Kienzler et al. (2015) found that installation of private precaution measure increased by 93% among residents that had experienced flooding reflecting their greater flood awareness. This fits the 'Learning from Floods' model where direct flood experience equals 'lessons learnt' and individual and collective learning and knowledge (Kuang & Liao, 2020). This can, however, vary with areas that are frequently flooded also having low perceptions of responsibility and lack of personal action (Fuchs et al., 2017). While direct experience increases flood risk perceptions immediately after an event, this reduces over time with flood memory (Lamond & Proverbs, 2009; Bubeck et al., 2012a). Sustainable flood memory and local knowledge and can be crucial to supporting preparatory and resilience-building actions (McEwen et al., 2017). However, studies suggest that awareness in response to flood events diminishes after 4 to 6 years and may completely decrease to minimal levels within 7 years (ICPR, 2002; Haer et al., 2017).

Several studies have investigated this impact of risk perceptions on risk-reducing behaviour by increasing preparedness, reducing vulnerability and improving effective flood risk responses (e.g. Birkholz et al., 2014; Cologna et al., 2017). A number of studies have also investigated the connection of risk perceptions and willingness to prepare and act for risk reduction (Grothmann & Reusswig, 2006; Siegrist & Gutscher, 2008; Bichard & Kazmierczak, 2012; Becker et al., 2014; Osberghaus, 2015; Rözer et al., 2016; Babcicky & Seebauer, 2017;

Fuchs et al., 2017; Lo & Chan, 2017), and to adapt to climate change for improved resilience (Mullins & Soetanto, 2011; de Koning et al., 2019; van Valkengoed & Steg, 2019). Although this connection is sometimes unclear and complicated by other factors (Wachinger et al., 2013), a number of these studies focus on driving factors for risk reduction behaviour such as Protection Motivation Theory (PMT). PMT consists of underlying threat-appraisal and coping-appraisal by individuals for motivation behaviours (Weyrich et al., 2020), but lacks consideration of individual's heterogeneity and influencing vulnerabilities (Weyrich et al., 2020). Further, similar to frequent flooding not necessarily equating to direct action and responsibility (Fuchs et al., 2017), lacking systematic efforts to develop adaptive risk response and incentives to act can reduce individual motivation behaviours even if risk perceptions are high (Ahadzie et al., 2016).

In a political and institutional context, risk perceptions and their implications are important to consider when designing and delivering effective FRM strategies (Cologna et al., 2017) (Buchecker et al., 2013; Birkholz et al., 2014) and risk assessments (Aerts et al., 2018). This particularly includes non-structural strategies that require individual involvement such as improving awareness, communication and/or understanding between decision-makers and the public (Klijn et al., 2008; Sayers et al., 2015a). Further, risk perceptions are also important for strategies focusing on public behaviour changes, sometimes referred to as the FRM *'behavioural turn'* (Kuhlicke et al., 2020) or *'transformative'* approaches (IPCC, 2014a), that address the ability and motivation of individuals to undertake adaptive, preventative and mitigation actions or measures, or improve local knowledge-sharing, education and social networks (IPCC, 2014a; Kuhlicke et al., 2020). These behavioural shifts are particularly noted during the 'Spheres of Change' framework that links personal perceptions to practical decisions and policies undertaken (O'Brien & Sygna, 2013).

Yet, few studies have investigated the opposite side of this feedback and any influence mitigation measures may have on risk perceptions. Some studies focus on the confidence in DRR measures in general (Wachinger et al., 2013), but lack consideration of the type of measure in place. One study that does focuses on this aspect is Ludy & Kondolf (2012), who analysed flood risk perceptions of individuals behind 1/100-year (1% Annual Exceedance Probability; AEP) standard of protection flood levees in California, US. The presence of flood protection in these areas results in land being officially recognised as outside the floodplain, but residual risk means the area is still vulnerable to events that exceed the 1/100-year threshold. However, the results indicate that residents are not only unaware of, and do not understand, these significant residual risks behind levees, but also have a low awareness of flood risk in general and do not understand flood terms such as "1/100-year flood" (Ludy & Kondolf, 2012).

2.6 Socio-hydrology

Research emerging as part of the wider field of socio-hydrology is increasingly modelling theoretical dynamics of coupled human-water systems, particularly for the interplay between floods and societies (Di Baldassarre et al., 2013b; Blair & Buytaert, 2016). The term socio-hydrology was first coined by Sivapalan et al. (2011), but research evaluating human adjustments to floods, such as White (1945), is not new and has been previously alluded to during the previous flood management research theme of this Chapter. Previous studies have also investigated how early settlers began co-evolutionary interactions with water to create a dynamic coupled systems (Kummu et al., 2011; Wang & Gao, 2020), and how human settlements and activities are shaped by flooding and flood risk (Di Baldassarre et al., 2013a). However, the scale of human interactions with hydrology (Blair & Buytaert, 2016) and the recognised fundamental role human activity plays in the water cycle in the Anthropocene (Van Loon et al., 2016) through reciprocal links in socio-hydrological systems (Di Baldassarre et al., 2013b), as well as encouragement from the current IAHS scientific decade, Pante Rhei, has resulted in a resurgence of this coupled human-water and inter-disciplinary field.

Two dominant socio-hydrology concepts highlighted in the literature are the levee effect and adaptation effect. The levee effect focuses on building and raising flood protection, or levees, to reduce flood frequencies and enable increased economic activity in at-risk areas (Buchecker et al., 2013). This link between population growth behind protection infrastructure has previously been noted in literature (Husby et al., 2014; Collenteur et al., 2015). However, the feeling of safety can decrease flood risk perceptions and in turn impact, and potentially increase, flood risk when less frequent but high impact events occur (Di Baldassarre et al., 2013b). This concept was first introduced by White (1945) for human adjustments to flooding, with the levee effect described by Tobin (1995) who noted that levees exacerbate flood losses in certain circumstances, such as levee failures, in a 'Levee Love Affair'. The levee effect or 'safe-development paradox' was also identified during Hurricane Katrina in the US, where federal efforts to make areas safe for development have inherently created highly susceptible areas places to catastrophic impacts from disasters (Burby, 2006).

In contrast, the adaptation effect highlights that frequent flooding can reduce societal vulnerability by enhancing coping and adaptation capacities, gained from recent flood memory and event experience (Di Baldassarre et al., 2015a). The impacts from flood incidents when a previous flood event has occurred in the same area are thus suggested to be much lower (Mechler & Bouwer, 2015; Kreibich et al., 2017, 2022). However, this adaptation effect cannot always be observed due to complications from individual perceptions and risk interpretations, and amount of socio-economic development driving preparatory actions (Fuchs et al., 2017).

Di Baldassarre et al. (2013b) outline the societal flood event responses as assumptions in their socio-hydrology model. Immediately after the occurrence of a flood, society either builds or raises levees, depending on economic wealth, or moves away from the at-risk area. This is determined by hydrological, economic, technological, and social factors that co-evolve over time (**Figure 2-5**). These includes Cost-Benefit Assessments (CBAs) that evaluate flood damages and economic-benefits in the area against building costs, whether protection assets can be built to a level equal or greater than previous flood levels, and previously mentioned dissipating social memory from less frequent flooding is also included (Di Baldassarre et al., 2013b).

However, this work remains largely theoretical and is primarily centred around hypothetical flood situations and public responses. Wesselink et al. (2017) conclude that this presents epistemological problems of humans differing from socio-hydrological models because they choose how to act on their perceptions and preferences, with these options and opportunities further compounded by differing socio-political contexts.

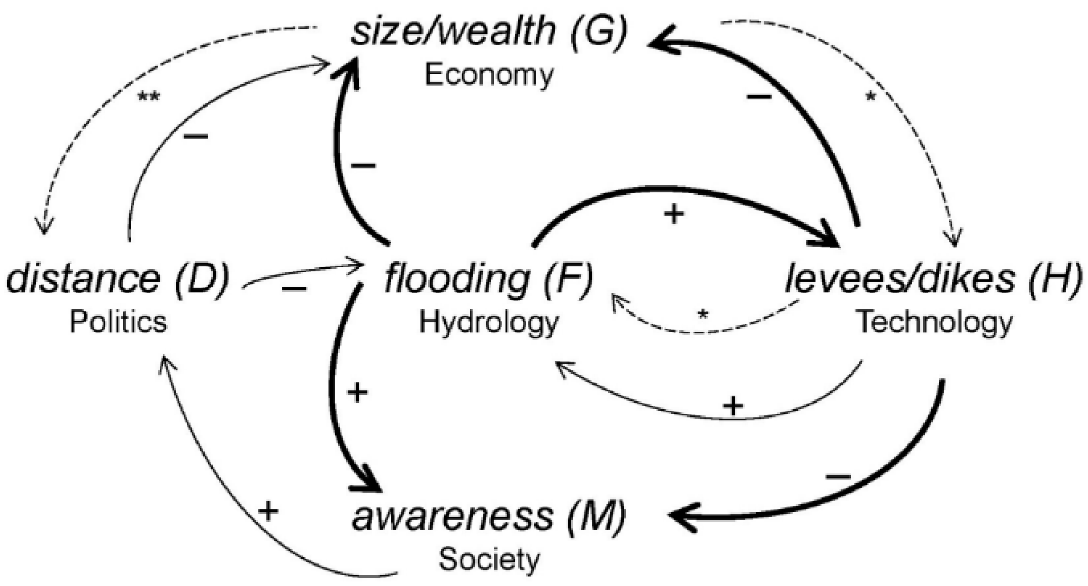

Figure 2-5: Schematic of the interconnecting inputs into a conceptualised socio-hydrology model of a flood event within a typical society. Source: Di Baldassarre et al. (2013b).

Whilst flood memory decreases in the model, risk perceptions are considered stationary processes rather than dynamic variables that can evolve overtime (Barendrecht et al., 2019). These heterogeneous differences and decisions are neglected within conceptualised socio-hydrological systems that are argued to instead be treated as educated human-flood system hypotheses (Wesselink et al., 2017).

A large proportion of socio-hydrology research therefore focuses on advocating for the research field and theoretical concepts, capturing human-social interactions in holistic system models (Di Baldassarre et al., 2014; Blair & Buytaert, 2016; Di Baldassarre, 2017; Pande & Sivapalan, 2017; Srinivasan et al., 2017; Wesselink et al., 2017) or further developing parameters (Barendrecht et al., 2019). Initial empirical studies are now applying real-time, case study data to models to account for two-way feedbacks between social and hydrological processes for floods. Ciullo et al. (2017) applied the socio-hydrology model to real situations: a technological system in Italy and an adaptive system in Bangladesh. The results indicated that technological systems have significantly lower flood risk than green alternatives, but much higher losses during severe, catastrophic events making them less resilient or capable of withstanding future environmental changes (Ciullo et al., 2017).

Further studies have expanded on socio-hydrology aspects. For example, Viglione et al. (2014) theoretically modelled risk coping by individuals from collective memory, risk-taking attitudes, and trust in protective works. The simulated results indicate good and bad combinations of these elements for societal development. Under-perceiving risk (i.e. high risk-taking, low collective memory and too much trust in protective works) resulted in lack of society and community development from high flood damages, while overestimating risk (i.e. high collective memory and no trust) resulted in a lack of community investment and economic growth (Viglione et al., 2014). Socio-hydrology concepts are also applied for modelling societal interactions with drought hazards (Van Loon et al., 2016).

Whilst the models remain theoretical, data relating to flood awareness and perceptions are cited as the most important element to correctly estimate the remaining variables within the system, and more data for other variables cannot compensate for absent awareness data (Barendrecht et al., 2019). Risk monitoring societies that continue to maintain high awareness and memories of flood events, in turn influencing preparatory and adaptive DRR measures, had lower modelled flood losses with no catastrophic impacts (Haer et al., 2020; Ridolfi et al., 2020).

2.7 Chapter Summary

This chapter has covered the existing literature of key themes explored in the thesis. This includes recent and changing flood risk, and the important developments of FRM that incorporates all aspects of flood risk for better assessment and analyses to manage flood risk and overall DRR. This chapter also reviews policy changes for flood management in England and the Netherlands and summarises the events that led to the policy change and the direction of policy and practice taken (e.g. structural protection, improved NBS and IWM, spatial and land-use planning, or improved strategies for societal flood risk elements such as preparation and recovery). Further, this chapter has also introduced the importance of flood risk perceptions and its impact on flood risk and its management, as identified as links between perceptions, policy, and practice in the Three Spheres framework, and introduced the interdisciplinary research field of socio-hydrology.

CHAPTER 3:

METHODOLOGY

CHAPTER 3: METHODOLOGY

3.1 Scope of Chapter

This chapter describes developing interconnections between social and physical geography for flood research and highlights the importance of applying an interdisciplinary approach in the research presented in this thesis. The resulting methodology, that addresses the use of structured (quantitative), semi-structured, and unstructured (qualitative) data, is presented for each research objective. Supplementary research chapters and the methodology for these are also considered here.

3.2 Interdisciplinary Science of Water and Social Systems

Water problems are complex in the manner which they weave water and society together. They are situated in complex webs of socio-political, economic, and environmental dynamics that connect natural and human systems across a variety of temporal and spatial scales (Fallon et al., 2021). Thus, FRM incorporates many different disciplines that vary in their research and communication methods (Towe et al., 2020). This complexity surrounding water- related issues and management often results in their categorisation as “wicked” problems that cannot be solved using traditional approaches, methods or technologies that assume these intricate socio-hydrological relationships are clear and linear (Fallon et al., 2021). “Wicked problems”, first described by Rittel & Webber (1973) for policy problems, defy rational and singular solutions, are dynamic and can be unstable, and have unclear cause and effect characteristics from influences by multiple factors and perspectives.

Addressing hydro-complex, and manifestly 'wicked', water problems require a range of solutions that focus on all social, physical, and economic aspects (Khan et al., 2010). However, notable separations between physical and social sciences are apparent, with a clear divide and low connectivity between research themes evident for water issues and FRM (Morrison et al., 2018). This is largely due to increasingly specialised disciplines within geography that have resulted in a lack of unity and systematic fragmentation of the subject (Bracken & Oughton, 2006). Yet rising global issues that intertwine humans, water and the climate, such as disasters, conflicts, changing demands and potential deficiencies, are progressively highlighting the problems that arise when these problems are investigated in isolation (Montanari et al., 2010). In response, there is a need for targeted, interdisciplinary approaches that seek to understand and address these mutually dependent and intertwined hydro-social issues and challenges (Montanari et al., 2010; Wesselink et al., 2017). This is driving a transformative field of hydrology, which has evolved from one traditionally centred on water quality to an active hydrology paradigm that reflects coupled human-hydrological systems and collectively combines hydrologists, social scientists, and atmospheric scientists (Vogel et al., 2015).

This understanding and necessity for transdisciplinary research is not new. Orens (1948) previously highlighted how the conjunction between physical and social scientists has important consequences for the future of both research fields. The introduction of the interdisciplinary journal *Water Resources Research* in 1964 further emphasised the need to combine the natural and social sciences when undertaking water-related research and management (Vogel et al., 2015). Yet a more recent resurgence and wider inclusion of interdisciplinary research is evident with the 2013-2023 'Panta Rhei – Everything Flows' IAHS scientific decade that concentrates on the linkages between water and societies, the launch of the *WIREs* Interdisciplinary Review journal in 2014 (Wesselink et al., 2017), and a 2018 special issue of the *Journal of Hydrology* that focused on socio-hydrology. Vogel et al. (2015) provide a good summary of progressing interlinked socio-hydrological system research that has developed interdisciplinary perspectives on the water problem. Similarly, mutual interdisciplinary human-flood research is identified in social science with 'hydrosocial' studies (Wesselink et al., 2017). The need for interdisciplinary research is therefore widely accepted (Morrison et al., 2018; Hartmann & Viglione, 2019), particularly surrounding future management and resilience of these systems (McEwen et al., 2013; Lund, 2015; Gilissen et al., 2016; Di Baldassarre et al., 2018; Rogers et al., 2020).

However, the application of interdisciplinary water research and, particularly for the focus of this research, integrative FRM science remains a challenge (Morrison et al., 2018). This includes the difficulty of capturing the dynamic interplaying human-water processes (Di Baldassarre et al., 2015a), that may or may not incorporate vulnerability aspects which are still difficult to address (Koks et al., 2015), as well as data intensive community analyses (Laurien et al., 2020). In turn, interdisciplinary emphasis is often realised as a multi or mixed-method approach. For instance, applying a combined method approach can aid investigations into varying FRM works, practices and implications (Bracken et al., 2016) as not one method can unpick complex FRM-themed strategies or views (Bracken et al., 2016).

Social science methods and data collection are also helpful to address evidence-based gaps that are associated with theoretical and modelled processes. This is accompanied by the growing era of "big data" for hydrology (Hutchins et al., 2017; Chen & Wang, 2018; Slater et al., 2019), FRM (Towe et al., 2020) and social sciences (Burrows & Savage, 2014; Luo et al., 2019; Diaz-bone et al., 2020). These developments have been supported by improved ability to examine, store and retrieve large amounts of hydrological data that can also result in new information sources, fill existing knowledge gaps, and improve the interconnectedness between social and physical disciplines (Vogel et al., 2015). Further, decision-making in FRM is increasingly dependent on availability and access to good quality data, with the big data era identifying a wider range and mix of structured and unstructured data at varying scales that require complex data integration (Towe et al., 2020).

The approach to big data taken in this research focuses on combinations of structured (e.g. quantitative), semi-structured (e.g. Geographical Information Systems; GIS processes) and unstructured (e.g. qualitative) data generated from diversified sources (Sheng et al., 2017). Philosophy also provides physical and social science research with general theoretical principles, thinking, and perspectives, that are used to obtain knowledge of reality (Moon and Blackman, 2014). More than one philosophical perspective, and associated characteristics, can resonate with research and these can change overtime (Moon and Blackman, 2014). The methods adopted in this thesis have roots in realist and constructionist perspectives, however the overall approach adopted is pragmatism that enables a compromise between empiricism and rationalism (Moon and Blackman, 2014), and applies a diverse method approach to understand the research problems presented in this thesis. This structured, mixed method approach that has been adopted combines quantitative and qualitative data methods to enable this research to explore the complex socio-hydrology problems within interdisciplinary FRM (Malina et al., 2011; Towe et al., 2020). The methodology for each research objective is detailed in the subsequent sections, with an overview of how these interlink with each other and the research themes in **Figure 3-1**.

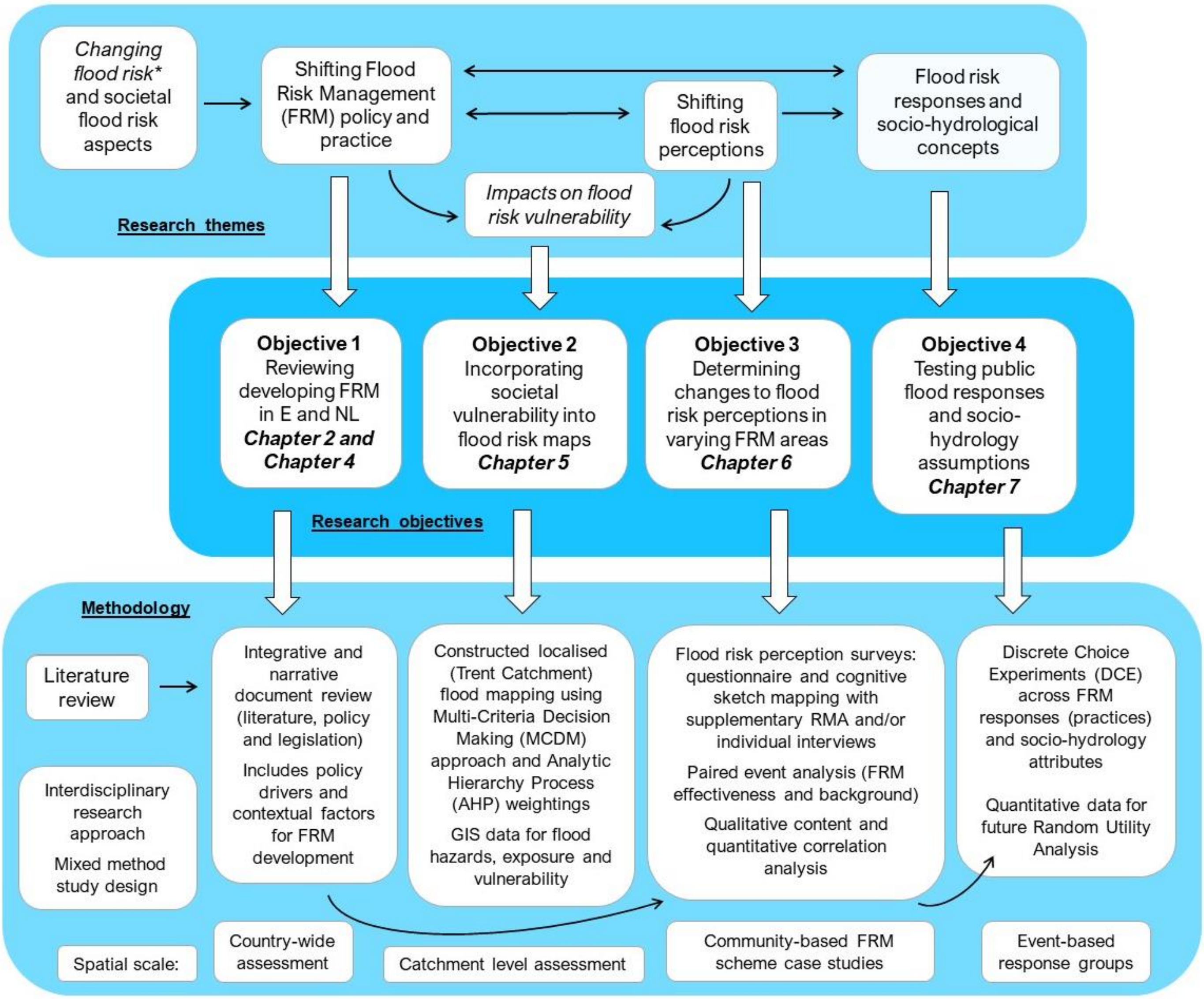

Figure 3-1: Methodology applied for each research objective and their connections to the interlinking research themes. Research objectives and methods are linked spatially, developing from a country-wide assessment to specific FRM strategy case study areas and flood experience response groups.

As previously mentioned, England and The Netherlands are good countries to compare as they are often considered to have a similar approach to managing flood hazards although they differ in level and history of flood risk, flood management and governance arrangements (Matczak et al., 2016), and may vary further in public perceptions and responses to flooding. The research objectives below were designed to be applied for both

England and The Netherlands and span different temporal scales from a countrywide assessment to case study and community-based analysis. However, data collected during this thesis differs between both countries due to data availability, collection methods, and global restrictions related to the Covid-2019 pandemic. Therefore, while research objectives 1 and 2 primarily focus on comparing FRM developments and flood risk perceptions in England and the Netherlands, a case study for the Netherlands has been identified through existing literature. Further, Chapter 8 for research objective 3 and supplementary data in Chapter 5 are primarily focused on England.

3.3 Research Objective 1: 'To evaluate the development of flood management policies and practices in England and the Netherlands from 1945 and compare the diversified approaches and internal and external policy drivers that have applied in both countries'

To assess shifting flood management, the progression towards FRM practices in England and the Netherlands has been reviewed and is presented in Chapter 4. This narrative review of policy uses unstructured national policy and legislative texts (from 1908 to the present), government reports, and existing academic reviews (e.g. Wesselink et al., 2015) to categorise previous policies and legislation into distinct management paradigms in England and the Netherlands. The countrywide geographical, socio-economic and governance conditions that have progressed and/or hindered this development to integrated FRM have been included throughout this chronological review. These highlight the location-specific, contextual, and historical factors that have been influential to the evolution of flood management policy and practice. Applying this historical development in the case of recent flood events and threats in England and the Netherlands, future directions of FRM have been suggested in this chapter. A discussion of policy change drivers, their supporting theories, and the applicability of these to the policy changes identified throughout the review concludes this chapter.

Existing literature was used as a starting point to quantify DRR developments for flood risks. Journal articles by Wesselink et al. (2007) for the Netherlands and Tunstall et al. (2004) and Johnson et al. (2005) for England have been particularly useful to frame the historical contexts of flood management in both countries. Policy documents were obtained primarily by online searches for England (legislation.gov.uk) and the Netherlands (government.nl and wetten.overheid.nl). Approximately 60 main policy documents and 99 supporting journal articles and government documents have been used to formulate the historic management progresses of England and the Netherlands from 1945 to the present, supplemented by contextual information in the Netherlands from 1100AD. Policy documents for the Netherlands that were in Dutch were translated for their inclusion in this review.

3.4 Research Objective 2: 'To discern the level to which current social vulnerability data can be incorporated alongside hazard and exposure data to produce and effective flood map'

Social vulnerability is often neglected or overlooked in flood risk analyses, with these tending to focus on tangible losses or characteristics of the hazard (Jongman et al., 2015; Mechler & Bouwer, 2015). While these are important factors for flood risk, societal elements need appropriate consideration alongside these as they can influence the amount of losses incurred (Birkmann, 2013) and are high dynamic (Kreibich et al., 2017). To determine whether social vulnerability, flood hazard and exposure data can be combined, vulnerability data from the ClimateJust flood vulnerability indices has been included alongside typical flood hazard and exposure datasets, discussed in Chapter 5, within a flood risk map for the River Trent catchment, England. The Trent catchment was chosen due to its local proximity and long history of surface water and fluvial flood risks (EA, 2010).

A 'Multi-Criteria Decision Making' (MCDM) approach has been applied in ArcGIS to combine weighted flood hazard, exposure, and vulnerability semi-structured and available data, based on Analytical Hierarchy Process (AHP), into high, medium, and low risk areas. This chapter also introduces the role of defined 'communities' within this analysis and its wider connotations for FRM.

3.5 Research Objective 3: 'To determine whether the flood risk perceptions of individuals changes depending on present flood management type'

To determine whether flood risk perceptions in England and The Netherlands vary depending on flood management type, or other contributing factors, a series of investigations were undertaken in locations where varying FRM strategies are present. Following the methodology of O'Neill et al. (2016), these investigations include a qualitative household questionnaire and cognitive sketch mapping exercise in case study locations, referred to together as the 'flood risk perception survey' in this thesis. Questionnaires are widely used during investigations of flood risk perceptions (e.g. Grothmann & Reusswig, 2006; Bubeck et al., 2012b) as they allow for large amounts of qualitative and quantitative data to be collected from respondents. The inclusion of a sketch map exercise enables respondents to illustrate the areas they perceive to be at risk, which can then be combined into density maps that provide a community assessment of flood risk (Brennan et al., 2016).

The questionnaire applied included open-ended, closed-ended and scale questions to investigate themes and influencing factors of individual flood risk perceptions (identified from previous studies) in relation to the present FRM strategy (**Table 3-1**). This included flood knowledge and level of known flood risk, feelings of worry towards flood risks, and perceived likelihood of future flooding. To assess attitudes towards the varying FRM strategies in case studies, questions were also asked around knowledge of FRM strategy in place, behaviour towards flooding and additional personal precautions undertaken, and level of inundation of properties if a flood occurred (Ludy & Kondolf, 2012). Public perceptions and knowledge around the global shift to risk-based FRM in general has also been investigated with questions on awareness of the term FRM, whether the FRM shift is perceived as positive or negative, and if this is better for DRR than traditional management. Socio-economic factors are included in most flood risk perception studies as they can be influential factors for flood risk perceptions and behaviours towards flood risks (Grothmann & Reusswig, 2006). Demographic data has therefore been collected as part of this questionnaire and analysed against other results and to identify any correlations with risk perceptions and to provide demographic backgrounds of the case study areas. The general questionnaire, that varied slightly with information on the present FRM in the area, and participant information sheet can be found in **Appendix 1**.

Cognitive sketch mapping is a practical data collection method that enables perceived at-risk areas to be illustrated on spatial maps by respondents (**Figure 3-2**) (O'Neill et al., 2016). The completed sketch maps, both in person and online, were georeferenced in ArcGIS and combined into a community flood risk perception density map for each case study area (Brennan et al., 2016; O'Neill et al., 2016), and are presented in Chapter 6.

Table 3-1: Information collected from participants during questionnaire and their link to themes and flood risk perception influences addressed in this chapter.

Theme	**Flood Risk Perception Factors**	**Information to be collected from participants**
Social/demographic characteristics	Demographics	Age Gender Home ownership Household structure Education level
Previous flood event experience	Situational factors of flood risk including level of experience	Years in community Experience of past events Frequency of past events Impact of past events
Level of flood knowledge and awareness	Awareness of flood risks	Aware of Risk Level of Risk Extent of flood knowledge Communication/information received on flood risks
Perceived level and worry of future flood risk	Future risk level judgements and effectiveness of FRM measures	Likelihood of future event Effectiveness of present FRM Level of worry of future floods Frequency of flooding of future floods Undertaken personal PFR and have flood insurance
FRM measures in place	Level of trust in FRM measures and responsibility and ownership of flood risk	Knowledge and awareness of FRM measures in place Responsibility of FRM Level of impact of future event on property Confidence in FRM in place FRM case study specific questions
Wider FRM shift	Not a flood risk perception factor, but linked to a wider discussion around policy, practice, and perception changes	Understanding of FRM shift Impact of FRM shift – positive or negative and improvements to DRR

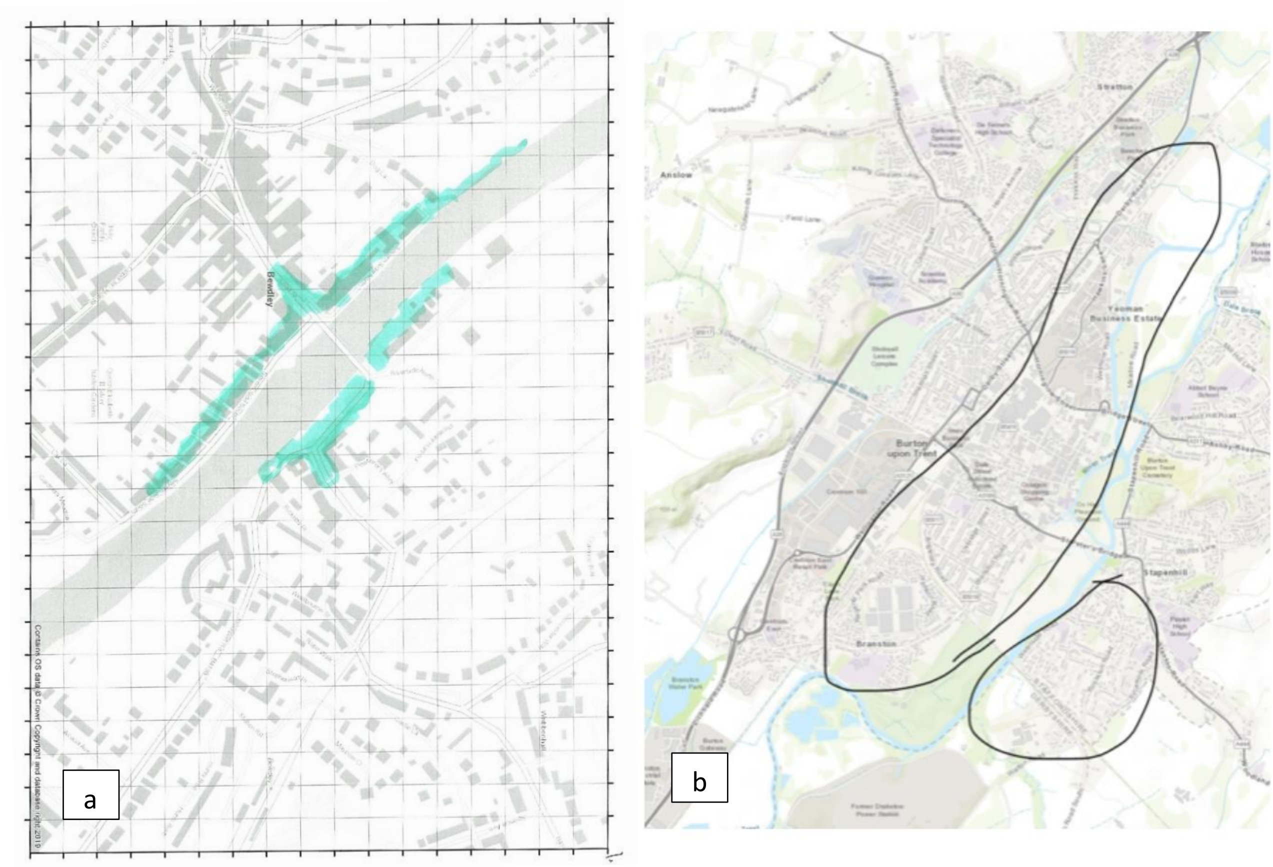

Figure 3-2: Two examples of sketch maps completed during the (a) door-to-door surveys in Bewdley and (b) online using ArcGIS Survey123 for Burton-upon-Trent.

A pilot study was undertaken to sense check the method and questions include, first with PhD students and academics at the University of Brimingham, and secondly in Kelverly Grove, a small fluvial flood risk area in West Bromwich that includes areas of low, medium, and high risk of flooding from the River Tame. The survey received a small response rate, but responses from participants provided helpful recommendations for conducting the survey in further case study areas. A follow up questionnaire to residents on why they did not complete the study indicated the primary reason for a lack of participation was that respondents were 'not at risk' with no other responses provided. Following the pilot study, the survey was initially implemented with an opt-in only approach, stated as necessary by the University of Birmingham Ethical Committee, that used leaflets to ask potential respondents to contact researchers if they were interested in participating in the flood risk perception survey rather than ‘cold-calling’. However, following a poor initial response rate, and clarification from RMAs including the EA of how they approach and engage with communities about flood risks, this was later changed to a door-to-door survey. The introduction of restrictions around the Covid-19 pandemic stopped all in-person contact with individuals that resulted in the flood risk perception survey being moved online, hosted by ArcGIS Survey123 online survey software that enabled respondents to complete both the questionnaire and sketch map. This survey was used in place of the door-to-door survey during Covid-19 restrictions.

Acknowledging the differing and developing FRM strategies identified in England and the Netherlands, present in the literature and narrative review in Chapter 2 and 4, locations where these varying FRM strategies have recently been implemented were used as case study areas to test flood risk perceptions. These were identified through press releases and updates on ongoing schemes, provided by the responsible RMA. Several areas were considered for both countries, however not all were included due to lack of community engagement or information on the FRM present, often when the scheme had been in place for a long time, or another scheme for the same type of FRM was more appropriate. Once appropriate case study locations had been identified, the RMA responsible was contacted for more information on the scheme and advice for engaging with the community. For the Netherlands, scheme locations were also dependent on support to translate the questionnaire and responses (e.g. some regional accents made conducting questionnaires difficult), and share these in case study locations.

The varying FRM case study locations in England were chosen as: structural protection in Burton-upon-Trent, PFR in Bewdley, PFR in Aston Cantlow, NFM in Herefordshire, and a combination of urbanised NFM with protection from changes in elevation in Selly Park. Two PFR schemes were included in this research as PFR is commonly applied in small, dispersed areas where a larger scheme is not cost-beneficial as only small amounts of properties are at risk. However, these areas often experience frequent flooding by being overlooked for larger schemes and are at equal, if not sometimes higher, risk when compared to larger engineered schemes (DEFRA, 2022). In the Netherlands, the case studies chosen were: the RftR bypass channel in Lent and MLS approach piloted in Dordrecht. Due to government restrictions that limited public contact and case study visits to the Netherlands, a third case study of dike protection has been generated from previous literature of flood risk perceptions in the Netherlands.

Flood risk maps of the case study areas were used to identify properties that were at flood risk, had previously flooded and/or had been included in the FRM scheme in question. This study therefore applied purposive sampling (Etikan et al., 2016) as residents in the area were invited to participate. This allows the most useful sample for the research purpose, of residents at flood risk with varying FRM strategies present, to be applied. There were some aspects of voluntary response and snowball sampling for the online survey that was also shared with groups and gatekeepers, however this remained within selected areas and still within the applied purpose sample. While survey bias was considered and reduced where possible, with no-leading questions and removal of any researcher values or opinions from questions (Galdas, 2017), the nature of the qualitative research and the flood topic mean some bias will remain as some residents are more likely to volunteer to participate than others. For instance, those who have previous experience of flooding or have an interest in the subject.

Background information and contexts of the flood management in case studies is presented in Chapter 6, with a review of flood management changes and large flood events that have occurred during these developments to determine the effectiveness of these measures in England, to some extent, as part of a paired event style assessment (Kreibich et al., 2022). The effectiveness of chosen FRM measures is an important research benchmark for these to be successful to manage rising flood risks (Hudson et al., 2014; Priest et al., 2016), but may also have implications for flood risk perceptions and responses. No large, fluvial flood events have occurred in the Netherlands since the 1993 and 1995 events. Therefore there are no recent fluvial flood for comparison and only the management background for Dordrecht and Lent can be provided in this section.

Further, the flood risk perception surveys (questionnaire and sketch maps) were applied to case studies in England and the Netherlands, in part, as Bachelor and Masters dissertation projects. The survey data from Burton-upon-Trent, Bewdley and Aston Cantlow was collected with support from Grady (2019) in a project supervised by Dr Anne Van Loon, and for Herefordshire and Selly Park with assistance from Flusk (2020), supervised by Dr Joshua Larson. For Dordrecht in the Netherlands, the data collection undertaken by Linnarz (2020) supervised by Dr.ir. Maurits W. Ertsen at Tu Delft, while data from the Lent case study were collected by Vaassen (2020) supervised by Dr.ir. Pieter van Oel at Wageningen University. The use of student projects enabled more data to be collected in the Netherlands, prior to and during global restrictions, and to fulfil University of Birmingham health and safety requirements. However, this resulted in the questionnaires varying, particularly in the Netherlands, as they have been adapted to fit social and cultural norms in each country and wider research objectives of student projects.

The results of these questionnaires are presented in Chapter 6. These results have been analysed based on percentage of results and using Spearman's rank to provide correlation coefficients across demographic and flood risk perception factors. Correlation of questionnaire data is commonly used in flood risk perception studies to identify the strength of relationships between variables (Grothmann & Reusswig, 2006; Ludy & Kondolf, 2012). Close-ended questions are difficult to analyse, but the method used in this thesis follows that of Grothmann and Reusswig (2006) that assigned binary values (0 and 1) to yes and no responses for questions such as gender and whether respondents are homeowners. Spearman's rank was used as the variables were excepted as nonparametric, nonlinear, and rank-ordered and calculated in SPSS software. Regression and ANOVA models that estimate how well variables predict dominant variables are often used to analyse flood risk perception questionnaire data. However, the dataset of multiple small case studies in this thesis was considered to reduce the statistical significance of the results, making them unlikely to reasonable predict variables, and therefore regression and variance analysis was not undertaken.

Supplementary interviews were carried out with RMAs and interested participants from case studies in England. As mentioned previously, when selecting case study areas, the RMA responsible for the scheme was contacted for more information on the scheme and advice on engaging with the community. During this, an interview was set up with someone from the RMA that implemented the scheme and covered factors that related to the scheme, flood risk of the area, and flood risk perceptions of the community the scheme may have influenced. 4 formal interviews and 2 informal interviews were carried out with RMAs for case study areas in England. No RMAs responded to requests for interviews for the case study areas in The Netherlands. 2 formal and 2 informal interviews were also carried out with residents of at-risk case studies in England. The interviews with residents were selected through judgment sampling, where the participants lived in the area and were well informed and interested in the scheme present. These residents were identified through suggestions from the RMAs, connections to the scheme in other way (for instance a member of the community group for the area) or when approached to complete a flood risk perception survey which turned into an informal interview when the residents were able to answer more in-depth questions and showed a willingness to provide a lot more information. **Table 3-2** includes the items covered in the interviews, that used open-ended questions, for both the RMA and resident interviews.

Table 3-2: Information collected during interviews with RMAs and homeowners and their link to themes and flood risk perception influence addressed in this chapter.

	Theme	**Flood Risk Perception Factors**	**Information to be collected from participants**
RMAs	FRM scheme in place	Perceptions and trust in FRM of the public prior to implementation	FRM scheme in place Decision of FRM type Public acceptance of FRM type over other measures Effectiveness of FRM Homeowner responsibility
	Level of public flood risk	Flood risk awareness and perceptions of the public	Understood flood risk Feelings towards flood risk
	Implications of FRM in place on flood risk perceptions	Perceptions and trust in FRM of the public subsequent to implementation	More awareness in area with FRM Change in feelings towards flood risk since FRM
Public	Previous flood event experience	Situational factors of flood risk experience	Years in community Experience of flood events
	Perceived level and worry of future flood risk	Awareness of flood risks	Aware of flood risks Personal PFR
	FRM measures in place	Level of trust and effectiveness of FRM measures	Feelings towards FRM Impact of FRM on flood risk perceptions Current flood risk perceptions

3.6 Research Objective 4: 'To test socio-hydrology concept response assumptions and public preferences to FRM measures'

To assess public responses to flood risk events and preferences to FRM approaches, an online discrete choice experiment, which included three choice card questions and follow up questions, was designed and shared using the same ArcGIS Survey123 software as the flood risk perception study. Choice experiments use illustrative cards that ask respondents to choose between multiple varying choices or situations per card that differ in attribute level, or to opt out and choose none of the options (**Figure 3-3**). When respondents choose their preferred option, their choice and driving attributes leading to their decision can be quantified.

Choice experiments have been successfully used in several studies, including decisions and preferences towards flood management (Zhai et al., 2007), non-structural flood management, changes in land use for flood protection (Ryffel et al., 2014), uptake of flood insurance (Botzen & Van Den Bergh, 2012; Botzen et al., 2013), and climate change mitigation in coastal areas (Remoundou et al., 2015).

The first choice card was a practice card, suggested as good practice by previous studies that implement choice experiments (Botzen et al., 2013), but contains varying attributes that are included on the following two cards. This enabled respondents to engage with an illustrative choice card with fewer attributes and options, and to be introduced to the general topic of the experiment. The second choice card focused on testing public choices towards different types of FRM strategies, particularly characteristics of structural protection infrastructure, PFR and NFM measures.

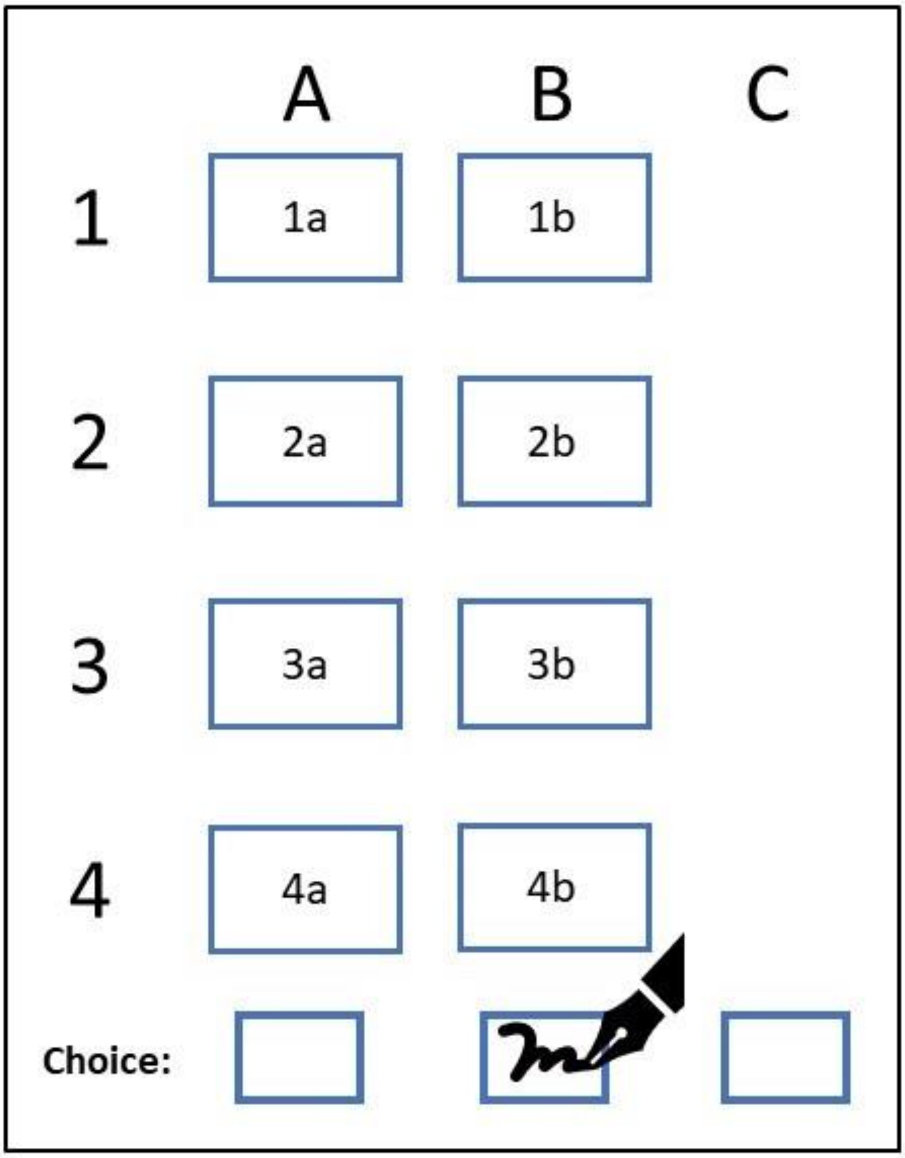

Figure 3-3: Example of a choice experiment card that displays variations (A and B) of the same attribute (numbered 1-4). Respondents can then choice their preferred option or opt out and choice neither (option C in this example).

The third choice card focused on socio-hydrology public response assumptions that have been well defined in recent literature. These assumptions suggest that subsequent to a flood event, the affected society will implement protection (i.e. structural systems) or relocate from the at-risk area (i.e. green systems) (Di Baldassarre et al., 2013b; Ciullo et al., 2017). These responses are in line with the socio-hydrology theoretical concepts of the levee effect and adaptation effect (Di Baldassarre et al., 2013b).

Table 3-3 provides the choice card attributes and levels that were included in the choice cards. While these choices are based on existing FRM types and understood theoretical concepts, choices on the cards are not titled and are instead referred to as A, B or C as suggested by previous studies to reduce any bias towards the option in question (Olschewski, 2013). Follow up questions referencing the respondents most and least important or influential factors as included for the second and third choice cards.

Participants from the flood risk perception study who were happy to be contacted were asked to participate in the choice experiment. The choice experiment was also shared online, using convenience but random sampling, to attract respondents who had experienced flooding, as well as those who would deem themselves as ‘not at risk’ from flooding. This chapter provides an initial look at the data collected, as well as considering the design of the experiment and justification for future use.

Table 3-3: Choice experiment attributes and levels included across all choice cards.

	Attribute	Varying attribute choices
FRM	Focus of management	Protection; prevention; preparation and recovery with slight protection
	Location of floodwater when management in use	Around community/settlement; upstream away from community/settlement; around individual properties
	Standard (level) of protection	1 in 100-year; 1 in 50-year; unknown
	Visible protection	Yes constantly; not to homeowners; temporarily during events
	Testing and monitoring	Tested and monitored; ongoing but not completed tested and monitored; tested but not monitored
	Homeowner contribution	Financial contribution; no homeowner contribution; must implement measures
	Environmental benefits	None with potential decrease; yes with increase; no change
	Residents remained informed on risk	No further information on flood risk; flood risk information at community level; flood risk information at individual level
	Settlement changes	Increase in settlement size; no change; no change or potential decrease
Socio-hydrology	FRM type	Structural protection; non-structural adaptation measures
	Flood risk frequency	Infrequent major flood events; frequent flood events
	Flood damages	Severe damages; less damages
	Settlement size	Large settlement size; smaller settlement size
	Settlement location	Close proximity to rivers; further away from rivers
	Economy size	Increasing economy size; no change or slight decrease in economy
	Awareness of risk	No flood risk awareness; high flood risk awareness

CHAPTER 4:

THE SHIFT TOWARDS INTEGRATED FRM IN ENGLAND AND THE NETHERLANDS

CHAPTER 4: THE SHIFT TOWARDS INTEGRATED FRM IN ENGLAND AND THE NETHERLANDS

4.1 Scope of Chapter

This chapter firstly provides a global introduction to FRM policy change, and then draws on the narrative review of policy and legislation documents alongside academic literature provided in Chapter 2 to identify and compare shifting management paradigms for England and the Netherlands, from 1945 to the present. These policy drivers behind these developments have been compared for both countries, with consideration towards the future FRM practices of both countries, identified from their development trends, concluding this chapter.

4.2 Introduction

The shift to FRM has been well documented in DRR literature, and observed in many countries, both globally (e.g. Bubeck et al., 2017; Chan et al., 2022; Penning-Rowsell & Becker, 2019) and in the EU (e.g. Matczak et al., 2016). Yet, variations in flood risk, contextual and historical factors that influence location specific FRM has resulted in significantly divergent, and sometimes conflicting, approaches to FRM (Sayers et al., 2015a; Wesselink et al., 2015). FRM strategies, governance, and development of approaches in England and the Netherlands have previously been described individually and in national comparisons (e.g. Klijn et al., 2008; van Buuren et al., 2015, 2018; Wesselink et al., 2015; Wiering et al., 2015; Bubeck et al., 2017). One of the largest of these studies was STAR-FLOOD, a study undertaken between 2012 and 2016 that included England and the Netherlands in several FRM comparison outputs (Dieperink et al., 2013; Hegger et al., 2016a; Kaufmann et al., 2016c; Matczak et al., 2016). Yet, key updates to FRM, particularly the introduction of resilience concepts, have occurred since the study’s conclusion. Future FRM choices in both countries are also a current relevant discussion point as both countries published new 6-year FRM plans in 2021 and 2022. Furthermore, to identify why both countries adopted specific FRM portfolios and approaches in response to flood risk, it is important to consider previous flood management strategies, their progression and policy drivers, as well as the supporting physical and socio-political characteristics of the country. Thus, in the context of the ‘Spheres of Change’, changes in personal and political spheres need to be observed to quantify the resulting policy and legislative impacts in the practice sphere (O’Brien & Sygna, 2013).

Shifting FRM is underlain by policy and legislative changes that alter the direction of management attention, effort and investment (Penning-Rowsell et al., 2017). Policy changes can be categorised as a modification of measures undertaken by government (and others) in response to, or anticipation of, changing circumstances and demands (Penning-Rowsell et al., 2006) that reflect management progression. These changes can be radical or incremental, and driven by catalyst events, change agents and new discourses and trends (Meijerink & Huitema, 2010; Bubeck et al., 2017; Wiering et al., 2018).

The idea that sudden, large ‘shock’ (Wiering et al., 2018) or ‘focussing’ (Birkland, 1998; Bubeck et al., 2017) catalyst flood events alter FRM policy is generally accepted in the literature. Kingdon's (1995) Multiple Streams theory suggests that a ‘policy window of opportunity’ occurs when three streams intersect: a problem (e.g. large-scale flooding), politics (e.g. political interest from media and public opinion determining the level or prioritisation) and policy (e.g. solutions from government agencies resulting in policy development). A severe and damaging flood creates shocks in society, attracts increased media attention and public awareness, and raises the visibility of flooding on political agendas for intervention (Johnson et al., 2005; Meijerink & Huitema, 2010; Kaufmann, 2018). This can provide policy advocates with opportunities to advance new solutions and concepts (Husby et al., 2014; Penning-Rowsell et al., 2017; Wiering et al., 2018), or can alternatively strengthen existing policies and positions in a 'recover and return' strategy (Kaufmann et al., 2016a; Wiering et al., 2018).

Previous studies have associated water management changes with major floods. For instance, Hurricane Katrina flooding in 2005 in the USA highlighted protection failures to progress alternative FRM strategies (Sayers et al., 2015a); major river floods in Europe (Hungary and Germany) and Asia (China and Thailand) shifted attention to ecosystem-based IWM (Meijerink & Huitema, 2010); and the 2004 Indian Tsunami improved warning and emergency planning policies (Sayers et al., 2015a). These abrupt policy changes may punctuate and destabilise relatively constant policy systems (Baumgartner & Jones, 1993), and introduce new actors to change decision-making structures and policy directions (Penning-Rowsell et al., 2017; Wiering et al., 2018). The Advocacy Coalition Framework (Sabatier, 1998) suggests that actor coalitions influence policy, politics and problem solutions with their distinctive beliefs. These actor coalitions and values can be highly resistant to change and contribute to policies progressing in one direction. However, new or changing actors can be successful in altering these (Pierce et al., 2017; Wiering et al., 2018).

Cumulative, smaller events over longer time periods and a continuous process of learning and adaptation can also enable incremental policy change (Baumgartner & Jones, 1993; Lane et al., 2013; Penning-Rowsell et al., 2017). This corresponds to Easton's (1957)

System Theory in the way that catalyst events and 'windows of opportunity' shape policy depends on these underlying contextual (e.g. technology, knowledge, socio-economic and political systems), behavioural (e.g. dominant attitudes, beliefs and values) and cultural developments (Penning-Rowsell et al., 2017). Catalyst events allow policy entrepreneurs to propose preferred solutions that were already 'on the shelf' from these developments (Penning-Rowsell et al., 2006; Wiering et al., 2018). Following events or policy change, problems can disappear from the political agenda with the belief that they have been addressed, or as new problems emerge, with policy changes reverting to incremental developments (Kaufmann, 2018).

England and the Netherlands are often described as exhibiting similar evolutions of management strategies over time. This comparable progression reflects, in part, a shared need to comply with EU water directives (Matczak et al., 2016). Although this now differs for England, several FRM changes between 2007 and 2020 adhere to these frameworks. Other FRM similarities include long-standing governmental roles in flood management (van Buuren et al., 2015), experience of managing large floods including the 1953 North Sea storm surge, and projected increasing flood impact from socio-economic and climatic changes (van Buuren et al., 2018). However, both countries remain focused on different national priorities, and have varying catchment geographies and socio-economic conditions that have shaped historic management choices and the diverging FRM practices and timings that are present currently.

This chapter draws on the narrative review of FRM developments in England and the Netherlands, from 1945 to present, included in the literature review in Chapter 2. This particularly makes use of the timeline of FRM developments in England (Figure 2-3) and the

Netherlands (Figure 2-4), as well as the summary tables of policy, legislative and strategy documents that consider the focus of management approach and whether each document impacts this (Table 2-2 for England and Table 2-3 for the Netherlands). However, governance structures, that proceeds this review in chapter 2, and flood risk should also be considered.

In England, an estimated 2.4 million properties (>77% residential) and half of prime agricultural land is at-risk from fluvial and coastal flooding. It has been suggested that a further 16 people are impacted by loss of services for every affected household (EA, 2020c) (Penning-Rowsell et al., 2006; EA, 2020c). Current anticipated annual flood damages are >£1 billion (Penning-Rowsell, 2015a), potentially rising to £26 billion by 2080 under a worst-case climate scenario and no additional adaptation (Morrison et al., 2018). The number of at-risk properties is also estimated to almost double by 2050 (EA, 2019d). In The Netherlands, the potential of flooding is much larger due to the low-lying delta position, with 26% of land below sea level, and a further 29% potentially at-risk from fluvial flooding from main rivers, including the Rhine and Meuse (which rise in France and Switzerland and flow through Germany), and other smaller watercourses and tributaries (Wiering & Winnubst, 2017). 70% of the population and GDP (~€455 billion) of the country is situated in these flood-prone areas (Jorissen et al., 2016), protected by 3500km of primary flood protection, 1400km of regional protection, and numerous canals and ditches (Cultural Heritage Agency, 2014; Wiering et al., 2015; Wiering & Winnubst, 2017).

4.3 Management paradigms in England and the Netherlands from 1945 to the present and future FRM directions

Flood management developments in England and the Netherlands (**Figure 4-1**) show a similar progression of FRM practices and policies developments. Both countries have evolved from a sole flood protection focus to integrated FRM. However this transition reflects dominant phases of flood management behaviours (Johnson et al., 2007) and historical backgrounds that include varying practices, resources, actors and their expertise, as well as flood risk factors from different geographical conditions.

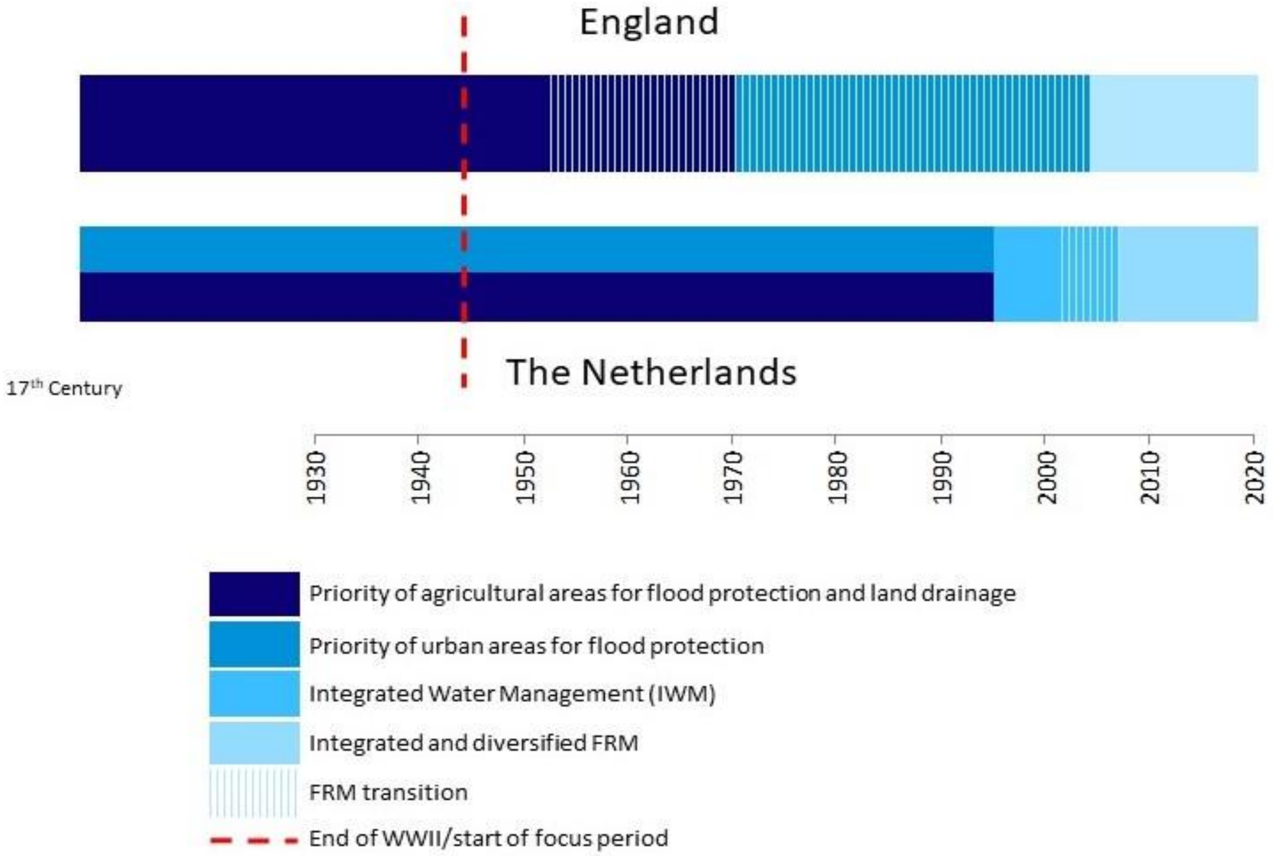

Figure 4-1: Fluvial flood management paradigms for England and the Netherlands from 1945, based on legislation and policy changes from both countries (Table 1 and Table 2). Similar progression has occurred from land drainage, agricultural land structural protection, urban flood protection, and FRM approaches but with differing timescales. IWM is also included for the Netherlands but not England.

Both countries have historically applied traditional approaches of land drainage and flood protection to reduce flood risks in agricultural areas. In the Netherlands, land drainage was important for early settlers but was strengthened from the 11th Century from institutionalised water management (Olsthoorn & Tol, 2001). Engineering developments improved land drainage with canals, windmills and dams, while also confining and strengthening river channels, (Hoeksema, 2006; Wesselink et al., 2007) many of which continue today in agricultural areas across the country.

Like the Netherlands, early land drainage and flood protection for agriculture began in England from the 13th Century, with modifications increased with help from Dutch engineers in the 17th Century. While this identifies an early, but slightly later, parallel between land drainage strategies of both countries, the spatial scale, necessity, and continual use of land drainage was smaller in England than in the Netherlands that has since decreased further. However, historic Land Drainage Acts, particularly the 1930 Act that termed river channels as 'arterial drains', in England still streamlined and strengthened agricultural drainage and downstream water conveyance (e.g. dredging) (Cubley, 1952; Johnson, 1954; Scrase & Sheate, 2005). Land drainage policies progressed as late as 1977 but reduced with decreasing agricultural importance and government priority (Scrase & Sheate, 2005)(Tunstall et al., 2004; Ash, 2008; Klijn et al., 2008; Wiering et al., 2015).

For flood management in the Netherlands, and prior to international cooperation, early settlers had limited options to reduce significant flood risk caused by geographical position and increasing land subsidence. Community action therefore focused on raising and defending land with flood protection, in early 'polders', that became a continual and traditional practice (Hoeksema, 2006; Wesselink et al., 2007; van den Brink et al., 2011). This was strengthened by connecting multi-beneficial river dikes into uninterrupted systems (Cultural Heritage Agency, 2014) with the heights of these continually increased following protection breaches and to counteract increasing flood hazards (Wesselink et al., 2015). This increasingly reinforced the protection strategy, further solidified by sunk costs and established technical-engineering knowledge (Wiering et al., 2015; Liefferink et al., 2018), increased risk behind protection infrastructure from economic development and the gradual institutionalisation of publicly funded flood safety and damage compensation.

These factors have created what is referred to as a technological and political 'lock-in' in the Netherlands (Wesselink et al., 2007), or a resulting path dependency focusing on flood protection that has been difficult to overcome. The Dutch Government response to the 1953 storm surge flooding demonstrated this core approach, as dike protection standards were significantly improved to1/1250-year and 1/2000-year standards for river dikes and 1/4000-year and 1/100,000-year standards for the coast to balance hazard probabilities and socio-economic consequences in a cost-beneficial approach (CBA) (Klijn et al., 2008; Wiering & Winnubst, 2017), and vulnerable estuaries closed and protected with the Delta Works (European Commission, 2018). Although new policy actors began to highlight ecological problems that altered some of the Delta Works construction projects, and improvements to flood forecasting and warning systems saw necessary FRM implementations, the path dependency of traditional flood defence remained the priority until the mid-1990s.

Emerging IWM concepts from growing ecological actors began to be adopted as policy options, with the 1996 RftR policy, following the 1989 Third Memorandum and alongside the Works in the River Meuse (*Masswerken*) programme, being the first, large deviation from traditional reliance on flood protection. These strategies integrate preventative flood safety, managed drainage and improved natural river environments to guarantee '*safety risk*' and reduce flood peaks (CW21, 2000). Although these strategies place a higher priority on flood risk prevention, they could still be considered as in accord with established and recognised Dutch engineered concepts. The inclusion of calamity polders, however, as a RftR approach to designate areas for controlled flooding (Rijke et al., 2012) represent a significant policy change towards FRM in the Netherlands that begins to highlight and manage potential flood risk uncertainties and protection failures not previously communicated (van der Brugge et al., 2005; Kaufmann, 2018).

While flooding is a significant and increasing problem in England, the reduced damage potential and fewer severe historic floods has resulted in a lower historic priority on flood protection and permissive government powers for flood management. An example of this is the increased flood protection for agricultural areas after the flooding in 1947, and the CBA to flood protection standards, based on probability and socio-economic consequences of flooding, and Thames Flood Barrier after the 1953 storm surge that shifted management priority to urban areas. These were built to the 1953 event flood-return period as a minimum (Waverley Committee, 1954; Penning-Rowsell et al., 2006; Hall, 2011), but generally flood protection in England is constructed to 1/100-year or 1/200-year standards. These lower flood protection standards were supported by approaches of increasing flood awareness, preparedness, spatial planning powers and private homeowner flood insurance for damages.

Thus, historic preferences of placing less emphasis on flood protection, and potentially filling in the at-risk 'gaps' with diversified FRM approaches, has facilitated the equal development of these strategies. For instance, the 1993 MAFF strategy included both structural protection and non-structural, and encouraged technically and environmentally sustainable measures for flood '*risk*' reduction for people and the developed and natural environment for the first time (DEFRA, 2004; Scrase & Sheate, 2005; Ash, 2008). This progression has been driven further by the statutory governmental role that also focused on strategies for, and to bring attention to, homeowner responsibility. This includes flood awareness, preparation and recovery strategies and the development of private flood insurance, first available in 1929. This equal development of diversified FRM strategies continued, and increased, as part of the holistic FRM portfolio in the 2005 Making Space for Water (MSfW) policy. This policy promoted sustainable and participatory FRM (Nye et al., 2011) and distinguished between resistant and resilient measures to 'live with flood risks' (DEFRA, 2004) that resulted in the 2007 FD implementation not requiring significant changes (Priest et al., 2016).

In a similar way to how the geography of the Netherlands has shaped the core defence approach in response to flooding, the development of diverse FRM strategies in England has been aided by the geographical conditions of most runoff and river flows being internally generated within the country, with catchments that cross country boundaries remaining in the UK (Wiering et al., 2015). Therefore, during a catchment-approach, propelled by EU directives, varying FRM strategies can be applied. For example, NFM and NBS in the upper catchment reaches can be combined with NBS, SUDs, PFR and flood protection in lower reaches (EA, 2019c; Wells et al., 2019). These can be further supported by underlying policies of improving flood awareness, social responsibility (e.g. the 'Know your flood risk' campaign) (Mees et al., 2016), contingency planning, and preparedness and recovery capacities.

Whilst policy has been constrained by historic management approaches in the Netherlands, there is a notable development to increase the inclusion of FRM approaches for flood safety. The three-layer 2009 MLS strategy was the first policy to combine flood protection (layer 1), spatial planning (layer 2) and disaster management (layer 3) (Kaufmann et al., 2016b; Jong and Brink, 2017) for a diverse FRM approach (Rijksoverheid, 2009). Since this strategy, campaigns to increase public flood awareness (e.g. OW Water), information sharing (e.g. 'Am I being flooded', *Overstroom Ik?* and National Information System Water and Floods, *Landelijk Informatresysteem Water en Overstroming*), contingency planning (e.g. Water and Evacuation project), and climate-proofing buildings (Ministerie I&W & Ministerie EZ, 2015; Delta Programme, 2021) to address previously overlooked flood risk aspects. However, dike flood protection remains the 'corner stone' of flood safety and continues to be progressed alongside, if not ahead of, FRM development. This includes the introduction of Delta Dikes, continuing dike strengthen (e.g. Flood Protection Programme; FPP) and higher flood protection standards for new dike stretches (Ministerie V&W, 2009).

This persistent foundation and remaining path dependency, which could now be argued to focus on technological advances of flood protection and *prevention* of Dutch flood safety, has resulted in FRM strategies acting as fail-safe or back-up measures rather than measures for individual safety cycle aspects. A further example of this is the Water Assessment (*watertoets*) spatial planning procedure that is not only supplementary to the engineered flood safety discourse, but also helps progress it by reducing the impact of development on the catchment and river widening schemes (van den Brink et al., 2011). Although adaptive, sustainable climate-resilient spatial planning in 'smart combinations' that balance protection (e.g. dikes), prevention (e.g. river widening and spatial planning) and preparation (e.g. disaster and contingency planning) has more recently been included in policy, there is limited evidence to indicate how these have been successfully applied. In contrast, the similar Sequential Test in England limits non-essential development in at-risk areas to reduce exposure and flood risk. In case of exceptions, and for developments in lower flood risk zones, flood-proof building regulations aim to make sure developments are safe for their lifetime without increasing risks elsewhere with no government funding available to protect properties built after 2012 and the introduction of the sequential test and National Planning Policy Framework (NPPF) (DEFRA, 2021).

4.4 Current and future FRM in England and the Netherlands

Recent policy changes for FRM in both England and the Netherlands can be seen as a gradual move towards achieving country-wide resilience and balanced FRM. The CBA approach, that has been primarily applied for flood protection in both countries, balances socio-economic benefits and has evidently prioritised large urban areas. However, this priority is gradually falling in the Netherlands with the construction of flood protection in rural areas along the River Meuse (Wesselink et al., 2007). This is also occurring in England with the removal of the urban area priority in the MSfW policy, OMs that address overlooked and neglected flood risks in rural and dispersed communities in England (Johnson et al., 2008), and the new FFA that supports continually flooded but neglected at risk areas (DEFRA, 2022). Focusing specifically on developing flood risk resilience, the Netherlands currently has a minimum mortality rate of 1/100,000-years for every individual living behind primary dikes (Delta Programme, 2021), and in England a 'national standard of flood resilience' (EA, 2019c, p. 18) has been suggested with the 2020 Flood and Coastal Erosion Risk Management (FCERM) strategy focusing on climate resilient places, with support from a Flood and Coastal Resilience Programme (FCRIP), resilient infrastructure and adaptation to flood risks (EA, 2020c).

In working to achieve this country-wide resilience, both countries show a progression towards well-balanced FRM that aims to cover all safety cycle aspects, and a closer alignment with each country's main policy focus. For instance, In the Netherlands holistic strategies to reduce potential flood impacts and increase water-resilience are being more widely included in policy (Delta Programme, 2021). Although this focus has reduced slightly in the 2022 NWP, the recognition towards accepting residual risk, improving climate adaptation policy and the future consideration of potentially needing alternative solutions (Government of the Netherlands, 2021b) the underlying intentions are still present. In England, there is an increasing focus on flood protection in England's FRM 'toolkit' (EA, 2019c) including the combination of permanent, demountable, and temporary flood protection infrastructure (EA, 2020c). This is further reinforced by new available funding streams (e.g. Frequently Flooded Allowance; FFA) that provide more opportunities to increase flood protection for properties that may have been previously overlooked.

Improving and diversifying FRM also aims to address previously discussed resilience capacities, including the capacity to resist with flood protection infrastructure and natural prevention approaches (e.g. IWM and NFM), and the capacity to absorb and recover with flood forecasting and warning systems and FRM strategies (Hegger et al., 2016a). Further, England's FRM policy is improving the capacity to adapt by establishing institutional learning, community-scale adaptation initiatives with local resilience fora, and including climate change and future uncertainties in FRM assessment, planning and policy (Hegger et al., 2016a). In some cases, this high level of stakeholder and community participation is even accounted for by funding for management schemes being supplemented by local communities through partnership funding (Priest et al., 2016; DEFRA, 2019). However, while policy makers, and particularly engineers, in the Netherlands have developed a high level of knowledge on improving flood safety, protection and integration with IWM and spatial planning to reduce flood consequences, as well as formalising the duties undertaken by relevant water RMAs (e.g. municipalities and WBs), further adaptation may be hindered by lack of public participation from low flood awareness and limited opportunities for community inclusion in FRM practice due to the dominant flood protection strategy (Hegger et al., 2016b, 2016a; Priest et al., 2016).

In England, the high degree of public participation in FRM remains driven by the frequency of reoccurring flood events. However, these recent UK flood events in winter 2019-2020, in addition to other major flood events since the implementation of the MSfW policy and subsequent FCERM strategy, raise questions over the effectiveness of England's FRM approach and future direction. In addition to the rising importance of increasing resilience, as well as greater availability of funding for FRM in overlooked areas, consideration of the 2018 Green Future 20-year plan will most likely result in increasing schemes that provide environmental benefits (e.g. NBS, NFM and SUDs). Like the Netherlands, consideration of alternative solutions identified through the FCRIP may further diversify, while strengthening, FRM in England with innovative approaches to reduce local flood risks. Thus, the future FRM strategy may represent a larger reliance on sustainably holding back water to reduce flood event severity, while making remaining at-risk rural and urban areas more resilient and protected against flood impacts with a combination of traditional and innovative methods. This is further suggested by recent government communication that acknowledge the increasing frequency of extreme flood events and suggest that it is impossible to protect every single household from these risk, and that the scale of flooding in some cases may increase so significantly that communities may have to relocate (EA, 2020b).

No major river floods have occurred in the Netherlands since 1995, but occasional flood threats and pluvial flooding, for example in February 2020 in Dordrecht and referred to as 'nuisance' (*overlast*), are projected to increase in frequency and severity. However, the difference in scale between river floods and pluvial flooding, and the differing attitudes towards these, may prevent any policies with respect to this type of flooding being acted on fully until a significant pluvial flood occurs. Additionally, when considering the technological and political lock-ins that continue to be strengthened by protection improvements, flood protection will likely remain the core FRM strategy but be increasingly supported by emerging approaches for other FRM aspects (e.g. the MLS strategy, a larger focus on spatial planning, and flood-proof buildings). Alongside these developing FRM approach, like in England, there has been a very notable shift in communication with consideration of protection infrastructure failures and remaining residual risk past design standards beginning to be included in policy. However, to fully support this advancement, the 'third layer' of Dutch FRM development that focuses on strategies to increase public engagement and flood risk awareness needs to be enhanced. Integrating these approaches with an increased uptake of FRM measures and presenting these as a viable option for Dutch flood safety, not only as back-up strategies to the technocratic approach, is required to deal with future uncertainties of flood risk in the Netherlands.

4.5 Policy Change Drivers and Development

The process of implementing and developing FRM strategies in England and the Netherlands reflects the varying policy change theories summarised above. While previous theories have been presented in isolation, this Chapter has identified the extent to which these theories are interconnected (**Figure 4-2**) with no sole driver resulting in policy change or policy development. A distinction must also be made between implemented policy and acted on policy.

While developments may emerge in policy, if there is a lack of consensus to progress, or act on, these policies, they often struggle to be adhered to completely. For example, IWM strategies were introduced in the Netherlands in the 1989 Third Memorandum to connect water, environmental and nature policies, but these strategies were not acted on completely until the 1993 and 1995 floods created an incentive for the RftR strategy. This is also seen in recent proactive FRM policy changes in the Netherlands (e.g. MLS) which were introduced following changing discourses surrounding future climate change projections, impacts, and potential flood protection failures. However arguably these strategies lack incentives and urgency to be fully acted on as no major floods or management failures have highlighted the need for new approaches to FRM (Van Doorn-Hoekveld, 2014).

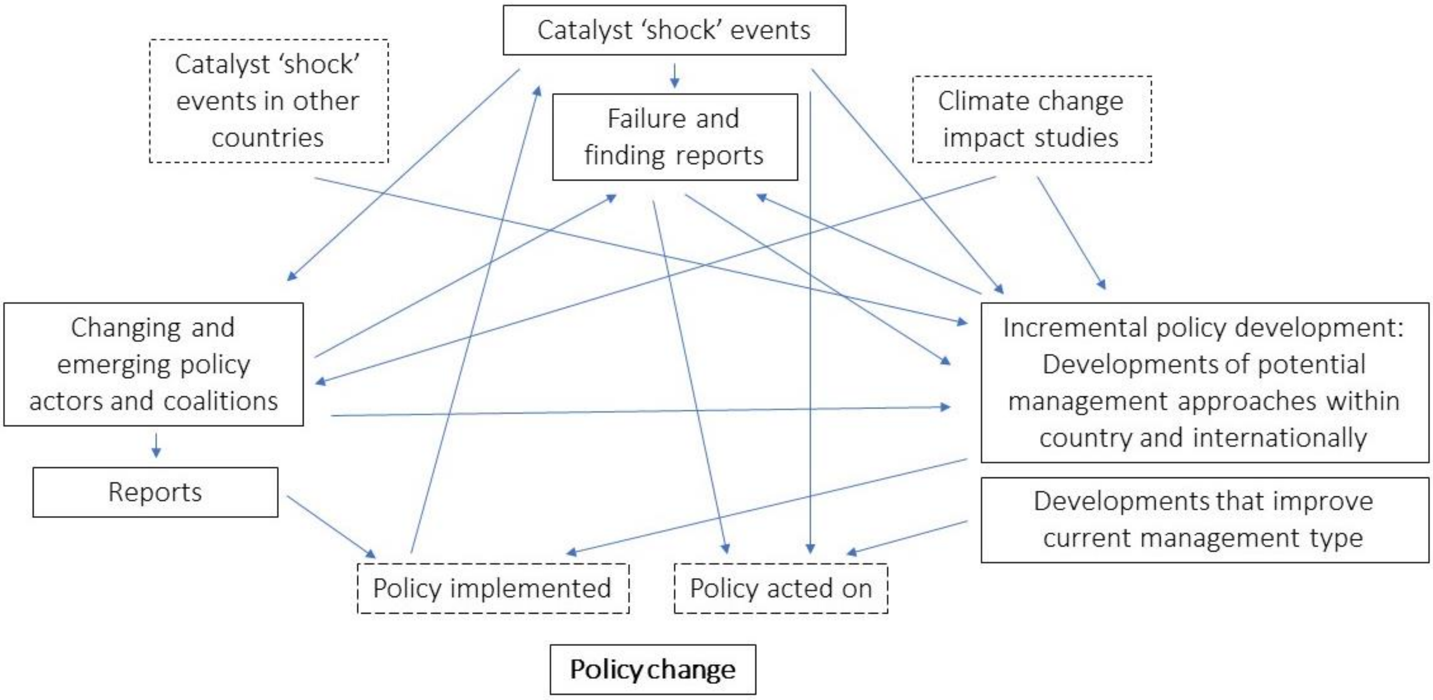

Figure 4-2: Interconnected policy change between drivers as observed by the Netherlands and England. Connections are represented through arrows, with solid lines representing policy change drivers identified through theories (Kingdon's Multiple Streams, Advocacy Coalition Framework and Easton's System Theory) and dashed lines representing policy change drivers identified from this FRM development review in England and the Netherlands.

Similarly, in England, powers to avoid floodplain development have existed since the 1947 Town and Country Planning Act but were largely ignored for other socio-economic priorities. The 1998 and 2000 floods further highlighted the problem, that resulted in more stringent spatial planning for flood risk policy in the 2001 PPG24 that introduced the Sequential Test (Johnson & Priest, 2008). Reoccurring flood events, particularly the catalyst events of 1947 and 1953, also highlighted the lack of private flood insurance take up that led to the ABI agreement (Penning-Rowsell, 2015b).

The largest driver to both implement, and act on, policy is thus in succession to a catalyst event, in line with Kingdon's 'policy window of opportunity' (Kingdon, 1995). However, this Chapter suggests that the type of strategy implemented depends on the level of occurrence of major 'focussing' flood events. When comparing subsequent policy changes in both countries, singular flood events resulted in improving current and stabilised management strategies in a 'recover and return response' described by (Kaufmann et al., 2016a). In contrast, the occurrence of two consecutive flood events altered policy directions and progressed new strategies and solutions. For both countries, the main factor in this is reoccurring events of similar or higher magnitudes which highlight the increasing impacts and potential threat(s) from more frequent and severe flood events (Johnson et al., 2005; Wesselink et al., 2015; Kaufmann, 2018). For example, in England the larger and singular flood events in 1947, 1953 and 2007 strengthened the dominant flood management approaches that were in place at the time that were, respectively, flood protection for agricultural areas, flood protection for urban areas, and diversified FRM. While the flood protection strategy focus may have shifted overtime with improving knowledge and technology, the underlying approach remained the same. Yet, consecutive flooding in 1998 and 2000 highlighted increasing impacts from potentially more frequent and severe events (Johnson et al., 2005) and resulted in a policy shift to integrated FRM, namely the 2005 MSfW policy which was subsequently strengthened and further diversified in policy after 2007.

In the Netherlands, engineers highlighted the inadequacies of dike protection since the 1930s but no action was taken until the 1953 flooding highlighted weaknesses and strengthened structural flood protection (Wesselink et al., 2007; Kaufmann et al., 2016a). The 1993 flood event began to reinforce flood protection but nationally had a limited response on altering policy (Kaufmann et al., 2016a). However, the combination of the 1993 and 1995 flood events enabled the progression of integrated IWM and preventative spatial planning concepts to alter the direction of flood safety policy and be implemented completely (Vis et al., 2003; Kaufmann, 2018). These examples can be characterised as following a pattern whereby singular flood events highlight the flood problem, which in turn increases and strengthens the approach in place, while multiple flood events in close succession indicate that the management approach will be potentially unable to deal with the future flood problems. The potential threat of flooding thus creates a demand for policy change and progresses new solutions.

While a catalyst event is needed to implement and act upon new policies, the way these new solutions emerge reflect both the Advocacy Actor Framework (Sabatier, 1998) and the research supporting important and necessary incremental developments for policy change (Easton, 1957). A number of contextual (e.g. technology and knowledge) and behavioural (e.g. values and beliefs) (Penning-Rowsell et al., 2017) developments have occurred in both countries to develop FRM strategies, as well as for IWM in the Netherlands. These 'on the shelf' solutions are often progressed by new and overlooked actors in policy niches, that are given a platform in policy arenas when catalyst events occur, by connecting them to the flood problem (Penning-Rowsell et al., 2006). For instance, in England, the Thames Storm Surge barrier that strengthened urban flood protection was implemented after severe flooding in 1953, but its adoption had previously been the subject of the earlier Thames Flood Act in 1879 (Penning-Rowsell et al., 2006).

In the Netherlands, technological and knowledge-based incremental developments to improve flood protection dikes that have reinforced the 'technological lock-in' (Wesselink et al., 2007), including improvements to protection standards, the reoccurring FPP, and more recent Delta Dikes. However, developing IWM concepts that were connected to the flood safety problem by changing coalitions of new ecologically-focused actors in the 1980s. The 1985 report Dealing with Water (*Omgaan met Water*) highlighted further engineered safety problems (RIZA, 1985; van der Brugge et al., 2005; Loorbach & Rotmans, 2006), while the winning 1986 national river management competition (*Netherlands – Riverland*) entry, Plan Stork (*Plan Ooievaar*), presented IWM as an alternative for flood safety and implemented in the 1989 policy (Rijkswaterstaat, 1989; van der Brugge et al., 2005). The 1993 Dutch World Wildlife Fund plan Living Rivers (*Levende Rivieren*) also connected IWM and flood safety to introduce preventative side channels and floodplain re-connections for the Rhine and Meuse, included in policy to form the RftR strategy (van der Brugge et al., 2005; Huitema & Meijerink, 2009). These actors were also successful in reducing ecological impacts from the Delta Works, and particularly the Eastern Scheldt, barriers that resulted in the world's first moveable panel barrier in 1986 with several restoration projects (van der Brugge et al., 2005; Wesselink et al., 2007; Wiering & Winnubst, 2017).

Smaller, non-catalyst flood events can also lead to incremental developments in FRM policy and practice. Flood events in the Netherlands in 1998, 2003 from localised dike failure (van der Brugge et al., 2005), and later in 2012 the fear of further dike failure (Cultural Heritage Agency, 2014), showed varying flood protection failures were not solely related to the height or strength of dikes. In contrast, external flood events such as in Europe in 2000, and in New Orleans, US, in 2005 did not directly impact the Netherlands but influenced policy by, respectively, progressing integrating spatial (e.g. floodplain widening, water storage and retention areas) and technical solutions (Ministerie V&W (CW21), 2000), and improving crisis management and communication as part of the MLS strategy (Slomp, 2012;

Kaufmann et al., 2016b). Global flood events can also therefore act as incremental influences for policy and practice development.

Due to the high protection standard and lack of catalyst flood events, these incremental developments have been notable in the Netherlands in recent years, with a clear shift towards more proactive policy changes focusing on potential future climate change and management failure events (e.g. MLS). Yet, as previously mentioned, these strategies reportedly lack incentives for complete implementation as no major flood incidents have highlighted the need for them (Van Doorn-Hoekveld, 2014). In England, incremental developments include the decreasing importance of agricultural drainage for urban protection (Tunstall et al., 2004) and advocates for comprehensive FRM options and NBS with increased ecological considerations (Fleming, 2002; DEFRA, 2005; Wiering et al., 2015; Wells et al., 2019). However, by implementing a lower standard of protection generally, and a portfolio of FRM approaches, England continually experiences reoccurring flood events.

While this reactive approach to policy change is often recognised as a negative, it has ensured that FRM strategies, as well as earlier protection-focused approaches, are continually strengthened and mostly acted upon fully. This reactive policy response is further showcased by strengthened management discourses identified from scrutiny reports (e.g. Waverley Committee, 1954; Bye & Horner, 1998; Pitt, 2008), that connect new and on the shelf solutions to management gaps or failures during significant flood events. Thus, in some cases, particularly the reactive response in England, current actor coalitions already in policy arenas can influence policy change as well as continuing to strengthen flood management practices.

4.6 Chapter Summary

This chapter has reviewed policy changes in England and the Netherlands and investigated the developments towards FRM in both countries. Flood management in the Netherlands was institutionalised earlier than in England, but several constrictions have resulted in a path dependency, or 'technological lock-in', on protection strategies. Contrasting effects in England have resulted in continual developments towards improved FRM practices, but continual flood events have highlighted recurring management failures which need to be addressed. Both countries show a progression towards FRM and resilience of some type, but while included in policy, there are differences in the level and extent of application of practices in both countries. This may be due to influences from varying policy drivers, identified from policy theory in this chapter, that highlight the interconnectivity of these theories and how multiple drivers may be required to successfully bring about policy changes that are fully acted on.

CHAPTER 5:

INCLUDING ‘VULNERABILITY’ IN FLOOD RISK MAPPING IN ENGLAND AND THE NETHERLANDS

This chapter incorporates some research that was subsequently included in the ‘**Flood: Aware, Inform, Resilient (FAIR) Approach to Flood Risk**’ project undertaken by Staffordshire County Council (LLFA). This project is part of the DEFRA and EA Flood and Coastal Resilience Innovation Programme Fund.

The project aims to develop a participatory approach to enable communities and RMAs to work in partnership to co-design specific innovative and community-led interventions for improved resilience to flooding (including reducing damage and disruption, speeding up recovery).

This project incorporates discussions and methods from the GIS flood risk assessment in this Chapter, including the combination of vulnerability and hazard data to define flood risk, to determine levels of flood risk and resiliency in Staffordshire communities.

CHAPTER 5: INCLUDING VULNERABILITY IN FLOOD RISK MAPPING IN ENGLAND AND THE NETHERLANDS

5.1 Scope of Chapter

This supplementary chapter provides a short discussion on the development of flood risk mapping, an important FRM component for DRR, and the extent of this in England and the Netherlands. Results from a trial method for including vulnerability data in a flood risk map for the Trent catchment, England, are included and discussed.

5.2 Introduction

The shift to dynamic, risk orientated FRM aims to reduce flood risks by equally considering hazard, exposure, and vulnerability through the combined application of structural and non-structural strategies (Merz et al., 2010). Non-structural FRM and adaptation measures focus on raising flood risk awareness and preparedness strategies to improve and enhance decision-making processes (Ward et al., 2013b; Sayers et al., 2015a). An important component of this is to provide readily available information on flood risk such as the preparation of flood risk maps to communicate risks amongst RMAs, partners, and the public, as well as aiming to promote risk-reducing behaviours (Ward et al., 2013b; Sayers et al., 2015a). In their review of emerging topics in FRM literature, Morrison et al. (2018) suggested that while most papers categorised within the theme of 'tools' for FRM focused on prediction, modelling and forecasting of flood risks, 33% of articles concentrated on flood risk assessment and planning. This includes examining existing and proposed tools to assess flood impact assessments, CBAs, and vulnerability to floods as well as flood risk mapping (Morrison et al., 2018). However, hazard projections and modelling are a likely source of discrepancies highlighting the need for caution among FRR decision makers (Kundzewicz et al., 2017).

In the UK, and in most European countries, developments in computing facilities, mathematical modelling and risk mapping have considerably improved the suite of tools available to study, assess and predict flood events which has, in turn, increased flood knowledge and information (Tunstall et al., 2004). A significant body of literature in this area focuses on flood mapping developments in Europe associated with the implementation of FD in 2007. The FD acknowledges that in many cases flooding is unpreventable and the FD seeks to reduce flood risk consequences with improved preparation, coping and adaptation capacities. These require member states to undertake and publish flood hazard maps (European Union Commission, 2007). Although the FD does not require transboundary flood risk modelling, the discrepancies in flood risk between neighbouring member states can be identified by exchanging information to create a mutual understanding of levels of flood risk, and thereby improve and integrate coordinated FRM by initiating transboundary flood risk discussions and cooperation (Priest et al., 2016).

FRM decision-making is increasingly dependent on available and accessible data. Although this has increased dramatically in recent years, particularly within the big data era, data is often derived from complex range of sources with a mix of structured and unstructured data at varying scales that require integration (Towe et al., 2020). Traditional flood management evaluated floods from a static, hazard-focused perspective that focused on hydrological parameters of discharge and inundation level that can be equally compared. However, this often neglects societal processes, such as vulnerability, or assume these to be constant and stationary rather than a highly dynamic assemblage of processes that play an equal part alongside hazard and exposure, which need to be addressed to reduce flood consequences (Ward et al., 2013b; Merz et al., 2014). Thus, if current and future flood risks are to be reduced, attention should be devoted to mapping vulnerability hotspots and improving the flood risk situation in these areas (Kundzewicz et al., 2017). Mapping vulnerabilities may also help in improving resilience capacities to absorb and recover from unexpected flood events with tailored, location-specific responses such as flood awareness and responsibility campaigns that aim to overcome key vulnerabilities or are directed towards vulnerable areas. Further, this risk information can improve capacity to transform and adapt by supporting institutionalised learning mechanisms such as learning-action alliances and an increased capability for communities to adopt new approaches (Hegger et al., 2016a).

Although flood risk assessments and their representation as flood maps have improved overtime to incorporate hazard and exposure, vulnerability still remains difficult to address (Koks et al., 2015). Some flood risk mapping studies consider several societal factors that are understood to increase flood risk vulnerability or reduce community resilience (Chen, 2021) and/or coping capacity (Dandapat & Panda, 2017) of at-risk individuals. However, the inclusion of vulnerability in flood risk assessments or visually represented in flood risk maps varies significantly. The factors included also depend on the individuals undertaking the assessments and their proposed approaches towards these. For instance, some recent studies have continued the traditional hazard focused approach to only focus on the physical conditions of the flood hazard in recent flood risk mapping assessments (Feloni et al., 2019), while others have begun to include separate aspects of exposure such as fixed assets and road networks (Hu et al., 2017). More recent studies may include aspects of vulnerability but focus on damage to the physical and built environment such as susceptibility of properties to physical and economic losses (Koks et al., 2015; Glas et al., 2019; Zhang et al., 2020), that may be considered elements of exposure by others, or simply include societal vulnerability as an assumed homogenous value for the entire population (Koks et al., 2015). All aspects of flood risk are important and require modelling and mapping, but to reduce overall flood risk all driving factors need to be considered.

Flood hazard and flood risk maps are a non-structural FRM method of communicating potential flood risks to the public to raise flood awareness in at-risk areas (Rollason et al., 2018). This has become more prevalent with the EU FD that requires flood risk information to be available to the public. However, the communication of flood risk maps may, in some cases, result in an increase of flood risk by increasing vulnerability. Most flood risk maps focus on flooding at given return period intervals, which is the basis for the current defined standard in the EU FD and US National Flood Insurance Programme and is widely used across the world when discussing flood events (Demeritt & Nobert, 2014). However, studies on public flood risk perceptions and understanding have indicated public confusion around the meaning of flood event return period (e.g. the 1/100-year event) (Highfield et al., 2013; Demeritt & Nobert, 2014). Considerations of using AEP percentages in place of return periods also suggest that the public struggle to ‘decode’ statistical probabilities (Demeritt et al., 2014. Thus, flood maps intending to raise awareness about flood risk levels and impacts may have the opposite effect and should therefore be designed to ensure public audiences can understand and interpret the information (Henstra et al., 2019).

5.3 Netherlands mapping

Flood hazard maps usually identify areas that are not defended by flood protection, such as those in England that consider present flood protection assets for flood risk output levels. However, due to the high protection standard and frequency of flood protection in the Netherlands that includes dikes, embankments, and other engineered assets, flood hazard and flood risk maps predominately focus on protected areas (de Bruijn et al., 2015). The Water Decree (*Waterbesluit*) that formally introduced national plans required under the WFD and FD frameworks require that flood risk maps for the Netherlands be produced, publicly shared, and updated by individual provinces every 6 years (Van Doorn-Hoekveld, 2014). While the provinces have always been responsible for general mapping, the first flood risk maps were produced using flood simulations by I&W with information provided by the provinces and WBs (Van Doorn-Hoekveld, 2014; de Bruijn et al., 2015). The 2007 Provisional Risk Map Regulation (*Regeling Provinciale Risicokaart*), updated in 2010, provides the framework for the risk maps: for flood zones, conditions of inclusion include areas with a probability of flooding exceeding 1/4000-years, river areas that were inundated or threatened by flooding in 1993 and 1995, and designated overflow areas (*Regeling Provinciale Risicokaart 2010)*. These flood hazard map outputs are available (Risicokaart.nl) as separate maps for very small, small, medium, and high probability events, or the chance of flooding in case of flood protection breaches (Risicokaart n.d.). Flood depths that correlate with varying public risk reduction actions and typical heights of property flood levels are also available. For example, in a flood depth of 80cm – 2m, the first floor of a property is deemed safe, while in a 2m – 5m flood depth area the second floor of a property is safe (Risicokaart n.d.). Flow velocity, flood timings, flood duration and source of flooding maps are also available (de Bruijn et al., 2015).

The VNK project (discussed in Chapter 4) focuses on flood risk consequences alongside flood hazard and exposure and uses decades of research to quantify probabilities and consequences for dike protection systems in the Netherlands (Jongejan et al., 2011; Jongejan & Maaskant, 2015). Between 2001 and 2006 the first project, VNK1, focused on sixteen dike rings and this expanded to include all major dike systems in the 2006 VNK2 study by Rijkswaterstaat and the I&W (Jongejan & Maaskant, 2015; Rijkswaterstaat VNK Project Office, 2015). Applying a country-wide probabilistic quantitative risk analysis, the probability of failure was calculated for statistically homogenous sections of dike systems to create scenario probabilities of economic damage and fatalities during a failure event (Jongejan & Maaskant, 2015). Economic damages consider potential flood depths, the area inundated and land use or infrastructure exposed, while the potential number of fatalities depend upon flood water rise rate and velocity, the population in the area, and the potential for evacuation (Rijkswaterstaat VNK Project Office, 2012).

The inclusion of evacuation levels is important as this can strongly influence the potential number of fatalities during dike breach events and are estimated by forecasting flood timings and considering whether the evacuation is organised or disorganised (Rijkswaterstaat VNK Project Office, 2012). Emergency measures and their effectiveness are not considered in failure probabilities, as these are based solely on dike flood protection failures as a product of strength (resistance) and weight of flood water (solicitation) (Rijkswaterstaat VNK Project Office, 2012). These economic damage and fatality scenarios can further be used in CBAs for future risk reduction interventions in line with the Delta

Programme and Delta Decisions, as well as spatial planning and crisis management that is part of the MLS scheme (Jongejan & Maaskant, 2015).

Alongside flood risk maps produced by Rijkswaterstaat, I&W and the provinces, in the Netherlands, flood risk maps have also been produced for academic research. Examples from de Bruijn et al. (2015) (**Figure 5-1**) show outputs of flood damage and flood fatality mapping. Existing damage and mortality functions (that calculate maximum damage and mortality rates for the relevant flood parameters based on the 1953 flood) with homogenous land use factors were applied across the country (de Bruijn et al., 2015). Unlike previous outputs that focus on risks within dike protection rings, hazard determining parameters are applied to both protected and unprotected areas, however regional waterways are not included due to insufficient data (de Bruijn et al., 2015). Social vulnerability data are included with individual factors combined to derive a flood fatality map that reflects: i. the flood probability; ii. the probability of reaching a safe area (considering evacuations and flood characteristic functions); and iii. the mortality of the people in flooded areas, a function of flood characteristics, area characteristics and social vulnerability and behaviour (de Bruijn et al., 2015). Social vulnerability and behaviour depend on flood risk preparation, experience, area knowledge, age, health, and quality of flood risk information provided alongside building vulnerability data to determine whether individuals are safe in their properties. However, these factors, while included, are not further explored within this Chapter.

This work by de Bruijn et al. (2015) develops previous work by (de Bruijn & Klijn, 2009) who devised a vulnerability rating of at-risk areas focusing on physical vulnerabilities of sudden flood onset, difficult terrain for evacuations and large proportions of people such as cities, towns, and large villages (de Bruijn and Klijn, 2009). However recently studies have started to include further social vulnerability elements. For instance, Kirby et al. (2019) devised a vulnerability index for the province of Zeeland using 25 characteristics that were thought to impact social vulnerability to flood risk. These include demographic, socio-economic, infrastructure and community data from the Statistics Netherlands service. While the study does not include flood hazard information, it is a good first approach to determining province-level flood risk socio-vulnerability that is equally important for level of flood risk, alongside evacuation, hazard characteristics and dike breach data, if a protection failure event were to occur in future (Kirby et al., 2019).

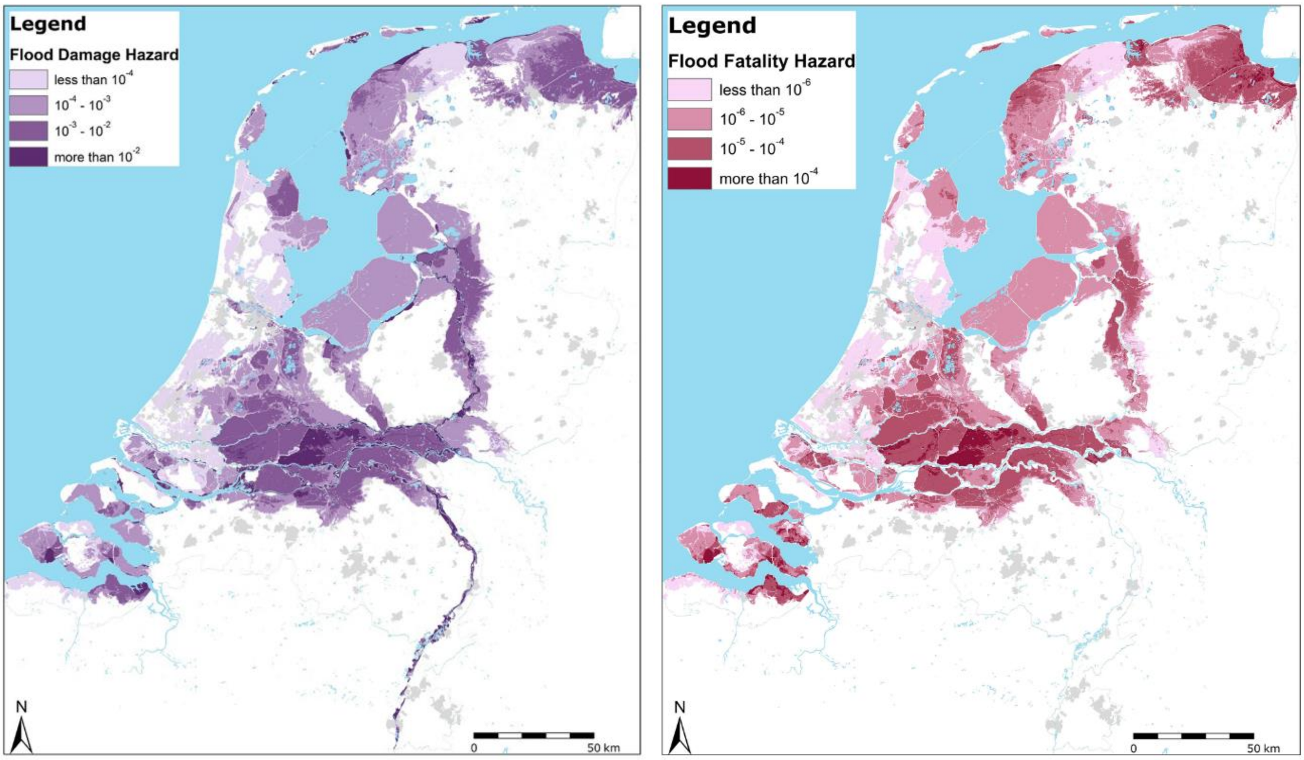

Figure 5-1: Flood risk map outputs for flood damages and flood fatalities in the Netherlands. Source: de Bruijn et al. (2015)

5.4 England mapping

In England, fluvial, coastal and pluvial flood risks are modelled and mapped nationally, with information of past flooding included to improve accuracy (HM Government, 2016; EA, 2018c). Data from local knowledge is included where possible (HM Government, 2016) but the level of detail and amount of this information is sometimes unclear. The EA's 'Flood Map for Planning' indicates flood zones for Risks of Flooding from Rivers and Seas (RoFRS) and supports the risk-based FRM approach applied in England (HM Government, 2016). Flood Zone 3 indicates land that has an annual chance of flooding that is greater than or equal to 1% from rivers, or 0.5% from the sea. Flood Zone 2 indicates land that has an annual chance of flooding between 1% and 0.1% for rivers, and between 0.5% and 0.1% for the sea. The outer boundary of Flood Zone 2 is described as the Extreme Flood Outline, with remaining areas in Flood Zone 1 that have an annual chance of less than 0.1% chance of flooding (HM Government, 2016). An additional Flood Zone 3b was previously used to indicate land in the functional floodplain. These outlines take flood protection structures into account for levels of flood risk, as well as separate derived maps that detail spatial flood defences and areas benefitting from food defence (Fielding, 2017).

In the public facing version of these maps, these risks have been converted into high, medium, low, and very low risks for both extent of flooding from rivers and seas, surface water and reservoirs (Gov UK, n.d.). Additional Risk of Flooding from Surface Water maps (RoFSW) are available and indicate high risk, medium risk and low risk of surface water depths and surface water velocity (Gov UK, n.d.). However, the information surrounding the maps state that only a strategic assessment on the potential risk and impacts of flood risk can be obtained from the maps. Flood hazard and risk maps are updated in line with the 6-

year cycle of the FD (EA, 2018c). Supporting communications of river levels, flood alerts and warnings are also available (Rollason et al., 2018) but are not included in the maps. Additional maps identify further flood risk exposure and provide information on impacts on people, quantified by data from the Office of National Statistics (ONS), services, the economy, and the environment (Gov UK, 2019). However, limited information is provided in these maps with only select flood risk areas available, which are identified by a preliminary flood risk assessment of flooding from main rivers, seas, and reservoirs for England (EA, 2018c). The EA has sought to identify smaller areas at risk in some recent projects, such as the regional Communities at Risk (CaR) project across the West Midlands. This used ArcGIS to group, or capture, properties at risk in varying sized buffers, and initially begin to create communities at flood risk to be used in future resilience policies and practices (EA, 2015a). Alongside indicative flood risk areas, this output is also publicly available (EA, 2021b).

Some governmental produced flood maps have begun to include vulnerability concepts and factors, such as the 2005 DEFRA ‘Flood Risks to People’ project that mapped risks of fatalities or serious casualties from flood events by including hazard and exposure elements alongside social vulnerability factors of age, health, and long-term disabilities from ONS census data (DEFRA & EA, 2006). ONS data are often used in flood risk assessments, for instance the use of the English Index of Multiple Deprivation, as information on property deprivation has to be submitted to achieve capital funding for flood reduction schemes (comments from LLFA), but these data are obtained separately. Further, large UK datasets that incorporate flood and census data to derive flood vulnerability indices are becoming more common. One of the largest is the ‘Climate Just’ dataset developed by the Joseph Roundtree Foundation and the University of Manchester that translated census data into five vulnerability indicators: sensitivity, enhanced exposure, ability to prepare, ability to respond and ability to recover (Lindley et al., 2011; Sayers et al., 2015b). Vulnerability index scores for defined census areas (Middle Super Output Areas; MSOAs) across the UK are then provided for this data (Lindley et al., 2011). While this information is recognised by government bodies, particularly the EA, these data are not incorporated into any government map outputs for flood risk.

5.5 Including Vulnerability in Flood Risk Maps for the Trent Catchments

Flood hazard maps are often created using statistical and data driven methods that include hydrological, topographical, Digital Elevation Model (DEM) and geomorphic data that is combined and processed in GIS (Mudashiru et al., 2021). This Chapter aims to incorporate flood hazard, exposure and vulnerability aspects for the River Trent catchment, England, and this is reflected in the chosen input information. However, the data included largely depends on the information available and in the correct GIS format, or data which can be successfully converted. Flood hazard data include: the national RoFRS and RoFSW datasets; Fluvial flood depths; modelled climate change impact on fluvial flood depths; historical flood outlines; and existing FCERM assets and conditions. Exposure data include: at-risk property density and property percentage for defined areas, sensitivity checked with the National Receptors Database (NRD) to remove properties of little significance to flood risk such as shed and garages and combined with urban and rural category data; Sites of Specific Scientific Interest (SSSIs); Agricultural land classifications; and Critical infrastructure (CI), with distance to these also included. The CI data were acquired from the NRD and include 100 types of critical infrastructure such as schools (all levels), hospitals, ambulance stations, fire stations, electricity sub-stations and water pumping stations. Vulnerability data include: the Climate Just dataset of Neighbourhood Flood Vulnerability Index (NFVI); and the Climate Just dataset of Individual Social Flood Risk Index (SFRI).

A popular method of processing these data, and the most commonly applied method for flood mapping between 2000 and 2021 (Mudashiru et al., 2021), is the Multi-Criteria Decision Making (MCDM) approach. MCDM enables chosen data to be integrated using a criteria classification of varying weightings for each piece of information that is commonly referred to as the Analytic Hierarchy Process (AHP) (Feloni et al., 2019; Mudashiru et al., 2021). This method enables experts' opinions for objective decision making to be considered in the weightings of variables based on their importance in a pairwise decision matrix (Adebimpe et al., 2021; Mudashiru et al., 2021). In the matrix, variables are assigned a scale value that determines their importance, such as the importance of value X compared to value Y, from a scale of absolute numbers (**Table 5-1**) (Saaty, 2008).

This method places a high amount of emphasis on what weightings are applied for chosen information which can create uncertainty. Fuzzy AHP (FAHP), an extension of the AHP process, seeks to reduce the uncertainty by modelling expert's weighting decisions in the fuzzy environment (Adebimpe et al., 2021; Mudashiru et al., 2021). AHP and FAHP have been applied during flood hazard, flood risk and vulnerability mapping studies (Feloni et al., 2019; Li et al., 2021). However, as the primary focus of this research is to incorporate vulnerability into risks assessments, while additionally seeking to compare the expert weightings, the AHP MCDM approach has been applied in this instance. Other applications of both methods include determining flood risk perception affecting factors with stakeholders (Buchecker et al., 2013) and measuring flood resilience of properties (Adebimpe et al., 2021).

Table 5-1: Scale values applied to determine the importance of criteria. Adapted from Saaty (2008).

Value of importance	**Definition**
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate importance
1/3, 1/5, 1/7, 1/9	Values for inverse comparison

For this risk mapping study, the pairwise matrix of values and components applied is presented in **Table 5-2**. To check for any consistencies across the values, the consistency of weightings were measured with a AHP consistency ratio calculated from lambda max (λmax; achieved by the average of the weighted sum values divided by criteria weights), the consistency index (λmax-*n*/*n*-1) and the random number index (for 11 numbers). The consistency ratio was 4% and therefore the matrix can be considered as having an acceptable consistency as this is <10% (Ishizaka & Siraj, 2020). Output tables for matrix weightings and consistency ratio calculations are given in **Appendix 2**. The list of data layers applied in flood risk map analysis for the Trent catchment are presented in **Appendix 3**. All data layers were reclassified into value classes and weighted with derived MCDM AHP values.

Arguably, the most intense interactions of risk are local, community-level interactions (Kruse et al., 2017). However, questions remain over what a 'community' is and how they can be quantified (Mulligan et al., 2016), with Bulley (2013) determining that communities need to be 'produced' first before they can be mobilised. The definition of community has expanded with social transformations, and now includes ‘virtual’, spatially extended, and ‘imagined’ communities alongside place-based communities (Mulligan et al., 2016). When focusing on flood risks, both academic and government studies define ‘community’ using geographically defined areas due to the nature of risk and for risk management purposes. For instance, ‘a place designated by geographical boundaries that function under the jurisdiction of a governance structure (e.g. town, city or county)’ (Abdel-Mooty et al., 2021, p. 2).

The place-based concept of community is applied here, using a similar approach to the CaR study that captured at-risk properties into communities using varying GIS buffer sizes for urban (100m) and rural (200m) areas. Different buffers sizes for urban and rural areas represent the difference in property density, and the size of communities in these areas. More properties are closer together in urban areas, that can result in larger communities and property clusters when buffering properties. The buffer size was therefore smaller to create communities that are more representative of urban communities, that are often smaller boroughs, housing estates or, in some cases, streets, within larger towns and cities. This differs to rural areas, where fewer properties are dispersed over larger areas and a larger buffer size is needed to include properties in villages that are more spread out, but still consider themselves a community. A minimum inclusion of 5 properties was also applied to remove single properties at high risk that might skew the results. Although place-based communities are applied here, further work is needed to address the concept of ‘community’ in flood risk analyses and DRR in both academia and policy, especially with the increasing importance and necessity of community flood resilience strategies.

Table 5-2: The AHP pairwise matrix applied to estimate weighting of each data factor listed.

Criteria	NFVI	SFRI	Flood warning areas	At-risk properties	C I	Agricultural land classes	SSSIs	Flood depths	CC impact on flood depths	Historic flooding	Existing protection assets	**Criteria weights**
NFVI	1	3	1	1	1	5	5	1	3	3	3	**0.1464**
SFRI	1/3	1	1/3	1/3	1/3	3	3	1/3	1	1	1	**0.0548**
Flood warning areas	1	3	1	1	1	5	5	1	3	3	3	**0.1464**
At-risk properties	1	3	1	1	1	5	5	1	3	3	3	**0.1464**
C I	1	3	1	1	1	5	5	1	3	3	3	**0.1464**
Agricultural land classes	1/5	1/3	1/5	1/5	1/5	1	1	1/5	1/3	1/3	1/3	**0.0243**
SSSIs	1/5	1/3	1/5	1/5	1/5	1	1	1/5	1/3	1/3	1/3	**0.0243**
Flood depths	1	3	1	1	1	5	5	1	3	3	3	**0.1464**
CC impact on flood depths	1/3	1	1/3	1/3	1/3	3	3	1/3	1	1	1	**0.0548**
Historic flooding	1/3	1	1/3	1/3	1/3	3	3	1/3	1	1	1	**0.0548**
Existing protection assets	1/3	1	1/3	1/3	1/3	3	3	1/3	1	1	1	**0.0548**

5.5.1 Results

This Chapter has produced a flood risk map for the River Trent catchment that has attempted to balance the different elements of flood risk equally: incorporating vulnerability factors alongside factors of hazard and exposure (**Figure 5-2**). While there is an identifiable spread of medium and high flood risk across the catchment, it is clear these are focused on the large to medium sized urban areas. This is particularly prevalent when noting that the only very high-risk area defined on the map is the largest urban area in the Trent catchment, Birmingham and its surrounding area. This has been captured as the 'community' with the highest risk which is most likely due to the significant surface water risks experienced in Birmingham (Adedeji et al., 2019) and the application of using GIS buffers for property-community capture in a densely urban area. High vulnerability levels are also experienced in Birmingham with high inabilities to prepare, respond, and recover identified within the NVFI (Sayers et al., 2015b).

To reduce the emphasis and influence of large urban areas, such as Birmingham, in the flood risk map, the final risk values have been altered to display the results as risk percentages within the community areas, rather than total sum (**Figure 5-3**) This offers a fairer approach to quantifying flood risks across the Trent catchment, with smaller urban areas and/or dispersed rural areas becoming more identifiable of their medium, high and very high risks in the output.

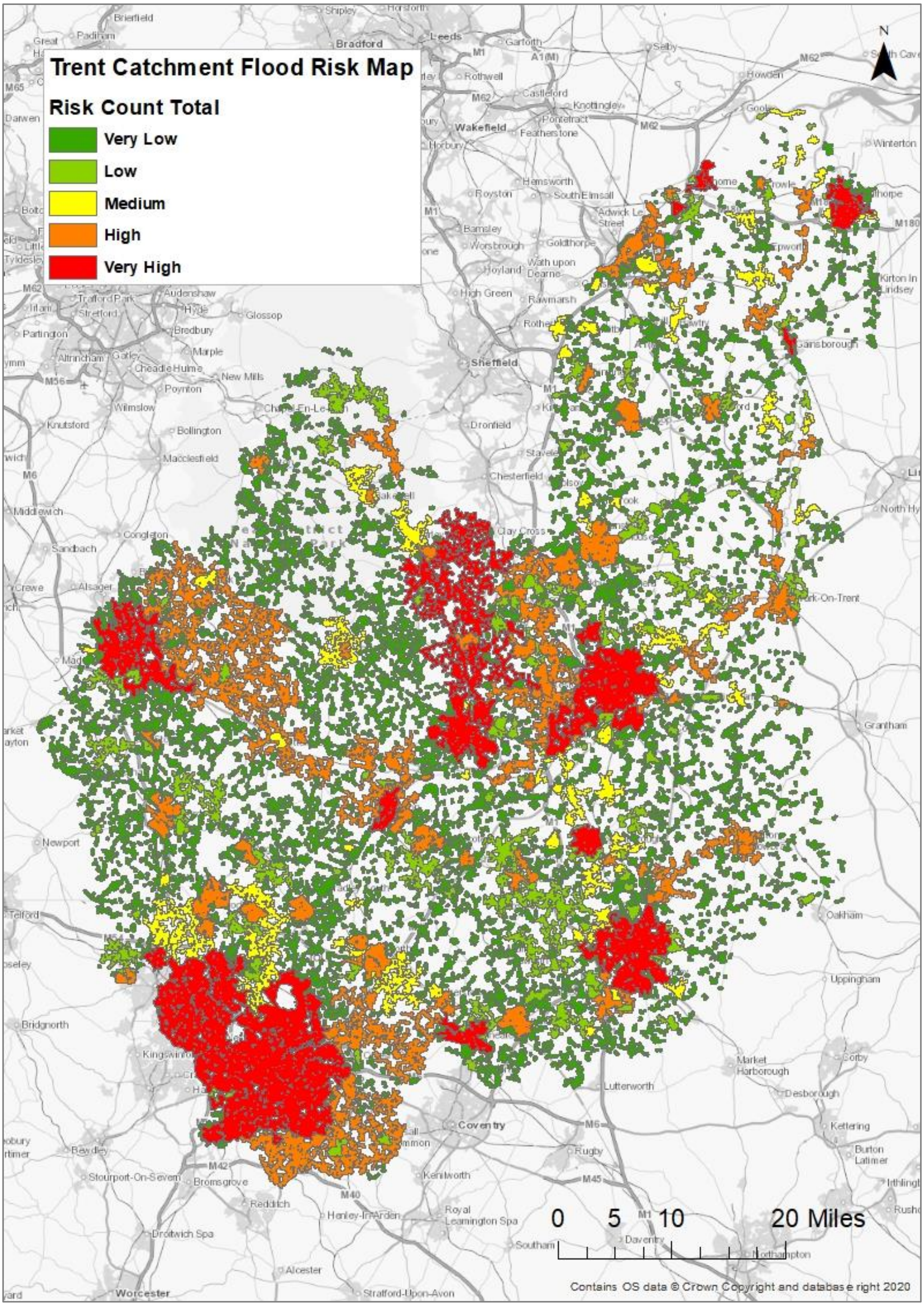

Figure 5-2: Communities at risk of fluvial and surface water flood risks in the Trent catchment by risk total. Output: ArcGIS.

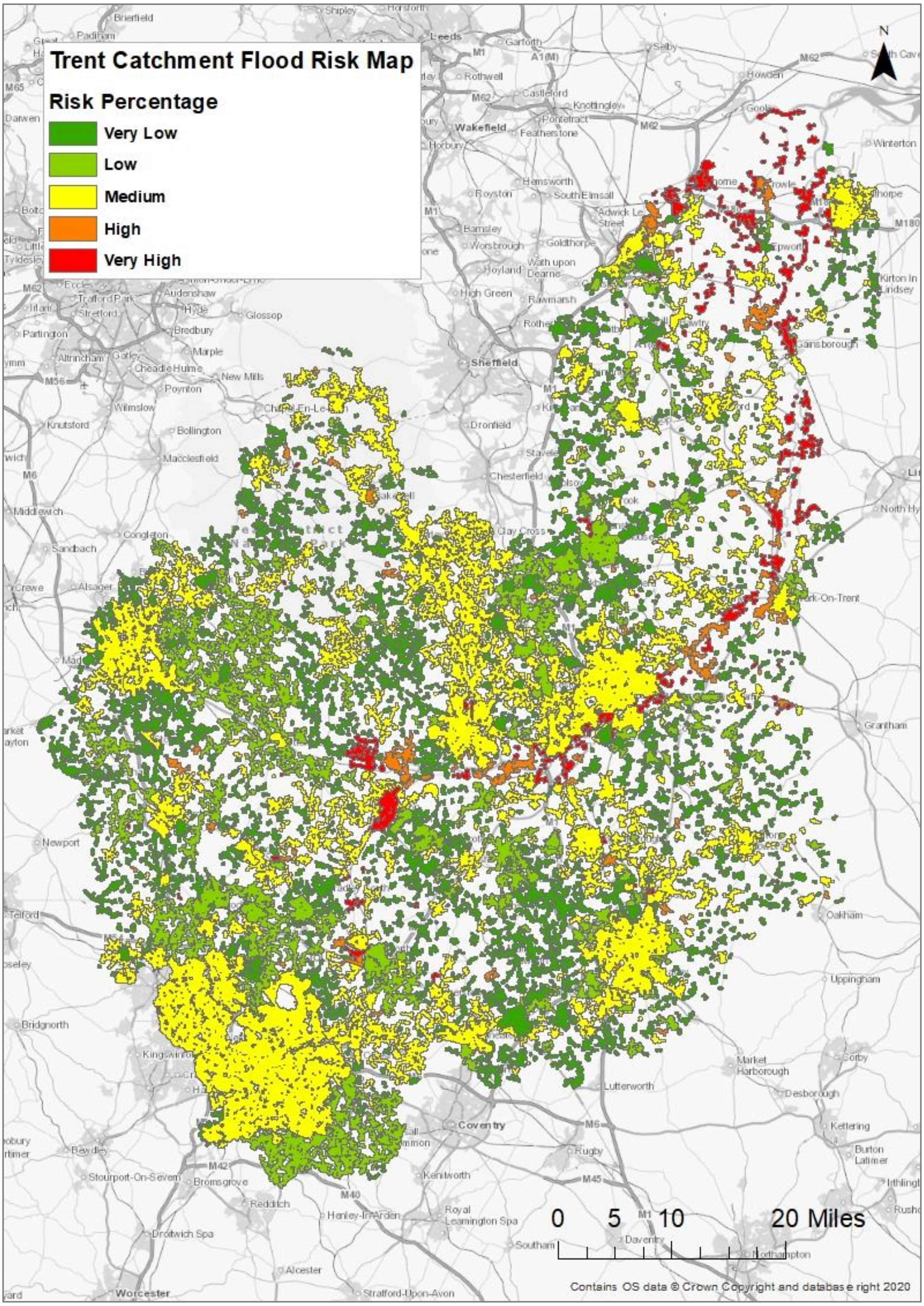

Figure 5-3: Communities at risk of fluvial and surface water flood risks in the Trent catchment by risk percentage. Output: ArcGIS.

By applying a percentage-based approach to the output, the risk priority to smaller, at-risk communities, where there may be as few as 6 properties that are all at risk (100%) and meet other risk requirements (e.g. no flood warnings, high vulnerability, and large flood risk depths), has increased. This is not a significant issue for this chapter, as it has effectively identified at-risk communities regardless of size. However, if this method were to be used to identify potential future FRM schemes, the size of communities and use of buffers may need revising to reach capital funding CBA requirements. To overcome this, communities can be divided by size prior to risk analysis (**Table 5-3**) to identify risks to small (6 – 100 properties), medium (100 – 5000 properties) and large communities (over 5000 properties). This can be beneficial in not only providing an overview of the most at-risk areas within the Trent catchment, but also applying targeted FRM approaches that suit the community size and structure.

Table 5-3: Highest ranked communities at flood risk divided into small, medium, and large by property counts. Communities have been named using a geographical location layer and give an indication of where the community is rather than the city, town, or village name.

Rank	Small communities	Medium communities	Large communities
1	West Lindsey	Stoke-on-Trent	Lichfield
2	South Derbyshire	South Derbyshire	Derby
3	Bassetlaw	South Derbyshire	Nottingham
4	East Staffordshire	Melton	Stoke-on-Trent
5	Cannock Chase	Newark and Sherwood	Leicester
6	North Lincolnshire	Charnwood	Stoke-on-Trent
7	Nottingham	Derbyshire Dales	North Warwickshire
8	Bassetlaw	Hinckley and Bosworth	Hinckley and Bosworth
9	Rushcliffe	Stoke-on-Trent	Derby
10	West Lindsey	Blaby	Cannock Chase

5.5.1 Discussion of Risk Layers and Risk Weightings

By applying the common MCDM AHP method any output will always be largely dependent on both the flood risk information included and the deemed importance, and derived weightings, of these data. The current priority of layers included for the Trent (**Table 5-4**) were identified based on supporting previous flood risk mapping studies (Chen, 2021), data availability, and researcher preference. However, by comparing the preferences of three experts in flood risk and FRM: a senior flood risk engineering consultant, a LLFA manager, and a senior academic, this hierarchy can be discussed and improved for future applications of the method or risk map criteria.

When considering the weighting decisions of the flood risk engineering consultant, the largest changes were to move SFRI and climate change flood depths impacts to high priority. The flood warning areas were also given a lower priority of a medium level. While no additional data were included, the need to consider critical infrastructure was highlighted with the reflection that this should not only be included as a high factor, if not equal to at-risk properties and/or higher than vulnerability factors, but that the critical infrastructure assets and services should be reviewed meticulously to make sure no important elements were missed.

When considering the weighting decisions from the LLFA manager, similar to the consultant, SFRI was moved to a high priory alongside the NaFRA dataset that includes the impact of FRM protection assets on risk levels. SSSI data was removed from the analysis, that was justified as SSSI sites often experience larger threats than flooding. Further, additional data was suggested as necessary such as debris factor of flood hazards, as this is a hazard to life even in low depths and velocities, asset and condition of drainage infrastructure, and significant land use changes that include agricultural practices to highlight land compaction from certain types of farming.

The weighting decisions from the senior academic further agreed to moving SFRI to a higher priority. Consideration was also given to moving historic flooding to a lower priority, given how individual flood events are changing with socio-economic developments in the catchment and climatic change.

Table 5-4: Data priority applied for the Trent catchment flood risk map produced categorised into high, medium and low priority and represented in the AHP pairwise matrix

Dataset Layer	Priority
Neighbourhood Flood Vulnerability Index (NVFI) (Climate Just)	High
Flood warning areas	High
At-risk property density in defined communities, by percentage and amount at risk	High
Critical infrastructure	High
Fluvial and surface water flood depths	High
Individual Social Flood Risk Index (SFRI) for fluvial & coastal and surface water (Climate Just)	Med
Historic fluvial flooding (recorded outlines)	Med
Climate change impact on fluvial flood depths	Med
NaFRA – Existing FCERM Assets and Condition	Med
Agricultural land classification	Low
SSSI areas	Low

While changes of data priority can result in different data and map outputs, this could also have been produced with varying scale values. The initial scale values used to calculate AHP weightings focused on the descriptive definitions accompanying the values, notably equal importance (1), moderate importance (3) and strong importance (5), rather than the values themselves to equal a high, medium, and low priority rating. Thus, by applying a greater spread of these values, that includes using very strong importance (7), extreme importance (9) and the intermediate importance (2, 4, 6, 8) values between these, a different result may have occurred.

Further, while the flood risk map data and information chosen for inclusion in the map were primarily based on available data, development of the flood risk map analysis identified potential issues with the data or missing information that could improve the output. For instance, by including the NVFI alongside the SFRI, this may be double counting vulnerability estimates that could highlight areas as more or less vulnerable to floods than in reality. Additionally, the flood depths that account for climate change largely focus on altering the depths within the river channels and already inundated areas. While this is an important factor for future risk to individuals and communities, it did little to alter the flood map and therefore this data should be reviewed and improved individually. Available data differs between fluvial and surface water flood risks, and this may also influence the results by skewing these towards one type of flood. Finally, the buffer size to capture communities may need to be altered, and further sensitivity checked along with the combination of data initially included, to make sure appropriate communities are created.

5.6 Chapter Summary

This Chapter has reviewed the flood risk maps available for England and the Netherlands and provided a short contribution to literature on including vulnerability data in flood risk maps as well as the use of communities and priority of data included. The NFVI provides a good first example of research to map vulnerabilities for flood risk across the country which has been applied to the flood risk map produced. The results indicate that for the River Trent catchment in England, calculated risk weighting (when summed) overlooks smaller dispersed 'communities' and highlights dense urban areas. While this is helpful for identifying areas where potential funding to reduce risks could be achieved, it does not give a fair representation of flood risks across the catchment. By representing risk as a percentage in relation to the size of the community equal attention can be given to small rural at-risk areas alongside urban population centres. However, more sensitivity testing and analysis is needed on all aspects of the method: data input, data weighting, and community capture.

CHAPTER 6:

THE IMPACT OF VARYING FRM PRACTICES ON FLOOD RISK PERCEPTIONS

This chapter incorporates background information for the Selly Park, Birmingham, case study that was included in Kreibich et al. (2022) and Kreibich et al. (2023) in prep.

Kreibich, H., Van Loon, A., Schroter, K., Ward., P.J., Mazzoleni, M., Sairam, N., Abeshu, G.W., Agafonova, S., AghaKouchak, A., Aksoy, H., Alvarez-Garreton, C., Anzar, B., Balkhi, L., Barendrecht, M.H., Biancamaria, S., Bos-Burgering, Bradley, C., Budiyono, Y., Buytaert, W., **Capewell, L**.*et al*. (2022). The challenge of unprecedented flood and droughts in risk management. *Nature*, 608: 80-86. https://doi.org/10.1038/s41586-022-04917-5

(**Appendix 4**)

This chapter also includes some elements of research in two UK MSc projects and to Dutch BSc projects (co-supervised by LC): Jessica Grady (2020) Perceptions of flood risk and associated personal costs from the changing approaches to flood risk management in the UK, MSc thesis: University of Birmingham, MSc in River and Environmental Management; Martijn Linnarz (2020) Changing Flood Risk Perceptions. BSc thesis: TU Delft, BSc in Water Resources Management; Hannah Flusk (2020) An investigation into the factors affecting flood risk perceptions in urban and rural UK communities where flood management practices are implemented. MSc thesis: University of Birmingham, MSc in River and Environmental Management; Saanne Vassen, (2020) Changing Flood Risk Perceptions as a Result of a Change in the Flood Risk Management Strategy in Nijmegen-Lent. BSc thesis: Wageningen University, BSc in Water Resources Management

CHAPTER 6: THE IMPACT OF VARYING FRM PRACTICES ON FLOOD RISK PERCEPTIONS

6.1 Scope of Chapter

This Chapter addresses the second research objective of this thesis by analysing flood risk perception survey and interview data in five case studies in England and two case studies in the Netherlands, with a third case study based upon the academic literature. The chapter first introduces the case studies in a paired-event style assessment that identifies the current FRM present, and then summarises and discusses the findings.

6.2 Introduction

Risk perceptions are important for DRR because they influence risk related decisions and behaviours that can impact social vulnerability from either motivating or unmotivating individuals to act and prepare for hazard risks, that in turn can increase or decrease losses and harm (Cardona et al., 2012; Birkmann, 2013; Wachinger et al., 2013; O'Neill et al., 2016). Several factors are thought to shape an individual's perception of risk including, but not limited to, demographics, risk knowledge, previous experience, cognitive responses (e.g. worry), and conditions of the hazard such as proximity, severity, and frequency of occurrence (O'Neill et al., 2016; Lechowska, 2018). Additionally, the trust and confidence in RMAs and DRR measures alongside perceived responsibility and ownership of reducing risks can have an impact on forming risk perceptions of individuals and collectives (Terpstra, 2011; Bradford et al., 2012; Wachinger et al., 2013). Communication and engagement of risk by media, RMAs, and peer and/or social network sources can further moderate risk perceptions (Haer et al., 2016; Mehring et al., 2018).

A feedback loop therefore exists between risk perceptions and DDR measures: perceptions drive protection motivation while DRR measures can also shape perceptions. This is important to recognise when delivering effective FRM strategies (Cologna et al., 2017), especially when emphasising non-structural, communicative and awareness raising measures or behavioural shifts. This feedback mechanism is understood in the literature, with several studies identifying the connection between risk perceptions and motivation to prepare for and undertake protection measures for flood risks (Grothmann & Reusswig, 2006; Siegrist & Gutscher, 2008; Bichard & Kazmierczak, 2012; Becker et al., 2014; Osberghaus, 2015; Rözer et al., 2016; Babcicky & Seebauer, 2017; Fuchs et al., 2017; Lo & Chan, 2017; Weyrich et al., 2020). However, while it is often included in theory and alongside other risk perception factors, few studies have investigated the opposite influence of mitigations measures towards risk perceptions. Further, awareness raising strategies, that are increasingly included as key FRM measures in combination with other FRM structural and non-structural strategies (Sayers et al., 2015a), are rarely evaluated to identify whether risk perceptions have been altered by engagement and awareness raising measures, or other FRM measures, whether negatively or positively.

England and the Netherlands are two countries that have been described as having similar evolutions of FRM but differ in literature when considering public flood risk perceptions and FRM participation (Priest et al., 2016). As identified in the Spheres of Change framework, personal perceptions and beliefs are linked to political systems and practical responses (O'Brien & Sygna, 2013). Individuals in the Netherlands are often described as having low flood risk awareness (Terpstra, 2011). This initially stems from political arrangements where the Dutch government, and by extension Rijkswaterstaat and the WBs, have a legal duty to protect the country from flood risks. By directly funding FRM practices with taxes and implementing compensation schemes for flood damage (e.g. the 1953 Flood Damage Act) (Gerritsen, 2005), an environment with limited opportunities of public participation in FRM has been created (Priest et al., 2016). Further, by implementing significantly high protection standards and few strategies that focus on, or even acknowledge, residual risk, it is assumed that a belief of complete safety has lowered flood risk awareness and perceptions (Terpstra, 2011). This strengthened and successful protection standard has also significantly reduced the frequency of fluvial flooding experienced by the country, and most individuals have no personal experience of flood risks or recollection of the last severe flood in 1953 that caused 1,836 fatalities (Terpstra, 2011).

On the other hand, the UK government only holds permissive powers to provide FRM in England and Wales, and while these powers are carried out by DEFRA, the EA and LLFAs in combination with other RMAs, at-risk households are responsible for reducing their own flood risk. Previous studies have identified differing levels of flood awareness in England that reflect the multifaceted nature of flood risk perceptions (Burningham et al., 2008; Bichard & Kazmierczak, 2012) and suggest that flood risk perceptions and awareness are lower in areas at-risk of flooding than expected (Harries, 2008; Lo & Chan, 2017). The availability of homeowner insurance policies from the 1920s, the continual inclusion and development of non-structural FRM strategies, and the introduction of legislation to support community resilience coordination and fora (e.g. the 2004 Civil Contingencies Act), such as Flood Action Groups (FAG), is thought to have resulted in a high degree of public participation within FRM (Priest et al., 2016). However, literature indicates that homeowners may be reluctant to admit, or unaware of, their responsibility for their own flood risk (Lamond & Proverbs, 2009; Bichard & Kazmierczak, 2012). Further, as identified previously, more recent FRM strategies in the Netherlands, and continuing strategies in

England, have focused on building country-wide resilience and holistically considering flood risk reduction for future events. This includes flood awareness, information, contingency and recovery campaigns and measures in the Netherlands in combination with prevention (e.g. RftR), preparation (e.g. MLS) and traditional protection strategies.

6.3 Case Study Locations

The survey was implemented in case studies in England and the Netherlands where differing FRM strategies are present. In England, this included case studies of structural protection in Burton-upon-Trent, PFR in Bewdley and Aston Cantlow, NFM in Herefordshire and a flood alleviation scheme in Selly Park, Birmingham that includes NBS aspects. For the Netherlands, the case studies include a RftR scheme in Lent, MLS in Dordrecht and a further case study of dike defence that been created from existing Dutch flood risk perception studies.

As previously noted in the methodology for this chapter (Chapter 3), the rationale for areas being included in the research is dependent on varying FRM strategies implemented in the community, with enough information on the scheme and opportunities for community engagement to facilitate the area acting as a case study. The literature and narrative review of FRM developments in England and the Netherlands (Chapter 2 and 4) supported the identification of varying FRM that could be used as case studies, with further information on the schemes identified from online searches (e.g. press releases) and by contacting the relevant RMAs. Supporting information for the case studies in the Netherlands, RftR in Lent and MLS in Dordrecht, is also available in academic literature and articles (e.g. Rijke et al., 2012; Slomp, 2012 for Lent, and Hoss et al., 2013; Hegger et al., 2014; Gersonius et al., 2015 for Dordrecht).

Further, to understand current FRM strategies, previous management history of the area must be considered. For risk perceptions, conditions of the hazard are also suggested as a controlling factor alongside trust in flood management and governance (O'Neill et al., 2016; Lechowska, 2018). **Table 6-1** provide background information on flood risk, including type of flooding experienced and any historic or recent flood events, and the FRM strategy present for each case study area. Additional information that summarises the changes in FRM between paired flood events, as well as changes in hazard, exposure, and vulnerability of the flood events (Kreibich et al., 2022), for the case studies in England are presented in **Appendix 5**. No recent flood events have occurred in case study areas to enable this analysis in the Netherlands.

Table 6-1: Flood risk and FRM strategy background information for case study locations in England and the Netherlands

FRM	Catchment	Flood Risk	Historic Flooding	Recent Flooding	FRM Strategy Present
Structural Protection in Burton-upon-Trent, East Staffordshire, England.	Part of the Tame, Ankle and Mease sub-catchment of the Trent catchment (drains 7,486km2 of central England) (Macdonald & Sangster, 2017)	Fluvial flooding from the River Trent that >3000km of the catchment through Burton-upon-Trent with several other tributaries and smaller watercourses (ESBC, 2008a). Localised pluvial flooding is also a significant risk (Staffordshire Prepared, 2019).	February 1795 flooding from snowmelt and intense rainfall was estimated as a 1/500-year (0.2% AEP) event (Black & Law, 2004). Flooding in May 1932 inundated 151,757ha of the Trent catchment (House of Commons, 1932). Countrywide flooding in 1947 inundated >121,400ha, several thousand properties and two breweries in Burton-upon-Trent (EA, 1997).	Localised flooding in Autumn 2000 inundated 40 properties from seepage and overtopping of flood protection (EA, 2001). However, flood levels of 3-4cm more would have overtopped defences and inundated 7,400 properties (EA, 2001; House of Commons, 2003). Flooding in 2012 (BBC News, 2012) and 2020 (after protection improvements) did not result in any flooding behind defences with 5336 properties protected (EA, 2020d). 18 properties outside of defences flooded (EA, 2022b).	The combination of flooding in 1932 and 1947 led to the construction of 9km long flood protection (33 sections of walls, embankments, and high ground) to a 1/100-year (1% AEP). (EA, 1997; ESBC, 2008a; EA, 2022b). Some sections were improved to a 1/200-year standard between 2005 and 2007 as phase 1 of the Burton FRM scheme (EA, 2022b). Phase 2 of the Burton FRM scheme was undertaken between 2019 and 2021 to improve all areas to 1/200-year and improve protection to 4,500 properties and 1000 businesses. Properties that flood in February 2020 were included in the scheme (EA, 2020d)(EA, 2022b).
PFR in Wribbenhall/ Beales Corner (north bank), Bewdley, Worcestershire, England.	Situated in the Middle Severn Corridor of the Severn catchment that covers 11,000km2 (EA, 2009). 4325km2 drains through Bewdley (NRFA, n.d.-b).	Fluvial flooding from the River Severn. 175 properties, including businesses, in Bewdley are at risk during a 1/100-year event (1% AEP) (EA, 2004). Groundwater, pluvial and sewer flooding is also a risk in the catchment (EA, 2014b).	Flooding in 1947 was the largest fluvial flood recorded where levels reached 5.82m (EA, 2014a). Flooding in 1998 reached 4.99m (EA, 2014).	Flooding in 2000 inundated >140 properties up to 1.5m (EA, 2004). Bewdley was flooded three times in 6 weeks on Nov 2nd (5.56m), Nov 9th (5.16m) and Dec 13th (5.31m) (EA, 2014). High river levels in 2008 (4.91m) and 2014 (5.04m) did not cause flooding (EA, 2014a). Recent flooding (after PFR installation) twice in February 2020 (5.24m 5.48m levels respectively) flooded 40 properties (EA, 2020d), and flooding in January 2021 flooded 19 properties (EA, 2021a).	Demountable barriers to a 1/100-year standard (1%) were implemented along Severnside (southern) bank of Bewdley to protect 272 properties (EA, 2021a). The Wribbenhall/Beales Corner (north bank) was included in a temporary barrier trial from 2007 to provide 1/10-year (10% AEP) standard of protection to 19 properties but the barriers become ineffective at >5m (EA, 2021a). A technical review of temporary barrier risks (Gov, 2014) resulted in a change of approach to PFR for 30 properties along the north bank, Bewdley (EA, 2014b, 2014c). PFR protection standards were reached during flooding in 2020 and 2021 that flooded properties while the temporary barrier failed (EA, 2021a).
PFR in Aston Cantlow, Warwickshire, England.	Part of the Avon catchment (2,893km2) that joins the River Severn at Tewkesbury.	Fluvial and pluvial flood risks result in 1 in 7 businesses and 1 in 10 properties are at flood risk across Warwickshire (WCC, 2016b). Aston Cantlow has been ranked 12th highest for flood risk in Warwickshire (WCC, 2016a).	Historic flooding in August 1993, July 1996, and April 1998 in Aston Cantlow (WCC, 2015) with other flooding across Warwickshire in Autumn 2000 and July 2005 (WCC, 2016a).	Flooding in July 2007 and November 2012 in Aston Cantlow internally flooded properties (WCC, 2015). The River Alne at Little Alne, upstream of Aston Cantlow, peaked at 3.38m during the 2007 event, 2.05m higher than normal range (Gov UK, n.d.). Highway flooding also resulted in bow waves that increased the internal flooding of properties (WCC, 2015).	A PFR scheme to a 1/100-year standard was implemented in January 2015 to protect 19 properties in Aston Cantlow (WCC, 2015). The final scheme was finalised in 2017 with 23 properties installing PFR (WCC, 2017). PFR measures are primarily resistance measures with flood proof doors, smart airbricks, and pumps and slumps to reduce all types of flood risk (fluvial, pluvial and groundwater) in Aston Cantlow (WCC, 2015).
NFM in Herefordshire, England.	Part of the Wye catchment that covers 4,285km2 across 2 countries and	Fast responding fluvial, from the River Wye and tributaries including the River Lugg, Yazor Brook and Rudhall Brook, and pluvial flood risks (EA & Natural Resources	Most significant flood in 1947 that inundated properties, transport links and critical infrastructure across the catchment (EA & Natural Resources Wales, 2016). Further	Flooding occurred across Herefordshire 2000, 2007 and 2012 (EA & Natural Resources Wales, 2016). More recent flooding (after NFM installation) in October 2019 and February 2020 saw ~286	Hereford County Council have undertaken the River Wye and River Lugg NFM pilot project in upper reaches of 7 catchments across Herefordshire. Measures have been installed to slow the flow, increase infiltration, and store water upstream (HCC, 2022).. The

	5 counties (Wye Catchment Partnership, 2020).	Wales, 2016) (Wye Catchment Partnership, 2020).	flooding during country-wide events in 1960 and 1998 (EA & Natural Resources Wales, 2016).	and 113 properties flooded by the River Wye and Lugg respectively, with 71 properties flooded by other tributaries and watercourses (HCC, 2021a). The 2020 event was calculated to between a 1/100 and 1/150-year event (Farley et al., 2020).	measures reduce the flood risk of 902 properties across Herefordshire (HCC, 2018) and by completion in 2021 has created ~4,410m2 of storage, 4.78ha of woodland and 795m of hedges, and improved 167.2ha of land (HCC, 2022).
Flood alleviation scheme that includes NBS in Selly Park, Birmingham, England.	Birmingham is situated in the Upper Tame catchment, part of the Trent catchment (Adedeji et al., 2019).	The most heavily urbanised catchment of its size (42% urban) (Lawler et al., 2006) that has resulted in significant pluvial flood risks, the second highest in the UK after London, (BCC, 2015). Selly Park is also at risk from the River Rea and the Bourn Brook with large areas at risk of a 1/50-year (10% AEP) event (EA, 2018d).	Several localised events in the last twenty years: 14 recorded flood events between March 1998 and March 2008 (Kotecha, 2008; BCC, 2017).	A further 13 events have occurred between April 2008 and February 2020 (BCC, 2017, 2018) including the 2018 flood event that inundated ~124 roads and ~1600 properties (Adedeji et al., 2019). Localised flooding also occurred in September and November 2019. The most severe flood events in Selly Park occurred in September 2008, June 2016, and May 2018 from intense convective and localised rainfall (Met Office, 2008; BCC, 2016). These events flooded 42, >100 and ~180 properties, respectively (BCC, 2011; BCC, 2016; EA, 2018d).	The Selly Park scheme has been split into Selly Park North (SPN) and South (SPS). The SPN scheme includes a flood storage area in Woodgate Valley and a flood culvert under the Pershore Road (at the confluence of the Rea and the Bourn Brook) with an overland flow route to direct flows to the culvert (Rea Catchment Partnership, n.d.-a), designed to a 1/100-year (1% AEP) standard of protection (EA, 2018d). The SPS scheme includes the construction of an embankment upstream of the Dogpool Lane Bridge to retain water during extreme rainfall and increased River Rea bank elevations below the bridge (Rea Catchment Partnership, n.d.-b). The scheme protects ~200 properties in SPS (EA & Rea Catchment Partnership, 2016). The SPS scheme was operational in 2018 and the SPN scheme in 2019 (EA, 2018d).
Bypass channel in Lent, Nijmegen, The Netherlands	Part of the Rhine catchment which then bifurcates into the River Waal, as well as the Nederrijn-Lek and the IJssel.	The Rhine the largest river in the Netherlands which has an average discharge of ~2,200m3/s at the German – Dutch border (Klijn et al., 2019). The River Waal separates Lent from the rest of the city of Nijmegen and creates 'bottleneck' that may lead to high river levels in this area (Wiering & Winnubst, 2017). River dikes have existed since collective-action and designed to provide protection against 1/1250-year (0.08% AEP) events (Kind, 2014).	There have been several large historic in the Netherlands. However, threats of flooding in 1993, and particularly, 1995 that resulted in the evacuation of 250,000 people along the Waal between Arnhem and Nijmegen due to fears of dike failures were policy catalysts (van Stokkom & Smits, 2002; Slomp, 2012). Although no flooding occurred along the Rhine branches, the evacuation increased financial flood losses to €400 million (2019 prices) (Wind et al., 1999) and highlighted the susceptibility of the Netherlands to future flood events.	No recent flooding has occurred along the Rhine branch of the River Waal.	RftR marked a change in direction in Dutch flood safety policy and practice (Rijke et al., 2012; Wesselink et al., 2015; Kaufmann, 2018). The Lent RftR scheme applies dike relocation to create a larger floodplain and a bypass channel. 50 properties being removed and relocated to create 'Room for the Waal' (Slomp, 2012). This increased the capacity of the Waal to 16,000m3/s (Rijke et al., 2012). The RftR project overall aims to increase flood safety while improving spatial planning and urban development (Slomp, 2012). The Room for the Waal channel was completed in 2016 after construction of the bypass channel, city island and 3 new bridges (Slomp, 2012), with the RftR programme completed in 2018 (Havinga, 2020).
MLS in Dordrecht, The Netherlands	Part of the Meuse catchment	The River Meuse is the second largest river in the Netherlands with a mean average discharge of ~230m3/s when entering the country (Klijn et al., 2019). Dordrecht has primary	The last significant flood in Dordrecht was the Saint Elizabeth Flood in 1421 that 'drowned' 17 villages (Esteban, 2021). The 1953 storm surge caused little damage to Dordrecht with surrounding dike rings	Some recent flooding occurred in Dordrecht in 2012, however there is limited information available about this event.	Part of the historic area is situated on top of a primary dike, the Voorstraat, but this is now insufficient in height (Hoss et al., 2013). Some properties also act as flood protection with support of demountable measures (Hegger et al., 2014) and are protected by the Maeslant and Hartel storm surge

		flood protection from 1/2000-year standard dikes (Gersonius et al., 2015; Hegger et al., 2014). However ~2000ha of the island, including the historic port, centre and recently built housing areas, are outside dike protection (Hegger et al., 2014). The area is at higher elevation than other areas but is at risk from both fluvial and tidal flooding (Gersonius et al., 2015).	being largely affected that reduced the potential impact on the island (Esteban, 2021).		barriers (Gersonius et al., 2015). In 'outside dike ring' areas, flood safety is the responsibility of residents, although the local government has a responsibility for spatial planning and evacuation plans (Gersonius et al., 2015; Hegger et al., 2014). The 'resilient island' of Dordrecht has since become the pilot area for the 3-layer MLS approach: protection/prevention from increasing dike measures that exist in the city to a tolerable risk level with reduced breach risk (layer 1), appropriate spatial planning from safety zones and improved critical infrastructure networks (layer 2) and crisis management from preventive evacuation and risk and crisis communication (layer 3) (Gersonius et al., 2015). Layers 2 and 3 are important as during disaster evacuation, only 15% of the population are estimated to be able to leave the island (Hoss et al., 2013). The MLS approach applied in Dordrecht has yet to be tested during a real-time flood event.

The structural protection scheme in Burton-upon-Trent has been in present since the combination of the May 1932 and March 1945 flood events (EA, 1997; ESBC, 2008a; EA, 2022b), comprising of 33 sections of walls, embankments and high ground originally constructed to a 1/100-year protection standard (1% AEP) (EA, 2022b). Localised flood breaches during the Autumn 2000 floods inundated 40 properties, but highlighted weaknesses in the height and structural condition of the defences (EA, 2019b). Concerns particularly surrounded the threat of flooding to 7,400 properties if flood water had increased by 3-4cm (EA, 2001; House of Commons, 2003). Subsequently, the flood protection was improved to a 1/200-year protection standard, between 2005 and 2007 as phase 1, and between 2019 and 2021 as phase 2 for a consistent standard of protection. The infrastructure protects 4,500 properties and 1000 businesses from flooding by the River

Trent and other watercourses (EA, 2022b), and recent flooding in February 2020 did not result in any flooding or failures behind the defences protecting 5,336 properties (EA, 2020d). Information provided by the EA also indicates that between 1980 and 2017, the defences were active for ~105 days, with the longest period of 18 days during flooding in 2012 as well as for 13, 13 and 10 days in 2000, 2007 and 2008 respectively (EA, 2019a).

The PFR scheme in Bewdley protects ~43 properties to a 1 in 30-year protection standard, with a mix of resistance and resilience measures, on the Wribbenhall/Beales Corner (northern) bank of the River Severn (EA, 2020). The area was previously part of national temporary barrier trial from 2007, that required a 270m long barrier of 1.8m and 1.25m high sections to be installed prior to flooding to provide a protect standard of 1/10-years (10% AEP) (EA, 2014a). However, concerns and a technical review of the risks of failure and sliding (Gov, 2014), and the barriers becoming inefficient when water levels reach 5m (EA, 2014a), prompted a change of approach to PFR. Complaints from residents to keep the barriers that they believed had worked well, as well as an perceived inequality for other areas having demountable barriers (EA, 2014c), resulted in the 1.25m high sections of the temporary barrier continuing to be installed (EA, 2018a). However, in February 2020 and January 2021, and since the installation of PFR, properties in Bewdley have experienced internally flooding (EA, 2020d). The events were larger than the standard of protection provided by the temporary barrier and PFR and both measures were overwhelmed leading to internal property flooding (EA, 2020d). The temporary barrier has been discontinued for future use following safety issues during the events (EA, 2021a), and a permanent protection scheme is now being developed for Bewdley (EA, 2022a).

A further PFR scheme, included as PFR is commonly applied in small, dispersed areas with small amounts of properties where a larger scheme is not cost-beneficial, in Aston Cantlow installed resistance measures in 23 properties to a 1/100-year (1% AEP) protection standard (WCC, 2015). This is typically a higher protection standard than most PFR schemes, which usually provide protection against 1 in 30-year flood events. The PFR installed in properties in Aston Cantlow was in combination with a community emergency plan and further non-structural FRM strategies (WCC, 2016b). However, no flood events have been reported for Aston Cantlow since the schemes implementation to provide information on the effectiveness.

The NFM pilot scheme in Herefordshire is part of the 2017-2021 EA NFM programme (EA, 2021d), that installed NFM measures in the upper reaches of 7 sub-catchments of the Wye catchment to protect 902 properties across Herefordshire (HCC, 2018). These 7 catchments are: Bodenham Brooks for Bodenham, Brimfield Brook for Brimfield and Orelton, the Cheaton, Cogwell and Ridgemoor Brook system for Leominster and Frome, Dulas Brook for Ewyas Harold, Pentaloe Brook for Mordiford, Tedstone Brook for Bromyward, and the Red, Norton and Twyford Brook system for Rotherwas and Hereford (HCC, 2018). While the NFM measures are considered to have reduced flood risks to properties, the limited evidence of efficacy is a known issue with NFM interventions (Wingfield et al., 2019). Flooding to properties in Herefordshire also occurred in October 2019 and February 2020 (HCC, 2021a) following the programmes completion. However, this may be due to NFM generally being more effective as small-scale measures for smaller, frequent events (Wingfield et al., 2019), with the impact on larger events, such as the 2020 events that had a return period of between 1/100 and 1/150-years, being less obvious. A second NFM project to increase the NFM in these 7 catchments is planned for 2022-2027 (HCC, 2022).

The Selly Park alleviation scheme is a combination of measures, including NBS, in Selly Park North (SPN) and Selly Park South (SPS). The divide in Selly Park is due to differing flood risks, particularly the nature of fluvial flooding and its management. SPN experiences fluvial flooding from the River Rea and Bourn Brook exceeding channel capacity, surface water flooding and sewer flooding that has been reduced with a flood storage area, culvert, and overland flow route to direct flows to the culvert (Rea Catchment Partnership, n.d.-a). Flooding in SPS occurs from the River Rea further upstream, again due to the constriction of floodwater flows by bridge infrastructure that has been reduced with the construction of an upstream embankment and raised elevations (Rea Catchment Partnership, n.d.-b). The SPS scheme was operational during the 2018 flood event that reduced property damage but the SPN was not yet operational (EA, 2018d). This case study was part of Kreibich et al. (2022) that is available in **Appendix 4**.

The scheme in Lent is one of, if not the most documented, RftR scheme in the Netherlands. The location of Lent and Nijmegen on the River Waal created 'bottleneck' that may lead to high river levels in this area (Wiering & Winnubst, 2017). This risk of flooding has now been reduced with the relocation of a dike to create a larger floodplain and bypass channel to increase the capacity of the River Waal from 15,000m^3/s to 16,000m^3/s (Rijke et al., 2012). Dordrecht in the Netherlands, often called the 'resilient island', is the pilot area for the implementation of the MLS policy. While there is some structural protection in Dordrecht, part of the historic area is outside dike protection (Hegger et al., 2014). This MLS approach applies existing dike and demountable flood protection (layer 1), safety zones and improved critical infrastructure networks (layer 2) and improved evacuation and crisis planning (layer 3) (Gersonius et al., 2015) to reduce flood risks. The combination of layers 2 and 3 are important as during a disaster requiring evacuation, only 15% of the population are estimated to be able to leave the island (Hoss et al., 2013). Although this is thought to have resulted in residents being more flood-aware with active in FRM planning and preparation (Hegger et al., 2014), the last significant flood event was in 1421 (Esteban, 2021).

A final case study of dike defence in the Netherlands has been generated through previous flood risk perception literature and studies. The Netherlands is arguably the most protected delta in the world (Wesselink et al., 2007). However, as previously stated, The extremely high standard of protection from dike defence, and statutory government duty to provide this protection, in the Netherlands is often suggested to be accompanied by low public flood risk awareness and incentives to prepare for potential flooding (Terpstra, 2011). Information from Botzen et al (2009b), Terpstra (2011), Mol et al (2020) and Terpstra & Gutteling (2008) (**Table 6-2**) has been used for this dike case study. Studies published in 2009 or before are mainly included as this was prior to any large FRM changes in the Netherlands, such as the MLS strategy. Terpstra (2011) and Mol et al. (2020) are included as they specifically consider trust in flood protection reducing flood perceptions and/or intentions towards individual flood preparedness and may provide an insight into temporal development of flood risk perceptions in the Netherlands. However, these studies are not directly comparable with each other, or the questionnaire included in this research, and this should be taken into consideration.

Table 6-2: Flood risk perception studies used for the dike defence case study and their factors

Study	Flood Risk Factors	Location
Terpstra & Gutteling (2008)	Flood risk perceptions, trust in risk management and flood risk responsibility	Ferwerderadeel and Dongeradeel, province of Friesland, prone to flooding from Lake IJssel and the Wadden Sea
Botzen et al. (2009a)	Flood risk perceptions - likelihood of risk events, likelihood and level of flood risk, and perceived flood risk	Random draws of participants that live in dike rings protected to a 1/1,250-year standard using an online survey
Terpstra (2011)	Intentions of flood preparedness considering risk perceptions, trust in public risk management and flood experience	Undefined
Mol et al. (2020)	Flood risk perceptions dependent on situational and geographical factors, emotive factors, trust in risk management and experience	Homeowners living in river floodplains with flood protection standards between 1/1,250 and 1/2,000-years using an online survey

6.1 Results

Across all case studies in England and the Netherlands, 168 valid questionnaires were completed between August 2018 and September 2021. For the five case studies in England, 95 valid questionnaires were completed. The number of responses were greatest for Selly Park and Burton-upon-Trent, with 32 and 26 respondents respectively, and lowest for Aston Cantlow and Bewdley, that received 9 and 10 responses respectively. In the Netherlands, 73 valid responses were collected across two case studies. There were 32 responses to the Dordrecht survey and 41 responses to the Lent survey.

The flood risk perceptions surveys were undertaken with assistance of BSc and MSc students in England and the Netherlands. In England, the data collected for the Burton-upon-Trent, Bewdley and Aston Cantlow case studies was supported by work from Grady (2020), with the data for the Herefordshire and Selly Park case studies supported by Flusk (2020). For the Netherlands, the Dordrecht case study was supported by Linnarz (2020), and the Lent case study was undertaken with support by Vassen (2020). This contribution focuses on administering the survey and results, with no shared analysis To improve the fit of the survey with social and cultural norms in the Netherlands, the questionnaires were altered slightly from that administered in case studies in England.

Overall, when combining responses for both countries the response rate for the flood risk perception survey was approximately 6.2%. The Netherlands case studies had a better response rate (21.5%) than those in England (8%). Response rates for each case study are included in **Table 6-3**. However, response rates are difficult to quantify for the surveys as almost all, except Dordrecht and Aston Cantlow, were shared online in community groups. The response rates for each case study therefore refer to the number of residents that were specifically invited to take part in the survey (e.g. through door-to-door contact, posted leaflets, or email). The final number of residents asked to participate is most likely much higher when online impact is considered. For instance, the Herefordshire survey was shared in online groups that have a combined number of approximately 23,937 members. The Selly Park questionnaire was shared in online groups with approximately 22,100 members, while the Burton-upon-Trent questionnaire was shared in online groups with approximately 7500 members. Small response rates decrease confidence in probability-based conclusions and increase the risk of non-response bias with errors and biases in results (Stedman et al., 2019). The results have therefore been analysed on percentage of results and Spearman's rank correlation coefficients, rather than regression or variance analysis, and supported by results from the sketch mapping and interviews.

Table 6-3: Socio-economic demographic breakdown across all case study locations in England and the Netherland with overall totals. Qualification abbreviations for undergraduate degree (UG D) and post graduate degree (PG D)

	England (Total)	Burton-upon-Trent *Structural protection*	Bewdley *PFR*	Aston Cantlow *PFR*	Herefordshire *Rural NFM*	Selly Park *Urban NFM with protection*	The Netherlands (Total)	Dordrecht *MLS*	Lent *RftR bypass channel*
Number of respondents *n* (%)	95 (100%)	26 (27.4%)	10 (10.5)	9 (9.5)	18 (19%)	32 (33.7%)	73 (100%)	32 (%)	41 (35.6%)
Response rate n %	95/1190 (8%)	26/600 (4.3%)	10/50 (20%)	9/40 (22%)	16/100 (16%)	32/400 (8%)	73/340 (21.5%)	41/250 (16.4%)	32/90 (35.6%)
Gender %									
Male	51.6%	42.3%	40%	33.3%	88.9%	46.9%	52.2%	43.2%	62.5%
Female	48.4%	57.7%	60%	66.7%	11.1%	53.7%	47.8%	56.8%	37.5%
Age %									
18-24 years	1.1%	3.8%							
25-34 years	12.6%	11.5%	60%		11.1%	21.9%	10.1%	13.5%	6.3%
35-49 years	22.2%	26.9%	20%	33.3%		15.6%	46.4%	59.5%	31.3%
50-69 years	45.3%	42.3%	20%	44.4%	50%	53.1%	34.8%	16.2%	56.3%
70+ years	18.9%	15.4%		22.2%	38.9%	9.4%	8.7%	10.8%	6.3%
Highest Qualification %									
GCSE	8.4%	7.7%	20%	33.3%	5.6%				
BTEC	5.3%	11.5%		22.2%	5.6%				
A Level	6.3%	7.7%			11.1%	3.1%			
UG D	34.7%	30.8%	30%	11.1%	38.9%	59.4%			
PG D	24.2%	3.8%	40%	11.1%	16.7%	3.1%			
PhD	3.2%				5.6%	6.3%			
NVQ									
HNC/D									
Other									
n/a									
Highest Qualification %								3.1%	
Middle School							5.8%	25.0%	8.1%
MBO							14.5%		5.4%
HBO							29%	62.5%	
UG D							17.4%	9.4%	24.3%
PG D							29%		54.1%
Other							4.3%		8.1%
Household Structure %									
Family	32.6%	34.6%	70%	22.2%	27.8%	28.1%		Removed from survey due to low response	40.6%
Couple	45.3%	42.3%	10%	44.4%	61.1%	53.1%			37.5%
Alone	22.1%	23.1%	20%	33.3%	11.1%	18.8%			21.9%
Homeowner %									
Yes	91.6%	84.6%	100%	100%	94.4%	90.6%	91.3%	84.6%	96.9%
No	8.4%	15.4%			5.6%	9.4%	8.7%	15.4%	3.1%

A breakdown of demographic factors for case studies in England and the Netherlands can be found in **Table 6-3**. All areas differ for background demographics, but a similar overall gender (51.8% Male and 48.4% female in England; and 52.2% male and 47.8% female in the Netherlands) and homeownership (91.6% homeowners and 8.4% not in England; and 91.3% homeowners and 8.7% not in the Netherlands) is present between the two countries. More females responded to the survey in 5 case study areas (Burton-upon-Trent, Bewdley, Aston Cantlow, Selly Park, and Dordrecht). However, the two case study areas with more males had very large differences in gender, with 88.9% male respondents in Herefordshire and 62.5% male respondents in Lent. More 50-69 aged respondents completed the survey in England (45.3%), whereas the most frequent age category in the Netherlands was 25-34 years (46.4%). Most respondents in England had an undergraduate degree (34.7%) compared to respondents in the Netherlands that more often held a postgraduate degree.

Type of employment was originally included in the questionnaire but was removed after all responses (either full-time employment or retired) matched the corresponding age brackets (e.g. either full time employment/self-employed or retired). In the online survey for Lent the household structure question was often neglected, potentially as it highlighted residents living alone, and the few responses received were removed from the analysis.

Awareness of flood risks has been quantified through three questions: whether participants are aware their (case study) area is at-risk from flooding, whether participants know their level of flood risk, and how informed and educated they feel they are towards these flood risks (**Table 6-4**). Out of all results for England, 6.3% of all respondents were unaware they lived in areas at-risk from flooding.

Table 6-4: Questionnaire responses to flood risk perception factors, including awareness, knowledge and known level of flood risks, whether respondents have been previously flooded, risk of future flooding, worry level and frequency to this potential future flooding and how much information they have received on their flood risk from any sources. Results show % or mean of scale used

	England (Total)	Burton-upon-Trent *Structural protection*	Bewdley *PFR*	Aston Cantlow *PFR*	Herefordshire *Rural NFM*	Selly Park *Urban NFM with protection*	The Netherlands (Total)	Dordrecht *MLS*	Lent *RftR bypass channel*
Aware area is at flood risk %									
Yes	93.7%	96.2%	100%	100%	77.8%	96.9%	91.3%	96.9%	86.5%
No	6.3%	3.8%			22.2%	3.1%	8.7%	3.1%	13.5%
Known level of flood risk %									
Yes	81.1%	76.9%	100%	77.8%	88.9%	75%	66.7%	56.3%	75.7%
No	8.4%	11.5%			5.6%	12.5%	18.8%	12.5%	24.3%
Unsure	10.5%	11.5%		22.2%	5.6%	12.5%	13%	31.2%	
Level of Risk Knowledge									
1-5 scale									
Mean	3.93	3.81	4.4	3.78	4.33	3.69	3.84	4.03	3.68
Std. d	*1.084*	*1.167*	*.699*	*.972*	*3.69*	*1.148*	.949	.999	.880
Previously flooded %									
Yes	67.4%	53.8%	90%	66.7%	88.9%	59.4%	59.4%	78.1%	8.1%
No	32.6%	46.2%	10%	33.3%	11.1%	40.6%	40.6%	21.9%	91.9%
Previous flood impact of those previously flooded %									
Directly	24.6%			16.7%	43.8%	42.1%	27.6%	20.8%	
Indirectly	53.8%	85.7%	55.6%	83.3%	31.2%	21.1%	72.4%	79.2%	
Both	21.5%	14.3%	44.4%		25%	36.9%			100%
Years in area									1-3 scale
Mean	Not necessary	20.56	14.20	20.61	18.37	14.63	Not directly comparable	38.91	2.57
Std. d		14.198	11.764	20.112	12.106	13.476		20.812	.555
Risk of Future Flooding									
1-5 scale									
Mean	3.26	2.88	3.0	3.33	4.00	3.19	3.75	3.91	3.62
Std. d	*1.383*	*1.243*	*1.414*	*1.323*	1.455	*1.376*	.991	.993	.982
Level of Flood Worry									
1-3 scale								1-5 scale	1-5 scale
Mean	1.62	1.46	1.7	1.22	1.88	1.75	1.48	1.19	1.73
Std. d	.655	*.582*	*.675*	*.441*	.697	*.622*	.779	.471	.902
Frequency of Flood Worry									
1-5 scale									
Mean	2.31	2.03	2.4	1.56	2.88	2.38	1.72	1.47	1.95
Std. d	*1.183*	*1.055*	*1.430*	*.527*	1.111	*1.264*	.968	1.018	.880
Informed of risks									1-4 scale
1-8 scale							Not directly comparable		
Mean	1.87	1.35	2.70	1.67	2.17	2.22		.97	2.92
St. d	*1.545*	*1.129*	2.312	1.118	1.978	1.560		.177	1.090

This was primarily in Herefordshire, where 77.8% of respondents were aware of their risks, followed by Burton-upon-Trent (96.2% aware) and Selly Park (96.9% aware). Participants in Bewdley and Aston Cantlow were all aware the area was at risk of flooding (100%). In the Netherlands, respondents in Dordrecht were more aware of their risk (96.9% aware) when compared with Lent (86.5% aware).

More respondents in England had flooded previously (67.4%) than the Netherlands (59.4%) but more participants in the Netherlands has experienced internal flooding (72.4%) compared to England (46.1%). Bewdley (90%) and Herefordshire (88.9%) and Dordrecht (78.1%) had the highest amount of previous flooding. Of these, Selly Park was the case study with most directly flooded participants (79%), although only 59.4% had previously flood experience, followed by Herefordshire (67.8%). In Dordrecht, 20.8% of respondents had direct experience of flooding. More respondents in Burton-upon-Trent had been indirectly affected (85.7%). In Aston Cantlow, 66.7% of respondents had flooded, with 16.7% of these directly and 83.3% indirectly. 8.1% of respondents had experienced flooding in Lent, but of the 100% was both directly and indirectly.

When asked if participants knew their level of risk, all respondents in Bewdley believed they knew their risk level (100%), whereas similar percentages of respondents thought they did in Aston Cantlow (77%), Burton (76.9%) and Selly Park (75.5%). Herefordshire is an interesting case for this answer, as the percentage has increased for known level of risk (88.9%) compared to risk aware (77.8%). For the Netherlands, Dordrecht decreases from awareness of risk to only 56.3% knowing their level of flood risk, whereas 75.7% of respondents in Lent said they knew their flood risk level.

Respondents were also asked to indicate their level of risk knowledge on a scale of 1-5. Comparing both countries overall, respondents in England thought they had slightly higher knowledge of the flood risk with a mean of 3.93 compared to 3.84 for the Netherlands. However, both countries perceived themselves to have an above mid-range of knowledge. The case study with the highest perceived knowledge was Bewdley (4.4 mean), followed by Herefordshire with 4.33, and the lowest was Lent (3.68 mean) followed by Selly Park (3.69 mean). Aston Cantlow had a mid-range mean of 3.78.

When considering likelihood of future flooding, respondents in the Netherlands felt they had a higher probability of being flooded (3.75 mean) than case studies in England (3.26 mean). This may be due to respondents in Dordrecht perceiving their chance of future flooding being higher than other case studies (3.91 mean) apart from Herefordshire (4 mean). Further, Burton-upon-Trent had the lowest average belief of future flooding out of all the case studies by 0.12 (2.88 mean), while Bewdley and Selly Park had mid-range means of 3.0 and 3.19, respectively. While participants in Dordrecht believed they have a high chance of future flooding, they have the lowest level (1.19) and frequency (1.47) of future flood worry. Lent had a higher response of level (1.73 mean) and frequency (1.95) of worry to Dordrecht and Aston Cantlow (1.56 mean) for frequency of worry (and 1.22 out of 3 for level). Herefordshire had the highest level of worry (1.88 mean) and the highest frequency of worry (2.88 mean). Selly Park also had a high level (1.75) and frequency (2.38) of worry.

Following the design of Ludy & Kondolf (2012), the perceived inundation depth to properties if a flood event were to occur was asked in all case study area (**Figure 6-1 A-E and Figure 6-1 F-G**).

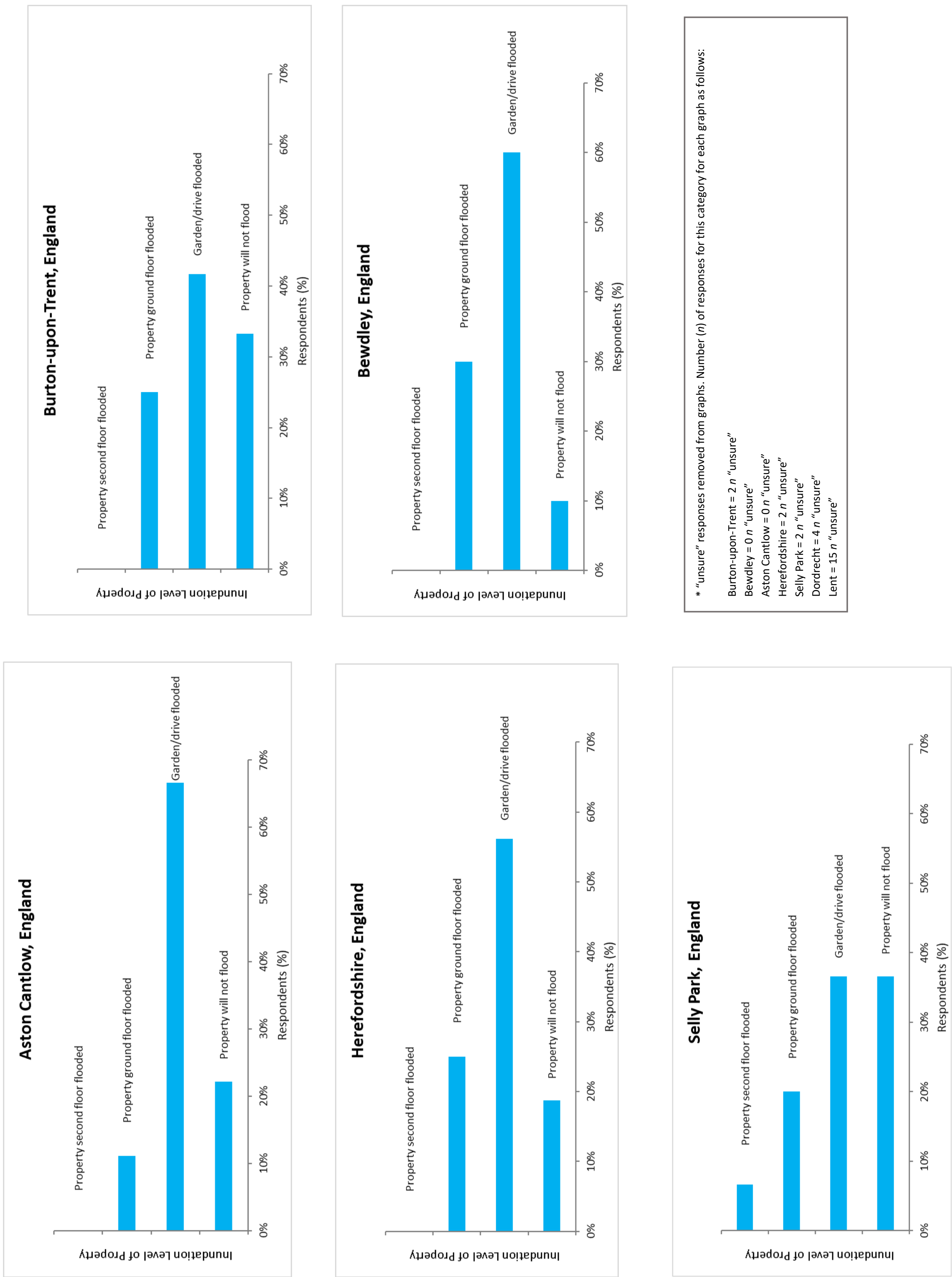

Figure 6-1 A-E: Graphs showing the level of inundation to properties respondents expect if a flood event was to occur in Burton-upon-Trent, Bewdley, Aston Cantlow, Herefordshire and Selly Park.

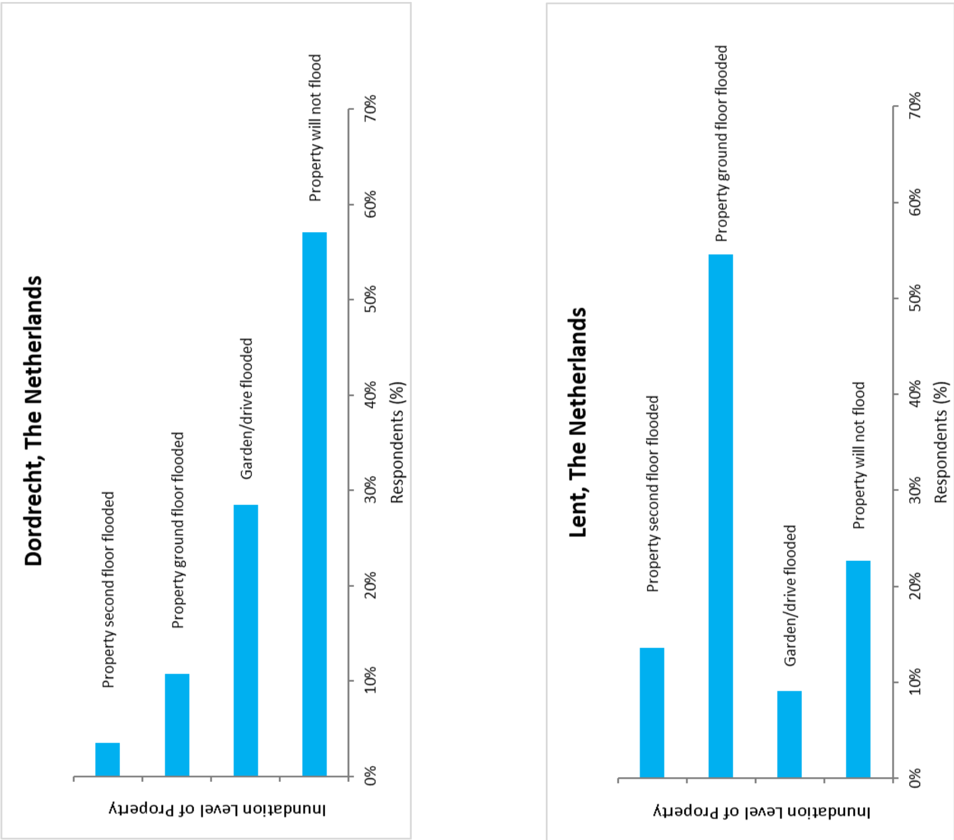

Figure 6-1 F-G: Graphs showing the level of inundation to properties respondents expect if a flood event was to occur in Dordrecht and Lent.

Any responses that stated participants were “unsure” were removed from the analysis, however, Lent has the highest amount of uncertainty with 15 respondents unsure of property levels. In Burton-upon-Trent most respondents thought their gardens or drives would flood (42%), followed by no flooding at all (33%), with 25% believing the ground floor of their property may flood. In the Bewdley case study, most respondents believed that their garden and/or drive would flood but not their properties (60%), with 10% believing they would not flood at all. In Aston Cantlow, the largest portion believed their garden/drive would flood (67%), followed by no flooding at all (22%) and internally inundating the ground floor of their properties (11%). Selly Park was the only case study in England that responded that their first floor would flood (7%), with 20% perceiving their ground floor at risk, and equally 37% believing their gardens/drives would flood and that they would not flood at all. Out of all case study, more respondents in Lent thought their first floor (14%) and ground floor (55%) would internally flood. 23% believed their properties would not be affected at all. Dordrecht had the highest number of responses that indicate properties would not flood (57%).

When considering present FRM (**Table 6-5**), overall respondents in England were more aware of what FRM was present in the communities. This may be largely due the Dordrecht case study having the lowest response to this question, with 37.5% of participants not aware of what FRM is present in their area. When asked if they were aware of the MLS strategy and if they believed Dordrecht was a 'flood resilient island', 12.5% of respondents agreed. 56.2% of respondents were unaware or unsure of any crisis management (e.g. for evacuation preparation or routes) in Dordrecht, but some respondents were aware of some spatial planning and the Voorstraat (dike). This is followed by Aston Cantlow, where 33.3% of respondents were unaware of what FRM was present, Selly Park with 25% unaware, Burton-upon-Trent with 23.1% unaware and Herefordshire with 11.1% unaware. Bewdley (100%) and Lent (97.3%) were the case studies with the highest knowledge of what FRM is present in their areas. However, when asked to consider the effectiveness of present FRM strategy on a scale of 1-5, Bewdley had the lowest mean (2.40). Burton-upon-Trent had the highest mean to this question (4.08), followed by Lent (3.76) and Herefordshire (3.72). Aston Cantlow had a mean of 3.11.

Table 6-5: Questionnaire responses to questions around FRM in place and general FRM shift, including understanding of the term 'FRM', whether this should improve DRR, and perceived responsibility of homeowners to flood risks. Results show % or mean of scale used

	England (Total)	Burton-upon-Trent *Structural protection*	Bewdley *PFR*	Aston Cantlow *PFR*	Herefordshire *Rural NFM*	Selly Park *Urban NFM with protection*	The Netherlands (Total)	Dordrecht *MLS*	Lent *RfR bypass channel*
Aware of FRM present %									
Yes	80%	76.9%	100%	66.7%	88.9%	75%	79.7%	62.5%	97.3%
No	20%	23.1%		33.3%	11.1%	25%	20.3%	37.5%	2.7%
Effectiveness of FRM present *1-5 scale*							Not directly comparable	Not included	
Mean	3.53	4.08	2.40	3.11	3.72	3.11			3.76
Std. d	1.165	1.055	.843	.928	1.054	1.263			*1.164*
Understand the term FRM %									
Yes	75.8	69.2%	90%	88.9%	88.9%	65.6%	24.6%	28.1%	21.6%
No	11.6	19.2%	10%	11.1%		12.5%	37.7%	71.9%	8.1%
Unsure	12.6	11.6%			11.1%	21.9%	37.7%		70.3%
Know of FRM shift %									
Yes	44.2	15.3%	80%	33.3%	88.9%	34.4%	49.3%	31.3%	64.9%
No	47.3	80.8%	20%	66.7%	5.6%	46.9%	17.4%	31.3%	5.4%
Unsure	8.4	3.8%			5.6%	18.8%	33.3%	37.5%	29.7%
FRM shift: positive or negative %									
Positive	58.9	42.3%	70%	77.8%	83.3%	50%	73.9%	81.3%	67.6%
Negative	9.6	15.4%	30%	11.1%	16.7%	6.3%	13%	9.4%	16.2%
No change	22.1	15.4%		11.1%		43.8%	11.6%	9.4%	13.5%
Unsure	8.4	26.9%					1.4%		2.7%
Improved DRR with FRM %									
Yes	56.8	46.2%	70%	55.6%	72.2%	53.1%	68.1%	65.6%	70.3%
No	14.7	26.9%	20%	11.1%	5.6%	9.4%	18.8%	18.8%	18.9%
Unsure	28.5	26.9%	10%	33.3%	22.2%	37.5%	13%	15.5%	10.8%
Current Responsibility: Homeowner %	32.6%	23%	60%	11.1%	38.9%	40.6%	Not directly comparable	59.4%	Not included
Prefer responsibility: Homeowner %	30%	23%	40%	0	38.9%	40.6%	Not directly comparable	9.3%	Not included
Trust in Authorities 1-5 scale	Not included	Not included	Not included	Not included	Not included	Not included	Not directly comparable	Not included	
Mean									3.54
Std. d									.730

Participants were also asked if they understood the term ‘FRM’, with more respondents in English case studies responding with yes (75.8%) than those in the Netherlands (24.6%). Dordrecht has the highest number of participants that were not aware what FRM meant (71.9%), followed by Burton-upon-Trent (19.2% responded ‘no’ and 11.6% responded ‘unsure’) and Selly Park (12.5% responded ‘no’ and 21.95% ‘unsure’). 70.3% of respondents in Lent answered ‘unsure’ to this question. When asked if respondents were aware of a shift in their country to focus more on FRM, with flood risk-based approaches, more respondents in the Netherlands (49.3% aware) were aware that in England (44.2% aware). Many participants in both case studies in the Netherlands answered unsure to this question (37.5% in Dordrecht and 29.7% in Lent). When considering if this shift is positive or negative, once a definition was provided to participants who were unaware or unsure, the Burton-upon-Trent case study had the lowest positive rating (42.3%). Herefordshire had the highest response to perceiving this shift as positive (83.3%), and Aston Cantlow also believed the shift to be positive (77%) However, it is important to point out that other than 20% of responses from Bewdley, no flood events had occurred in case studies to highlight any inefficiencies in the present management or paradigm shift to respondents. Once a definition had been provided, 67.6% in Lent thought it was positive and 16.2% thought it was negative. Further, 18.9% thought it would not protect them more than traditional management.

Respondents in all case studies except for Lent were also asked if they knew who was responsible for flooding and who should be responsible. More respondents in Bewdley (60%) and Dordrecht (59.4%) thought that the homeowner is responsible for reducing flooding to properties than any other case study. While this is standard practice for England, Dordrecht is one of the few places in the Netherlands where homeowners are responsible for reducing their flood risks and 59.4% of respondents are aware of this. Respondents in Aston Cantlow (11.1%) and Burton-upon-Trent (23%) were less likely to think homeowners are responsible for their flood risk. When asked who should be responsible for flood risk reduction, no changes between this and the previous question of who is responsible was identified in Burton-upon-Trent (23%), Herefordshire (38.9%), or Selly Park (40.6%). However, responses of 'homeowner should be responsible' in Aston Cantlow decreased by 11.1% to 0%, in Bewdley decreased by 20% (from 60% to 40%), and in Dordrecht decreased the most by 50.1% (from 59.4% to 9.3%). In Lent, respondents were asked to rate their confidence in authorities on a scale of 1-5 (as this was felt as a better question for the case study), with a mean of 3.54.

An additional question asked whether respondents understood what it means when flood events are described as year return periods or events, for instance 1/100 or 1/200-years. Overall, in England, 66.3% of respondents thought they knew what it meant when flood events were referred to in years, while 13.7% did not know and 20% were unsure. In the Netherlands, 71% of respondents said they did know what 1/100-year flood events meant, while 11.6% did not and 17.3% were unsure. If respondents answered that they did know what was meant by a 1/100-year event they were asked to provide a short description for this. The text responses for Burton-upon-Trent, as an example in which 67.4% believe they knew what 1/100-year flood events were referring to, were split into five categories based on the answer: height, risk, probability, years, and no answer. Responses such as "flood height, need defences in local areas" and "the return periods of a flood of a particular height" are classed as height. Responses such as "higher the number, higher the risk" and "risk of event" are classed as risk. Responses such as "1 in 100 means there is a 1% chance of a flood in a year" are classed as probability alongside responses that simply state “probability” or “likelihood” of flooding. Responses such as “could occur in 100, 200 or 500 years”, “you can expect the river level to peak at a certain height once in so many years” and “there’s a single chance of flood events occurring anytime within a period of years” are classed as years. Some responses are more difficult to categorise, such as “it’s an event that is predicted to happen one in a period covering x years, at any point over that period” and “1 in 100 years, probability”. However, as these have both mentioned occurring once within the years period, they have been classed as years.

Of the responses, 3.7% were classed as height, 6.3% were classed as risk, 36.8% were classed as probability, 20% were classed as years, and 33.7% provided no answer. These unanswered questions could be considered as the respondent not necessarily knowing the answer when asked to provide detail and have subsequently been classed as not understanding the term. Therefore, alongside respondents whose responses were consider to refer to years, 53.7% of respondents who answered yes are understood to not fully understand the term 1/100-year flood event, as suggested by Demeritt & Nobert (2014) and (Highfield et al., 2013). The answers categorised as height and risk are also vague, and therefore this percentage could be as high as 63.2% of respondents who reside in flood risk areas not understanding the primary categorisation of flood events.

Finally, respondents were asked if they had undertaken their own precautionary measures and whether they believe they should be responsible for installing their own precautionary measures, questioning both future flooding and their responsibility toward flood preparation. In Dordrecht, only 9.4% of people had undertaken their own precautionary measures to flooding, with 25% of respondents believing it necessary, 31.3% believing it unnecessary, and 43.8% unsure. Out of the case studies in England, Herefordshire had the highest number of respondents that had implemented their own measures for flooding with 72.2%, followed by Bewdley (70%), Selly Park (40.6%), Burton-upon-Trent (25.9%) and Aston Cantlow (22.2%). When asked if they perceive this to be necessary, more respondents in Herefordshire believed it was (88.9%), followed by Bewdley (80%), Burton-upon-Trent (55.5%), Selly Park (46.9%) and Aston Cantlow (66.7%). Some respondents also answered unsure to this question in Burton-upon-Trent (25.9%), Selly Park (21.9%), and Aston Cantlow (11.1%).

To provide some flood risk perception of individuals residing behind dike infrastructure in the Netherlands, studies by Terpstra & Gutteling (2008), Botzen et al. (2009b); Terpstra (2011), and Mol et al. (2020) have been reviewed with criteria that correlates to this study presented here as a case study. The results from Terpstra & Gutteling (2008), who investigated fluvial and coastal flood risk perceptions in Ferwerderadeel and Dongeradeel, Friesland, are presented in **Table 6-6**.

Botzen et al. (2009b) investigated the risk perceptions of individuals that live within 1/250 standard of protection dike rings. When asked to rank risks on a scale of 1-10, 20% of respondents ranked flooding as the second lowest category of risk (2 on 1-10 scale).

Further, respondents rated storm risk (82%), burglary (79%), traffic accident (69%), car theft (69%), house fire (67%), terrorist attack (56%), and car fire (50%) more likely to cause financial risks to their properties than a flood event. When solely consider flood risk probability, 72% of respondents rated their flood probability as small in either ‘no flood risk’ (11%), very small flood risk (31%) or small flood risk (31%) categories.

Table 6-6: Flood risk perception study results from Terpstra and Gutteling (2008)

	Mean score	Scale	Standard deviation
Risk perceptions and trust (n = 658)			
Personal risk	2.40	1 no – 5 high personal risk	1.02
Salience (importance)	1.77	1 hardly – 5 very salient	0.78
Severity of personal consequences	3.46	1 not severe – 5 very severe	1.20
Likelihood of event in next 10 years	2.26	1 not likely – 5 very likely	0.99
Fear	2.53	1 no – 5 much fear	0.98
Control	3.10	1 no control – 5 much control	0.76
Trust: credibility	3.29	1 no – 5 much trust	0.85
Trust: expertise	3.77	1 no – 5 much trust	0.68
Disaster preparedness (n = 340)			
Responsibility of preparedness	3.05	1 self-responsible – 5 government responsible	0.89
Attitude towards preparedness	3.50	1 negative – 5 positive attitude	0.83
Intention to prepared	2.73	1 no – 5 high intention	0.68
Damage mitigation (n = 318)			
Responsibility of mitigation	3.99	1 self-responsible – 5 government responsible	0.85
Attitude towards mitigation	2.99	1 negative – 5 positive attitude	0.98
Intention to mitigate	2.47	1 no – 5 high intention	0.99

Results from Mol et al. (2020) indicate few respondents consider the probability of a flood as high or very high (<5%), and that a large proportion of respondents (28%) do not believe a flood will ever occur that will impact their property. When considering damages, results from Botzen et al. (2009b) of respondents behind dikes with a standard of protection of 1/1250-years indicate that 27% of respondents thought that if a flood were to occur, they would suffer no to very little damages of under €100, €60,900 lower than typical flood damage costs per property at the time of the study (2009 prices).

Spearman's correlation was calculated across the socio-economic and main influencing factors of flood risk perceptions for all areas, except the dike defence literature case study. The correlation coefficient matrixes for each case study area are presented from **Table 6-7** to **Table 6-13**, with the results of any significant correlations at the 0.05 level (*) or 0.01 level (0.01) highlighted.

Although the datasets were small, some significant correlations were identified. For the Burton-upon-Trent case study (**Table 6-7**), positive correlations were identified between effectiveness of FRM measures present, in this case structural protection, with years lived in area (0.05 level) and information received about flood risks (0.01 level). This confidence in present FRM was also negatively correlated with flood worry. Level that properties would be inundated to was significantly correlated with years a respondent had lived in the area (0.01 level). Responses from individuals who believed they would be impacted by future flooding showed a positive correlation with level of property inundation (0.05 level) and frequency of worry (0.01 level). The only socio-economic factors that showed a positive correlation with flood perception factors were level of worry with education level (0.05 level) and gender (0.05; relating to male respondents in the analysis).

In Bewdley (**Table 6-8**), previous flood experience had negative correlations with almost all other factors, particularly level of flood worry, future flood likelihood, level properties would be flooded if an event occurred, and installing own PFR at the 0.01 level, and frequency of worry, having flood insurance and years respondents had lived in the area at the 0.05 level. Risk knowledge was negatively correlated with number of sources of flood information has been received from (0.01 level).

Table 6-7: Burton-upon-Trent correlation coefficient matrix.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Gender	X																		
2. Age	-.388	X																	
3. Qualification	-.045	-.091	X																
4. Homeowner	.066	.270	-.106	X															
5. Household Type	.276	-.399*	-.130	.030	X														
6. Years in Area	-.244	.603**	-.233	.425*	-.121	X													
7. Flood Risk Aware	-.171	-.309	.394	-.085	.270	-.128	X												
8. Flood Knowledge	-.114	.077	-.090	.311	-.158	.260	.292	X											
9. Previous Flooding	.144	.233	.209	.247	.088	.319	-.185	-.343	X										
10. Previous flood frequency	.090	.397*	.226	.253	.138	.352	-.086	-.231	.865**	X									
11. Worry for flooding	-.389*	.120	.479*	-.254	.111	.058	.169	-.136	.190	.237	X								
12. Worry frequency	-.251	.153	.361	-.064	-.026	-.147	-.045	-.177	.220	.213	.656**	X							
13. Future floods	.012	.157	.181	-.033	.109	.128	-.216	-.295	.393*	.305	.469*	.290	X						
14. Future flood likelihood	-.145	.125	.301	.308	.110	.106	-.041	.137	.414*	.419*	.433	.537**	.398*	X					
15. House inundation	-.155	.274	.091	.334	.149	.551**	-.057	.091	.330	.275	.405*	.270	.594**	.489*	X				
16. Info received	-.108	.199	.028	-.133	-.085	.335	.263	.236	-.059	-.023	.058	-.127	-.182	-.287	-.141	X			
17. Confidence in FRM	-.111	.109	-.267	.046	.032	.402*	.243	.217	.055	.147	-.353	-.515	-.342	-.286	-.273	.518**	X		
18. Personal PFR	-.007	.372	.215	.259	.043	.353	.121	-.181	.562	.630**	.227	.397*	-.040	.191	.222	.168	.192	X	
19. Flood insurance	.007	-.110	.094	.462*	.154	.130	.330	.331	.308	.262	-.153	-.228	-.134	.137	.000	.277	.465	.173	X

Table 6-8: Bewdley correlation coefficient matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Gender	X																		
2. Age	-.161	X																	
3. Qualification	-.049	-.474	X																
4. Homeowner	.	.	.	X															
5. Household Type	.529	-.567	.287	.	X														
6. Years in Area	.138	.780*	.787*	.	-.310	X													
7. Flood Risk Aware	.	.	.	.	.	.	X												
8. Flood Knowledge	-.432	.487	-.629	.	-.767**	.527	.	X											
9. Previous Flooding	.272	-.264	.512	.	-.266	-.550	.	.257	X										
10. Previous flood frequency	.219	.835**	-.617	.	-.303	-.734*	.	.458	-.358	X									
11. Worry for flooding	.0	-.913	.378	.	.288	-.730*	.	-.256	.385	-.786**	X								
12. Worry frequency	.0	-.750*	.242	.	.220	-.389	.	-.274	.000	-.708*	.730*	X							
13. Future floods	-.366	-.220	.259	.	.040	-1.22	.	-.176	-.266	-.303	.161	.567	X						
14. Future flood likelihood	.0	-.686*	.443	.	.202	-.515	.	-.407	.000	-.848**	.668*	.829**	.717*	X					
15. House inundation	.244	-.646*	.378	.	.119	-.393	.	-.238	.133	-.835**	.679*	.787**	.512	.882**	X				
16. Info received	.402	-.651*	.686*	.	.763*	-.532	.	-.782**	.060	-.647*	.351	.453	.332	.524	.464	X			
17. Confidence in FRM	.323	.063	-.128	.	.220	-.074	.	-.213	-.264	.226	-.320	-.250	-.299	-.372	-.346	.142	X		
18. Personal PFR	-.089	-.836**	.537	.	.261	-.825**	.	-.252	.509	-.820**	.756*	.690*	.261	.631	.565	.586	.000	X	
19. Flood insurance	-.203	-.630	.757*		.151	-.786*	.	-5.25	.199	-.777*	.541	.693*	.631	.832**	.623	.613	-.110	.739*	X

However, future flood likelihood showed a positive correlation with frequency of worry and levels of inundation of properties in potential future events. Age and years lived in area were significantly correlated with installing own PFR measures (0.01 level) and previously flood experience was significant correlated with age (0.01 level), but no other demographic factors showed any real significant correlation.

The results from Aston Cantlow (**Table 6-9**) show less correlations that previous datasets, likely due to the size of the data applied. The only significant correlation identified at the 0.01 level was between age and future flood likelihood. Other positive correlations at the 0.05 level include education with future flood likelihood; confidence in present FRM, in this case PFR, with frequency of worry and installing own PFR measures; years lived in area and level of worry; level of believed risk knowledge with frequency of worry and installing own PFR; and flood insurance and amount of flood risk information received.

Responses from Herefordshire (**Table 6-10**) indicate several inter-correlations within the data. Experience of previous flooding significantly correlates with risk awareness and frequency of flooding at the 0.01 level, with further correlations with level of worry, being impacted by a future flood and likelihood of flooding, level of potential inundation in properties, installing own PFR and having flood insurance cover at the 0.05 level. Risk awareness significantly correlated with amount of information received (0.01 level) and believed level of property inundation (0.05 level). Level of inundation in properties showed further correlation with believed future flood events (0.01 level) and level of worry (0.05 level). Installing own PFR showed strong correlation with future flood risks and inundation of properties (0.01 level), and these factors, in addition to level of worry, all showed significant correlation with insurance uptake (0.01 level).

Table 6-9: Aston Cantlow correlation coefficient matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Gender	X	-.439																	
2. Age	-.439	X																	
3. Qualification	.204	-.518	X																
4. Homeowner	.	.	.	X															
5. Household Type	-.098	-.443	.498	.	X														
6. Years in Area	.365	.285	-.224	.	-.285	X													
7. Flood Risk Aware	.	.	.	.	.	.	X												
8. Flood Knowledge	-.144	.155	.177	.	-.606	-.105	.	X											
9. Previous Flooding	.500	-.098	.612	.	.195	.000	.	-.144	X										
10. Previous flood frequency	.342	.038	.657	.	.152	.160	.	.042	.878**	X									
11. Worry for flooding	.378	-.277	.000	.	-.277	.725*	.	.109	-.189	-.055	X								
12. Worry frequency	.316	-.139	.387	.	-.463	-.260	.	.776*	.316	.370	-.060	X							
13. Future floods	-.250	.439	.306	.	-.073	-.411	.	.361	.500	.439	-.661	.395	X						
14. Future flood likelihood	.468	-.800*	.707*	.	.233	.017	.	.189	.234	.224	.531	.311	-.211	X					
15. House inundation	.273	-.564	.200	.	-.048	.129	.	.110	-.109	.075	.557	.259	-.655	.434	X				
16. Info received	.000	-.005	-.020	.	.085	.612	.	-.336	.000	.171	.661	-.507	-.437	.214	.265	X			
17. Confidence in FRM	.204	-.369	.458	.	-.229	-.205	.	.560	.204	.339	.231	.678*	.153	.631	.367	.089	X		
18. Personal PFR	-.189	.111	.000	.	-.664	.000	.	.764*	-.189	-.055	.357	.478	.189	.265	.124	.165	.694*	X	
19. Flood insurance	.000	-.390	.204	.	.195	.000	.	-.144	.000	.098	.378	-.158	-.250	.515	.273	.680*	.612	.378	x

Table 6-10: Herefordshire correlation coefficient matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Gender	x																		
2. Age	-.460	x																	
3. Qualification	-.131	.014	x																
4. Homeowner	-.686**	.585*	-.072	x															
5. Household Type	-.098	-.052	-.288	.471*	x														
6. Years in Area	-.011	-.090	-.230	-.157	-.045	x													
7. Flood Risk Aware	-.236	.546*	.198	.454	-.074	-.404	x												
8. Flood Knowledge	-.687**	.263	.459	.600**	.098	-.158	.331	x											
9. Previous Flooding	-.438	.853**	.131	.686**	.098	-.335	.661**	.313	x										
10. Previous flood freq	-.228	.255	.243	.535*	.364	-.204	.149	.312	.535*	x									
11. Worry for flooding	-.575*	.683**	-.178	.549*	-.039	-.093	.189	.100	.575*	.072	x								
12. Worry freq	-.492*	.691**	-.066	.533*	.062	-.007	.420	.127	.634**	.136	.793**	x							
13. Future floods	-.125	.525*	-.288	.343	.000	-.198	.189	.125	.500*	-.106	.550*	.507*	x						
14. Future flood freq	.000	.438	.131	.171	-.065	-.442	.189	-.042	.500*	.012	.500*	.412	.667**	x					
15. House inundation	-.223	.629**	-.286	.325	-.109	-.199	.527*	.195	.474*	-.208	.479*	.364	.613**	.334	x				
16. Info received	-.123	.499*	.296	.273	-.265	-.360	.603**	.307	.399	.119	.356	.416	.368	.368	.376	x			
17. Confidence in FRM	.368	-.235	.416	-.351	-.126	-.253	-.121	-.112	-.224	-.201	-.294	-.325	-.256	.320	-.243	-.110	x		
18. Personal PFR	-.175	.668**	-.101	.391	-.034	-.455	.564*	.351	.570*	.010	.298	.261	.614**	.439	.831**	.441	.011	x	
19. Flood insurance	-.570*	.668**	-.101	.391	-.034	-.402	.265	.351	.570*	-.074	.614**	.462	.614**	.439	.655**	.247	-.191	.723**	x

For socio-economic factors, age was positively correlated with risk awareness. Gender was negative correlated with risk knowledge (0.01 level), relating to females, and level and frequency of flooding (0.05).

For Selly Park (**Table 6-11**), age showed positively correlations with previous flood events, information received, undertaking own PFR measures at the 0.01 level, and risk knowledge at the 0.05 level. Gender is also negatively correlated with previous flooding, undertaking personal and flood insurance. Installing own PFR also significantly correlated with previous flooding, and level and frequency of flooding, at the 0.01 level, and number of information sources at the 0.05 level. Level and frequency of flooding also shows a significant correlation with perceived property inundation levels in properties in future events. Level of worry has a positive correlation with future flood likelihood at the 0.05 level.

Few significant correlations were also identified in the Dordrecht case study data (**Table 6-12**). Significant correlations were shown between years lived in area and previous flood frequency (0.01 level), and between believed understanding of risk with previous flooding and previous flood frequency (0.01 level). Future likelihood of flooding also positively correlated with previous flooding (0.05 level) and frequency of these events (0.01 level), but a negative correlation has been noted between level of inundation of properties in future events and previous flood experience (0.05 level). Positive correlations were also shown between experiencing a future flood and level of information received on flood risk (0.05 level); understanding flood risk and knowing what FRM is present (0.05 level); and gender (for male residents) and previous flood (0.05 level).

Table 6-11: Selly Park correlation coefficient matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Gender	X																		
2. Age	-.234	X																	
3. Qualification	.359*	-.080	X																
4. Homeowner	.128	.044	-.163	X															
5. Household Type	-.049	-.165	-.380*	-.109	X														
6. Years in Area	-.349	.699**	.038	-.073	.006	X													
7. Flood Risk Aware	-.169	-.096	.114	-.058	-.247	-.287	X												
8. Flood Knowledge	-.238	.356*	.091	.158	-.072	.206	.306	X											
9. Previous Flooding	-.394*	.494**	-.149	-.048	-.072	.438*	.217	.184	X										
10. Previous flood frequency	-.364*	.638**	-.080	-.006	-.133	.592**	.193	.357*	.887**	X									
11. Worry for flooding	-.318	.339	-.040	-.105	-.408*	.106	.231	.083	.386*	.436*	X								
12. Worry frequency	-.243	.402	-.089	-.031	-.386*	.107	.250	.052	.476**	.557**	.796**	X							
13. Future floods	-.129	.174	.085	.128	-.254	.174	.191	.085	.243	.286	.349	.400*	X						
14. Future flood likelihood	-.258	.153	-.116	.018	-.236	.050	.270	.161	.167	.176	.418*	.324	.611**	X					
15. House inundation	.126	.101	.271	.056	-.283	.029	.196	-.102	.253	.198	.471**	.484**	.357*	.214	X				
16. Info received	-.155	.513**	.084	.100	-.148	.320	.237	.595**	.305	.430*	.191	.264	.228	-.015	.121	X			
17. Confidence in FRM	-.086	-.013	-.089	.007	.239	.124	-.303	.292	-.115	.003	-.300	-.297	-.305	-.138	-.291	.219	X		
18. Personal PFR	-.371*	.584**	-.122	.048	-.114	.443*	.149	.314	.555**	.668**	.456**	.469**	.012	.018	.340	.354*	-.036	X	
19. Flood insurance	-.363*	.088	-.073	.014	.072	.050	-.121	.264	.266	.316	.268	.317	.177	.075	-.023	.130	.008	.146	X

Table 6-12: Dordrecht correlation coefficient matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Gender	X																			
2. Age	-0.16	X																		
3. Qualification	0.48	-.136	X																	
4. Homeowner	-.232	.328	-.078	X																
5. Household Type	.079	-.339	-.197	-.198	X															
6. Years in Area	.077	.570**	-.165	.107	.002	X														
7. Flood Risk Aware	.139	.328	-.322	-.032	.261	.302	X													
8. Flood Knowledge	-.237	.223	-.299	.217	-.083	.108	.320	X												
9. Known level of flood risk	-.141	-.156	-.101	.142	-.028	-.222	.142	.491**	X											
10. Previous Flooding	-.215	.083	-.173	.339	.105	.127	.339	.603**	.234	X										
11. Previous flood frequency	-.063	.376*	-.077	.082	.025	.603**	.276	.513**	-.024	.569**	X									
12. Worry for flooding	.011	-.107	.042	-.401*	.014	-.127	.077	-.241	-.202	-.208	-.210	X								
13. Worry frequency	-.173	.181	-.067	-.260	-.191	.014	.111	.187	.017	-.031	-.062	.560	X							
14. Future floods	-.028	.369*	-.156	-.077	.074	.353*	.385*	.085	-.101	-.032	.122	-.030	.266	X						
15. Future flood likelihood	-.206	.217	.020	.000	-.122	.266	.205	.331	.068	.392*	.516**	.209	.194	.339	X					
16. House inundation level	-.041	.161	-.103	-.305	-.090	.090	.136	-.184	.252	-.443*	-.166	.141	.145	.159	.212	X				
17. Info received	.139	.328	-.322	-.032	.261	.302	1.000**	.320	.142	.339	.276	.077	.111	.385*	.205	.136	X			
18. Known FRM	.067	.283	-.287	.232	.180	.220	.232	.408*	.243	.215	.202	-.183	.213	.360*	.173	.041	.232	X		
19. Personal PFR	-.028	.196	-.113	.058	-.112	.017	.058	.215	.007	.170	.037	-.138	.022	.138	.134	-.243	.058	.249	X	
20. MLS known	-.394*	.107	.057	.119	.072	-.029	.119	.189	.084	.351*	.260	-.130	-.009	.135	.213	-.067	.119	.154	.256	X

In the Lent case study (**Table 6-13**), limited correlations were identified. Likelihood of property flooding positively correlated with years in area (0.01 level) and level of risk awareness (0.05 level). Level of flood risk awareness negatively correlated with information received (0.05 level). Level of property inundation had the most significant positive correlations, at the 0.01 level, with flood risk understanding, known level of flood risk, worry level, worry frequency and likelihood of properties flooded in the future. Likelihood of properties flooding in the future also negatively correlated with information provided (0.05 level).

Table 6-13: Lent correlation coefficient matrix

	1	2	3	4	5	6	7	8	9	10	11	13	14	15	16	17
1. Gender	X															
2. Age	.003	X														
3. Qualification	-.166	-.154	X													
4. Homeowner	.134	.100	.257	X												
5. Years in Area	-.179	.073	.323	-.013	X											
6. Flood Risk Aware	-.048	-.168	.305	.077	.038	X										
7. Flood Knowledge	-.011	.018	-.034	-.091	.045	.404*	X									
8. Known level of flood risk	-.113	-.073	-.003	-.224	.031	.230	.798**	X								
9. Previous Flooding	.349*	-.088	-.166	-.227	.035	-.116	.089	.027	X							
10. Worry for flooding	.087	.098	.016	.053	.082	-.261	-.043	.029	-.079	X						
11. Worry frequency	.071	.030	.175	.043	.157	.027	.129	.082	-.064	.782**	X					
12. Future flood likelihood	.063	-.123	.150	.198	.427**	.388*	.205	.076	.043	.325*	.432**	X				
13. House inundation level	-.030	.109	.042	.192	.118	.243	.414*	.364*	-.159	.409*	.377*	.605**	X			
14. Info received	.011	.179	-.048	-.259	-.199	-.369*	-.161	.013	-.128	.057	-.155	-.384*	-.082	X		
15. FRM Effectiveness	.021	.112	.280	.216	-.238	.159	.277	.212	-.209	-.083	-.015	-.303	-.100	.271	X	
16. Personal PFR	-.191	-.044	-.232	.066	.136	.060	.126	.094	-.142	.310	.291	.259	.280	-.273	-.235	X

Figures 6-2 to **6-8** display the density maps created for each case study by combining the individual respondent sketch maps. Discussion of these produced density maps is also provided in the following discussion sections. However, while it is recognised that the produced density maps can be compared to maps produced by RMAs for each location, as mentioned in Chapter 5, flood hazard mapping is just another representation of flood risk using defined hydrological and topographical data. Although these maps lack modelled information, they are made up entirely of local knowledge and represent their own outcome of local, known risks which are most important to the respondents.

Finally, Supplementary formal interviews were undertaken with the primary FRM scheme RMAs for Bewdley (EA), Aston Cantlow (Warwickshire County Council) and Herefordshire (Herefordshire County Council). An informal interview was undertaken with the primary RMA for Burton-upon-Trent (EA) but a formal interview was declined due to current workloads. No response for a formal or informal interview was received from any RMAs for Selly Park, but two informal interviews and a site walk-over with interested residents and members of the FAG was undertaken. Several attempts were made to find an RMA in the Netherlands that would discuss the measures in Dordrecht and Lent, and while contact at the WBs, Provinces and Rijkswaterstaat was made, no formal or informal interviews were completed. Informal interviews were undertaken with academics in the Netherlands (VU Amsterdam, IHE Delft, Deltares, and Wageningen University), however these focused on discussing the schemes and flood risk perceptions in general. Interview transcripts are available in **Appendix 6** if available.

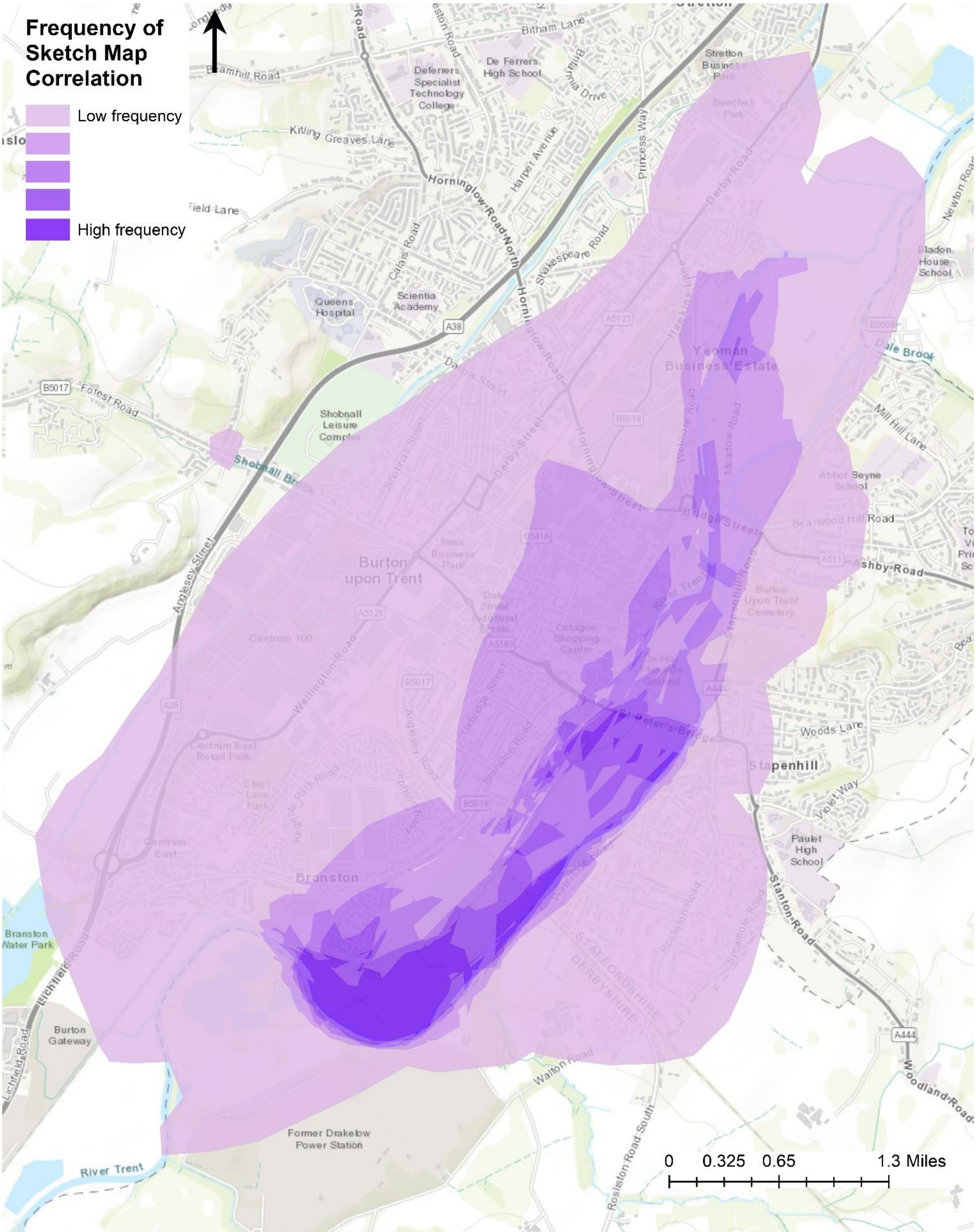

Figure 6-2: Burton-upon-Trent produced flood risk perceptions density map.

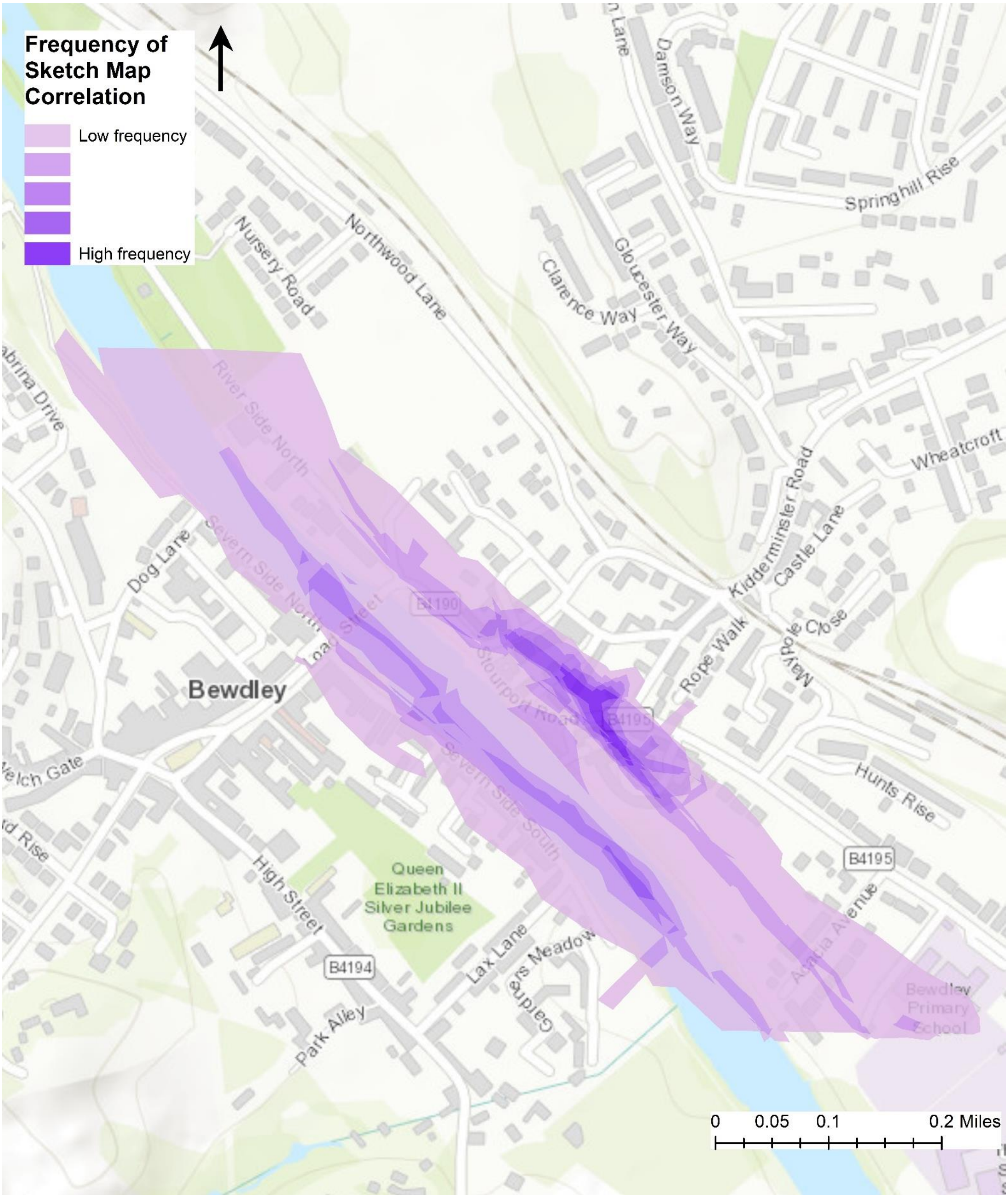

Figure 6-3: Bewdley produced flood risk perceptions density map.

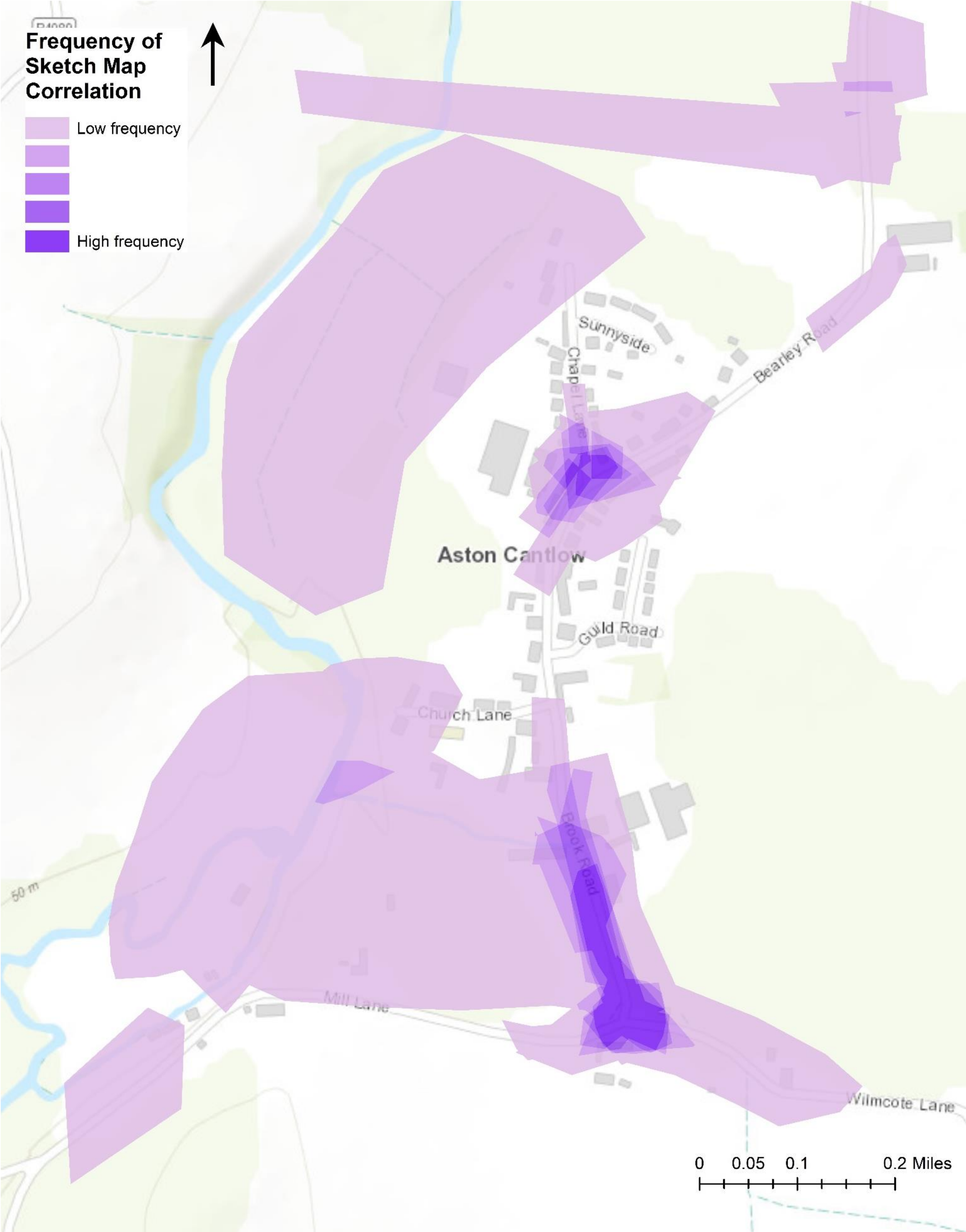

Figure 6-4: Aston Cantlow produced flood risk perceptions density map.

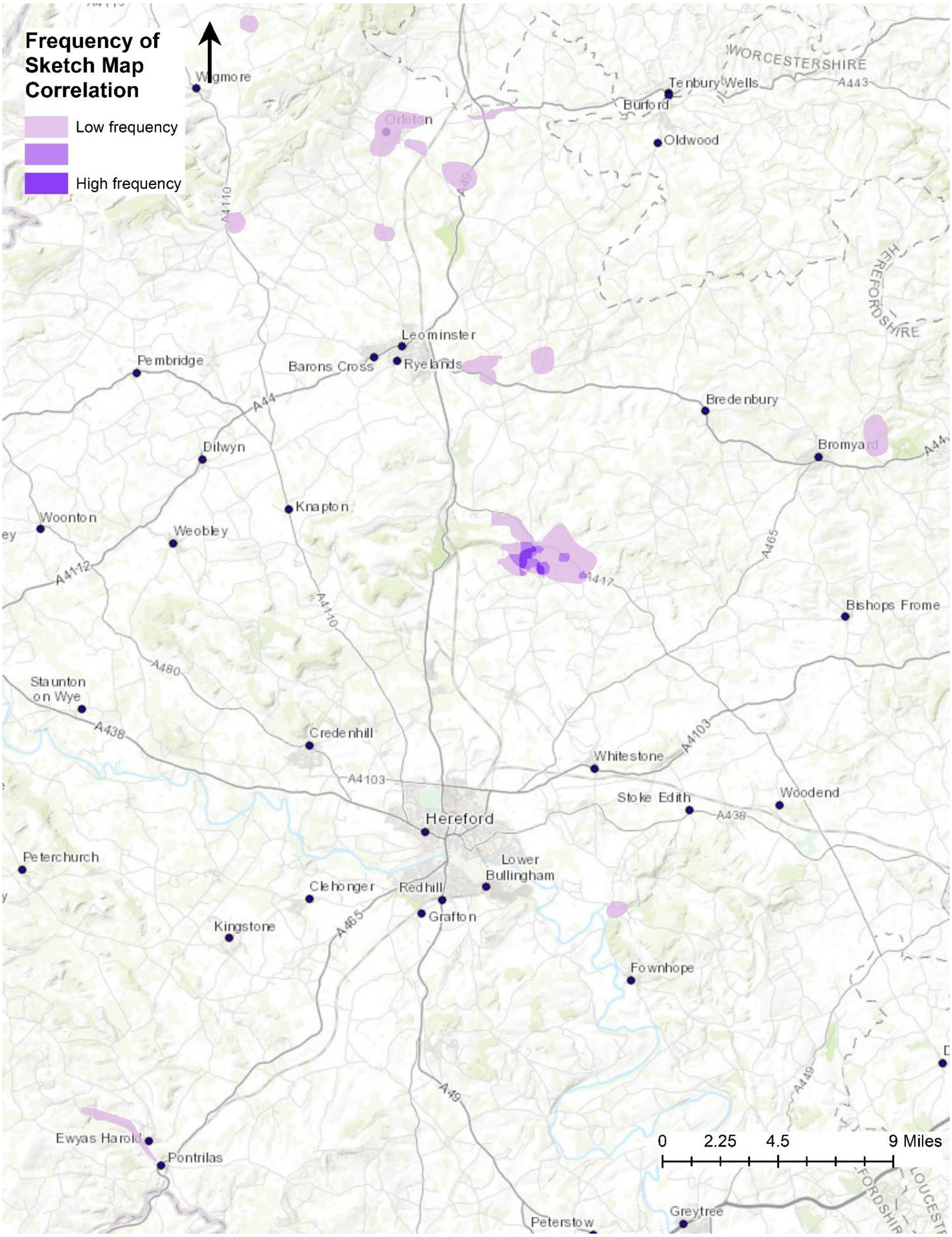

Figure 6-5: Herefordshire produced flood risk perceptions density map.

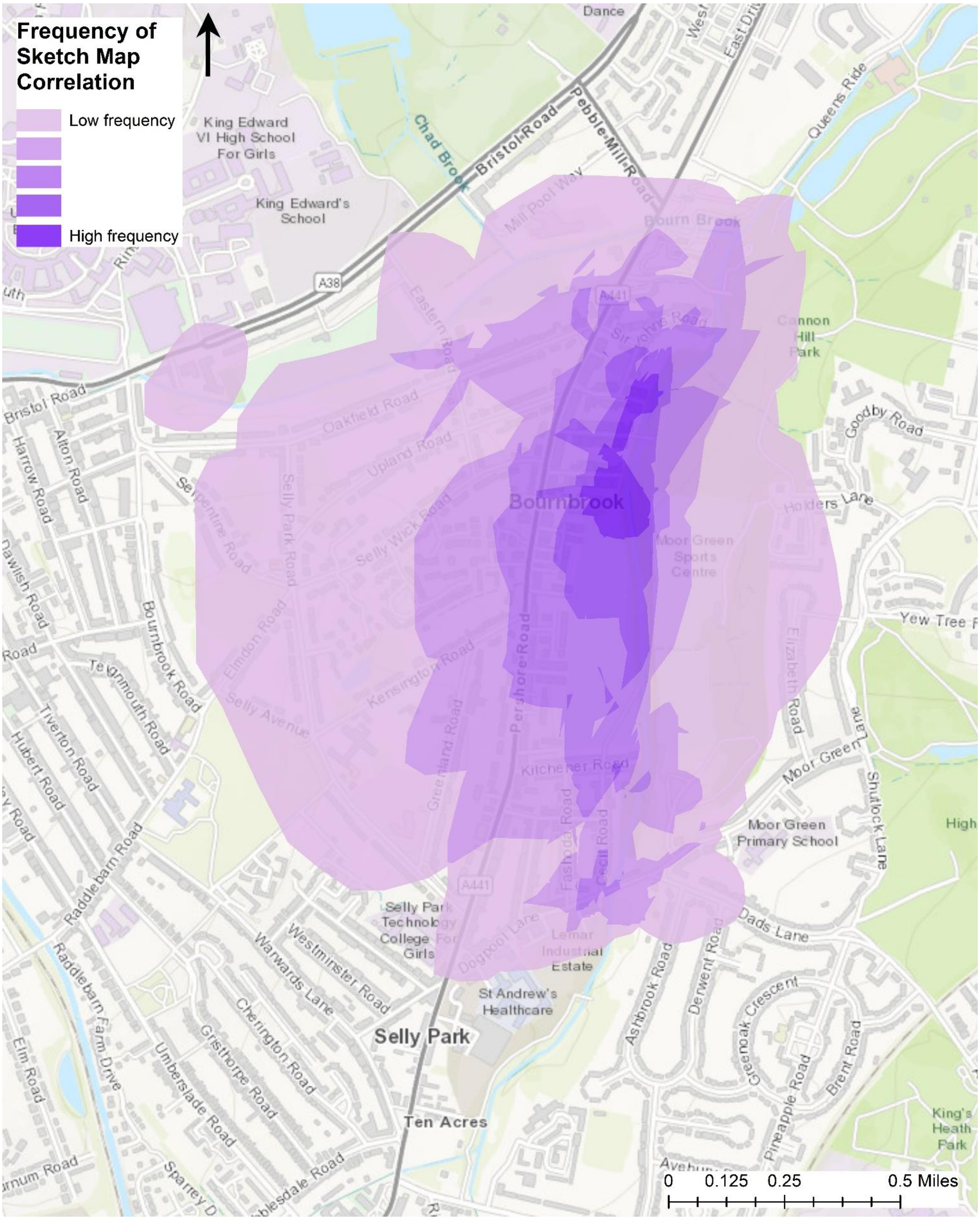

Figure 6-6: Selly Park produced flood risk perceptions density map.

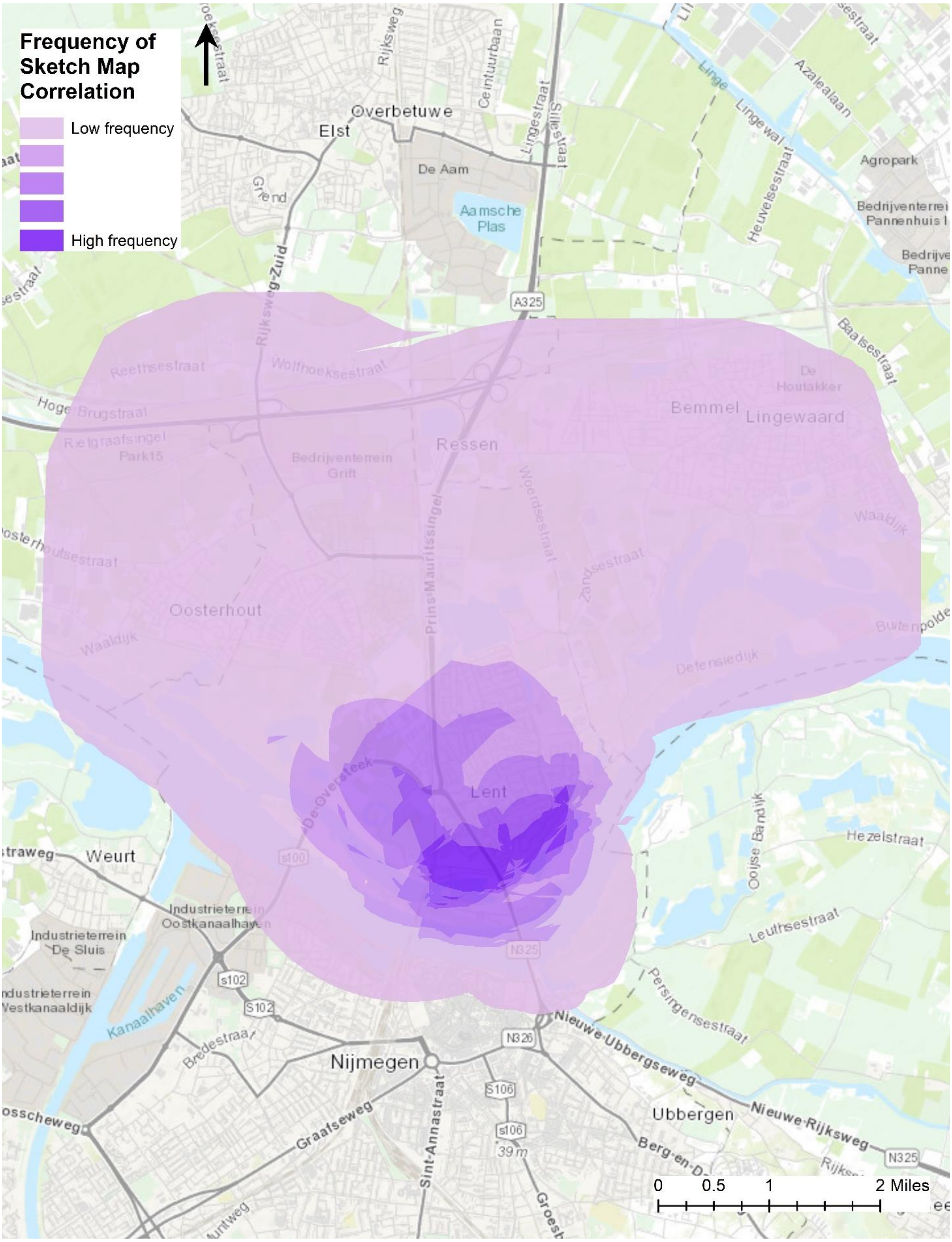

Figure 6-7: Lent produced flood risk perceptions density map.

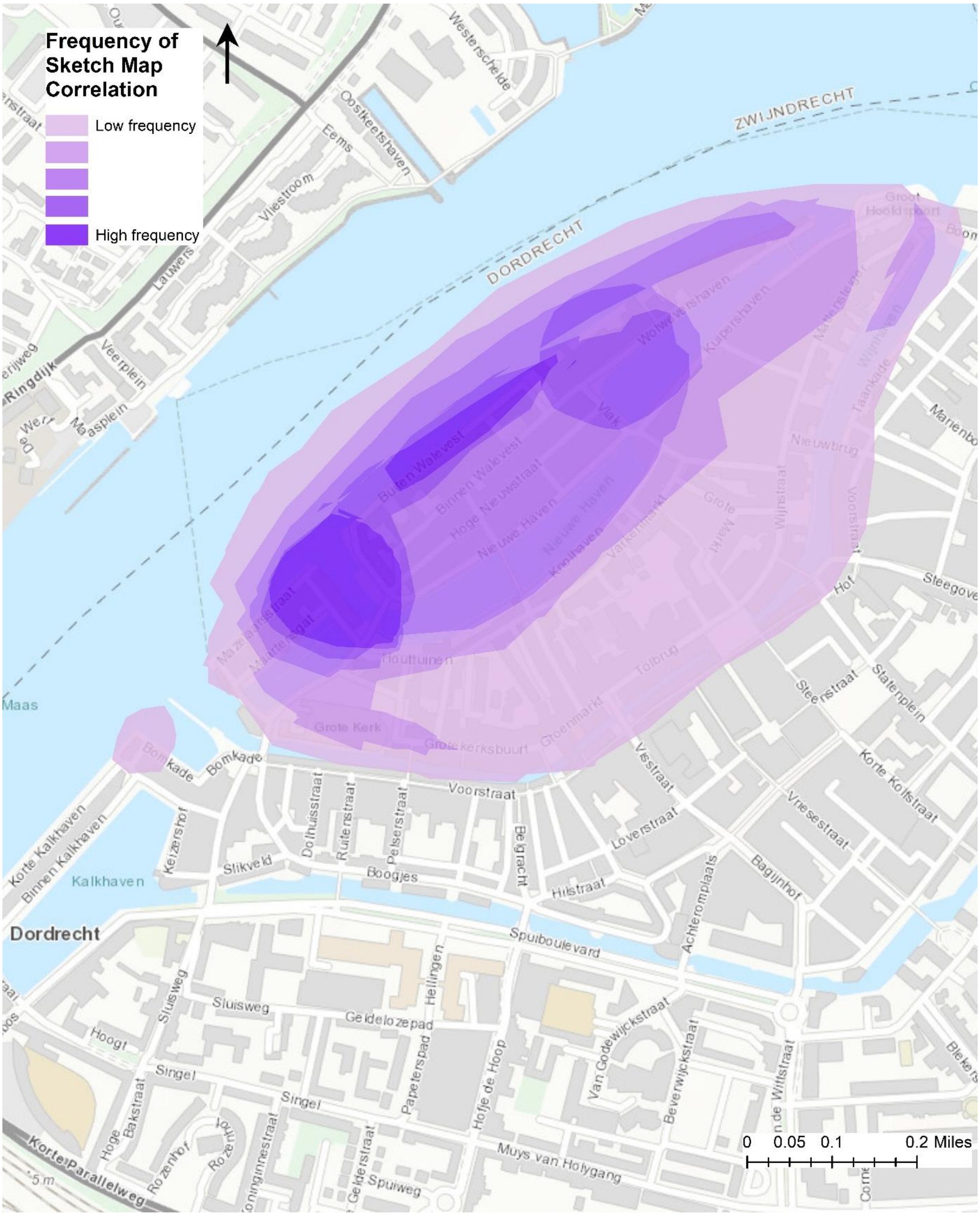

Figure 6-8: Dordrecht produced flood risk perceptions density map.

6.2 Discussion

Comparing the case study area types, Selly Park and Burton-upon-Trent are large urban areas with higher densities of at-risk properties, particularly when compared to smaller, rural case study areas such as Bewdley and Aston Cantlow. The higher number of responses in Selly Park and Burton-upon-Trent were therefore expected, and is further consistent with the FRM types chosen for the study: flood protection and alleviation schemes to protect large areas in Burton-upon-Trent (>5,600 properties) and Selly Park (>300 properties), and smaller PFR schemes in Aston Cantlow (PFR installed on 36 properties) and Bewdley (PFR installed on 43 properties) that reduce risks to much fewer, dispersed properties when a larger scheme is not cost beneficial. This was known prior to the study and is the reason why two PFR case studies were included.

However, when comparing response rates, the larger areas had smaller response rates, for instance 4.3% and 8% respectively for Burton-upon-Trent and Selly Park, when compared to the smaller case studies, for instance 20% and 22% in Bewdley and Aston Cantlow, respectively. These response rates are thought to decrease further when considering the impact of online searching of the survey, although the final amount and response rate of this is unknown. Small response rates decrease confidence in probability-based conclusions and increase the risk of non-response bias with errors and biases in results (Stedman et al., 2019). However, small survey response rates are considered to be an issue with a number of social research studies, with response rates to questionnaires reported to have largely decreased over the past couple of decades (Carley-Baxter et al., 2009; Stedman et al., 2019) with 'survey fatigue' suggested as a reason for reducing responses, particularly in areas where several surveys have been administered on the same concept (e.g. flooding) (Sinickas, 2007).

This may have been an issue in some areas, particularly as, in England, the EA have confirmed that they are other RMAs use a survey approach to engage with, and gather data from, residents at flood risk. This may also have been a reason for limited responses in the Netherlands, with Lent and Dordrecht well known for deviating from traditional Dutch dike defence. While no flood risk perception studies for Lent were identified during literature searches, although this was mentioned during some informal conversations with Dutch academics, flood risk perception studies using public questionnaires have previously been conducted in Dordrecht (Bockarjavo et al., 2009; Herwig, 2017). When compared with these previous studies, the door-to-door response rate is similar to the response rate Herwig (2017) received when using this method (32 responses in this study compared to 36 responses in their study). To increase response rates, like the Lent questionnaire, an online survey could also have been developed which Herwig (2017) used to attract 28 more responses. Further, a postal survey could have been implemented such as Bockarjavo et al. (2009) who had 314 responses (response rate of 22.3%) in their study. Postal surveys have been used in a number of flood risk perception studies (e.g. Terpstra, 2011; Buchecker et al., 2016), and while this was not possible or appropriate at the time (e.g. this would have required a Dutch response address), this could be considered for future studies. Again, postal survey response rates are suggested to have declined over recent years (Stedman et al., 2019), and it is unknown whether this would have increased response rates.

While the relationship with socio-economic factors and flood risk perceptions were not the primary focus of this chapter, socio-economic and demographic characteristics are recognised to influence risk perceptions (Botzen et al., 2009) and some discussion may be relevant. When considering homeownership, more homeowners completed the survey that non-homeowners. This may have an impact on flood risk perceptions in all case studies as previous literature has identified homeowners are suggested to exhibit more flood risk awareness (Grothmann & Reusswig, 2006) of up to 56% when compared to those who rent (Gotham et al., 2017). However, this assessment is not supported in all studies, with similar flood risk perception levels between homeowners and renters also identified (Kellens et al., 2013). No significant correlation was identified between homeownership and perception factors in any case studies, but this may have had an influence of flood risk perceptions overall.

Across most case studies, and particularly in England, more respondents in the 50-69 years category participated in the study (with the exception of Bewdley). In Lent more individuals in the 50-69 years category completed the survey, and in Dordrecht more respondents were between 35-49 years old. The importance of age for risk perception varies across the literature. Some studies identify a positive relation between older respondents with risk perceptions (Botzen et al., 2009; Wang et al., 2018) and precautionary behaviour to flooding (Grothmann and Reusswig, 2006; Lechowska et al., 2018), while others show the opposing trend of older individuals more likely to have lower risk perceptions (Botzen et al., 2009). Studies investigating the capability of older adults to respond to flood risk information and communications have further identified strategies can be largely ineffective on older populations and age does not alone determine experience and higher perceptions (Walkling and Haworth, 2020). However, this chapter identified some significant correlations between age and years in area and previous flooding in 5 out of 7 case study areas. This highlights that while age does not directly equal experience, the two are closely linked and as experience of flooding, which is a direct factor for risk perceptions, may sometimes present as age and years in area.

Like the relationship between age and risk perceptions, the influence of education level differs across literature. While a positive relationship is generally considered, indicating that education increases individual awareness of hazards (Lechowska et al., 2018), other studies have identified no relationship (Grothmann and Reusswig, 2006). Further, trends of individuals with higher education levels, and inferred higher income levels, having lower risk perceptions have been presented (Botzen et al., 2009), with individuals with less education more worried and aware of flood risks (Bradford et al., 2012). This little effect on flood risk perceptions and precautionary behaviour (Grothmann & Reusswig, 2006; Botzen et al., 2009b; Bubeck et al., 2012a) is therefore not expected to largely skew any results. Some correlations between education and perception factors (with future flood likelihood in Aston Cantlow; worry in Burton-upon-Trend; and information received and flood insurance in Bewdley) have been identified in this chapter. However, these are not consistent enough to confirm this relationship and may be influenced by other case study-specific factors.

The final socio-economic factor in this chapter that may have an influence on risk perceptions is gender. More females responded to the questionnaire in all case studies apart from Herefordshire and Lent. Studies suggest men and women determine risks differently and women are more likely to judge risks from hazards higher than men (Botzen et al., 2009). However, several studies have found no relationship with gender and risk perceptions, with some determining other factors, such as cultural values or if there are children within the household, influence this gender-risk relationship (Lechowska et al., 2018). Significant correlations between gender and flood risk perception factors were identified in 3 case studies in this chapter. These were level of worry and gender (males) in Burton-upon-Trent, previous flooding, installing personal PFR and having flood insurance with gender (females) in Selly Park, and flood knowledge, flood worry (level and frequency) and flood insurance in Herefordshire. These support the argument for no direct relationship between gender and risk perception, and that other area characteristics may be influencing these results.

Burton-upon-Trent: Structural Protection

Burton-upon-Trent had the lowest response rate out of all case studies in this chapter. Like the low response rate received in the pilot study in Kelverly Grove, West Bromwich, this may indicate that, in general, residents in Burton-upon-Trent perceive themselves to not be at risk of flooding and are subsequently disinterested to participate in studies around this. This was supported by Burton-upon-Trent having the lowest mean when considering future flood likelihood.

This low risk perception may be related to respondents having a lot of confidence in the structural protection that surrounds Burton-upon-Trent, with this case study having the highest mean when considering how effective the present FRM strategy is. This confidence in present FRM was negatively correlated with flood worry, suggesting that overall respondents that are confident in the protection are not generally worried about flood risks. These results fit with the 'levee effect' concept for structural protection, in which individuals do not fully consider or understand residual risks for an illusion of complete safety. Effectiveness of FRM was also positively correlated with years in area and information received about flood risks. Thus, respondents who have lived in the area for longer and/or have received more information on the flood risks and flood protection in Burton-upon-

Trent have higher confidence in the structural FRM measures. Information provided by the RMA responsible, during an informal interview, identified that the structural protection in Burton-upon-Trent had successfully protected the area during several events (105 days between 1980 and 2017) and particularly during flooding in 2012, 2000, 2007 and 2008. The protection infrastructure was also regarded as successful during flooding in 2020 that internally inundated properties outside of protected areas but protected >5000 properties. Respondents that have lived in the area and witnessed the structural protection working during these events may therefore have a higher confidence in measures, resulting in a lower risk perception to flooding.

This relationship is further supported by a quarter of respondents indicating their property would be internally flooded (ground level) during future events, which correlates significantly with the years respondents have lived in the area. This may indicate that respondents that have lived in the area for longer have seen surrounding flood incidents (of the floodplain and unprotected areas) while they have not flooded. Respondents who had direct experience of previous floods (14.3% of those previously flooded) indicated these to have occurred in 1999 and 2007. Around these times protection infrastructure was used for 13 days (during 2000 and 2007 event), and there may have been further localised flooding of Burton-upon-Trent from other sources (e.g. drainage infrastructure that outfalls to the River Trent backing up). The remaining 85.7% of respondents that were indirectly impacted (85.7%) may also have seen the flood protection or floodplain (that is significantly large in some areas) in use.

While some respondents believed they would experience internal flooding, most respondents believed only their garden and/or drive would flood during an event (42%), they would not be impacted at all (33%). This could be an influence from the nature of FRM in place, in which structural protection aims to keep water away from properties. However, it could also be from respondents unaware or underestimating their residual risks, influenced by the successful FRM present. Almost a quarter (23.1%) of respondents were unaware of what FRM was present in Burton even though it has been active for past events. This result of some individuals being unaware of their risks was supported from comments by the RMA, who indicate the graph that indicates how often the flood protection has been used was designed to purposely engage in areas where several individuals are unaware of not only their residual risk, but their risk at all. This again reflects the levee effect where complacency of flooding can increase flood risks if breaches occur. However, only a small number of respondents indicated they were unaware of their risks (3.8%) in Burton-upon-Trent, supporting the argument these risks could be underestimated due to the successful FRM reducing regular flooding.

When considering ‘FRM’ in general, most respondents (69.2%) had heard of the term but only a quarter (15.3%) were aware there had been a shift towards varying FRM and away from traditional protection. This again is comparable with the type of area and FRM present, as larger urban areas with a considerable number of at-risk properties and historic experiences of flooding qualify for large protection schemes under funding rules. These factors, or again the confidence in measures, may have influenced the lowest positive rating (42.3%) of applying FRM instead of sole structural protection and whether respondents believed FRM options would be better at reducing risks to properties (46.2%). Further, respondents in Burton-upon-Trent were less likely to know or think homeowners should be responsible for flood risks (both 23%), that relates to the negative perception towards risk-based FRM approaches, confidence in the (government funded) structural protection present, and a perception that no other option would be as successful at protecting from flood risks identified from the data.

However, some respondents in Burton-upon-Trent do believe they will experience future flooding, with these respondents identifying internal flooding to their properties in potential future events and a higher level and frequency of flood worry. The results of future flood likelihood also showed a correlation between previous flooding, supporting the argument that previous flood experience is a dominant factor for higher perceptions of flood risk. These results that indicate that flood risk is still a concern for some participants can be supported by results from the sketch mapping exercise. The density map for Burton-upon-Trent (**Figure 6-2**) shows most respondents believed areas in the south of Burton-upon-Trent were more at risk than other areas, despite comments that flood water has sometimes encroached upon gardens in the south-east of Burton-upon-Trent. The higher risk perceived in the south of the town may also be due to the embankment that is present here, and close to properties, that is a focal point with a raised walkway rather than a wall. Thus, like the adaption effect, visibility of flood event, particularly smaller frequent events if they were to occur, may increase the awareness of flood risk. The sketch map result also indicates that some respondents in Burton-upon-Trent are aware the whole area is still at-risk from residual flooding (past the design standards) from the River Trent, despite the strong influence of the protection.

Bewdley: Property Flood Resilience

Bewdley was the only case study identified in which all respondents were aware of their flood risk, believed they knew their level of flood risk, and knew what FRM measures were present. Almost all respondents had previously experienced flooding, with almost half of these respondents being directly impacted by previous flood incidents and the case study had the highest score for perceived level of flood risk knowledge out of all case studies. However, when considering the likelihood of being impacted by future floods, the resulting response in Bewdley had a mid-range mean (3.0), the second lowest in all case studies after Burton-upon-Trent. Most respondents (60%) also believed that their garden and/or drive would flood but their properties would not, with a small number believing they would not flood at all.

Further, when questioned about the effectiveness of the PFR measures in place, respondents in Bewdley had the lowest confidence in the measures. This low confidence in the PFR, as well as a contrasting low perception of future flooding, is likely due to the contentious issue of discontinuing the temporary barrier after 16 years and a version of the levee effect for this type of management. Residents requested to keep the temporary barrier, rather than install PFR, as it had previously shown no failures to residents at the time. Although there had been some safety failures of leaking and sliding in places, identified by RMAs but not residents, that prompted the review and subsequent decision to remove the barrier, no property flooding had occurred. This is supported by recorded flood peaks in Bewdley since 2000, and prior to flooding in February 2020, where no event in the 20-year period had reached >5m to overtop the temporary protection standard and highlight their limitations to residents.

Information provided during the interview with the RMA indicates that residents in Bewdley were very aware of their flood risks, and already had an informal (now formalised) FAG set up prior to the PFR option decision in 2014. It is therefore likely that respondents were not underestimating their flood risks, and instead perceived their flood risks to be significantly reduced by the illusion of complete safety from the temporary barriers.

"*The temporary barrier had kept back so many small floods over the past 15 years, so maybe they took it for granted that this was the solution and the residual risks were only in the back of people minds.*"

"People wanted to keep [the] temporary barrier … Came up with a compromise the have a temporary barrier as well and that this would be another line of defence and would keep the roads open … But this would have to be through a partnership approach."

Comments from Bewdley PFR RMA interview.

While future flood likelihood was low, level and frequency of worry was high, with frequency of flood worry having the second highest result of all case studies. Residents also believed they are well informed by flood information sources on their flood risk, which may be due to the heavy involvement and "partnership approach" by relevant RMAs, noted in the RMA interview. This large amount of engagement and involvement by RMAs may also be the reason respondents in Bewdley are the most aware homeowners are responsible for their flood risk, as well as the large decrease in responses of 'homeowner' when asked who should be responsible for managing flood risk. Residents may therefore believe they are unable to reduce flood risks themselves as it is a main river flood problem and may feel some inequality that the opposite side of the River Severn has a demountable scheme, managed by the RMA, when their temporary barriers are being removed for a strategy that requires complete homeowner responsibility. It is noted that the sketch density map for the area (**Figure 6-3**) highlights a larger risk on the Beales Corner/Wribbenhall side of Bewdley, as this is more important to the respondents, but that flood risk on Severnside has also been indicated by some respondents.

Further, while 20% of residents participated in the survey after February 2021, most flood risk perception surveys for the case study were completed prior to the consecutive flood events in February 2020 and January 2021.Bewdley is the only case study that experienced flooding during completion of the survey, and **Table 6-14** presents the differences between responses with and without the data collected after February 2021. After the two flood events that flooded 40 and 19 properties, respectively, flood risk knowledge, likelihood of being affected by future flood events, and level and frequency of worry for future flooding all increase. Effectiveness of measures shows a decrease, which may be due to both the PLR measures and the temporary barrier failing during all recent events. Complacency of residents towards installing PFR, potentially influenced by the confidence in the temporary barrier that held back smaller flood events in the 20 year period prior, contributed to PFR failure but water levels that remained higher than previously was also contributed to failure of the measures. Thus, the occurrence of a flood is identified to be a key deciding factor for flood risks, worry and effectiveness of measures.

Table 6-14: Changes in mean and percentage of some responses in Bewdley before and after flood events in 2020 and 2021

	Responses prior to 2020 and 2021 flood events	Responses after 2020 and 2021 flood events
Flood risk knowledge Mean	4.38	4.40
Affected by future floods %	50%	60%
Likelihood of future floods Mean	2.63	3.00
Level of Worry for future floods Mean	1.5	1.7
Frequency of worry for future floods Mean	1.75	2.4
Effectiveness of present FRM Mean	2.63	2.40

“With PFR people are more complacent, with the first flood in Winter 2020 the PFR wasn’t installed properly by homeowners, there were flood gates that residents did not install properly, so the effectiveness wasn’t as good in the first event.”

“It was a range of factors but [the] main one was due to the scale of the flood event … each property has a different standard of protection and in some cases this design level was exceeded … The main issue was the flood water was up so long in both these events (12-24 hours) that the PFR was not designed to cope with the type of event.”

Comments from Bewdley PFR RMA interview.

Further comments indicated that the flood events have in turn increased the level of worry for residents, but these events have also increased the likelihood of a larger, passive, protection scheme in the area. Engagement around effectively applying PFR had also increased prior to the 2021 event, in which the measures worked to a better standard. However, while the scheme had a “good uptake that is not always seen across the country” for PFR (comments from Bewdley RMA interview, Appendix 6: p307), work towards a capital scheme may once again result in residents becoming complacent over their risk, with the PFR measures acting as a ‘back-up’ or not installed at all.

“PFR has definitely got a role there and it will help with smaller floods … Should still have a second layer of protection … I think people might get complacent and not install their PFR … maybe a third that might not deploy their measures”

Comments from Bewdley PFR RMA interview.

Aston Cantlow: Property Flood Resilience

All respondents in Aston Cantlow believed they were aware of the flood risk in the area, with a mid-range belief of their flood risk knowledge. Over half (66.7%) of respondents had flooded previously with most of these in relation to indirect impacts. This correlates well with the produced sketch and density maps of the area (**Figure 6-4**) where the areas most highlighted as at flood risk are the two access roads into Aston Cantlow, as well as the roads in the central residential area. Aston Cantlow is therefore at-risk from being isolated during flood events from highway (road) flooding, and this is a known risk to respondents.

Although Aston Cantlow is at risk from several flood risk sources, with comments from the RMA during an interview highlighting both highway flooding and flooding from agricultural and farmland runoff (comments from Aston Cantlow RMA interview, Appendix 6: p311) risk perception are recognised to be medium to low (1.22 out of 3 median for level, 1.56 out of 5 for frequency). More respondents also believed their garden and/or drive around their property is more likely to flood or experience no flooding at all, with a small amount considering it to be likely the ground floor of their properties may flood. This may be due respondents perceiving highway flooding to be a larger issue, or that respondents have confidence in the passive, resistance measures PFR measures implemented as part of the FRM scheme in the village.

Confidence in the effectiveness of PFR measures was above the median and lower than some case studies, such as Burton-upon-Trent, but was higher than Bewdley that applies the same type of FRM. This may be due to fewer available options to protect Aston Cantlow, that experiences fluvial from main rivers and ordinary watercourses, as well as flooding from pluvial sources, highways, and overland flow from neighbouring rural areas, compared to Bewdley that was involved in the temporary barrier trial for main river flooding. PFR measures in Bewdley, however, apply a mix of active (meaning they need to be installed prior to the flood) resistance and resilience measures, whereas Aston Cantlow PFR focuses on passive (always in place) resistance measures. This passive strategy, following resident "push back" on active measures that was highlighted by the RMA, may have influenced participant confidence in PFR measures. Similarly, more respondents in Aston Cantlow the Bewdley perceived the shift to FRM as positive, but fewer respondents thought it would be better at reducing risks as traditional defences. Confidence in PFR measures was also positively correlated with frequency of worry and installing own PFR measures. Thus, respondents that were also more confident in measures still had high levels of worry and were more likely to have undertaken their own precautionary measures.

"The PFR on the schemes we have delivered are generally well received … There is resident push back about PFR interventions. I think a lot of them are against barriers attached to their property which has a bit of a stigma around them … Make it abundantly clear to all the barriers are there and they have clearly gone on holiday … I think the passive measures do go down better largely because of the stigma of having such things on your property. One of the great successes of the schemes we have delivered is the passive measures we have fitted so far have all blended well with the properties."

Comments from Aston Cantlow PFR RMA interview.

However, when considering responsibility of flood risk and FRM, respondents in Aston Cantlow had the lowest awareness around homeowners being responsible for reducing their personal flood risks, with responses decreasing even further to 0% of participants believing homeowners *should* be responsible for managing these flood risks. While respondents have a low belief of homeowner ownership of flood risk and measures, as part of the PFR scheme the homeowner must maintain and store the measures correctly so they can reach their lifespan. This requirement of responsibility is further highlighted by comments from the RMA interview, in which they state homeowners have a responsibility to maintain the PFR measures for the duration of its life (PFR measures generally have a 20-30-year lifespan in FCERM schemes).

"Once we have installed, there is a warranty period and guarantee with the manufacturer and statutory limitations thereafter, but it is down to the homeowners then to maintain the product for the duration of its serviceable life. The contractor at the point of install should have the conversation with the homeowner on what is required and how it should be maintained, and also how they should be stored, quite importantly."

Comments from Aston Cantlow PFR RMA interview.

In addition to the limited knowledge of risk responsibility, over a quarter of respondents were unaware of what FRM was in place, and as the case study has the highest mean for years lived in the area out of all the case studies in England, these respondents are not believed to have recently moved to the area. Respondent were therefore not included in the scheme or have become complacent over their risks and individual PFR as FRM measures. This complacency can increase flood risks as, while the measures are passive and do not require active installation, PFR requires continual maintenance to remain effective over their lifetime. Focusing on this high mean for years lived in the area by respondents, positive correlations were identified between this and level and frequency of worry, level of risk knowledge, installing personal PFR, having flood insurance cover and receiving information on flood risk information received. Residents that have lived in the area for longer believe they are more aware and prepared to deal with their flood risks, confirmed by the RMA that the Aston Cantlow community generally had "a high level of knowledge" going into the scheme (Comments from Aston Cantlow RMA interview, Appendix 6: p311).

Herefordshire: Natural Flood Management

Respondents in Herefordshire were most unaware of their flood risks compared to other case studies (22.2% unaware), but a larger percentage felt they knew their level of flood risk. This indicates that some respondents may be aware of the level flood risks in the area but are unaware of their direct flood risk. This was further understood with a high, and second highest, mean of risk knowledge for all case studies. Respondents in the Herefordshire case study had also experienced more previous flooding than other areas and had the highest likelihood of future flooding than any other case studies. This case study also had the highest level and frequency of worry of all case studies. Experiencing frequent flooding therefore significantly increases risk awareness of respondents. In this case study, frequent flooding was also found to influence the belief of future flooding and worry around this risk, including level of property inundation in these future events, and increase the likelihood of respondents installing personal PFR measures and having flood insurance.

However, respondents in the Herefordshire case study also had a high confidence in the implemented NFM measures throughout the upper reaches in catchments across Herefordshire, and the highest response to perceiving the FRM shift to be positive and whether FRM would improve DRR. This may be in result of the communication and engagement community campaigns that have been undertaken alongside the implementation of NFM. This engagement was highlighted during the interview with the RMA for Herefordshire, where communities in all catchments were invited to publicly open events to learn more about the NFM project and measures as well as setting up community groups to keep discussion going. Landowner engagement on NFM opportunities as part of the project was also undertaken with subsequent visits to see working NFM measures.

"We wanted to involve communities [so] we did launch events in the catchments. We worked in publicly open events and talked about what we were doing and people could ask questions. Mostly they were supportive and positive, [and] after this they set up community groups in the catchment areas so they could find out more about the projects and could tell us about their local knowledge of flooding. We had plans that people could annotate, what had flooded and where. They appreciated being involved … When we did the launch event, we had a lot of people to start with, roughly 140 people attended … We had catchment advisors that went out and engaged with land owners and gave them tailored advice about free tailored NFM opportunities on their land."

Comments from Herefordshire NFM RMA interview.

Flooding across Herefordshire had occurred prior to this survey being undertaken. As the catchments affected are very rural, with widespread flooding across the county, there is limited information on the areas affected. These events may have influenced the high level of flood risk knowledge observed in the case study area, and well as the worry and high likelihood of future flooding perceived by respondents. However, these recent events did not impact the confidence of respondents in the NFM measures installed. This may be due to the type of measures applied throughout the catchments, that often only alleviate flooding during smaller, frequent events, or the previously discussed engagement around the project.

"The problem is [there is] no evidence on her effective [NFM is] … It was a pilot project to gather evidence to develop understanding of knowledge gaps … Natural Flood Management is not going to stop the massive floods, and this is a hard message to get across. People want to know they are never going to flood again. I think there is always going to be concern from residents … Since the project came about we have been approached by other residents and areas of the parish where they have experienced flood issues, or they see farmers land with water running off it and they want to sort it out to reduce the flood risk. So there has

definitely been a link between big floods and people wanting to see action. It is always going to be playing on their minds until there are no floods."

Comments from Herefordshire NFM RMA interview.

Finally, the sketch map, and final density map, exercise for Herefordshire (**Figure 6-5**) suggests that this method is inappropriate for implementation when considering catchment-scale flood risks. Varying maps were required for each area of the catchment the NFM scheme and the flood risk perception survey was undertaken, but due to the large spatial scale of risks, only three respondents indicated the same areas to be at risk. The overall coverage of the sketch maps across the catchment also estimated ~16km^2, and although they may potentially have accurately pointed out several local flood risks across the catchment, the map output provides little information.

Selly Park: Combined NBS and Protection (Elevation Change) Alleviation Scheme

After the two PFR case studies in England, Selly Park had the highest amount of residents aware their area is at risk of flooding, a high number of respondents who had previously flooded, and the highest number of respondents who had been directly flooded. While this previous flood experience was the largest for all case studies, most likely in relation to flooding experienced in Selly Park in 2008, 2016 and/or 2018, there was a low mean for future likelihood of flooding. Mixed results were also present for future inundation level of this, with most respondents believed their properties would not flood or their drive/garden would flood. However, almost a quarter of respondents thought the ground level would flood and a portion of respondents (7%) also indicated they thought the first floor of their properties would flood.

Background on at-risk properties in Selly Park is important here, as a lot of properties are old, terraced houses with cellars. This basement level of properties may be what respondents are referring to with ground floor and/or first floor. Alternatively, respondents may be very worried for future flooding, that was identified with a high level and frequency of flood worry. Further, after Dordrecht, 37% of respondents believing their properties would not flood was the highest percentage, and higher than those in the Burton-upon-Trent case study. This may be due to the confidence in the recent FRM schemes, that are separate for SPN and SPS, designed to keep flood water away from properties using retention basins and visibly higher ground. However, as there has been no large flood to test whether the infrastructure is effective in severe events, several residents may still be concerned about their flood risks and level of inundation.

No formal interviews were conducted with RMAs for Selly Park, but two interviews were undertaken with residents in SPN and SPS that had different perceptions towards the alleviation schemes. While the resident from SPS had lived in the area during the 2018 floods, they had not directly flooded. However, their responses to questions about awareness of the SPS scheme and flood issues highlight that individuals in SPS are still concerned over future floods as the scheme in place had not been tested enough during the 2018 flood incident that it was operational for.

On the other hand, the SPN resident had lived in the area since 1979 and experienced flooding in 2008, 2012, 2016 and 2018. While the participants property was not directly flooded, several of their neighbours' properties were directly affected. However, the respondent was extremely confident and reassured by the scheme, commenting "they changed the landscape in such a way that I can't conceive how we can flood again in the same way" (comments from SPN resident interview, Appendix 6: p322). While they mentioned that the scheme has not yet been necessary and that there is still uncertainty on whether it will be effective, as the SPN scheme was not operational during the 2018 event, the resident is still confident no flooding of SPN will occur from the Bourne Brook in the future. Further, the resident was asked if they would have preferred a different FRM type scheme but noted that the terraced properties in the area make PFR difficult and this scheme was the best option.

"We really needed that scheme, really, really. In a terraced house, I could get self-sealing airbricks and do all that stuff but if neighbour does not, we've had it. I cannot control what happens so it would be the same".

Comments from SPN resident interview.

For the sketch map (**Figure 6-6**), more responses focus of the SPN side of Selly Park, which may be due to more responses being received from SPN or that there are higher perceived risks associated with the Bourn Brook, that had previously inundated the area during large events when flowing to its confluence with the River Rea, rather than the River Rea itself which primarily affects SPS. Further, the SPS alleviation scheme was active during the 2018 flood event and was successful in reducing flooding to properties, although some were still inundated with surface water. The SPN scheme was not operational until 2019 and may be perceived as the primary flood risk until there is evidence it was successful.

Lent: Room for the River Bypass Channel

Results from the Lent case study indicates that respondents had a higher flood risk awareness, experience of direct flooding and likelihood of future flooding than expected. Over half of respondents also expect this future flood risk will inundate the ground flood of properties, with almost a quarter believe it will flood the second floor of properties. This scale of flooding in the Netherlands is comparable with the threat to life and significant flood event that would occur if the River Rhine branches in the Netherlands overtopped flood safety infrastructure. The scale of this river flooding may therefore be known by respondents. However, there were also several respondents (23%) that believed their properties would not be affected at all during future events. Lent also received the highest number of answers of 'unsure' to this question. As previously discussed in Chapter 5, flood hazard maps in the Netherlands provide inundation levels that correspond to depths including that of properties. This shows that while the maps and depth analysis are publicly available, many respondents may have not previous used these outputs or are unaware they exist. Further, the contrast in respondents perceiving their future property impacts may overall results indicate there is a low awareness of how large future flooding may be.

When asked about FRM, a significant number of residents in Lent were unsure on the term (70.3%) with a small amount also stating they did not know what it meant. However, flood management in the Netherlands is referred to as 'flood safety' and this low response may be due to language style. However, when the term had been explained to them, residents believed that FRM, was largely positive (67.6%), although some disagreed with it being a positive shift from traditional management (16.2%) and not better at protecting them than previous engineered defence strategies (18.9%).

When questioned on the effectiveness of the RftR strategy in place, respondents had a good confidence in the scheme (effectiveness mean of 3.76). Rather than responsibility, respondents in Lent were also asked to rate their confidence in the authorities on a scale of 1-5, with a high resulting mean of 3.54. However, negative correlations between level of flood risk awareness and information received indicates the more information received the more risk aware respondents believe they have had less information on their flood risk. Likelihood of properties flooding in the future was also negatively correlated with information provided. Therefore, not only do respondents that have received more information on their flood risk think they have a lower awareness of flooding, but they also believe they are less likely to be flooded in future. This may be due to the communication of flood risks and the RftR programme increasing flood safety against risks in future, or the high confidence in the general defence strategy and FRM governance in the Netherlands. On the other hand, level of property inundation had positive relationships with flood risk understanding, known level of flood risk, worry level, worry frequency and likelihood of properties flooded in the future identifying that some respondents understand their severe flood risk that may increase in the future.

The sketch map for Nijmegen and Lent (**Figure 6-7**) shows that Lent and the new island that has been created by the RftR bypass channel are perceived to be most at flood risk. This may be due to the previous bottleneck of the river that was removed for this area with the bypass, or that lowering the dike with the bypass channel itself, so residents can see more of the river, is influencing this risk. No RMAs responded to requests for an interview in Lent.

Dordrecht: Multi Layered Safety

Dordrecht had a high percentage of residents who were aware the area was at risk of flooding (96.9%), but this decreased to the lowest across all case studies when asked if respondents knew the level of this risk (56.3%). This decrease in Dordrecht from higher awareness level of risk to lower knowledge flood risk level may be due to the situation of Dordrecht outside typical dike defences that are built to certain standards, and thus cannot be quantified as easy in probability to individuals. Further, while Dordrecht is outside the typical structural protection and are implementing MLS that includes crisis management for when a flood event does occur, the case study had the highest number of responses that indicate properties would not flood (57%). This is in contrast with a high amount of previous flood experience in the area (78.1%), of which over a quarter was direct flood experience. This may be due to respondents in Dordrecht perceiving themselves to see be protected against flooding like other areas in the Netherlands, or that previous floods were not as bad as they feared. Supporting this, a negative correlation has been noted between level of inundation of properties in future events and previous flood experience, with respondents that have previously experienced flooding less likely to believe their properties will occur any damages in future events. This may correlate slightly with the sketch map for Dordrecht (**Figure 6-8**) where most respondents believe the area closest to the river is most at risk, with few participants indicating areas further into Dordrecht.

The residents in Dordrecht that indicated they were aware of what FRM is present (following the same language issues as Lent) were asked to clarify what these were, with the answers ranging from watersheds, sandbags, dikes and barriers. ‘Voorstraat’ was the highest response from 8 participants that refers to the front shopping street in Dordrecht that extends for 1.5m and is itself a primary flood defence. The Voorstraat is however much lower than other dikes in the country and requires the use of ‘stop-logs’ or demountable barrier type infrastructure to be implemented between properties that are also part of the defence.

However, no responses referred to the MLS strategy, with respondents asked subsequently if they were aware of MLS strategy or if they agreed with Dordrecht named ‘resilience island’ less than a quarter of respondents (12.5%) of respondents said yes to both questions. Further, over half of respondents (56.2%) were also unaware or unsure of any crisis management including evacuation preparation or routes. Thus, while some respondents are aware of some spatial planning to reduce flood risks, in the form of Voorstraat, other aspects of the spatial planning for flood safety and MLS is not well known in Dordrecht. There were limited correlations between flood risk perception factors with and respondents aware of the MLS strategy in place.

However, a high number of respondents did indicate that they are aware reducing flood risk is a homeowner responsibility in Dordrecht (59.4%), but when asked who should be responsible for this, the inclusion of homeowners had the biggest decrease of all case studies Dordrecht decreased the most by (decrease of 50.1% to 9.3%). This may be due to Dordrecht being outside government funded protection and feel this is unfair. Like the Lent case study, no RMA returned the requests for an interview about the scheme of flood risks.

Dike defence Literature Case Study

The overall results from all dike case studies included indicate that overall risk perceptions in the areas surveyed had low flood risk perceptions (Terpstra and Gutteling, 2008; Botzen et al., 2008), particularly for Terpstra and Gutteling (2008). These results differs from Dutch case studies included in this Chapter which, although they had low levels of worry towards their risks, have a higher flood awareness likelihood that they will be flooded in the future than expected, and higher than some case study areas in England.

Yet the results from Botzen (2009) indicate over a quarter of respondents believed 'no to very little damages' would occur during a flood. While this is not directly comparable to the other case studies in the Netherlands, Dordrecht had the highest level of respondents who believed they would not flood (57%) during an event when asked about future potential inundation levels. On the other hand, over half of respondents in Lent believed they would be inundated inside the ground floor of their properties. The results for Lent could be considered similar to the dike defence case study in this instance of future flood damages to properties, while Dordrecht is more likely to perceive lower damages would occur.

The results from Terpstra and Gutteling (2009), that linked believed governmental responsibility and low personal intent to prepare for flooding, may also be the case here. While low levels of personal preparation have been identified in both case studies in the Netherlands, higher homeowner responsibility was recognised in Dordrecht. Thus, while residents are aware they are responsible for reducing their risks, few have taken steps to reduce this. High trust in authorities identified by other studies (Terpstra, 2011; Mol et al.,2020) were however not identified in this study. While respondents in Lent did have high trust in authorities (3.54), this would not be considered significant trust.

6.3 Chapter Summary

This chapter has investigated flood risk perceptions in 5 different case studies for 4 different FRM types in England, and in 2 different FRM case studies in the Netherlands with a further case study identified from the literature. The results found that FRM type may have an effect on future perceived likelihood of flooding, particularly larger schemes in urban areas such as Burton-upon-Trent (structural protection), Selly Park (combination of structural and NFM type measures) and Lent (RftR engineered bypass). However, other factors are also important in influencing flood risk perceptions, such as whether the FRM in place has been successful (e.g. Bewdley and Dordrecht). Level of engagement may also alter perceptions with more engagement and political involvement increasing levels of risk knowledge (e.g. Bewdley) and less decreasing flood awareness (e.g. Aston Cantlow) and worry of future floods (e.g. Dordrecht). Both countries were also found to have a similar awareness of flood risk, with the largest divergent surrounding future worry of flood risks. The sketch and density mapping provided a good illustration of main perceived risks in case study areas, but this worked better in smaller to medium size areas where single roads or flood sources could be observed.

CHAPTER 7:

PUBLIC FLOOD RESPONSE CHOICE EXPERIMENTS

CHAPTER 7: PUBLIC FLOOD RESPONSE CHOICE EXPERIMENTS

7.1 Scope of Chapter

This Chapter provides an initial look at the data obtained by applying a Discrete Choice Experiment (DCE) to test preferences to FRM types as well as theoretical socio-hydrology model response assumptions. These measures and assumptions were designed as three unnamed choice cards, or “choice sets”, with which respondents were asked to identify their preference. While this originally intended to focus on respondents from at-risk case study areas in England, to increase response rates the choice experiment was shared within the public that assume themselves to not be at-risk from flood events. This has allowed analysis across three distinct groups: respondents with no flood experience, indirect flood experience and direct flood experience. This chapter focuses on these initial results and analysis.

7.2 Introduction

Continuous interactions between water and humans have not only shaped societies, but also the protection systems within them (Barendrecht et al., 2017). These outcomes of DRR practices and policies, including those focused on FRM, are continually influenced by political systems and their belief paradigms (O’Brien & Sygna, 2013). While the chosen FRM practices are primarily the decision of RMAs and political structures, public opinion is also important as public interest and media attention is able to alter the priority of items on political agendas (Penning-Rowsell et al., 2017) and have an influence on personal behaviours that can alter risk levels (Birkholz et al., 2014). Chapter 6 has provided some consideration towards these behaviours in relation to varying FRM practices, but implications can particularly be noted in comments from the RMAs surrounding PFR measures in Chapter 6. Personal preferences to types of FRM are therefore important but may be overlooked.

> "*People wanted to keep the barrier… Looked at PFR as a better solution given the number of properties and cost benefits but came up with a compromise to have the temporary barrier as well*." – comments from Bewdley RMA

Emerging socio-hydrology literature is drawing theoretical conclusions around the reciprocal interactions of water and humans, building on earlier literature of societal adjustments to floods (White, 1945). Two primary concepts within this have been named the levee effect (Di Baldassarre et al., 2013b) and the adaptation effect (Di Baldassarre et al., 2015b), or technological systems and green, adaptation systems (Di Baldassarre et al., 2013b; Ciullo et al., 2017). These can equate to assumptions of public responses to flood events, in which societies either move away from the river or build continuously higher levees (Di Baldassarre et al., 2013b). This in turn has impacts on the frequency and size of floods that may impact societies, as well as the economy, size and awareness of flood risks by the society and settlement itself (Di Baldassarre et al., 2013b). However, these assumptions and concepts are largely theoretical, and while real-life data is beginning to be included, this focuses on applying case studies to models that match the characteristics of each system (Ciullo et al., 2017).

Discrete Choice Experiments (DCE) are a method that can test decisions and preferences for varying multi-attribute choices (Rasid & Haider, 2002). Established with the theory of value by Lancaster (1966) and initially applied for market research, DCE approaches are emerging for environmental economics and identifying preferences for valuing hazard mitigation (Olschewski et al., 2013). In a typical DCE procedure, respondents are provided with a certain scenario such as a hazard event (Olschewski, 2013). Participants are then provided with a choice card, or “choice set”, that presents a set of options that are characterised by different levels of attributes, with respondents asked to choose their preferred option (Remoundou et al., 2015). Respondents can also opt-out of the options, remaining at a business as usual situation (Remoundou et al., 2015).

DCE have been successful in several studies, including preferences towards flood management in Japan by Zhai et al. (2007). Rasid & Haider (2002) also conducted DCE for analysis of public preference for non-structural measures in the US. Several studies also focus on implementing DCE to identify preferences for uptake of flood insurance (Botzen & Van Den Bergh, 2012; Botzen et al., 2013). Once respondents have made their choices, statistical analysis can be conducted by applying the Random Utility Model from Random Utility Theory that assumes the utility (U_{ij}) of alternatives in each set *(j*) chosen by individuals (*i*) can be modelled as the sum of a systematic and deterministic component (V_{ij}) and a random, stochastic component (E_{ij}) (Rasid & Haider, 2002; Ryffel et al., 2014; Remoundou et al., 2015). However, due to a limited response rate in this Chapter, an initial look at the data obtained from the DCE will be provided with a short contribution to the literature on public preferences to developing FRM measures in England and realistically determining socio-hydrological model assumptions.

44 respondents to the flood risk perception study in case study areas that provided their contact details were asked to participate in this research objective. However, as this number

of potential respondents was already limited, few responses were obtained. To increase response data, the choice experiment was shared with individuals across social media who would deem themselves as ‘not at risk’ from flooding in a convenience sampling approach.

7.3 Choice Experiments

This DCE uses three choice cards for respondents, with the first two focusing on FRM choices, and the third and final card focusing on socio-hydrology assumptions of public responses to flooding. The first card (**Figure 7-1**) is a practice card, suggested as good practice by previous studies (e.g. Botzen et al., 2013). The choice card included two options (A and B) with some defining attributes of flood protection, notably two varying levels of structural flood protection.

The second card (**Figure 7-2**) reflects the use of three different types of FRM: structural protection, NFM and PFR. Option A, designed around structural protection, includes a focus on visible protection, a protection standard of 1/100-years (1% AEP), no environmental benefits and a further decrease in these (Sayers et al., 2015a), and no information on risk will be provided in future. While some variables are based on the literature and notable issues with structural protection, for instance infrastructure missing societal factors of flood risk that has been alluded to by including a no risk information variable (Burby, 2006; Merz et al., 2010; Birkholz et al., 2014), other variables are typical conditions related to structural protection when in use, for instance location of floodwater, or in some cases requiring partnership funding (DEFRA, 2019) as a financial contribution from residents. Testing and monitoring is also included as well as increases to settlement sizes with developments behind the protection infrastructure (Di Baldassarre et al., 2018; Mård et al., 2018)

Option B, designed around NFM, highlights some known issues with implementing in the upper reaches of catchments NFM such as the limited evidence base (Dadson et al., 2017; Wingfield et al., 2019), as well as the positives of providing wider environmental benefits and increasing community and landowner engagement in flood risks, such as those identified as part of the Wye and Lugg NFM project in Herefordshire (HCC, 2022). Other variables include holding water back upstream, no visible protection to homeowners but contributions from landowners (Holstead et al., 2017), and engagement around flood risks provided on community level.

Option C, designed around PFR, focuses on preparation and recovery for flood events, homeowner responsibility for implementing temporary measures, testing but not monitoring, and flood risk information at an individual level. This aspect of increasing flood risk information is included as PFR can be understood to have the ability for increasing the resilience of both the properties and residents to cope with flood damages (Adedeji et al., 2018), although whether this occurs could be debated, and as frequent flooding is suggested to increase adaptation (Di Baldassarre et al., 2015b). A lower standard of protection is included, and while PFR measures may not be 1/50-year standard (2% AEP) research indicates they are only effective up to 600mm, while some argue 900mm, to property the structural integrity of properties (Webber et al., 2021) that they are located on.

The third choice card (**Figure 7-3**) focuses on the technological and green, adaptation systems that are created when settlements either (A) build levees to reduce frequent flooding and provide benefits to the settlement (e.g. increase in economy and size) but potentially increase complacency around residual risks of severe floods past protection standards; or (B) move further away from rivers that results in more frequent flooding that is potentially less damaging due to increase adaption and resilience, but less settlement benefits (Di Baldassarre et al., 2013b, 2015b; Ciullo et al., 2017). These factors have been included as varying attributes for their inclusion on the choice card.

The scenario for the first two choice cards focused on actions prior to a flood, while the third choice card focused on actions undertaken after a flood. These were predominately included for respondents who had not previously flooded or are unaware of flood risk and their associated FRM.

> "**Scenario 1: You are at risk of flooding. You are able to choose what management is installed to reduce flood risks to you and your community. What would *you* choose?**"

> "**Scenario 2: You have been flooded! You are able to choose what response is taken to the flood event in your community. What would *you* choose?**"

After respondents had chosen their preferred options for the second and third choice cards, they were asked two follow up questions of which attribute was more and least important during their decision. This is not commonly included in DCE, however as the response rate was anticipated to be lower than previous DCE studies, it was included for another aspect of discussion.

Attribute	Option A	Option B
Standard (level) of protection	1 in 200-year flood events Probability to be overtopped annually 0.5%	1 in 100-year flood events Probability to be overtopped annually 1%
Type of protection	Temporarily during events	Constant
Homeowner contribution	Community involvement with plans	Financial contribution
Environmental benefits	No change	Decrease
Residents remained informed on risk	Yes - Flood risk information at individual level	No - No further information on flood risk

Figure 7-1: The first and practice choice card used in the choice experiment that has two choices with varying levels of flood protection attributes.

Attribute	Option A	Option B	Option C
Focus of Management	Protect Protection from flood events	Prevent Prevention of flood events	Prepare Recover Protect Preparation and recovery from flood events Slight protection
Location of floodwater when management in use	Around community/ settlement	Upstream away from community/ settlement	Around individual properties
Standard (level) of protection	1 in 100-year flood events Probability to be overtopped annually 1%	Unknown	1 in 50-year flood events Probability to be overtopped annually 2%
Homeowner contribution	Financial contribution from community funding or increase in taxes	Landowner agreement but no homeowner contribution	Must implement measures when instructed
Testing and monitoring	Tested Monitored	Ongoing but not completely tested Monitored	Tested Not monitored
Environmental benefits	None with potential decrease in benefits	Yes with increase in benefits	No change
Visible protection	Yes constantly	Not to homeowners	Temporarily during events
Settlement changes	Increase in settlement size	No change	No change or potential decrease
Residents remained informed on risk	No further information on flood risk	Flood risk Information at community level	Flood risk information at individual level

Figure 7-2: The second choice card in the choice experiment that includes attributes to describe (option A) structural protection, (option B) NFM measures and (option C) PFR strategies.

Attribute	Option A	Option B
Flood Risk Management type	Structural protection	Non-structural adaption measures e.g. planning and preparing
Flood risk frequency	Infrequent major flood events that overtop protection	Frequent flood events of all sizes
Flood damages	Severe damages during major flood events	Less damages during major flood events from learned increased adaptation
Settlement size	Large size of settlement - Continually increasing	Small size of settlement - Potentially decreasing
Settlement location	Close proximity to rivers	Further away from rivers
Economy	Increasing size of economy in settlement	No change or slight decrease in size of economy in settlement
Awareness of risk	No flood risk awareness	High flood risk awareness

Figure 7-3: The third choice card in the choice experiment that describes socio-hydrology concepts and response assumptions of (option A) the levee effect: building levee following a flood event and (option B) the adaption effect: moving further away from the river and adapting to frequent flooding.

7.4 Results and Discussion

Overall, 50 responses to the DCE were received. Out of these responses, 6 respondents had been indirectly impacted by a flood event, and 6 respondents had been directly impacted by a flood event. **Table 7-1** presents an overview of the initial flood risk questions that were asked prior to the three choice cards. This has been broken down by respondent flood experience to enable three groups: no flood, indirect flood, and direct flood. These questions asked participants whether they know they live in an at-risk flood area, whether they know and understand their level of flood risk, and how informed they are on these flood risk. These will be given in respondent numbers (*n*) rather than percentages due to the small sample size. **Figure 7-4** displays the results for all respondents for all choice cards.

Table 7-1: Results from at-risk questions for each of the three choice experiment groups: no flood, indirect flood, direct flood. Results given in numbers (n) due to low responses. Mean for informed on flood risk is a 1-4 scale as it does not include unsure respondents

		All responses	Group 1: No flood	Group 2: Indirect flood	Group 3: Direct flood
Response n		50	38	6	6
Aware live in at-risk area	Yes	16	7	4	5
	No	19	17	2	0
	Not at risk	15	14	0	1
Know and understand level of flood risk	Yes	20	13	3	4
	No	21	17	2	2
	Not at risk	9	8	1	0
How informed about your flood risk	Not	17	14	3	0
	Sort of	13	11	2	0
	Quite	10	8	0	2
	Very	7	4	0	3
	Unsure	3	1	1	1
	1-4 scale	2.1	2.1	2	3.6

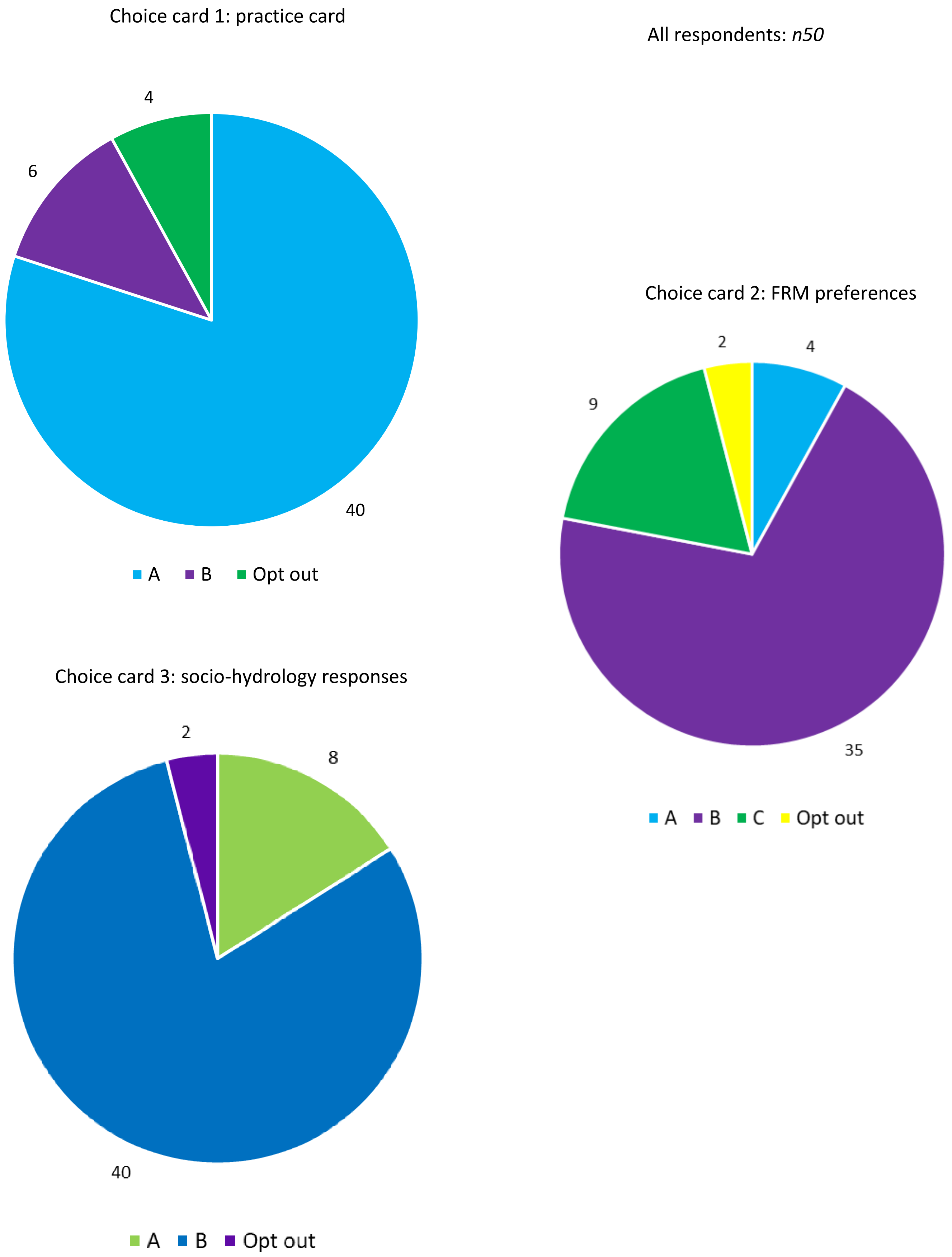

Figure 7-4: Results for all respondents for the first, practice choice card that introduced the FRM variables for the subsequent choice cards

For the first choice card, out of 50 responses, 40 participants chose option A. This option displays flood management with attribute levels of a higher, but temporary, standard of protection (1/200-year standard), no change to environmental benefits, and flood risk awareness for respondents remaining informed on risk at the individual level. It also included homeowner contribution with community involvement rather than financial contributions. 6 respondents chose option B, that displayed a lower, but still large, 100-year standard of protection for permanent protection, decreasing environmental benefits, no information to keep residents aware of their risk and a financial contribution from respondents. 4 respondents also opted out of the choice card. This choice card was primarily to introduce the topic to respondents, particularly those that have not previously flooded or live in areas where no flood management is present and therefore do not understand the topic. While the majority of respondents chose option A, if the full risks of installing and maintaining temporary protection, such as temporary barriers or PFR, had been explained to participants this may have had an influence on the results. However, the decreasing environmental conditions and financial contribution may still have been viewed as a negative for respondents.

The results for the second choice card, focusing on public FRM preferences, indicate that 4 respondents chose option A, based on aspects of structural protection, 35 respondents chose option B, based on NFM, and 9 respondents chose option C, based on the characteristics of individual PFR. Option B, the NFM influenced option, as the most chosen option, and option A, structural protection, the least chosen is an interesting result, as socio-hydrology human adaptation literature (e.g. Burby, 2006; Di Baldassarre et al., 2018) consistently assume structural protection, and similar types of this FRM infrastructure like embankments, dikes and raised land, is the preference to protect properties. When broken down into respondent groups based on flood experience, option B, the NFM based FRM choice, still had the most respondents with 4 responses who had direct experience, 5 responses who had indirect flood experience, and 26 responses that had no experience of flooding. All the respondents that chose option C, PFR, had experienced an indirect flood (1 responses) or no flood (8 responses), with no participants who had previous direct flood experience choosing this option. Option A, structural protection was chosen by 1 respondent that had direct flood experience, and 3 respondents with no flood experience. The choice to opt out was also chosen by 1 respondent with direct flood experience and 1 respondent with no experience.

After choice cards 2 and 3, respondents were asked about their choice of attributes. **Table 7-2** presents the most important attributes for card 2, FRM preferences, and **Table 7-3** shows the least important attributes, with these responses also identified for each flood experience group. Overall, environmental benefits was the most important attribute and visible protection was the least. When broken into flood experience response groups, environmental benefits were the priority for respondents with no flood experience, that is comparable with the NFM influenced FRM option being chosen as the preferred option for Card 2. However, visible protection being the least important is interesting as historically protection schemes have sometimes not been implemented due to disruptions of nice landscapes, for instance in Bewdley. Residents informed of risk was also an important factor for respondents with no flood experience and for one respondent that had direct flood, but a least important factor for those with indirect flood experience. Protection standard was also not chosen as an important factor for those with direct flood experience, but this may be due to the type of FRM (e.g. for NFM is prevention) being a higher priority.

Table 7-2: Most important attribute ratings for all respondents and broken down by flood experience groups (no flood, indirect flood, and direct flood) for FRM preferences in choice card 2. Number 1 refers to the attribute with most responses to 'most important attribute'. Attributes that received no responses are in grey.

Most important attributes	All respondents		Group 1: No flood		Group 2: Indirect flood		Group 3: Direct flood	
	Attribute	*n*	Attribute	*n*	Attribute	*n*	Attribute	*n*
1	Environmental benefits	12	Environmental benefits	11	Environmental benefits	1	Focus of protection	2
2	Focus of protection	12	Focus of protection	9	Focus of protection	1	Location of floodwater	1
3	Location of floodwater	9	Location of floodwater	7	Location of floodwater	1	Testing and monitoring	1
4	Residents remaining risk informed	4	Residents remaining risk informed	3	Visible protection	1	Residents remaining risk informed	1
5	Homeowner contribution	4	Homeowner contribution	3	Settlement changes	1	Environmental benefits	0
6	Visible protection	3	Protection standard	2	Homeowner contribution	1	Homeowner contribution	0
7	Protection standard	2	Visible protection	2	Residents remaining risk informed	0	Protection standard	0
8	Testing and monitoring	2	Testing and monitoring	1	Protection standard	0	Visible protection	0
9	Settlement changes	1	Settlement changes	0	Testing and monitoring	0	Settlement changes	0

Table 7-3: Least important attribute ratings for all respondents and broken down by flood experience groups (no flood, indirect flood, and direct flood) for FRM preferences in choice card 2. Number 1 refers to the attribute with most responses to 'least important attribute'. Attributes that received no responses are in grey.

Least important attributes	All respondents		No flood experience		Indirect flood experience		Direct flood experience	
	Attribute	*n*	Attribute	*n*	Attribute	*n*	Attribute	*n*
1	Visible protection	15	Visible protection	13	Residents remaining risk informed	2	Residents remaining risk informed	2
2	Settlement changes	9	Settlement changes	8	Visible protection	2	Location of floodwater	1
3	Location of floodwater	6	Location of floodwater	5	Homeowner contribution	1	Testing and monitoring	1
4	Environmental benefits	4	Environmental benefits	4	Protection standard	1	Homeowner contribution	1
5	Homeowner contribution	4	Focus of protection	4	Testing and monitoring	0	Settlement changes	1
6	Focus of protection	4	Testing and monitoring	2	Settlement changes	0	Focus of protection	0
7	Residents remaining risk informed	4	Homeowner contribution	2	Environmental benefits	0	Environmental benefits	0
8	Testing and monitoring	3	Residents remaining risk informed	0	Focus of protection	0	Protection standard	0
9	Protection standard	1	Protection standard	0	Location of floodwater	0	Visible protection	0

The results for the third choice card, that tested socio-hydrology response assumptions, had 8 responses for option A, build levees or structural protection, 40 responses for option B, to adapt to flooding and move further from the at-risk area, and 2 responses to opt out. Within socio-hydrology literature, these assumptions are considered 50/50. After a flood event, half the affected people will move away from the area, and half of them will build levee when economically possible. In the wider literature of human adaptation, building and strengthening structural protection has been a consistent trend in settlements to enable economy activity (Di Baldassarre et al., 2018; Ferdous et al., 2020). However, the results from this chapter have indicated a notable shift of public responses towards adaptation preference rather than building structural protection. This is in line with the wider shift to FRM and building resilience.

However, when considering flood experience there is a significant different between responses from participants that have the direct experience of flooding compared to respondents that have indirect experience of flooding and or no experience at all. Out of the 6 responses that have direct experience, 4 opted for option A, structural protection, and 2 opted for option B, adaption. Following actual property damage during flood events, the primary goal may therefore be to protect from future damages regardless of the associated negatives.

The most (**Table 7-4**) and least important attributes (**Table 7-5**) for this choice card showed that flood damages were the most frequent important factor for no flood group, and for a couple of respondents in the direct flood group. FRM type was the highest chosen for the direct flood group, which for the socio-hydrology choice card focused on structural protection or non-structural adaptation measures. However, respondents that chose flood risk type as their most important attribute also varied in which option they chose. Economy was the least important attribute for both the no flood group and the direct flood group. However, the indirect flood group's most frequent least important attribute was awareness of risk. This could potentially be related to previous experience of flood hazards by this group, and while it was indirect in their area, it did not largely affect them so they require no further knowledge on it.

Table 7-4: Most important attribute ratings for all respondents and broken down by flood experience groups (no flood, indirect flood, and direct flood) for socio-hydrology response assumptions in choice card 3. Number 1 refers to the attribute with most responses for 'most important attribute'. Attributes that received no responses are in grey.

Most important attributes	All respondents		No flood experience		Indirect flood experience		Direct flood experience	
	Attribute	*n*	Attribute	*n*	Attribute	*n*	Attribute	*n*
1	Flood damages	25	Flood damages	23	FRM type	2	FRM type	3
2	FRM type	7	Settlement location	4	Flood risk frequency	2	Flood damages	2
3	Awareness of risk	6	Awareness of risk	4	Awareness of risk	2	Settlement size	1
4	Settlement location	4	Settlement size	3	Flood damages	0	Flood risk frequency	0
5	Settlement size	4	FRM type	2	Settlement size	0	Settlement location	0
6	Flood risk frequency	4	Flood risk frequency	2	Settlement location	0	Economy	0
7	Economy	0	Economy	0	Economy	0	Awareness of risk	0

Table 7-5: Least important attribute ratings for all respondents and broken down by flood experience groups (no flood, indirect flood, and direct flood) for socio-hydrology response assumptions in choice card 3. Number 1 refers to the attribute with most responses to 'least important attribute'. Attributes that received no responses are in grey.

Least important attributes	All respondents		No flood experience		Indirect flood experience		Direct flood experience	
	Attribute	n	Attribute	n	Attribute	n	Attribute	n
1	Economy	18	Economy	13	Awareness of risk	2	Economy	4
2	Settlement size	10	Settlement size	10	Flood risk frequency	2	FRM type	1
3	Awareness of risk	7	Settlement location	4	Settlement location	1	Awareness of risk	1
4	Settlement location	5	FRM type	4	Economy	1	Flood risk frequency	0
5	FRM type	5	Awareness of risk	4	FRM type	0	Flood damages	0
6	Flood risk frequency	5	Flood risk frequency	3	Flood damages	0	Settlement size	0
7	Flood damages	0	Flood damages	0	Settlement size	0	Settlement location	0

7.5 Chapter Summary

This chapter has introduced a DCE to test public preferences for FRM, across three types of FRM: structural protection, NFM and PFR, and conceptual socio-hydrology responses assumptions that individuals and collectives are expected to take after flood events according to socio-hydrology models. As a limited response rate was gained from respondents in the case studies who have previously flooded, not at-risk respondents asked to participate enabled the DCE to test the preferences of respondents against their flood experience and in three groups: no flood experience, direct flood experience and indirect flood experience. While the results for the FRM choice card showed a majority preference for NFM influenced FRM, the socio-hydrology responses found significant differences between respondents that had previous, direct flood experience and no experience at all.

CHAPTER 8:

SYNTHESIS, CONCLUSIONS, RECOMMENDATIONS FOR FUTURE RESEARCH, AND IMPLICATIONS FOR FUTURE FRM POLICY AND PRACTICE

CHAPTER 8: SYNTHESIS, CONCLUSIONS, RECOMMENDATIONS FOR FUTURE RESEARCH, AND IMPLICATIONS FOR FUTURE POLICY AND PRACTICE

8.1 Scope of Chapter

This Chapter syntheses and concludes the key findings across the objectives of this thesis and the main themes: FRM policy, practice, perceptions, and responses to flood risk. This Chapter demonstrates the extent to which these research objectives have been addressed. Finally, some conclusion with the limitation of this thesis provided.

8.2 Summary of Findings

Continuous interactions between floods and human have shaped societies, flood risks and protection systems over centuries. Within this extended system, changing elements can influence other factors with unintended consequences (Barendrecht et al., 2017). This thesis has specifically investigated this feedback mechanism and the continuous interactions between FRM, flood risk perceptions and public responses, that are often overlooked. Consideration has also been given to exploring how holistic flood risk, equally including societal vulnerabilities, can be represented for this management. Figure 8-1, adapted from Figure 1-1 that introduced the continuous co-evolvement of flood risk, FRM and risk perceptions, identifies some main findings from this thesis. These recognised linkages between policy, practice, and personal perceptions for FRM further reflect the interconnecting 'Spheres of Change' theory where transformations undertaken within each sphere can in turn influence the others and the wider system (O'Brien & Sygna, 2013).

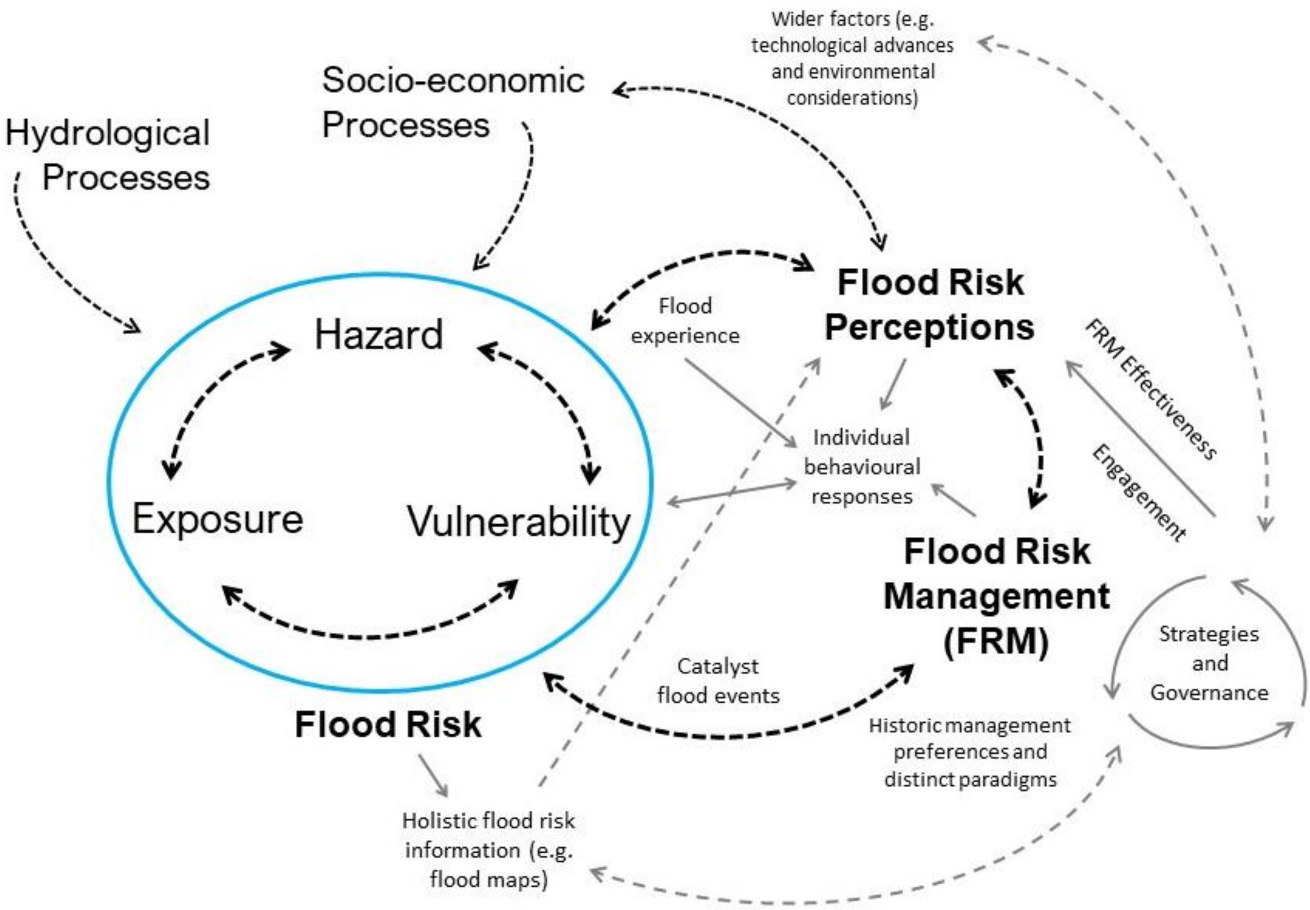

Figure 8-1: Schematic illustration of co-evolving flood risk, FRM and flood risk perception elements with some findings from this thesis between these linkages.

The first research chapter, Chapter 4, draws on the literature and narrative policy and legislation document review in Chapter 2, to quantify the management directions taken in England and the Netherlands to facilitate the present FRM in both countries. This historic development has been categorised into distinct management paradigms for England and the Netherlands. This identified that although there are some comparisons between both countries, this progression differs in both timings of practices and the priorities behind these. While similarities can be considered between current FRM strategies being implemented in both countries (e.g. RftR and MLS in the Netherlands, with NFM and PFR in

England), the focus behind these differs, continuing to reflect historic management preferences and flood risks.

In the Netherlands, the only viable defence strategy by early settlers has been reinforced overtime, with a government duty to protect against flood risks, to create a path dependency or technical lock-in (Wesselink et al., 2015) on dike defence policy. Although RftR is considered by many as change of approach, this strategy can be argued to continue the engineered defence strategy but with a renewed focus on prevention as well as protection. Further, while 'flood safety' approaches have begun to consider residual risks, more recent FRM approaches being applied in the Netherlands act as back up or 'fail-safe' measures to support traditional structural protection that does not cope well with future uncertainty. In England, lower flood risk and permissive flood management powers has seen FRM used to 'fill in the gaps' left by lower standards of structural protection. This has enabled equal development of FRM approaches, progressed, or hindered, in part by continual flood events in recent years that call into question the effectiveness of the FRM 'portfolio' approach. FRM should therefore be separated into governance and strategies, and while each of these continuously influence the other, both have an affect on the overall FRM direction of a country.

The policy drivers for changing management paradigms were also investigated, with a finding of this thesis that the type of policy change from catalyst flood events depends on the level of occurrence. One catalyst flood event often results in strengthening the current management strategy in place in a 'recover and return' response, for instance the 1953 storm surge in the Netherlands that increased the defence policy in law, and the 2007 floods in England that saw 92 recommendations to the current FRM approach published in an independent review, many of which were taken forward. However, the occurrence of two, recurring flood events, such as the 1993 and 1995 events in the Netherlands and the 1998 and 2000 floods in England, creates a demand for policy changes, that often progresses new strategies, by highlighting the present approach is unable to deal with potential future flood threats. This thesis also makes a distinction between implemented policy and acted on policy. Proactive approach to flood risk are considered in literature to be more beneficial (Merz et al., 2010), with theories highlighting incremental policy changes brought in by new actors and technological improvements that are representative of the proactive policy approaches currently shaping FRM in the Netherlands (e.g. with the introduction of the MLS approach). However new policies are not fully acted on until a catalyst event creates an opportunity or incentive for new policy to be acted on or adhered to. This further identifies that while policy theories may focus on changes in isolation, this thesis has found these are largely interconnected.

The second research chapter of this thesis, Chapter 5, provides a contribution to FRM literature by providing an approach that equally represents of flood hazard, exposure, and vulnerability in a flood risk map for the Trent catchment, England. This particularly focused on how societal flood vulnerability data can be included in flood risk maps, that are difficult to address and often not included in flood risk assessments and analyses (Jongman et al., 2015; Koks et al., 2015). This outcome applied different area buffers, representative of the varying urban and rural communities, alongside a MCDM AHP approach that could be replicated for other catchments or at-risk areas. This chapter further highlights that different representations of this risk can identify different risk levels for the same areas that should be considered by RMAs seeking to reduce these risks.

Chapter 6 provides a contribution to FRM and DRR literature by investigating the influence of FRM on individual flood risk perceptions. By applying a flood risk survey in at-risk case study areas that have varying FRM strategies implemented, this thesis identified the potential impact of the levee effect (Burby, 2006; Di Baldassarre et al., 2018) behind structural protection in Burton-upon-Trent and temporary barriers in Bewdley. Although there were failures with the temporary barrier in Bewdley, this was perceived as successfully holding back floodwater during events by the community. This can be further compared to the NFM case study in Herefordshire, where flood experience and living alongside flood risks, as well as engagement on viewing the NFM measures in place, may have influenced perceptions of a high likelihood of future flooding and increased flood risk awareness. Visibility and experience of flooding, often determined by FRM and an illusion of complete safety, therefore have an influence on perceptions of flood risk.

Lack of frequent flooding may also increase complacency with flood risks, even if there has previously been direct flooding in the area. Respondents in Aston Cantlow had low perceptions of future flooding with some unsure of what FRM was present or that homeowners are responsible for these flood risks. Further complacencies around flooding and PFR measures after they were installed is thought to have increased flood impacts and overall flood risk in Bewdley during the recent events. Complacency from lack of flooding can therefore increase the flood risks of individuals generally and may specifically affect homeowners that are required to install and maintain PFR measures to a greater level.

Reflecting the findings on developing FRM, and how governance and strategies influence each other and the overall FRM, the complacencies and perceptions around flooding identified in this chapter may also be influenced by differing administration and engagement that supports the implementation of FRM measures. Areas where more or recent engagement has accompanied the FRM, for instance Herefordshire, or where other political and public pressures around flooding are present and/or constant, for instance Bewdley, have higher levels of flood risk perceptions even when flood risk uncertainties remain. Although this higher engagement may also centre around recent flood incidents, like flood memory, memory of engagement and information around flood risks may decrease, for instance in Aston Cantlow that implemented PFR in 2014, to influence flood risk perceptions and overall flood risk. Type and source of flood risk may also influence perceptions, with individuals determining it is a problem external to them that may be altered by engagement and information on risks.

Finally, this chapter also contributed to the literature on flood risk perception in the Netherlands and identified a higher flood awareness than previous studies have shown, including the dike defence case study included in this chapter from available literature. This increased flood risk awareness was particularly present when considering the RftR Lent case study. While other factors could again influence perception, for instance the heavy engagement around the scheme, the dike defence removal to increase visibility of flood risks and increase flood risk perceptions corresponds with the adaption effect concept. Although respondents in Dordrecht believe they have a high flood risk awareness and knowledge, awareness of the MLS strategy (that importantly considers evacuation routes and actions when these are not possible), and perceptions of likelihood of future flooding and homeowner responsibility (in which Dordrecht is outside dike protection) was low. This is more aligned with previous literature on flood risk perceptions in the Netherlands and supports previous findings that ‘implemented policy’ and ‘acted on policy’ are different and that experience of flood events may be as influential as the levee effect in creating a complacency of flood risks or the illusion of complete safety.

Finally, Chapter 7 contributed to the literature on FRM and socio-hydrology by introducing a DCE to test public preferences to FRM and theoretical socio-hydrology response assumptions included in models. For public FRM preferences, the results indicate that NFM and NBS are preferred to structural protection, that has historically been considered the preferred approach to FRM, and PFR based measures. This may have been influenced by the multi-beneficial focus of the scheme to both FRM and wider issues, including improvement to environmental conditions that was the highest attribute of importance, despite uncertainties that remain for this approach. Yet while environmental benefits were important to respondents that had experienced direct flooding, other attributes like holding water higher in catchments and away from properties were more important. The findings from the response assumption experiment also determined that flood experience may have an influence on response assumptions, with more respondents choosing the choice that mirrors the levee effect, building higher structural protection, than the adaption effect and moving away from at-risk areas. The latter, however, was the overall preference when considering all responses.

8.3 Conclusions

This research has applied an interdisciplinary approach to investigate shifting flood management strategies in England and the Netherlands, from traditional structural flood management towards integrated FRM concepts. This identified varying levels, timescales, and measures of FRM across policy and practice in England and the Netherlands. While

England is applying and developing FRM approaches as equal measures, first introduced to fill in the gaps, the Netherlands are applying FRM as a 'back-up', or more accurately, a second and third layer to residual risks from engineered flood safety in the Netherlands. Further, while strategies may be included in policy, the level of implementation depends on the occurrence of catalyst events, and specifically, one flood event to strengthen policy and two consecutive flood events to create a demand for new approaches.

Overall, when considering flood risk perceptions, FRM strategies were identified to have an impact on these in the tested case studies in England and the Netherlands. However, the influence of other factors, that the chosen FRM strategy present may be amplifying, may have a greater impact on perceptions than the FRM itself. This primarily includes, but is not restricted to, experience of flood events and level of flood frequency, engagement and/or political pressure and community involvement that accompany FRM, and spatial scale and type of flood risks

Further, this thesis has provided a contribution to the FRM and socio-hydrology literature using participatory choice experiments to test public preference to FRM and socio-hydrology response assumptions. Emerging NFM concepts were identified as the preferred approach to FRM, while the adaptation effect, and moving away from at-risk areas, was overall the chosen response. However, flood experience was found to be a significant factor in choices of both experiments and the importance of attributes that underlined these choices.

8.4 Recommendations and Opportunities for Future Research

A higher response rate to the both the flood risk perception survey and DCE would have increased the significance of results and conclusions in this thesis. This could be achieved by expanding the survey into more at-risk case study areas with varying FRM, or by applying multiple questionnaire techniques at the same time. For instance, using a postal survey alongside an online and door-to-door survey. Clarification from other studies that have applied flood risk perception surveys also indicate they use companies that specialise in door-to-door administration of questionnaires to improve response numbers and rates. A different method of data collection may also have been more appropriate for this study, such as focus groups within each case study area that would have provided more data with fewer participants. Although, this technique is considered to have more bias that a public questionnaire that can be administrated to a wider audience, a slight bias already exists with individuals interested in the subject more likely to respond to the questionnaire.

Additionally, to collect a larger dataset of flood risk perceptions social media platforms could be used, with searches specified for at-risk or target areas. Twitter is a platform that is commonly used for media coverage of disaster risks, as a communication tool for disaster risks by RMAs, and a way to identify areas that have been impacted after events (Bruijn et al., 2020). However, the social media site could also be used to collect a large dataset of perceptions. Twitter provides an API to access large amounts of daily tweet counts for selected terms. An example of this for daily tweet counts for ‘flood’, ‘floods’, and ‘flooding’, excluding certain words following a sensitivity test, and a percentage change between the frequency of tweets to counteract increasing twitter activity can be identified in **Figure 8-2**.

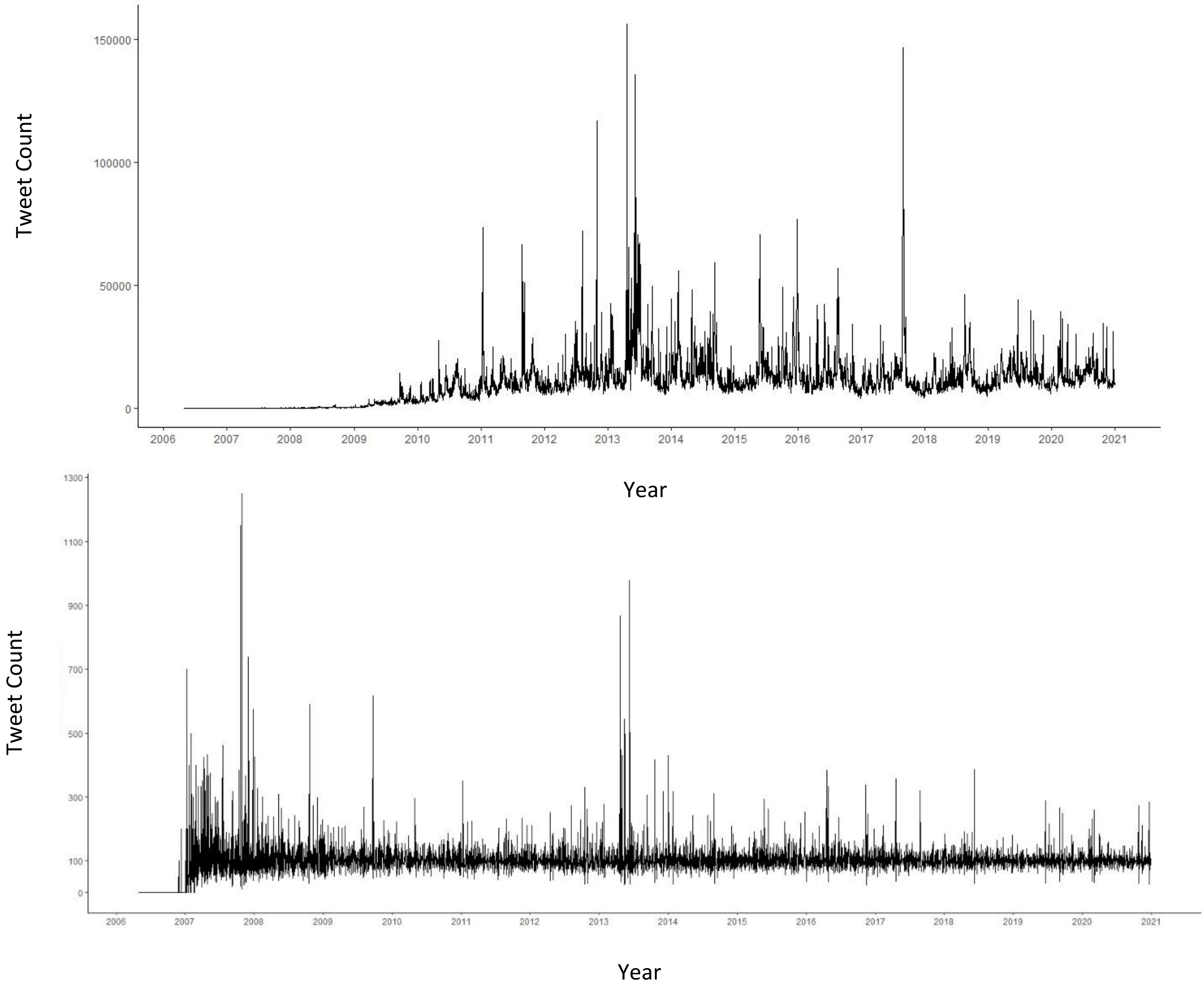

Figure 8-2: Graphs displaying (A) tweet frequency for flood related tweets on Twitter between 2006 and 2021 and (B) percentage of Tweet frequency change for flood related Tweets on Twitter between 2006 and 2021.

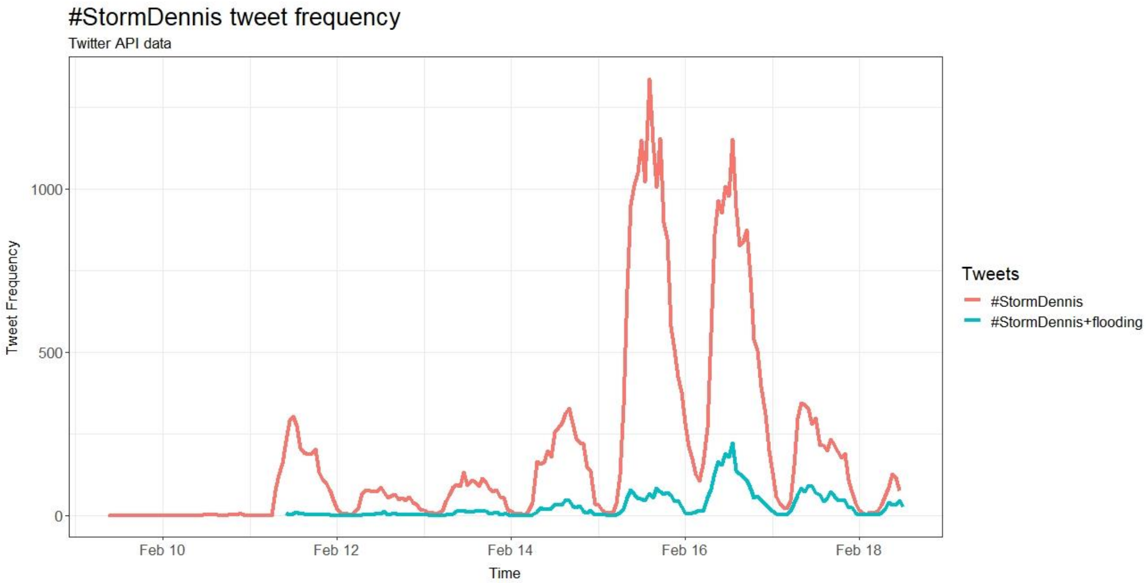

Figure 8-3: Tweet frequency for Storm Dennis and Storm Dennis flooding between February 10th and February 18th

An example of the application of this during Storm Dennis flooding in February 2020 is presented in **Figure 8-3**. Further, sentiment analysis could be applied to categorise any emotions conveyed in the tweets, such as fear, anger, or sadness (Kumar and Jaiswal, 2018; Bec, 2019), into positive or negative responses to flood risks or FRM.

Although this research has included public preference for responses after a flood, this decision, to move away or build levees, is not always a realistic option to individuals that live in at-risk areas, particularly those who are more vulnerable. While risk-based FRM measures have been developed to reduce this risk, as well as other non-structural measures risk measures, this thesis has shown that these measures are not always effectives and can have stigmas attached to them. Further research should therefore be done towards the limitations of these measures, and how they can be overcome, particularly for the most vulnerable areas that will be predominately affected by climatic and socio-economic increases in flood risks. Within this thesis, and specifically for FRM in England, not enough attention has been paid to how and why some FRM schemes are implemented over other options or areas equally, or more, at-risk. Although this was considered when discussing certain FRM strategies being cost-beneficial for areas with more individuals at-risk, this is based on number, and type, of properties to provide a damage value. This however overlooks several societal vulnerabilities that may make areas more at risk to flooding, with individuals that find it harder to recover after events that is not considered when funding scheme. An extension of this research, applying the flood risk mapping from Chapter 5, could therefore aim to provide realistic economic damages in more high-risk areas (considering vulnerability), based on intangible impacts of flooding rather than solely potential property damage. By applying information about current schemes against these holistic flood risk maps, missed or underestimated areas of high flood risk could be considered.

8.5 Implications for Future FRM Policy

Several implications for FRM policy and practice have been identified in this thesis. Firstly, when considering FRM policy in general this thesis has identified a grey area between policy implemented and acted on. To have a true ‘proactive’ approach, flood policy must start being acted on once implemented rather than waiting for an incentive, often a catalyst event. Further, when including non-structural FRM approaches in at-risk areas and where the effectiveness of strategies is not as obvious when compared to non-structural schemes, these should be regularly checked or given a specified lifespan, like with physical measures, that is in line with research on flood memory. This would mean continual and incremental engagement and awareness campaigns need to be implemented, and individuals may remain more aware of their flood risks and less likely to become complacent. The publication of scrutiny reports after large flood events should also conclude how effective these non-structural, mainly awareness raising strategies have been in a similar way to failures of structural protection.

This thesis has also identified complacency of flood risks in several areas, but this particularly becomes an issue when considering this in case studies where homeowner intervention is required. Aston Cantlow and Dordrecht have both been identified to be unaware of their flood risks or FRM present in their area, either PFR or MLS, that requires some homeowner responsibility. However, in Aston Cantlow, without proper maintenance of PFR these measures may fail to be as effective as required, further complicated by highway flooding that could cut the area off during an event. Risks in Dordrecht are even greater with the potential for individuals to be unaware of evacuation routes or actions when threat to life river floods occur. These issues of safety need to be addressed in policy and explained to homeowners in these at-risk areas before a catalyst flood occurs.

Further, while the lifetime of flood-proof measures in the Netherlands are unknown, PFR schemes in England are given a lifespan of 30 years. In this time, once signed off by the installation contractor, they are understood to be 'protected' by the responsible RMA. However, in literature on flood memory it is suggested that after a flood event has occurred, flood memory will reach minimal levels after 7 years. There are therefore 23 years remaining years of 'protection' where flood complacency could result in minimal flood awareness in addition to minimal support during events. This also raises the issues of new buyers moving into areas and being unaware of any PFR on their properties or that these require regular maintenance. A maintenance schedule, or PFR registry that provides reminders for homeowners, should therefore be implemented as a minimum.

Whilst this recommendation has focused on PFR, residual risks remaining past design standards of other FRM measures are also important, particularly in the Netherlands with design standards of 1/1000 and higher. Further, these risks should be communicated to individuals in a way that can be understood. Although this research did not focus on communication of flood risks, questions surround the 1/100-year event identified that even respondents who believe they understand this may still be misrepresenting the term and their overall flood risks. Improvements to this communication of risks must be central to all FRM now and in the future.

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Appendix 1: Questionnaire and Participant Information Sheet

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Research use only, please leave blank.
Participant number: ________________

Flood Risk Perceptions survey

This survey is part of the Shifting Flood Risk Management (FRM) in England and the Netherlands: Public Flood Risk Perceptions and Responses doctoral research project at the University of Birmingham.

Thank you for agreeing to take part in this research. There are two parts of this survey: a questionnaire and a sketch map exercise.

Any personal information will be kept anonymous and confidential. If you are posting your survey back to the research team, please also include your sketch map and consent form.

School of Geography, Earth and Envi:Sci, University of Birmingham

Flood Risk Perceptions Survey

Demographic Background

Some of these questions contain information about yourself. However, all answers are anonymous, and postcodes will be kept confidential at all times.

1. Please provide the first line of your address and postcode

   ____

   ____

2. Please choose your age bracket

   18-24 25-34 35-49

   50-70 70+

3. Please specify your gender

   Male Female Non-Binary

   Prefer not to say

4. Do you own your own home?

   Yes No

5. How many years have you lived and/or worked in this community?

   ____

6. What best describes your household structure?

   Living alone
   Two parent family
   Single parent family
   Couple without children

7. What is your employment status?

   Full time employment
   Part time employment
   Self employed
   Not employed

8. What is your highest education qualification?

   ____

Experience of Flooding

9. Has a flood event occurred in the area while you have lived here?

   Yes No

10. If yes, how were you affected?

    Directly Indirectly Both

11. When was the last this occurred? Directly and indirectly

    ____

12. How many times has this occurred since you have lived at this address? Please provide a number

    ____

Knowledge of Your Flood Risk

13. Are you aware you live in an area that is at-risk from flooding?

    Yes No

14. On a scale of 1-5, with 5 being very well informed and 1 being not informed at all, what would you say is your level of knowledge about your flood risk?

    5 - Very well informed
    4 - Well informed
    3 - Somewhat informed
    2 - Not very informed
    1 - Not informed at all

15. Do you know and understand your level of flood risk?

    Yes No Not Sure

16. What would you say is your level of flood risk?

    ____

17. Do you understand what it means when flooding is described as one (1) in 100, 200, or 500 year events?

    Yes No

18. If yes, could you provide a short description.

    ____
    ____
    ____
    ____

Future Flood Risk

19. Do you think you will be affected by flooding in the future?

    Yes No Not Sure

20. If yes, how do you think you will be affected?

    Directly Indirectly Both

21. On a scale of 1-5, with 5 being extremely likely and 1 being extremely unlikely, what do you think is the likelihood of future floods affecting you or your property?

    5 – Extremely likely
    4 – Likely
    3 – Somewhat
    2 – Unlikely
    1 – Extremely Unlikely

22. If your property were to flood, what level do you think the water would reach?

    Unsure
    My property will not flood
    Property not flooded but garden and/or drive flooded
    Property flooded - ground floor
    Property flooded - first floor
    Not sure

23. On a scale from 1-3, with 3 being extremely worried and 1 being not worried, how worried are you about future flooding?

    3 - Extremely worried
    2 - Somewhat worried
    1 - Not worried

24. How often do you worry about future flooding?

    5 - Most of the time
    4 - Often
    3 - Sometimes
    2 - Rarely
    1 - None of the time

Flood Risk Management Strategy Present in Your Area

25. Do you know what type of flood management is present in your community?

    Yes No

26. If yes, what are they?

    ____

27. What level (or standard) of protection does the type of flood defence provide?

    ____

28. If level of protection is unknown, please choose one of the options below.

    Small floods
    Severe floods
    All floods
    Not sure

    [Information about the scheme in the area if this is unknown]

29. On a scale of 1-5, with 5 being extremely effective and 1 being extremely ineffective, how effective do you think the Flood Risk Management type present in your community is?

    5 – Extremely effective
    4 – Effective
    3 – Somewhat effective
    2 – Ineffective
    1 – Extremely ineffective

30. Have you received information about the flood management in your community from any of the following? Please select all that apply.

    Local Council
    Environment Agency
    Insurance Company
    Flood group/warden
    National Government
    Fire/Police service
    Newspaper/magazine
    Television/radio news
    Friends/relatives
    Have had none at all

31. Do you understand the term 'Flood Risk Management'?

    Yes No

32. If yes, please could you provide a short description.

    ____
    ____
    ____
    ____
    ____
    ____
    ____
    ____
    ____

33. Have you been aware of the shift from structural flood defence to Flood Risk Management that includes more natural, risk-based approaches?

    Yes No Not Sure

    [A short description of FRM will be provided if the participant chooses No or Not Sure]

34. Do you think this shift to Flood Risk Management will be positive or negative for flood defence in your community?

    Positive
    Negative
    No change

35. Do you think Flood Risk Management, rather than solely using traditional flood defence structures, will be better at reducing flood risk in your community?

    Yes No Not Sure

Flood Risk Responsibility

36. Who is currently responsible for flood protection in your community?

    You/your household
    Local Council
    National Government
    Environment Agency
    Fire/Police Service
    Not sure

37. Who should be responsible?

    ____

38. Have you taken any extra precautionary measures to defend your property against flooding and reduce your flood risk?

    ____

39. Do you believe it is necessary to undertake your own precautionary measures and prepared for floods?

    Yes No Not Sure

40. Are you insured against future floods?

    Yes No Not Sure

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Participant Information Sheet

Doctoral Research Project: Shifting Flood Risk Management (FRM) in England and the Netherlands: Public Flood Risk Perceptions and Responses

Purpose of this study

This research project is exploring changing flood risk perceptions and responses with developing Flood Risk Management (FRM), ranging from traditional structural defences to varying FRM strategies, in case study locations in England and Netherlands. To do this we would like participants to complete a questionnaire survey and mapping exercise to gauge their flood risk perceptions. We would also like participants to indicate if they would be interested in receiving information on a second experiment, that will evaluate personal responses to flood events, when this is available.

Research team and funders

This is a PhD research project from the school of Geography, Earth and Environmental Sciences (GEES) at the University of Birmingham, UK. This research is funded by DREAM (Data, Risk and Environmental Analytical Methods), through two RCUK funding councils: the Natural Environment Research Council (NERC) and Economic and Social Research Council and (ERSC). This project has also been supported by the UK Environment Agency, who have provided advice on engaging with communities in flood risk areas.

Participants in the study

This research project would like members of the public over the age of 18 that live in at-risk areas, which will act as case study locations for the study, to take part in the project.

Personal data will be kept confidential, and all responses provided in any part of the project (the questionnaire survey, mapping, and response experiment) will be anonymous in when reporting findings and result, and in any subsequent publications. Each participant will be provided with an ID number and only the primary researcher and supervisors will have access to any personal information. This study will also abide by the UK's 2018 Data Protection Act (DPA) and General Data Protection Regulation (GDPR).

Flood risk perception (questionnaire and mapping) survey

We would like participants to firstly complete a questionnaire survey that investigates the individual's risk perception, and secondly draw on a map of their area where they believe to be at risk from flooding to create a flood risk perception sketch map.

Questions include flood knowledge, experience, future likelihood of flooding, and perceptions towards the FRM strategy in place, general shifting FRM, and responsibility of flooding. The survey should not take longer than 10 minutes to complete. For the mapping exercise, a blank map of the case study will be provided for areas of flood risk to be drawn by the participant. While addresses of the respondents may be known to the researchers, these will be kept confidential.

Flood response experiment

A second part of this research project will investigate responses of participants to flood risk. We ask participants to take part in an experiment to test this. More information about this will be available soon, and we ask interested participants to let us know if they would be interested in receiving this information when it is available.

Withdrawal from the study

Participants will be free to withdraw from completing the study at any time. You do not have to provide a reason for this withdrawal, and you will also have 14 days after each phase to remove your contribution to the project. This data will be deleted and destroyed if desired.

Study outcomes

Research articles will be written for each part of this study, and these can be made available to participants if they wish.

Review of the research project

This study has been reviewed by senior lecturers at the University of Birmingham and has been given approval by the University of Birmingham Ethics Committee.

More information

If you have any questions, would like more information on the research project, or would just like some more information on flood risk in your area, please contact **Lucinda Capewell** LKC756@bham.ac.uk (PhD student at the University of Birmingham, UK). To contact the project supervisors, please email Dr Anne Van Loon A.F.VanLoon@bham.ac.uk or Dr Chris Bradley C.Bradley@bham.ac.uk.

You can also view the supporting background to this research and other similar work by the University of Birmingham Hydrological Extremes research group at https://hydrologicalextremes.org

Complaints

If you wish to make a complaint or raise a concern about this project, please contact Dr Martin Widmann by email: M.Widmann@bham.ac.uk

Alternatively, you can contact the project supervisors Dr Anne Van Loon or Dr Chris Bradley.

Appendix 2: MCDM AHP Calculation Tables and Process

Pairwise comparison matrix with AHP fractions as percentages.

Criteria	NFVI	SFRI	Flood warning areas	At-risk properties	C I	Agricultural land classes	SSSIs	Flood depths	CC impact on flood depths	Historic flooding	Existing protection assets
NFVI	1	3	1	1	1	5	5	1	3	3	3
SFRI	0.33	1	0.33	0.33	0.33	3	3	0.33	1	1	1
Flood warning areas	1	3	1	1	1	5	5	1	3	3	3
At-risk properties	1	3	1	1	1	5	5	1	3	3	3
C I	1	3	1	1	1	5	5	1	3	3	3
Agricultural land classes	0.2	0.33	0.2	0.2	0.2	1	1	0.2	0.33	0.33	0.33
SSSIs	0.2	0.33	0.2	0.2	0.2	1	1	0.2	0.33	0.33	0.33
Flood depths	1	3	1	1	1	5	5	1	3	3	3
CC impact on flood depths	0.33	1	0.33	0.33	0.33	3	3	0.33	1	1	1
Historic flooding	0.33	1	0.33	0.33	0.33	3	3	0.33	1	1	1
Existing protection assets	0.33	1	0.33	0.33	0.33	3	3	0.33	1	1	1
Sum	6.72	19.66	6.72	6.72	6.72	39	39	6.72	19.66	19.66	19.66

Normalised pair-wise comparison matrix calculated by AHP values divided by criteria column sum. Criteria weights calculated by mean criteria AHP row values. Criteria values total 0.1 (100%).

Criteria	NFVI	SFRI	Flood warning areas	At-risk properties	C I	Agricultural land classes	SSSIs	Flood depths	CC impact on flood depths	Historic flooding	Existing protection assets	**Criteria weight**
NFVI	0.1488	0.1526	0.1488	0.1488	0.1488	0.1282	0.1282	0.1488	0.1526	0.1526	0.1526	**0.1464**
SFRI	0.0491	0.0509	0.0491	0.0491	0.0491	0.0769	0.0769	0.0491	0.0509	0.0509	0.0509	**0.0548**
Flood warning areas	0.1488	0.1526	0.1488	0.1488	0.1488	0.1282	0.1282	0.1488	0.1526	0.1526	0.1526	**0.1464**
At-risk properties	0.1488	0.1526	0.1488	0.1488	0.1488	0.1282	0.1282	0.1488	0.1526	0.1526	0.1526	**0.1464**
C I	0.1488	0.1526	0.1488	0.1488	0.1488	0.1282	0.1282	0.1488	0.1526	0.1526	0.1526	**0.1464**
Agricultural land classes	0.0298	0.0168	0.0298	0.0298	0.0298	0.0256	0.0256	0.0298	0.0168	0.0168	0.0168	**0.0243**
SSSIs	0.0298	0.0168	0.0298	0.0298	0.0298	0.0256	0.0256	0.0298	0.0168	0.0168	0.0168	**0.0243**
Flood depths	0.1488	0.1526	0.1488	0.1488	0.1488	0.1282	0.1282	0.1488	0.1526	0.1526	0.1526	**0.1464**

CC impact on flood depths	0.0491	0.0509	0.0491	0.0491	0.0491	0.0769	0.0769	0.0491	0.0509	0.0509	0.0509	**0.0548**
Historic flooding	0.0491	0.0509	0.0491	0.0491	0.0491	0.0769	0.0769	0.0491	0.0509	0.0509	0.0509	**0.0548**
Existing protection assets	0.0491	0.0509	0.0491	0.0491	0.0491	0.0769	0.0769	0.0491	0.0509	0.0509	0.0509	**0.0548**

Calculation of consistency of pairwise matrix by AHP percentages times criteria weight.

Mean of row values to produce weighted sum value.

Criteria	NFVI	SFRI	Flood warning areas	At-risk properties	C I	Agricultural land classes	SSSIs	Flood depths	CC impact on flood depths	Historic flooding	Existing protection assets	**Weighted sum value**
NFVI	0.1464	0.4393	0.1464	0.1464	0.1464	0.7322	0.7322	0.1464	0.4393	0.4393	0.4393	3.9539
SFRI	0.0181	0.0548	0.0181	0.0181	0.0181	0.1644	0.1644	0.0181	0.0548	0.0548	0.0548	0.6385
Flood warning areas	0.1464	0.4393	0.1464	0.1464	0.1464	0.7322	0.7322	0.1464	0.4393	0.4393	0.4393	3.9539
At-risk properties	0.1464	0.4393	0.1464	0.1464	0.1464	0.7322	0.7322	0.1464	0.4393	0.4393	0.4393	3.9539
C I	0.1464	0.4393	0.1464	0.1464	0.1464	0.7322	0.7322	0.1464	0.4393	0.4393	0.4393	3.9539
Agricultural land classes	0.0049	0.0080	0.0049	0.0049	0.0049	0.0243	0.0243	0.0049	0.0080	0.0080	0.0080	0.1049
SSSIs	0.0049	0.0080	0.0049	0.0049	0.0049	0.0243	0.0243	0.0049	0.0080	0.0080	0.0080	0.1049
Flood depths	0.1464	0.4393	0.1464	0.1464	0.1464	0.7322	0.7322	0.1464	0.4393	0.4393	0.4393	3.9539
CC impact on flood depths	0.0181	0.0548	0.0181	0.0181	0.0181	0.1644	0.1644	0.0181	0.0548	0.0548	0.0548	0.6385
Historic flooding	0.0181	0.0548	0.0181	0.0181	0.0181	0.1644	0.1644	0.0181	0.0548	0.0548	0.0548	0.6385
Existing protection assets	0.0181	0.0548	0.0181	0.0181	0.0181	0.1644	0.1644	0.0181	0.0548	0.0548	0.0548	0.6385

λ max = 17.2945

$$\frac{\lambda \textbf{ max - n}}{\textbf{n - 1}}$$

Consistency index = 0.62945

Random index for 11 criteria = 1.51

Consistency ratio = 0.41

Appendix 3: Supporting Data for Trent Catchment Flood Mapping

Data layers used in flood risk assessment of the River Trent catchment, including list of Critical Instructure, with their sources

Data	**Source**	**Reason**
Trent catchment outline		
Local authority areas	ONS	Community
Building Outlines	OS open data – Local	Community
National Receptor Database (property points)	EA partnership data	Community
Urban areas classification	OS open data – Stragei	Community
UK River and Watercourse Networks	OS open data – Open Rivers	Risk Assessment
Risk of Flooding from Rivers and Sea (formerly known as NaFRA dataset)	EA open data – RoFRS	Risk Assessment
Flood Zone 2 and 3 (Fluvial Flooding Extent)	EA open data – Flood map for planning (FZ2 and FZ3)	Risk Assessment
Flood Warning and Alert areas	EA open data – Flood Alerts	Risk Assessment
Historic Flood Map and Recorded Flood Outlines	EA open data	Risk Assessment
Risk of Flooding from Surface Water (1 in 30, 100, and 1000) Extent	EA partnership data	Risk Assessment
Fluvial Flood Depths (1 in 1000)		Risk Assessment
Surface Water Flood Depths (1 in 1000)		Risk Assessment
Fluvial Flood Depths with Climate Change (1 in 1000)		Risk Assessment
Neighbourhood Flood Vulnerability Index (NFVI) and Social Flood Risk Index (SFRI)	Climate Just open data	Risk Assessment
Agricultural Land Classifications	Magic open data – Natural England	Risk Assessment
SSSI areas	Magic open data – Natural England	Risk Assessment
Spatial Flood Defences (0-1000)	EA open data	Scheme comparison
Flood Defence Benefitting Areas	EA open data	Scheme comparison
6 Year Capital Program 2018/19 - 2020/21 Provisional & Completed Schemes	EA open data	Scheme comparison
Indicative Flood Reduction Schemes Allocation Programme	EA partnership data	Scheme comparison

Appendix 4: Kreibich et al. (2022). The Challenge of Unprecedented Floods and Droughts in Risk Management. Nature. 608

Kreibich et al. (2022). The challenge of unprecedented floods and droughts in risk management. *Nature*. 608

Unprecedented floods and droughts: challenges for risk management

Heidi Kreibich, Anne F. Van Loon, Kai Schröter, Philip J. Ward, Maurizio Mazzoleni, Nivedita Sairam, Guta Wakbulcho Abeshu, Svetlana Agafonova, Amir AghaKouchak, Hafzullah Aksoy, Camila Alvarez-Garreton, Blanca Aznar, Laila Balkhi, Marlies H. Barendrecht, Sylvain Biancamaria, Liduin Bos-Burgering, Chris Bradley, Yus Budiyono, Wouter Buytaert, Lucinda Capewell, Hayley Carlson, Yonca Cavus, Anaïs Couasnon, Gemma Coxon, Ioannis Daliakopoulos, Marleen C. de Ruiter, Claire Delus, Mathilde Erfurt, Giuseppe Esposito, Didier François, Frédéric Frappart, Jim Freer, Natalia Frolova, Animesh K Gain, Manolis Grillakis, Jordi Oriol Grima, Diego A. Guzmán, Laurie S. Huning, Monica Ionita, Maxim Kharlamov, Dao Nguyen Khoi, Natalie Kieboom, Maria Kireeva, Aristeidis Koutroulis, Waldo Lavado-Casimiro, Hongyi Li, Maria Carmen LLasat, David Macdonald, Johanna Mård, Hannah Mathew-Richards, Andrew McKenzie, Alfonso Mejia, Eduardo Mario Mendiondo, Marjolein Mens, Shifteh Mobini, Guilherme Samprogna Mohor, Viorica Nagavciuc, Thanh Ngo-Duc, Huynh Thi Thao Nguyen, Pham Thi Thao Nhi, Olga Petrucci, Nguyen Hong Quan, Pere Quintana-Seguí, Saman Razavi, Elena Ridolfi, Jannik Riegel, Md Shibly Sadik, Elisa Savelli, Alexsey Sazonov, Sanjib Sharma, Johanna Sörensen, Felipe Augusto Arguello Souza, Kerstin Stahl, Max Steinhausen, Michael Stoelzle, Wiwiana Szalińska, Qiuhong Tang, Fuqiang Tian, Tamara Tokarczyk, Carolina Tovar, Thi Van Thu Tran, Marjolein van Huijgevoort, Michelle van Vliet, Sergiy Vorogushyn, Thorsten Wagener, Yueling Wang, Doris E. Wendt, Elliot Wickham, Long Yang, Mauricio Zambrano-Bigiarini, Günter Blöschl, Giuliano Di Baldassarre

Risk management has reduced vulnerability to floods and droughts globally[1,2], yet their impacts are still increasing[3]. An improved understanding of the causes of changing impacts is therefore

needed, but has been hampered by a lack of empirical data[4,5]. Based on a new global dataset of 45 pairs of events that occurred within the same area, we show that risk management generally reduces the impacts of floods and droughts, but faces difficulties in reducing the impacts of unprecedented events of a magnitude not experienced before. If the second event was much more hazardous than the first, its impact was almost always higher. This is because management was not designed to deal with such extreme events. For example, they exceeded the design levels of levees and reservoirs. In two success stories, the impact of the second, more hazardous, event was lower, as a result of improved risk management governance and high investments in integrated management. The observed difficulty of managing unprecedented events is alarming, given that more extreme hydrological events are projected due to climate change[3].

Observed decreasing trends in the vulnerability to floods and droughts, owing to effective risk management, are encouraging[1]. Globally, human and economic vulnerability have dropped by ~6.5 and 5 times, respectively, between 1980–1989 and 2007–2016[2]. However, the impacts of floods and droughts are still severe and increasing in many parts of the world[6]. Climate change will likely further increase their impacts due to projected increases in the frequency and severity of floods and droughts[3]. The economic damage of floods is projected to double globally[7] and that of droughts to triple in Europe[8], for a mean temperature increase of 2°C.

The purpose of risk management is to reduce the impact of events through modifying the hazard, exposure, or vulnerability: According to UN terminology[9], disaster risk management is the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses. Hazard is a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation; exposure is the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas; and vulnerability are the conditions determined by physical, social, economic and environmental factors or processes[10,11,12,13] which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. In order to be effective, risk management needs to be based on a sound understanding of these controlling drivers[14,15]. Past studies have identified increasing exposure as a primary driver of increasing impacts[3,4], and vulnerability reduction has been identified to be key for reducing impacts[16,17]. However, ascertaining the combined effect of the drivers and the overall effectiveness of risk management has been hampered by a lack of empirical data[4,5].

Here, we analyse a new dataset of 45 pairs of flood or drought events that occurred in the same area on average 16 years apart (hereinafter referred to as paired events). The data comprise 26 flood and 19 drought paired events across different socio-economic and hydro-climatic contexts from all continents (Figure 1a). We analyse floods and droughts together, because of the similarity of some of the management methods (e.g. warning systems, water reservoir infrastructure), the potential for trade-offs in risk reduction between floods and droughts, and therefore value for the management communities to learn from each other[18]. The impact, quantified by direct (fatalities, monetary damage), indirect (e.g. disruption of traffic or tourism) and intangible (e.g. impact on human health or cultural heritage) impacts, is considered to be controlled by three drivers: hazard, exposure and vulnerability[3]. These drivers are quantified using a large range of different indices, for example the standardised precipitation index, the number of houses in the affected area and risk awareness, respectively (Extended Data Table 1). The three drivers are considered to be exacerbated by management shortcomings. Hazard may be exacerbated by problems with water management infrastructure such as levees or reservoirs[19]. Exposure and vulnerability may be worsened by suboptimal implementation of non-structural measures such as risk-aware regional planning[20] or early warning[21] respectively. We analyse management shortcomings and their effect on the three drivers explicitly, as this is where improvements can start, e.g. by introducing better strategies and policies. Data availability understandably varies among the paired events, and this introduces inconsistency and subjectivity. The analyses are therefore based on indicators-of-change to account for the different monitoring between paired events in respect to measured variables, data quality and uncertainty. These indicators-of-change represent the differences in impact, hazard, exposure, vulnerability and management shortcomings between the first event ("baseline") and the second event, categorised as large decreases/increases (-2/2), small decreases/increases (-1/1) and no change (0) (Extended Data Table 2). To minimise the subjectivity and uncertainty of indicator assignment, indicators-of-change with sub-indicators are used, and a quality assurance protocol is implemented.

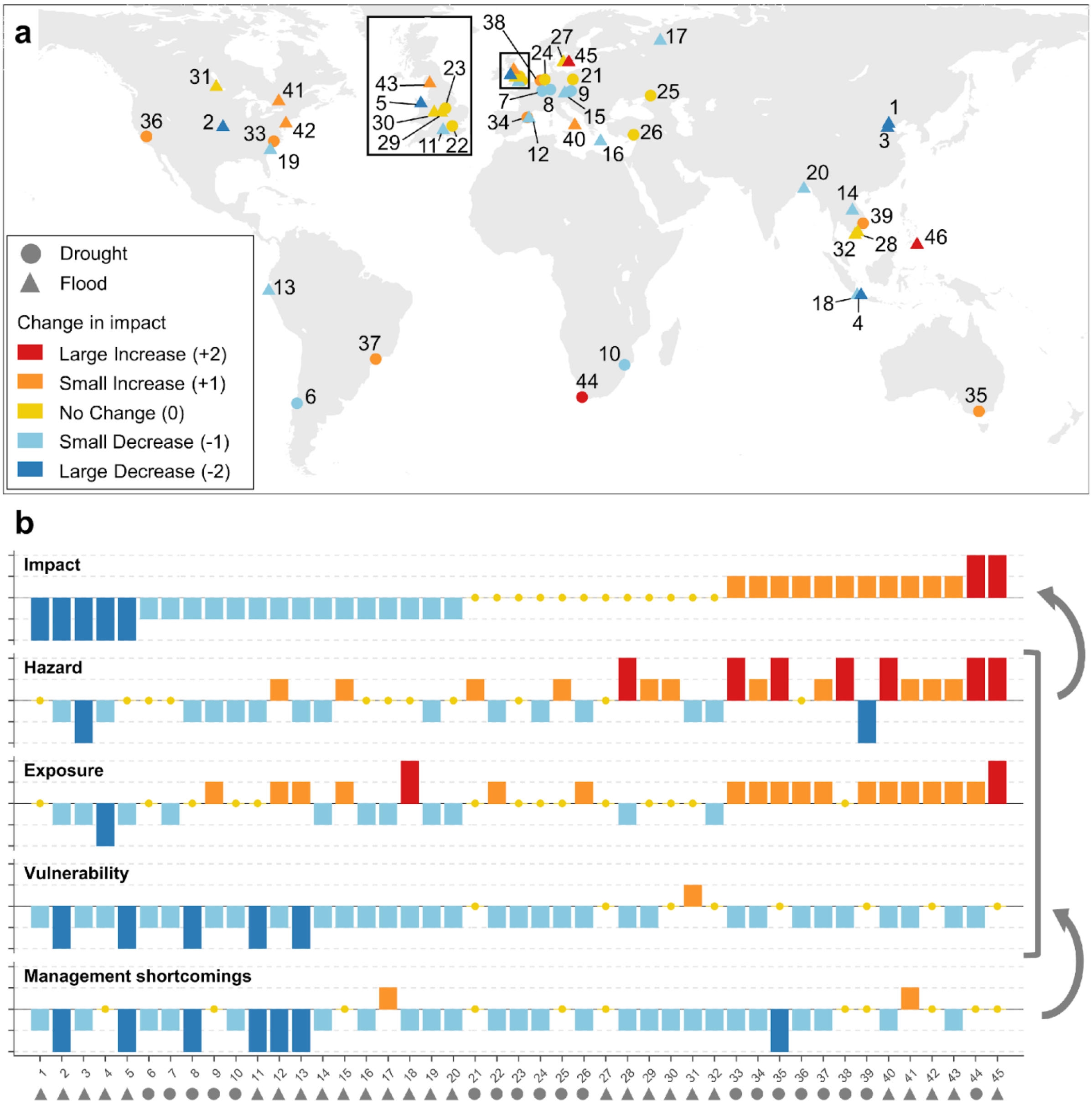

Figure 1 Location of flood and drought paired events coloured according to changes in impact (a) and their indicators-of-change, sorted by impact change (b). Numbers are paired event IDs. Impact is considered to be controlled by hazard, exposure and vulnerability, which are exacerbated by risk management shortcomings. Maps of the paired events coloured according to the drivers and management shortcomings are shown in Extended Data Figure 1.

The majority of paired events show decreases in management shortcomings (71% of paired events) (Figure 1b), which reflects the fact that societies tend to learn from extreme events[22]. Most cases also show a decrease in vulnerability (80% of paired events) since societies typically reduce their vulnerability after the first event of a pair[21]. The five paired events with a large decrease in impact (dark blue, top left of Figure 1b) are associated with decreases or no change of all three drivers. The two paired events with a large increase in impact (red, top right of Figure 1b) are associated with a large increase in hazard and small or large increases in exposure.

Drivers of changes in impact

Changes of flood impacts are significantly and positively correlated with changes of hazard ($r = 0.64$, $p \le 0.01$), exposure ($r = 0.55$, $p \le 0.01$) and vulnerability ($r = 0.60$, $p \le 0.01$) (Figure 2a), which is in line with risk theory[3]. While a previous analysis of eight case studies[21] had identified vulnerability as a key to reducing flood impacts, this new, more comprehensive dataset suggests that changes in hazard, exposure and vulnerability are equally important, given that they correlate equally strongly with changes of flood impact. Changes of drought impacts are significantly correlated with changes in hazard and exposure but not with changes in vulnerability (Figure 2c). This suggests that changes in vulnerability are less important for drought impact than for flood impact, which is also consistent with those event pairs for which only vulnerability changed (Extended Data Table 3). However, quantifying the contribution of individual drivers, such as vulnerability, is difficult with this empirical approach, as there are only a limited number of cases where only one driver has changed. There are three cases where only the vulnerability changed between events, hazard and exposure did not, two cases where only hazard changed and no case where only exposure changed (Extended Data Table 3). Additionally, paired events without a change in hazard (0) are analysed in more detail to better understand the role of exposure and vulnerability (Extended Data Figure 2). In all these paired events, a reduction in impact was associated with a reduction in vulnerability, highlighting the importance of vulnerability. In 5 of these 8 cases with a decrease in impact there was also a decrease in exposure, while in one case (floods in Jakarta, Indonesia in 2002 and 2007 (ID 18)) there was a large increase in exposure. In the paired event of droughts in California, USA (1987-1992 and 2011-2016, ID 36) an increase in exposure and a reduction in vulnerability increased impact, which points to the more important role of exposure in comparison with vulnerability in this drought case (Extended Data Figure 2).

Generally, the changes of the drivers are not significantly correlated with each other, with the exception of hazard and exposure for the case of floods ($r = 0.55$; $p \leq 0.01$) (Figure 2a). This finding may be explained by the influence of hazard on the size of the inundation area, and thus on the number of people and assets affected which represent exposure.

The sensitivity analysis suggests that the correlation pattern is robust, as visualized by the colours in Extended Data Figure 3. The pattern of p-values is also robust for the flood cases, although they become less significant for the droughts because of the smaller sample size (Extended Data Figure 3).

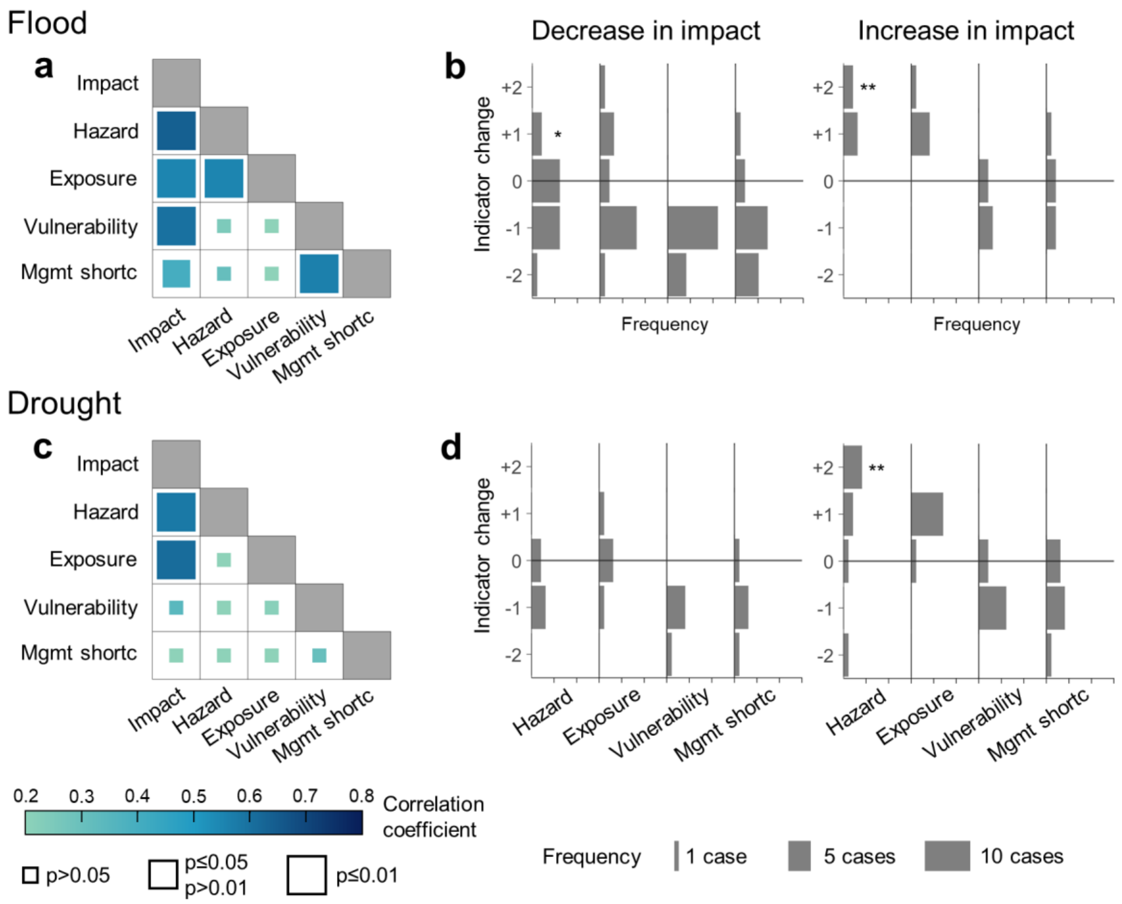

Figure 2 Correlation matrix of indicators-of-change for flood (a) and drought (c) paired events. Colour of squares indicates Spearman's rank correlation coefficient, their size the p-value. Histograms of indicators-of-change of floods (b) and droughts (d) stratified by decrease (n = 15 and 5 paired events for floods and droughts) and increase (n = 5 and 8 paired events) in impact. * denotes the success stories of Box 1. ** denote pairs where the second event was much more hazardous than the first ("unprecedented")

We split the paired events into groups of decreasing and increasing impact in order to evaluate their drivers separately (Figure 2b, d). Overall, the frequency of drivers is similar for floods and droughts. Most flood and drought pairs with decreasing impact show either a decrease in hazard (10 pairs, 50%) or no change (8 pairs, 40%). Exceptions are two flood pairs that are success stories of decreased impact despite an increase in hazard as detailed in Box 1. The change in exposure of the pairs with decreased impacts (Figure 2b, d) ranges from a large decrease to a large increase, while vulnerability always decreased. All cases with a large decrease in vulnerability (-2) are associated with a decrease in impacts. Overall, the pattern suggests that a decrease in impacts is mainly caused by a combination of lower hazard and vulnerability, despite an increase in exposure in 25% of cases.

The role of hazard and vulnerability in impact reduction can be exemplified by the pair of riverine floods in Jakarta, Indonesia (ID 4 in Figure 1). The 2007 event had a flood return period of 50 years while it was 30 years for the 2013 event[23], i.e. the hazard of the second event was smaller. The vulnerability had also decreased as a result of improved preparedness resulting from a flood risk mapping initiative and capacity building programs implemented after the first flood, to improve emergency response of the citizens, as well as by an improvement of the official emergency management by establishing the National Disaster Management Agency (BNPB) in 2008. Additionally, exposure was substantially reduced. Whilst the first flood caused 79 fatalities and direct damage of 1.3 billion Euro, the second event caused 38 fatalities and 0.76 billion Euro of direct damage.

Another example is a pair of Central European droughts (ID 9). During the 2003 event, the minimum 3-month Standardised Precipitation Evapotranspiration Index (SPEI3) was -1.62 while in 2015 it was -1.18, i.e. the hazard of the second event was smaller[24]. The vulnerability was also lower in the second event, because the first event had raised public awareness and triggered an improvement of institutional planning. For instance, the European Commission technical guidance on drought management plans[25] was implemented. Many reservoirs were kept filled until the beginning of summer 2015, which alleviated water shortages for various sectors, and in some cities (e.g. Bratislava, Bucharest) water was supplied via tanks[26]. Additionally, water use and abstraction restrictions were implemented for non-priority uses including irrigation[26]. The impact was reduced from 17.1 to 2.2 billion Euro, despite an increase in exposure because of the larger drought extent affecting almost all of Europe in 2013.

Most flood and drought pairs with an increase in impact also show a larger hazard (11 cases, 85%, Figure 2b, d). For six of these paired events (46%), the second event was much more hazardous than the first (hazard indicator-of-change +2), while this was never the case for the pairs with decreasing impact. Of the pairs with an increase in impact, 12 (92%) show an increase in exposure and 9 (69%)

show a small decrease in vulnerability (vulnerability indicator-of-change -1). Overall, the pattern suggests that the increase in impact is mainly caused by a combination of higher hazard and exposure, which is not compensated by a small decrease in vulnerability.

The role of hazard and exposure in increasing impact is illustrated by a pair of pluvial floods in Corigliano-Rossano city, Calabria, Italy (ID 40). The 2015 event was much more hazardous (+2) than the one in 2000 with precipitation return periods of >100 years and 10-20 years, respectively[27]. Also, the 2000 event occurred during the off-season for tourism in September, while the exposure was much larger in 2015 because the event occurred in August when many tourists were present. The interruption of the peak holiday season caused severe indirect economic damage. Another example is a pair of droughts (ID 33) affecting North Carolina, USA. Between 2007 and 2009, about 65% of the state was affected by what was classified as an exceptional drought, with a composite drought indicator of the US Drought Monitor of 27 months[28], while between 2000 and 2003 only about 30% of the state was affected by an exceptional drought of 24 months[28]. The crop losses in 2007-2009 were about 535 million Euro while they were 497 million Euro in 2000-2003, even though vulnerability had been reduced due to drought early warning and management by the North Carolina Drought Management Council established in 2003.

Effects of changes in management on the drivers

The correlations shown in Figure 2a, c also shed light on how management affects hazard, exposure and vulnerability and thus, indirectly, impact. For flood paired events, changes in management shortcomings are significantly positively correlated with changes in vulnerability ($r = 0.56$, $p \leq 0.01$), and both are significantly positively correlated with changes in impact (Figure 2a). For the droughts, however, these correlations are not significant (Figure 2c). Thus, achieving decreases in vulnerability, and consequently in impact, by improving risk management (i.e. reducing management shortcomings) seems to be more difficult for droughts than for floods. This difficulty may be related to spillover effects, i.e. drought measures designed to reduce impacts in one sector can increase impacts in another sector. For example, irrigation to alleviate drought in agriculture may increase drought impacts on drinking water supply and ecology[29].

The paired floods in the Piura region, Peru (ID 13) illustrate how effective management can reduce vulnerability, and consequently impact. At the Piura river, maximum flows of 3367 and 2755 $m^3 s^{-1}$ were recorded during the 1998 and 2017 events, respectively, i.e. hazard showed a small decrease (-1). Around 2000, the national hydrometeorological service started issuing medium-range weather forecasts that allowed preparations months before the 2017 event. In 2011, the National Institute of Civil Defence (INDECI), and the national Centre for the Estimation, Prevention, and Reduction of Disaster Risk (CENEPRED) were founded which, together with newly established short-range river flow forecasts, allowed more efficient emergency management of the more recent event. Additionally, NGOs such as 'Practical Action' had implemented disaster risk reduction activities, including evacuation exercises and awareness campaigns[30]. All of these improvements in management decreased the vulnerability. The impact of the second event was smaller with 366 fatalities in 1998 compared to 159 fatalities in 2017, despite an increase in exposure due to urbanisation and population increase.

When the hazard of the second event was larger than that of the first (+1, +2), in 11 out of 18 cases (61%) also the impact of the second event was larger, irrespective of small decreases in vulnerability (light blue dots/triangles) in 8 of these cases (Figure 3). There are only two paired events in our dataset for which a decrease in impact was achieved despite the second event being more hazardous (highlighted by the green circle in Figure 3). These cases are considered success stories and are further discussed in Box 1. For the two paired events (ID 21 & 30) where the only driver that changed was hazard (+1), the impacts did not change (0) (Extended Data Table 3). Water retention capacity of 189,881 thousand m^3 and good irrigation infrastructure with sprinkling machines was apparently able to counteract the slight increase of hazard for the drought paired event in Poland in 2006 and 2015 (ID 21). The improved flood alleviation scheme implemented between the paired flood events (2016 & 2018), protected properties without failures in Birmingham, UK (ID 30). There are, however, seven cases for which the second event was much more hazardous (+2) than the first (highlighted by the purple ellipse in Figure 3), i.e. events of a magnitude locals have likely not experienced before. We term these events, subjectively, as unprecedented; almost all had an increased impact in spite of improvements in management.

One unprecedented pluvial flood is the 2014 event in the city of Malmö, Sweden (ID 45). This event was much more hazardous than the one experienced a few years before, with precipitation return periods on average of 135 years and 24 years, respectively, for six hours duration[31]. The largest 6-hours precipitation measured at one of nine stations during the 2014 event corresponded to a return period of 300 years. The combined sewage system predominant in the more densely populated areas of the city was overwhelmed, leading to extensive basement flooding in 2014[31]. The direct monetary damage was about 66 million Euro as opposed to 6 million Euro in the first event. An unprecedented drought occurred in the Cape Town metropolitan area of South Africa, in 2015–2018 (ID 44). The drought was much longer (4 years) than the drought experienced previously in 2003–2004 (2 years). Although the Berg River Dam had been added to the city's water supply system in 2009, and local authorities had developed various strategies for managing water demands (e.g. water restrictions, tariff increases, communication campaign), the second event caused a much higher direct impact of about 180 million Euro[32] as the water reserves were reduced to virtually zero.

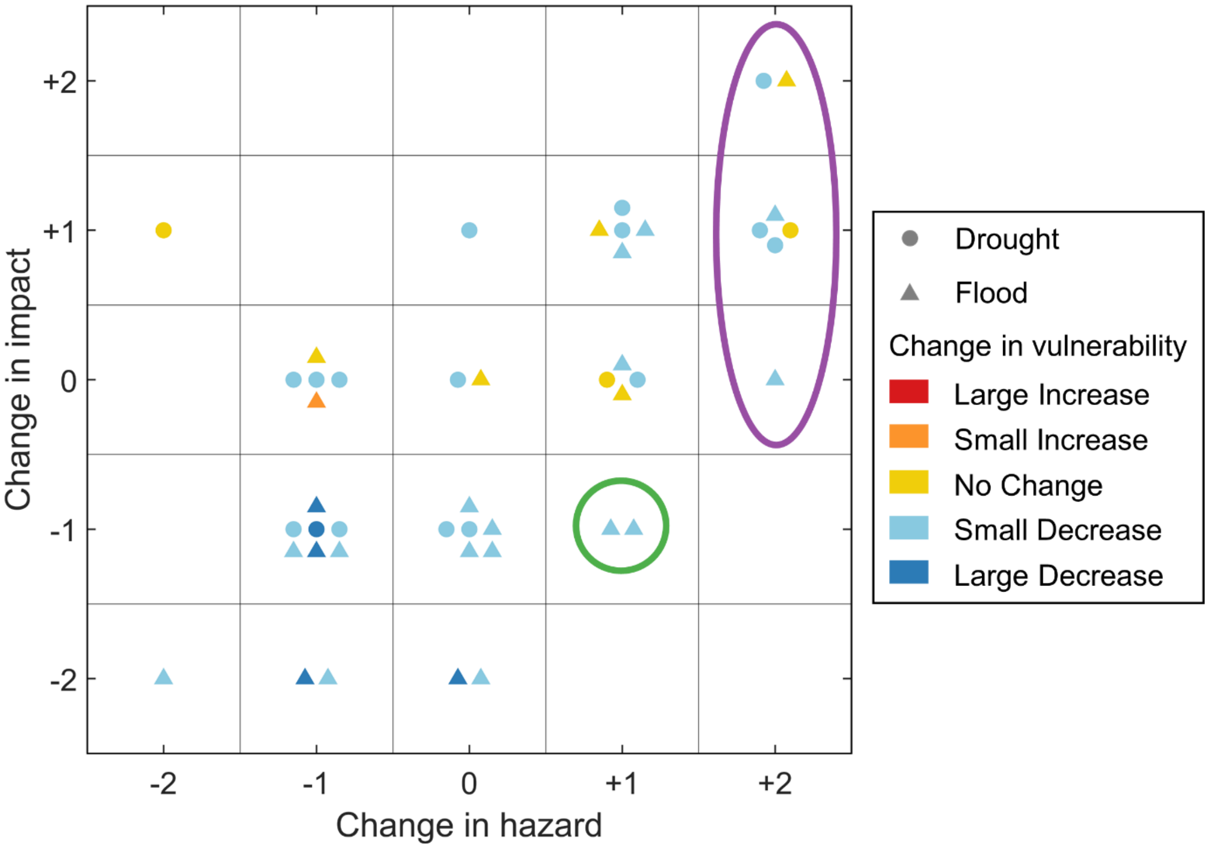

Figure 3 Relationship between change in hazard and change in impacts with the categories: lower hazard & lower impact: 10 cases; higher hazard & higher impact: 11 cases; lower hazard & higher impact: 1 case; higher hazard & lower impact: 2 cases. Circles and triangles indicate drought and flood paired events, respectively; their colours indicate change in vulnerability. Green circle highlights success stories (n=2) of reduced impact (-1) despite a small increase in hazard (+1). Purple ellipse indicates paired events (n=7) with large increase in hazard (+2), i.e. events that were subjectively unprecedented (i.e. likely not experienced before by locals).

Box 1 Success stories of decreased impact despite increased hazard

The dataset includes two cases in which a lower impact was achieved despite a larger hazard of the second event, making these interesting success stories (Figure 3). Both cases are flood paired events, however of different types, i.e. pluvial and riverine floods (Table 1). The cases have in common that institutional changes and improved flood risk management governance were introduced and high investments in integrated management were undertaken, which led to an effective implementation of structural and non-structural measures, such as improved early warning and emergency response to complement structural measures such as levees (Table 1).

Table 1 Characteristics and commonalities in flood management of the two success stories

	Pluvial floods in Barcelona, Spain (ID 12)		**Riverine floods in Danube catchment in Germany and Austria (ID 15)**	
Event characteristics	**1995**	**2018**	**2002**	**2013**
Hazard (hazard indicator-of-change +1)	Duration: 4 hrs; average event precipitation: 38 mm	Duration: 21 hrs; average event precipitation: 45 mm	7700 m^3s^{-1} peak discharge at gauge Achleiten	10100 m^3s^{-1} peak discharge at gauge Achleiten
Impacts (impact indicator-of-change -1)	33.6 million Euro*	3.5 million Euro	4 billion Euro*	2.32 billion Euro
Commonalities in management changes - potential factors of success				
Institutional changes, improved governance	Reorganization of early warning and emergency response after 1995 with improved collaboration between municipality, Catalonia and State Agency of Meteorology		Flood information service HORA for Austria went online in 2006; reorganization of flood warning and emergency response units with improved collaboration across federal states and transnationally	
High investments in structural and non-structural measures	About 136 million Euro* invested in structural measures alone, following the Integrated Sewerage Plan of Barcelona		~3.6 billion Euro* invested in flood risk management between events on structural and non-structural measures including new legislation and building codes in Germany and Austria	
Strongly improved early warning and emergency response	New radar and lightning network plus operative mesoscale meteorological models in Catalonia, real time control system based on rain gauge network and water level monitoring in Barcelona		Technical improvements of weather forecasts in Germany, much higher penetration rate of flood warnings and more effective flood response actions among citizens	

* calculated as costs at the time of the second event

Whilst it is known that vulnerability reduction plays a key role in reducing risk, our paired-event cases reveal that when the hazard of the second event was higher than the first, a reduction in vulnerability alone was often not sufficient to reduce the impacts of the second event to be lower than that of the first.

Our analysis of drivers of impact change reveals the importance of reducing hazard, exposure and vulnerability to achieve an effective impact reduction (Figure 2). While previous studies have attributed a high priority to vulnerability reductions[17,21], the importance of considering all three drivers identified here may reflect the sometimes limited efficiency of management decisions resulting in unintended consequences. For example, levee construction aiming at reducing hazards may increase exposure through encouraging settlements in floodplains[33,34]. Similarly, construction of reservoirs to abate droughts may enhance exposure through encouraging agricultural development and thus increase water demand[35,36].

Events much more hazardous than preceding events (termed unprecedented here) seem to be difficult to manage, as in almost all the cases considered here the impact increased (Figure 3). This finding may be related to two factors. First, large infrastructure such as levees and water reservoirs play an important role for risk management. These structures usually have an upper design limit up to which they are effective, but once a threshold is exceeded, they become ineffective. For example, the unprecedented pluvial flood in 2014 in Malmö, Sweden (ID 45), exceeded the capacity of the sewer system[31] and the unprecedented drought in Cape Town (ID 44) exceeded the storage water capacity[37]. This means that infrastructure is effective in preventing damage during events of an already experienced magnitude, but often fails for unprecedented events. Non-structural measures, such as risk aware land-use planning, precautionary measures and early warning can help mitigate the consequences of water infrastructure failure in such situations[21], but a residual risk will always remain. Second, risk management is usually implemented after large floods and droughts, while pro-active strategies are rare. Part of the reason for this behaviour is a cognitive bias associated with the rarity and uniqueness of extremes, and the nature of human risk perception, which makes people attach a large subjective probability to those events they have personally experienced[38].

On the other hand, two case studies were identified where impact has been reduced despite an increase in hazard (Box 1). An analysis of these case studies identifies three success factors. These are effective governance of risk and emergency management including transnational collaboration such as in the Danube case; high investments in structural and non-structural measures and improved early warning and real time control systems such as in the Barcelona case. We believe there is potential for more universally applying these success factors to counteract the current trend of increasing impacts associated with climate change[3]. These factors may also be effective in the management of unprecedented events, provided they are implemented pro-actively.

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Data and Methods

The concept of paired events aims at comparing two events of the same hazard type that occurred in the same area[21] in order to learn from the differences and similarities. This concept is analogous to paired catchment studies, which compare two neighbouring catchments with different vegetation in terms of their water yield[39]. Our study follows the theoretical risk framework that considers impact as a result of three risk components or drivers[3]: hazard, exposure and vulnerability (Figure 4). Hazard reflects the intensity of an event, such as a flooded area or drought deficit, e.g. measured by the standardised precipitation index. Exposure reflects the number of people and assets in the area affected by the event. Consequently, the change in exposure between events is influenced by changes in the population density and the assets in the affected area (socio-economic developments) as well as by changes in the size of the affected area (change of hazard). Vulnerability is a complex concept, with an extensive literature from different disciplines on how to define, measure and quantify it[13,40,41,42]. For instance, Weichselgartner[43] lists more than 20 definitions of vulnerability, and frameworks differ quite substantially, e.g. in terms of integrating exposure into vulnerability[11] or separating them[3]. Reviews and attempts to converge on the various vulnerability concepts stress that vulnerability is dynamic and assessments should be conducted for defined human-environment systems at particular places[12,44,45]. Every vulnerability analysis requires an approach adapted to its specific objectives and scales[46]. The paired event approach allows detailed context and place-based vulnerability assessments which are presented in the paired event reports as well as comparisons across paired-events based on the indicators-of-change. The selection of sub-indicators for the characterisation of vulnerability is undertaken with a particular focus on temporal changes at the same place. All three drivers, i.e. hazard, exposure and vulnerability can be reduced by risk management measures. Hazard can be reduced by structural measures such as levees or reservoirs[19], exposure by risk-aware regional planning[20], and vulnerability by non-structural measures, such as early warning[21].

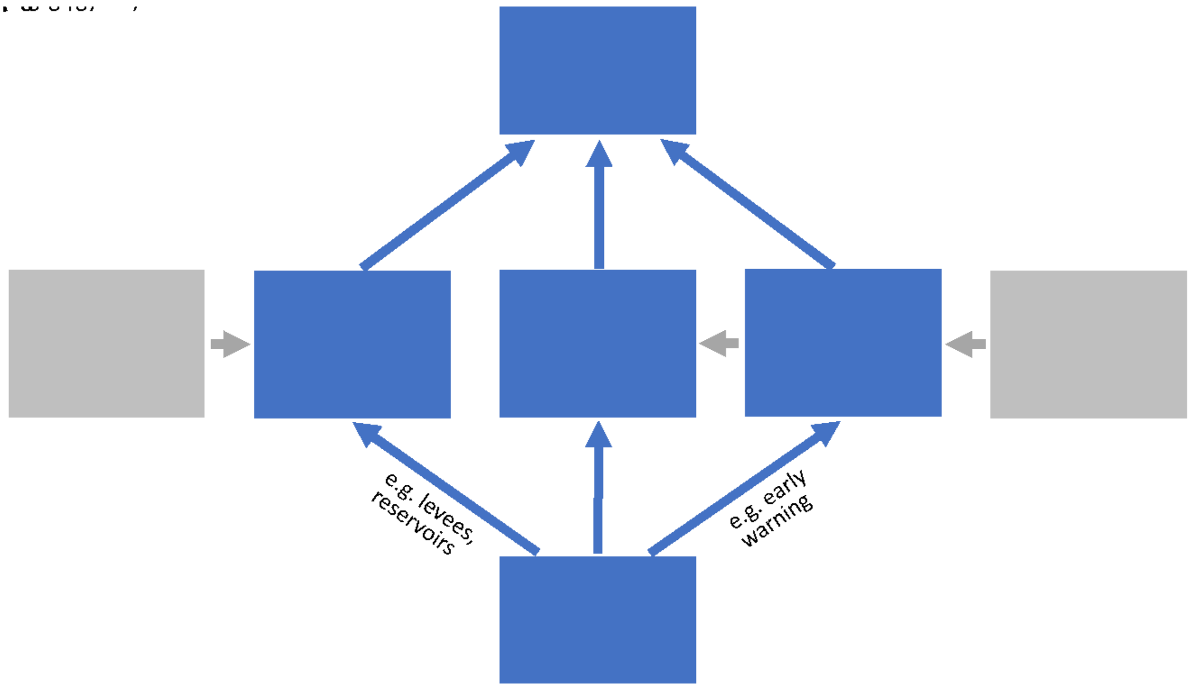

Figure 4 Theoretical framework used in this study (adapted from IPCC[3]).

Our comparative analysis is based on a novel dataset of 45 paired events from around the world, of which 26 event pairs are floods and 19 are droughts. The events occurred between 1947 and 2019, and the average period between the two events of a pair is 16 years. The number of paired events is large enough to cover a broad range of hydro-climatic and socio-economic settings around the world and allows differentiated context specific assessments on the basis of detailed in-situ observations. The flood events include riverine, pluvial, groundwater and coastal floods[47,48,49,50]. The drought events include meteorological, soil moisture and hydrological (streamflow, groundwater) droughts[51]. The rationale for analysing floods and droughts together is both, due to their position at the two extremes of the same hydrological cycle, and also the similarity of some management strategies (e.g. warning systems, water reservoir infrastructure), potential trade-offs in the operation of the same infrastructure[52], and more general interactions between these two risks (e.g. water supply to illegal settlements that may spur development and therefore flood risk). There may therefore be value for the management communities to learn from each other[18].

The dataset comprises: (1) detailed review-style reports about the events and key processes between the events such as changes in risk management (see supplementary information); (2) a key data table that contains the data (qualitative and quantitative) characterising the indicators for the paired events, extracted from the individual reports (see supplementary information) and (3) an overview table providing the indicators-of-change between the first and the second event (Table 2). In order to minimise the elements of subjectivity and uncertainty in the analysis we (i) used indicators-of-change as opposed to indicators of absolute values, (ii) calculated indicators from a set of sub-indicators (Extended Data Table 1), and (iii) implemented a quality assurance protocol. Commonly, more than one variable was assessed per sub-indicator (e.g. flood discharges at more than one stream gauge, or extreme rainfall at several meteorological stations). A combination or selection of the variables was used based on hydrological reasoning on the most relevant piece of information. Special attention was paid to this step during the quality assurance process, drawing on the in-depth expertise on events of one or more of our co-authors. The assignment of values for the indicators-of-change, including the quality assurance, was inspired by the Delphi Method[53] that is built on structured discussion and consensus building among experts. The process was driven by a core group (HK, AvL, KS, PW, GdB) and was undertaken in the following steps: (a) on the basis of the detailed report a core group member suggested values for all indicators-of-change for a paired event; (b) a second member of the core group reviewed these suggestions. In case of doubt, both core group members rechecked the paired event report, and provided a joint suggestion; (c) all suggestions for the indicators-of-change for all paired events were discussed in the core group to improve consistency across paired events; (d) the suggested values of the indicators-of-change were reviewed by the paired event report authors; (e) finally, the complete table of indicators-of-change (Table 2) was reviewed by all authors to ensure consistency between the paired events. Compound events were given special consideration, and the best possible attempt was made to isolate the direct effect of the floods and droughts from those of concurrent phenomena on hazard, exposure and impact, based on expert knowledge of the events of one or more of the co-authors. For instance, in the course of this iterative process it became clear that fatalities during drought events were not caused by a lack of water, but by the concurrent heatwave. It was thus decided to leave out the sub-indicator 'fatalities' in the drought impact characterisation. The potential biases introduced by compound events are further reduced by the use of the relative indicators-of-change between similar event types with similar importance of concurrent phenomena.

The indicator-of-change of impact is composed of the following sub-indicators: number of fatalities (only for floods), direct economic impact, indirect impact and intangible impact (Extended Data Table 1). Flood hazard is composed of the sub-indicators precipitation/weather severity, severity of flood, antecedent conditions (only for pluvial and riverine floods), as well as the following for coastal floods only: tidal level, storm surge. Drought hazard is composed of the duration and the severity of drought. Exposure is composed of the two sub-indicators people/area/assets exposed and exposure hotspots. Vulnerability is composed of the four sub-indicators lack of awareness and precaution, lack of preparedness, imperfect official emergency/crisis management and imperfect coping capacity. Indicators-of-change including sub-indicators were designed such that consistently positive correlations with impact changes are expected (Extended Data Table 1). For instance, a decrease in "lack of awareness" leads to a decrease in vulnerability and is thus expected to be positively correlated with a decrease in impacts. Management shortcomings are characterised by problems with water management infrastructure and non-structural risk management shortcomings, which means that non-structural measures were not optimally implemented. These sub-indicators were lumped into indicators-of-change for impact, hazard, exposure, vulnerability and management shortcomings, to enable a consistent comparison between flood and drought paired events. This set of indicators is intended to be as complementary as possible, but overlaps are hard to avoid because of the interactions between physical and socio-economic processes that control flood and drought risk. Although the management shortcoming indicator primarily relates to the planned functioning of risk management measures, and hazard, exposure and vulnerability primarily reflect the concrete effects of measures during specific events, there is some overlap between the management shortcoming indicator and all three drivers. Extended Data Table 1 provides definitions and examples of description or measurement of sub-indicators for flood and drought paired events.

The changes are indicated by -2/2 for large decrease or increase, -1/1 for small decrease or increase, or 0 for no change. In the case of quantitative comparisons (e.g. precipitation intensities, monetary damage) a change of less than ~50% is usually treated as a small change, and above ~50% as a large change, but always considering the specific measure and paired events. Extended Data Table 2 provides representative examples from flood and drought paired events showing how differences in quantitative variables and qualitative information between the two events of a pair correspond to the values of the sub-indicators ranging from large decrease (-2) to large increase (+2). We assume that an event is unprecedented in a subjective way, i.e. has likely not been experienced before, if the second event of a pair is much more hazardous than the first (hazard indicator-of-change +2).

Spearman's rank correlation coefficients are calculated for impact, drivers and management shortcomings, separated for flood and drought paired events. Despite the measures taken to minimise the subjectivity and uncertainty of indicator assignment, there will always be an element of subjectivity. To address this, we carried out a Monte Carlo analysis to test the sensitivity of the results: 1000 times 80% of the paired event samples are randomly selected, separately for flood and drought events. For each sub-sample correlation coefficients and p-values are calculated, obtaining a total of 1000 correlation and 1000 p-value matrices. The 25th and 75th quantiles of the correlation coefficients and p-values were calculated separately, both are shown in Extended Data Figure 3.

Table 2: Indicators-of-change and sub-indicators indicate large change (-2/2), small change (-1/1) or no change (0) from the first event used as baseline to the second event of a pair.

a Flood	*Management*	*Hazard*	*Exposure*	*Vulnerability*	*Impacts*

Paired event ID	*Hazard type*	*Area*	*Years of events*	Problems with water management infrastructure	Non-structural risk management shortcomings	**Summary management shortcomings**	Antecedent conditions	Precipitation/weather severity	Severity of flood	**Summary hazard**	People/area/assets exposed	Exposure hotspots	**Summary exposure**	Lack of awareness and precaution	Lack of preparedness	Imperfect official emergency/crisis management	Imperfect coping capacity	**Summary vulnerability**	Number of fatalities	Direct economic impacts	Indirect impacts	Intangible impacts	**Summary impacts**
1	pluvial flood	City of Beijing, China	2012 & 2016	-1	NA	-1	0	0	0	0	0	0	0	-1	-1	-2	0	-1	-2	-2	-1	NA	-2
2	riverine flood	Kansas catchment, USA	1951 & 1993	-2	-2	-2	0	-1	-1	-1	-2	0	-1	-1	-2	-2	-1	-2	-2	-2	NA	NA	-2
3	riverine flood	Baiyangdian catchment, China	1963 & 1996	-1	-1	-1	1	-2	-2	-2	-2	2	-1	-1	-2	0	0	-1	-2	-1	NA	NA	-2
4	riverine flood	Jakarta, Indonesia	2007 & 2013	1	-1	0	0	-1	-2	-1	-2	NA	-2	0	-1	-1	NA	-1	-2	-2	-2	NA	-2
5	coastal flood	North Wales, UK	1990 & 2013	-1	-2	-2	NA	NA	0	0*	-2	0	-1	-2	-2	-2	NA	-2	0	-2	NA	NA	-2
11	groundwater flood	West Berkshire, UK	2000-2001 & 2013-2014	-1	-2	-2	-1	1	-1	-1	0	0	0	-1	-1	-2	-2	-2	0	-1	-1	0	-1
12	pluvial flood	Barcelona city, Spain	1995 & 2018	-2	-2	-2	0	0	1	1	1	1	1	0	-1	-2	-1	-1	0	-1	-1	-1	-1
13	riverine & pluvial flood	Piura region, Peru	1998 & 2017	NA	-2	-2	0	-2	-1	-1	1	1	1	-2	-2	-2	0	-2	-2	1	1	NA	-1
14	riverine flood	Mekong river, Cambodia	2000 & 2011	0	-1	-1	0	-2	0	-1	-1	0	-1	-1	-1	-1	0	-1	-1	0	0	1	-1
15	riverine flood	Danube catchment, Austria, Germany	2002 & 2013	1	-1	0	1	1	1	1	1	NA	1	-1	-1	-1	-1	-1	-1	-1	NA	NA	-1

16	riverine flood	Crete, Greece	1994 & 2015	-2	-1	-1	1	-1	0	0	-1	-1	-1	-1	-2	-1	-1	-1	0	-1	-1	0	-1
17	riverine flood	Sukhona catchment, Russia	1998 & 2016	1	0	1	-1	2	0	0	-1	0	-1	0	-1	-1	-1	-1	0	-2	NA	NA	-1
18	riverine flood	Jakarta, Indonesia	2002 & 2007	0	-1	-1	0	0	1	0	2	NA	2	-1	-1	-1	NA	-1	0	-2	-2	NA	-1
19	coastal flood	Charleston, USA	2016 & 2017	-1	-1	-1	NA	-1	-1	-1*	-2	0	-1	0	-1	0	0	-1	-1	-2	1	NA	-1
20	coastal flood	Coastal region of Bangladesh	2007 & 2009	-1	-1	-1	NA	-2	0	0*	-2	0	-1	-1	-1	-1	0	-1	-2	-2	NA	2	-1
27	pluvial flood	Malmö city, Sweden	2007 & 2010	0	NA	0	-1	NA	0	0	0	0	0	0	0	0	0	0	0	0	NA	NA	0
28	pluvial flood	Ho Chi Minh City, Vietnam	2010 & 2016	-1	-1	-1	0	2	2	2	0	-1	-1	-1	-1	0	-1	-1	0	1	-1	0	0
29	riverine & pluvial flood	Birmingham, UK	2008 & 2016	1	-1	-1	0	0	1	1	0	NA	0	-2	-1	-1	-1	-1	0	-1	0	0	0
30	riverine & pluvial flood	Birmingham, UK	2016 & 2018	-1	-1	-1	-1	0	1	1	0	NA	0	0	0	0	0	0	0	-1	0	0	0
31	riverine flood	Assiniboine catchment, Canada	2011 & 2014	-1	-1	-1	-1	1	-1	-1	0	0	0	1	1	0	1	1	0	0	NA	0	0
32	riverine, pluvial & coastal flood	Can Tho city, Hau river, Vietnam	2011 & 2016	0	-1	-1	-1	1	-1	-1	-2	0	-1	0	NA	NA	0	0	0	0	NA	NA	0
40	pluvial flood	Corigliano-Rossano city, Italy	2000 & 2015	-1	-1	-1	0	0	2	2	1	0	1	-1	-1	0	1	-1	0	1	1	NA	1
41	riverine flood	Ottawa river, Canada	2017 & 2019	1	0	1	1	0	1	1	1	0	1	-1	-1	-1	0	-1	0	0	0	1	1
42	riverine flood	Delaware catchment, USA	2004 & 2006	0	0	0	-2	2	1	1	1	1	1	-1	0	0	NA	0	1	1	NA	NA	1
43	riverine flood	Cumbria, UK	2009 & 2015	0	-1	-1	1	1	1	1	2	1	1	-1	0	-1	0	-1	0	1	0	NA	1
45	pluvial flood	Malmö city, Sweden	2010 & 2014	0	NA	0	0	NA	2	2	2	0	2	0	0	1	0	0	0	2	NA	NA	2

b Drought

Paired event ID	*Hazard type*	*Area*	*Years of events*	Problems with water management infrastructure	Non-structural risk management shortcomings	**Summary management shortcomings**		Duration of drought	Severity of drought	**Summary hazard**	People/area/assets exposed	Exposure hotspots	**Summary exposure**	Lack of awareness and precaution	Lack of preparedness	Imperfect official emergency/crisis management	Imperfect coping capacity	**Summary vulnerability**		Direct economic impacts	Indirect impacts	Intangible impacts	**Summary impacts**
6	meteorological drought	Maule region in Central Chile	1998 & 2013	NA	-1	-1		2	-2	0	1	-1	0	0	-1	-1	NA	-1		-1	NA	NA	-1
7	meteorological & hydrological drought	Lorraine region, France	1976 & 2018	-2	0	-1		-1	0	0	0	-1	-1	-1	-1	0	-1	-1		-1	0	0	-1
8	meteorological & hydrological drought	South-West Germany	1947 & 2018	-2	-1	-2		0	-1	-1	1	-1	0	-2	-1	-1	-2	-2		0	-1	-1	-1
9	meteorological drought	Central Europe	2003 & 2015	NA	0	0		0	-1	-1	1	0	1	-1	-1	-1	NA	-1		-2	0	-1	-1
10	hydrological drought	Limpopo catchment, Mozambique	1991 & 2005	NA	-1	-1		-1	-1	-1	0	0	0	NA	NA	-1	NA	-1		0	-1	NA	-1
21	soil moisture drought	Wielkopolska Province, Poland	2006 & 2015	0	0	0		1	0	1	0	0	0	NA	NA	NA	NA	0		0	0	NA	0
22	hydrological drought	Ver catchment, UK	2003-2006 & 2010-2012	0	-1	-1		-1	0	-1	1	0	1	-1	-1	-1	-1	-1		0	0	0	0

23	meteorological & hydrological drought	UK	2003-2004 & 2005-2006	-1	0	-1		2	-1	0	-1	1	0	-1	-1	0	-1	-1		0	0	0	0
24	hydrological drought	Meuse and Rhine catchments, EU	1976 & 2003	-1	-1	-1		-1	-1	-1	1	0	0	-1	-1	-1	NA	-1		0	0	NA	0
25	meteorological, soil moisture & hydrological drought	Don catchment, Russia	1972 & 2010	1	-1	0		1	0	1	1	-1	0	-1	-2	-2	-1	-1		1	0	0	0
26	meteorological drought	Seyhan River Basin, Turkey	1973 & 2014	-2	-1	-1		-2	0	-1	2	1	1	-1	0	-1	-1	-1		NA	NA	NA	0
33	meteorological, soil moisture & hydrological drought	North Carolina, USA	2000-2002 & 2007-2009	NA	-1	-1		1	2	2	1	NA	1	NA	-1	0	NA	-1		1	NA	NA	1
34	meteorological drought	Catalonia, Spain	1986-1989 & 2004-2008	0	-1	-1		1	1	1	1	1	1	-1	-1	-1	-1	-1		1	1	0	1
35	meteorological drought	Melbourne, Australia	1982-1983 & 2001-2009	-2	-1	-2		2	0	2	1	0	1	-1	0	0	NA	0		1	1	1	1
36	hydrological drought	California, USA	1987-1992 & 2012-2017	0	-1	-1		0	0	0	1	0	1	-1	-1	0	NA	-1		1	NA	1	1
37	hydrological drought	Sao Paulo, Brazil	1985-1986 & 2013-2015	-1	-1	-1		1	1	1	1	1	1	0	-1	-1	0	-1		NA	0	1	1
38	meteorological & hydrological drought	Raam catchment, The Netherlands	2003 & 2018-2019	0	-1	0		1	2	2	0	0	0	-1	-1	0	1	-1		2	NA	1	1
39	meteorological, soil moisture & hydrological drought	Central Highlands, Vietnam	2004-2005 & 2015-2016	-1	0	0		-2	-2	-2	1	0	1	0	0	-1	-1	0		2	1	0	1
44	meteorological drought	Cape Town area, South Africa	2003-2004 & 2015-2017	NA	0	0		2	2	2	1	1	1	-1	-1	-1	NA	-1		2	2	NA	2

* For coastal floods, additionally hazard sub-indicators tidal level (tl) and storm surge (ss) are determined as follows: ID 5: tl=0, ss=-1; ID 19: tl=+1, ss=-1, ID 20: tl=+1, ss=0

Data availability

The dataset containing the individual paired event reports and the key data table will be made available via GFZ Data Services.

Data and Methods References

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Author contributions

Heidi Kreibich initiated the study. Heidi Kreibich, Anne F. Van Loon, Kai Schröter, Philip J. Ward, and Giuliano Di Baldassarre coordinated the data collection and designed the study. All co-authors contributed data. Maurizio Mazzoleni additionally designed the figures, and he and Nivedita Sairam contributed to the analysis. Heidi Kreibich, Günter Blöschl, Philip J. Ward, Anne F. Van Loon, Kai Schröter and Giuliano Di Baldassarre wrote the manuscript with valuable contributions from all co-authors.

Competing interests

The authors declare no competing interests.

Appendix 4: Paired Flood Event Tables with Changes in FRM, Hazard, Exposure and Vulnerability for Case Studies in England

Burton-upon-Trent: 2000 and 2020 flood events paired study				
	FRM Actions	Hazard	Exposure	Social Vulnerability
Pre 2000	Flood defences built along left bank of River Trent to 1/100-year standard after 1932 and 1947 events (ESBC, 2008a), areas of defence improved in 1961, 1962, 1984 and 1995 (ESBC, 2008b).			
2000 Flood Event		Autumn 2000 was the wettest autumn recorded in a series from 1766. Trent @ Drakelow gauge recorded 3.79m and 385m3/s (NRFA, n.d.-d), estimated as a 1/45-year (2.2% AEP) event (EA, 2019b).	4,500 residential and 1000 business properties are protected by 1/100-year standard protection infrastructure (EA, 2022b). 40 properties behind defences experienced flooding from overtopping or seepage (EA, 2001).	Limited information available on vulnerability in Burton-upon-Trent.
Between 2000 and 2020	Phase 1 of Burton-upon-Trent FRM improvement works undertaken between 2005 and 2007, Phase 2 of works started in 2019 to increase entire flood protection scheme to 1/200-year standard (EA, 2022b).			
2020 Flood Event		Trent at Drakelow Park gauge 3.8m and 384.2m3/s (NRFA, n.d.-d) similar sized event equals similar estimated 1/45-year return period and AEP. Hazard equal to 2000 event, if not slightly increased.	Increased protection standard to 1/200-year of 5.3km of 9km structural protection, and 1/100-year standard of remaining 3.7km reduced exposure of 5,500 properties (EA, 2001). Reduced exposure compared to 2000 event.	Limited information available on vulnerability. NVFI for Burton-upon-Trent from 2011 census data indicates vulnerability ranges from UK average, to very high and acute (the highest) (Sayers et al., 2015b). Potential increased vulnerability from lack of frequent flooding and high standards of protection may have attributed to low flood risk awareness (Burby, 2006) and increased vulnerability.
Post 2020	Phase 2 of Burton-upon-Trent FRM scheme completed and all 9km sections of defences increased to 1/200-year standard. FRM scheme increased to include Branston area that flooded in February 2020 (EA, 2022).			

Bewdley: 2000 and 2020 flood events paired study				
	FRM Actions	Hazard	Exposure	Social Vulnerability
Pre 2000	No evidence of FRM strategies or measures in place. NRA suggested permanent barrier but took no further action after negative public survey.			
2000 Flood Event		Highest river levels in 50 years. River levels reached 5.56m, 5.16m and 5.31m in 6 weeks (EA, 2014a)	140 properties flooded up to depths of 1.5m on both sides of Bewdley, joined together by a Grade 1 listed bridge (EA, 2004). Several listed buildings.	High vulnerability from Town flooded three times in 6 weeks (EA, 2014a). Increased vulnerability.
Between 2000 and 2020	Demountable barrier operational for Severnside, Bewdley. Beales Corner protected by temporary barriers during 2008 and 2014 event but just within river level height of being effective (2014). Technical review identified PFR as the only viable option (EA, 2014b). PFR surveys undertaken in 2015 with planned implementation between 2015-2017 (EA, 2014b).			
2020 Flood Event		Wettest Feb on record with 150% the monthly average rainfall over west midlands in 9 day-period between Feb 8th – 16th, increasing to 200% over Worcestershire (EA, 2020d). River levels reaches some of the highest not seen since 2000. Increase in hazard. River levels almost as high as 2000 at 5.48m. Slight decrease in hazard compared to 2000 event.	Reduced exposure from with demountable barriers on Severnside. Limited protection from temporary barrier (1/10-year standard). PFR measures installed (1/100-year standard) overtopped during event that flooded 40 properties. Overall reduced exposure but Wribbenhall/Beales Corner side of Bewdley remaining exposed. Residents may argue in increase in exposure from removal of temporary barriers but actual decrease in exposure from 2000 event with increase in protection standard.	NFVI from 2011 census data for Bewdley indicates vulnerability ranges from UK average to relatively high (Sayers et al., 2015b). Potential low awareness of flood risk to increase vulnerability as residents believed to be protected by the barrier. No event had shown the risks presented by the EA. Increase in vulnerability.
Post 2020	Further flooding in 2021. Current permanent solution in consultation for Wribbenhall/Beales Corner side of the River Severn in Bewdley.			

Aston Cantlow: 2007 and 2014 flood events paired study				
	FRM Actions	Hazard	Exposure	Social Vulnerability
Pre 2007	Limited information is available for Aston Cantlow. Land drainage improvements undertaken and River Alne flood warnings in place but no other FRM measures			
2007 Flood Event		Highest water levels recorded for the River Alne at Little Alne at 3.38m - 2.05m higher than normal range (Gov UK, n.d.). Intense and extreme rainfall event over western and south-western England that followed previous events in June (WCC, 2015). Catchment was saturated and water table was high.	Small village on the east bank of the River Alne bounded by hills to the east and south. Flooding from river Alne, surface water, ground water with highway flooding from bow waves to 23 properties. Several properties internally inundated in 2007 but no confirmed amount published. Over 2000 properties flooded across 75 communities in Warwickshire (Warwickshire County Council, 2016a; Warwickshire County Council, 2011).	4 listed buildings are at risk from flooding. Flooding results in village being cut off from wider area (WCC, 2015).
Between 2007 and 2014	Warwickshire County Council allocated £210,233 for 2007 flood restoration to communities and investments in flood prevention (Warwickshire County Council, 2008b). CCTV investigation undertaken to alleviate some flooding. Additional events in 2008 and 2012, the latter which caused 300 incidents of flooding to be reported to WCC and severe road flooding in Aston Cantlow (WCC, 2016)			
2014 Flood Event		Limited information available other than flood event inundating unknown number of properties in Aston Cantlow.	Limited information on changes to exposure. No FRM in place so risk remaining to 23 properties.	NVFI from 2011 census data indicates Aston Cantlow has a relatively low social vulnerability (Sayers et al., 2015b).
After 2014	Flooding across Warwickshire in 2016 but no information that Aston Cantlow was largely affected. PLR scheme undertaken in Aston Cantlow. Village prioritised due to frequency and impacts of previous flooding (WCC, 2015).			

Herefordshire: 2007 and 2020 flood events paired study				
	FRM Actions	Hazard	Exposure	Vulnerability
Pre 2007	Traditional management within urban areas but limited information.			
2007 Flood Event		River Wye peaked at 480m³/s (NRFA, n.d.-c), lower than previous 2000 event (661m³/s) and calculated as 1/23-year event (HCC, 2009). River Wye was not largely overtopped but tributaries and smaller catchments were. River Lugg floods calculated as 1/20-year event (HCC, 2009). Rainfall in July 2007 ~427% increase of monthly average between 1971-2000 (189mm) resulted in widespread flash flooding across the catchment (HCC, 2008).	Flood event caused ~£650,000 in insured damages, larger event in damages than previous 2000 event by ~£600,000 (HCC, 2008). Evacuations of residents undertaken across the county (ref). No number of properties provided.	Little information available for vulnerability of residents in Herefordshire. Flooding in July 2007 followed significant flash floods across Herefordshire in June 2007 that caused >£50,000 in insured flood damaged (ref).
Between 2007 and 2020	Improved emergency planning following 2007 (HCC, 2008). Hereford defence built in 2008 to protect 200 properties (EA & Natural Resources Wales, 2016) Most urban areas have alleviation/protection schemes including Hereford, Leominster, Ross-on-Wye and Hampton Brook (EA & Natural Resources Wales, 2016). River Wye and Lugg NFM project between 2016-2021 created ~4,410m² of attenuation areas, 4.78ha of woodland and 140 channel barriers with further measures such as soil improvements undertaken (HCC, 2022).			
2020 Flood Event		Wye at Belmont peaked at 579m³/s on 27th October 14:30, the highest level since gauge installed in 1970. Event calculated as a 1/25 – 1/30-year flood (Farley et al., 2020). River Lugg peaked at 65.1m³/s calculated between a 1/30 to 1/50 flood event Rainfall event calculated as a 1/75-year event at Vowchurch, <10 miles south-east from Hereford (Farley et al., 2020). Increase in hazard.	~286 properties internally flooded from the River Wye, ~113 properties internally flooded from the River Lugg and ~71 properties internally flooded from other watercourses in Herefordshire (HCC, 2021a). Limited information available of exposure for 2007 so no changes identified.	NVFI from 2011 census data indicates vulnerability in rural areas is relatively low, but urban areas range from UK average to relatively high and very high (Sayers et al., 2015b). Flooding subsequent to October 2019 event (HCC, 2021a) may have reduced coping capacity, increasing vulnerability to flooding. Increased vulnerability.
Post 2019	Repair works to protection infrastructure and new alleviation and PFR schemes (HCC, 2021b). Additional funding for second Wye and Lugg NFM project (HCC, 2022).			

Selly Park: 2008. 2016 and 2018 flood event paired study				
	FRM Actions	Hazard	Exposure	Vulnerability
Pre 2008	No significant FRM in place.			
2008 Flood Event		Intense rainfall event, 80mm recorded in 48-hour period (Clayton, 2008). River Rea gauge recorded 71.9$m^3/_s$ (NRFA, n.d.-a).	Primarily residential, urban area with dense Victorian terraced housing.	No severe floods since 1929 may have resulted in low flood risk awareness. Minimal warning times for localised flooding.
Between 2008 and 2016	Flood risk assessed, risk maps and plans created. River and sewer flows modelled, and warning systems improved with new gauges. Bridge altered and raised defences constructed.			
2016 Flood Event		Intense rainfall, 111mm in 48-hour period (BCC, 2016) followed earlier events: 8th and 10th June. River Rea gauge recorded 73.6$m^3/_s$ (NRFA, n.d.-a) equalling 5% AEP 1/20-year event (EA, 2018d). Increase in hazard compared to 2008 event.	Exposure levels remain the same as 2008 event.	No large floods since 2008 but awareness increased from public engagement and information campaigns (BCC, 2015). NVFI from 2011 census data indicates vulnerability in Selly park is relatively low (Sayers et al., 2015b). SPS community-led Flood Action Group formed after 2008 with action plans. Improved warning system.
Between 2016 and 2018	SPS and SPN alleviation schemes designed. SPS alleviation scheme active.			
2018 event		Intense rainfall, 58.6mm in 1-hour period (Met Office, 2018) equalling 1/200-year return period (EA, 2018d). River Rea gauge recorded 82.3$m^3/_s$ (NRFA, n.d.-a) equalling 2% AEP 1/50-year event (EA, 2018d). Increase in hazard compared to 2016 event.	SPS alleviation scheme active that successfully reduced exposure to Bourn Brook flooding. SPN delayed that left SPN exposed to events. Decrease in exposure compared to 2016 event.	Community-led action and plans from flood action plans. The short period between the 2016 and 2018 flooding may have reduced coping capacity as residents were still dealing with previous flood damages and some had only just returned to properties. Increase in vulnerability from 2016 event.
Post 2018	SPN and SPS alleviation schemes active. Flood wall altered.			

Appendix 6: Interview Transcripts

Bewdley RMA transcript

Interviewer:
What is your role?

Interviewee:
Manager / senior adviser, for partnerships and strategic overview, project manager Bewdley. Bigger ones go to National Team.

Interviewer:
In relation to the current scheme in place on Beales corner, why was Property Flood Resilience chosen?

Interviewee:
There is a whole flooding page on the Bewdley Parish/Town Council website that has all reports and all previous reports we've done, as well as the newsletters. Theres a report we did early on looking at the best longer-term solution at Beales Corner that was undertaken in 2014, but things have changed a lot since that time. Options as part of treasury guidance it comes down to cost benefits, weighed up in the multi-coloured manual approach.
Completed an analysis 6-7 years ago, but we would have looked at the costs against the benefits for property flood resilience was the most viable option, so cost tended to be a lot less per property for property flood resilience than on a bigger scheme, and there is not many properties there, and at the time we could not justify a bigger/wider scheme like at the other side for Severnside.
Recently Boris Johnson promised to "get Bewdley done", as there is the cost-benefit side of it, and then how much contribution you can attract to a scheme and 6 years ago, looking at partners, we couldn't get any wider contributions for it but can look at options to undertake a wider scheme now. The business case now looks at wider areas of at-risk areas, and not just the economics but a strategic case and case for change in more detail, that will support better options for the future.

Interviewer:
So PFR was primarily chosen as dependent on costs and not necessarily topography of the area?

Interviewee:
Yes topography, local conditions and not just the economics but a range of factors.
Local conditions influence the [PFR] option, as they made it more challenging to do a wider scheme, how you would have to tie in with the ground conditions as you would get seepage through the ground, made it harder to do a bigger scheme then.
PFR had its challenges but has generally been quite effective.
The last couple of years we had 2 big floods and have installed a lot of PFR across the west mids and it is one areas where it's been well tested. So technical viability comes into it as. Most solutions are technically viable but engineers design and build, but usually comes down to costs when constraints are involved. Further constraints of the schemes including - constrictions include the bridge and several listed properties.

Interviewer:
Did residents want PFR at the time? Because you have kept the temporary barrier in Bewdley when I thought the idea was to replace the temporary barrier?

Interviewee:
The background to scheme was not a blank canvas, they had recent flooding and the temporary barrier was a trial – report done on it for undefended the banks of the River Severn. Ironbridge still using a temporary barrier. Trial started in 2006/2007.
Since then we have looked at risks around the barrier, so assumption was that the temporary barriers had done really well, some minor flood events but it had held them back quite well, now slightly more mixed with recent floods in last two years, with both events exceeded the design threshold of it 1/10-year. Up to that point, in first 15 years had performed really well. People wanted to keep temporary barrier, but the ideal

solution was a wider scheme but could not be justified. At the end looked at PFR as a better solution given the number of properties and cost benefits.
Came up with a compromise to have a temporary barrier as well, and that this was another line of defence, and would keep the roads open as well to a point especially Kidderminster Road, but this would have to be through a partnership approach so would have to be with Bewdley Town Council and community. Community volunteers were used to minimise the cost, to show commitment and allow us to continue deploying by giving the homeowners and community ownership around it. The Community Plan was Town Council led and volunteers and groups were set up locally to be clear around emergency response and responsibilities such as flood wardens or flood volunteers; they put themselves on a rota for flood events. Liaison officers questioned the public, wearing hi-vis, keeping people out of working areas, and things like that.

Interviewer:
Do you think that was maybe the first time you saw homeowner responsibility or had you seen home owner interventions before then?

Interviewee:
This is quite an involved community, vulnerable, elderly, retired people but are quite clued up on flood risk and they all use the Bewdley gauge and they all signed up to the flood warnings so there was a level of engagement and involvement before 2014 when we started looking at the PFR scheme, they had an informal flood group and forum. Residents quite vocal and involvement and communicated with us quite regularly. They formally set up a flood group in 2014/15 when we started looking at the options.

Interviewer:
Were they more aware of their risks before the PFR scheme went in? They just assumed the barrier was working and not realising they were at-risk?

Interviewee:
Most were aware they were at risk; those properties that are tenanted or set back from the river a bit, and perhaps they were not as aware of the risk. And the temporary barrier had kept back so many smaller floods over the past 15 years, so maybe they took it for granted that this was the solutions and the residual risks were only in the back of peoples minds.
Last couple of years we have seen the real risk of what can happened so now in the forefront of peoples minds, so I think that was why the community are pushing for a wider capital scheme, so that is what is looked at now by the Team. If want to speak on a wider issue contact them on that email address.

Interviewer:
Would you say that residents are more aware now because of the flood events or because of the PFR?

Probably the flood events have brought it home. With the PFR quite a mixed response with taking ownership and awareness of the risks, because the scheme had gone on for a while due to listed buildings taking time, because needed new products to come on the market and be developed – e.g. timber flood doors, and because of the flood events we had to go back with over the last couple of years with snagging. With PFR people are more complacent, with the first flood event in Winter 2020 the PFR wasn't installed properly by homeowners, there were flood gates that tenants had misplaced it or not installed properly, so the effectiveness wasn't as good in first event. We did some work with the homeowners after that to try to stop tenants becoming complacent. The January flood this year, that was a similar level, measures worked more effectively. Have done so much more engagement with the resident's group, the town council around the effectiveness of PFR, explaining it's not going to stop flooding completely but it will just minimise the impact and buy people more time so that they can make plans to move furniture.
I think this was difficult message to get across as people think they have the PFR and that was the solution and they're fine, but it's not always that straight forwards for PFR there is always maintenance and storage, and general awareness of what PFR can and can't do.

Interviewer:
I looked at the report you sent, talks about how effective it was in the 2020 / 21…..
It wasn't a failure of the PFR it was just the residents storing it and installing it?

Interviewee:
Yes, it was a range of factors but main one was due to the scale of the flood event, the PFR mentions that each standard of protection (protection meaning minimises flood risk – doesn't offer complete protection) – each property has a different level of protection and in some cases this design level was exceeded, so the flood depts were too great. The main issue was the flood water was up so long in both these events (12-24 hrs) that the PFR wasn't designed to cope with the type of event, this was the main reason for the last two events. The measures worked really well with the types of flood events seen over the previous 15 years. Unfortunately, from one perspective, the temporary barrier had kept these flood events back, so PFR wasn't tested or in place at that point so it was the scale that caused the problem.

Interviewer:
What are your next steps? (see Wider scheme email). Are you looking at what Boris said with wider option now? Are you going to continue with PFR in the area?

Interviewee:
Yes, in terms of our PFR scheme that we rolled out to 46 properties in the area. A couple of properties we managed to protect after the last event. Originally the scheme was 45 we had a good uptake that isn't always seen across the country, 44 – 45 properties signed up so thats really positive. We've completed all the measures now, just some minor snagging items to do. We delivered it on an old PFR framework, so we got separate designers, who did original surveys and we got contractors to install measures. The original designer is coming back in doing post inspection audits, its an independent assessment to ensure all the measures have been covered and all openings identified in original survey have been sorted., . so original designers coming back in as an independent assessment. All the openings of the original survey have been addressed, all measures are in place so first phase done. First phase of the inspection order has been done, access has been difficult especially with Covid have only been able to access half of the properties, if we can't get access all have hand over packs delivered to each property. All the agreements have been signed by the homeowners, maintenance signed, and general flood advice guidance for plans and stuff like that. If we can't get access for a post inspection order we will just have to send letters those so to close the scheme down. I've been involved 6-7 years and it's dragged on for a long time and now trying to tie up issues but now each property has some measure in place. The pub has had various issues with the electrics, saturation not just flood depth. PFR has definitely got a role there and it will help with smaller flood events. The capital scheme, if can find the funding, will be the preferred option for the public spending but also in terms of the benefits it can offer, it's a passive solution as well, the option hasn't been decided yet but likely to be a glass panel up to the wall so wouldn't have to have public installing their measure in time or incorrectly, it would help to protect the roads and the properties, wider benefits for a wider scheme, but just the technical challenges that we talked about and the funding.

Interviewer:
Do you think that the homeowner responsibly but would continue with the wider scheme?

I think people might get complacent and not install their PFR, I forgot to mention we had a trial run to get them to install their PFR and we had the town council involved to keep them engaged, like a test so people installed their PFR and we employed the temporary barrier, to keep them engaged. Flood warnings were sent out and we got people to install their PFR. But recently with resources at the moment and also haven't had the time.

Interviewer:
Would this continue even with the capital scheme?

Yes, it's difficult to say those at highest risk have massive measures, the timber front doors on the listed ones and PVC on the unlisted ones, so 19 properties behind the temporary barriers, Beales Corner, the highest risk. So should still have a second layer of protection, some have got carrier barriers, aluminium across rails, some have active measure, so those with the highest risk would deploy these measures. And even if a scheme was in place perhaps those who feel not as high risk or those that are tenanted and not fully aware of the risk if they haven't been there so long, so maybe a third that might not deploy their measures.

Interviewer:

Do you think the residents would contribute to the wider scheme? Like the Partnership funding, as there are no businesses that side which is why they didn't get the funding in the first place because the other side has the larger financial….. do you think they would contribute?

Its difficult, the town side - there are businesses and also 300 residential properties so more benefits. But 44 properties on Beales Conner and some isolated properties and their mostly residential. Policy funding process, Bewdley scheme is heavily supported by the reginal flood costal committee, national grated aid funding that can attract through the partnership funding allocator, this gives a percentage but to make the scheme viable need to get it to 100%. Aid alone give 40-50% policy score but then you need to top it up with private or public contributions, or use local levy distributed by the RRFC which we work closely with and Bewdley, due to the key area and sensitivity to politics Bewdley was seen as a key area to invest in so got a big chunk of local levy so didn't need any private contributions to the scheme ,then with the PFR it might become more relevant for the wider scheme but very difficult to get private contributions. With the Bewdley scheme the homeowner contribution is the ongoing storage and maintenance of the measures, that regular maintenance and inspection on the seals. The doors themselves should last 20 years plus so this is the homeowners contribution and we made this quite clear, but for a wider scheme by experience they did a lot of fund raising and residents did contribute to the bigger scheme on the Bradley Broadway scheme? I think it could be if funding was that important and there was still a gap local fund raising could fill some of that.

Interviewer:
Do you think that the residents, at the moment are still quite worried about the flood risks, after the last two flood events?

Interviewee:
Yes definitely, the ammunition of the flood risks to fight for a wider scheme the PFR will do so much but the wider scheme would give more certainty and a higher level of protection, it would be that passive solutions and what the residents are pushing for at the moment. There are some businesses on the Beales corner site, just upstream from the bridge, through the recent updates of the partnership funding rules summer 2020, we can also provide to non-residential properties so we are looking to see if we can work with them to protect themselves with PFR as they may not be covered under the PFR so wouldn't want to leave them isolated. They can't attract granted aid but can use liquid? levy to protect non-residential properties. So on the new 60 programme which started this year we are able to protect non-residential properties.

Interviewer:
So sounds like your PFR will continue in Bewdley for the next 6 years?

Interviewee:
I think with the changing partnership funding rules I think it's going to go on a bit, with this scheme as it is, will be tied up within the next few months. But colleagues are looking at those non-residential properties, whether it will be an extension of my scheme or if it will be another piece of work with the wider scheme. It would be expected that with private businesses they would be able to contribute to some of those measures, and due to the size of the properties it would cost more.
This scheme has had a lot more engagement compared to other schemes so a lot more going on regarding communications and engagement, but also around the innovation and developing new potdex? New National Team set up is worth speaking to, we are speaking to them as well, they are setting up a new PFR framework. Looking at areas that can't be protected by the wider scheme. So quite a lot of PFR scheme on the next 60-year program so new framework that will follow closely the Siria? Guidance. Will email this through. Can provide you with contacts for the National Team.
Will also sent through the case study through, work in progress.

Another challenge was the change in British standards and kite marking a product, new standards that the new framework will take into account around the testing of products. Impact testing, different saturations of flooding's, lots more thorough testing around the products, old products tested now looking to test them on the new standards.

Interviewer:
If they don't meet the new standards, do you have to re-issue them?

Interviewee:
We won't use any product on new schemes that don't meet the new standards but the old schemes we wouldn't change the measures. Will send you the case study and siria guidance.

Warwickshire County Council RMA

Interviewer:
Last year in 2018 we tried to do a flood risk perceptions questionnaire survey in Aston Cantlow, so in one of the PFR schemes that you do didn't get a good response rate and couldn't go back due to covid. Going back now to round up some of the data to make it more interesting. Not many properties had PFR anyway but those that did we had a poor response rate, so instead we are talking to some of the stakeholders that were involved in some of the schemes to try and get more information.

We do have an online questionnaire survey now and I know that a few of the areas in Warwickshire have had the PFR so, I suppose this was a few years ago, but do you have any contacts that I could share a survey?

Yes, we still have communication so I can put you in contact with that i.e eastthorpe. We did a scheme in Penmire Close in Grendon?? Wouldn't have thought you would get a very good response from that because it's sheltered housing but they are all borough properties, but we could probably find you a borough contact and overarching one. We've done schemes in Ladbrook in Southam not sure what the response rate in that community would be but we could certainly find you a contact in this parish. I believe we have parish council contacts for Ladrook, also for Cherrington ?? we can send stuff on your behalf. Hartley/hardwick again we have contacts, don't know what the response rate would be. Nether Whitacre – not a scheme I was heavily involved in, again we can send you one of the contacts which is the parish council, we can tell you when we have delivered schemes and find you some contacts.

Interviewer:
Great thank you, we have contacted Aston Cantlow, this was because they had the most properties and had already been done before you moved onto the next schemes, parish councils don't reply to students, emailed them a few times but had no response. So maybe if it was possible, can I send you the link? Or you send me the contacts?

If I send you the parish council details it could be GDPR issues, so I will go with whichever is more appropriate. In eastthorpe we have a flood group only 5 properties, so would hope you get a decent response. Cherrington is an active community so I think you would get a good response. Grendon ladbrook, Kite, Hardwick, might be a case of taking your chances and see what comes back.

I could send you the survey, but if you are happy that would be great.

Interviewer:
Why did you choose PFR for all the schemes in all the areas? Why not natural flood barriers or some sort of structural protection in the rural areas?

Warwickshire as part of our local flood risk management strategy we produced certain water management plan, on our website, schematic maps and ranking on the web site. Essentially it is our risk index for all of our communities in Warwickshire so it splits the county to about 2165 kilometre grid squares. In one or two locations we've merged those grid squares, they are a commonality in issue so can't be separated. We have been working on, more focus on delivery schemes initially to the top 40 most at risk locations in Warwickshire within reason. We've gone quite a way through that now, certainly we have delivered to the top 40 the other ones still outstanding are in our forward programme, capital programme. So that's basically a risk that derives

from two sources, 1 is a historic flood risk of known events that have happened or been reported, and the other 1 is a ranking based on the predicted risk from flood modelling from certain sources of outlines ?, we basically look for critical infrastructure, private properties and commercial properties and assign them all awaiting essentially. Through a metrics table we provide a score and give a ranking but that's how we identify most of these schemes initially. We put those forward for submission on perhaps allocation for subsequent grant in aid for example, from the environment agency, but then it can be a year before delivery of when we begin working on the business case.
With some of the smaller schemes, there aren't that many properties, so the economics can be quite tight and it will typically be the option that will be most cost beneficial, so the one that box ticks the greatest amount of economic damages compared to the overall construction costs. That will be taken forward as the preferred option. For example, somewhere like Easthorpe where you have 5 properties, obviously it will be a big civil engineering scheme to try protect 5 properties you will struggle to get the damages high enough to justify the big feats of engineering. What we always do in business cases we start the long list of options which will be everything – we could do this, or we could do that, then we get 5 short list options, that will normally include a "do something or do nothing" scenario. PFR response is quite often included in the shortlist. Will also include options like building a large embankment or retaining area or a hard engineering type aspect but with the ones that we are looking at here, the economic case is that PFR would be the most appropriate solution. NFM is a tricky one, at the moment theres a lot of noise about it, it's tricky for us on a scheme to quantify the benefits of NFM - to work out the amount of damages achieved with offset, lots of work going on in the background to get the work in place where NFM can be more widespread we find it difficult to attract the funding in NFM type scheme that being said there are a couple of locations within Warwickshire that NFM is being looked at, its put down as [village location] almost entered phase two site acceptances scheme. We are moving toward a delivery of a PFR scheme for Longley and in partnership with Warwickshire Wild Life Trust, looking at having some NFM interventions there to complement that scheme.
In locations like Charington we have a very active community flood group (called SAFAG?), working as part of a wider partnership in some of the locations in Warwickshire and Gloucestershire which is stour catchment. And they are looking at potentially NFM type interventions being put in upstream, in the charington catchment, to benefit Charington and also to have wider implications across the Stour.
We do the same really, the NFM it's a tricky one to work out, I think hopefully looking forward it we be mainly standardised approaches how things will be assessed, it would be great to start incorporating some of the NFM interventions in some of these schemes. Certainly using them as a bolster to the adapting climate but also some of the wider benefits a vast presenting transfer and creatings habitat as well things like that are a great help to get into some of these schemes.

Interviewer:
Going back to the PFR Scheme, in Bewdley they didn't want PFR at all, that's the reason why they kept the temporary barriers because the residents were so unhappy with the PFR. How have the residents responded in the areas where you have implemented the PFR? I suppose it's a rural area so they probably already understand their flood risk?

Yes, the PFR on the schemes we have delivered are generally well received some of the ongoing schemes that were looking at, at the moment, there is a resident pushback about PFR type interventions. I think a lot of them are against barriers attached to their property which has a bit of a stigma against them. What we try and do is have a cannon ball style event in the village hall when we took on a business case and moving towards having that side of the EA and take them to a presentation on what the process will be i.e getting the legal agreement signed and getting the property survey done we try to get our contractors to come along and get the survey done as well, try to capture the specifics of what's involved but also take some brochures to show some examples of type of door or air brick or barrier looks like and having that face to face meeting and taking physical examples does help allay quite a few of their fears. What we generally do in Warwickshire is Warwickshire balls through a scheme fund the basic requirements for the property so normally a house that will be AB style front door or barrier or whatever and then we say to the residents if you want a different product to reach a design level aesthetics, so you might want a composite door or a wooden door for example. These things are available, we would normally fund the basic product and then allow the resident to top that up to get the product of their desired specification. We're thinking of a property we helped where it was desired to have council barriers across a drive way, the property itself had apprehension about that, they didn't want to go on holiday and erect those barriers and make it abundantly clear to all and sundry can see the barriers are there and in situ and they have clearly gone on holiday, so lets rob the place. So we were able to put a wooden door heritage style barrier across the driveway which did look like a wooden substantial gate from the roadside, you wouldn't be able to tell the difference. With most of the advancements, to the untrained eye, you wouldn't know what the difference is. Really the only sticking point is there are a lot of people who were worried about stigma attached at actually the point of resale. But it then comes down to all of this explanation and knowledge is out in these communities are the higher risk ones the local habitants are aware that they are in a community subject to flooding.

Interviewer:
Is that since the scheme, have they become more aware or had the residents in the community already had a high level of floor knowledge?

They were generally a community of having a high level of knowledge going into it.

Interviewer:
Is it easier to work with when the residents already know their risk, or does it make it more difficult so there are so many different opinions towards is?

It depends, sometimes if they are naive to how their risk can be managed they are more accepting of the increases of the business case. Sometimes when they are quite active, there is a risk they say why can't you build an embankment or a retaining area? And then it becomes a case of trying to explain the economics, it really depends on the location, there are lots of schemes we have partnered with in the high risk locations or having flood groups as well. We will deliver a scheme and with all these big schemes, it depends on those characters will work with you or push back slightly. It's always a healthy debate it really depends on the location.

Interviewer:
How effective has the PFR been in the areas, I've looked at the newsletter but that just talks about implementing the scheme and I haven't seen anything about if there has been any events since in these areas?

Aston Cantlow would have been tested, we have had some near misses in cases such as eastthorpe but on the whole we are still waiting for the interventions to be tested. we have had one or two failures on a property in eastthorpe, unfortunately there was a failing on one of the pumps, which did result in minor unrest to essentially not a habitable space but damage caused to items like washer dryer and boiler damaged, but unfortunately it was the first time the pump had been called into action so it was lucky that it was a smaller scale than a big one. Some of the schemes as well are old framework contractor went into liquidation and we have found one or two issues with a couple of the products they installed towards the end of their collapse period. so we did do some follow up surveys with an independent surveyor and we did identify some defects that were resolved, we are waiting with baited breath.

Interviewer:
Do the residents implement them themselves based on the warnings?

In Warwickshire we generally have a preferential path in PFR measures, we would rather put in a self closing air brick to an air brick cover, we'd rather put in a flood door and a floor barrier and obviously we are quite keen on southam rating sump pumps and stuff. Always in Warwickshire it 3am in the morning so we want the measures to be there all reasonable times we will put in ??? but only where there is a necessity and it can't be avoided and that because it does require human interaction to keep an eye and it helps I think as well places like Grenden, we have done it in sheltered accommodation as it were, not sure whether or not I would want those residents to install barriers in anger. Again some of the communities there are one or two more age advanced than others and I think they would struggle to deploy barriers if they had to at short notice. Typically because I'm working with groups where we have things in development or delivery, where there are active measure like barriers or sandbagging we do like to have some plan to establish who is vulnerable or who who might need more support, who need checking up on so we try to start those conversations so if we can design out the risk that is what we would do at the first stage.

Interviewer:

Do you think people are more interested in implementing passive measures than having the barriers to do themselves?

I think the passive measures do go down better largely because of the stigma of having such things on your property. one of the great successes of the schemes we have delivered is the passive measures we have fitted so far have all blended well with the properties. For example, Cherrington a lot of Cotswold stone in the buildings because we used it in parts of heritage products it does tie in with the aesthetics.

Interviewer:
Would you say, that there is a homeowner responsibility? Did any properties have measures prior to your scheme?

It's a mixed bag, to answer the first question, once we have installed, there is a warranty period and guarantee with the manufacturer and statutory limitations thereafter but it is down to the homeowners then to maintain the product for the duration of its serviceable life.
The contractor at the point of install should have the conversations with the homeowner on what is required and how it should be maintained and also how they should be stored, quite importantly.
(for second question) Again its a mixed bag, obviously high risk locations, there are some properties that have property flood already in place if a homeowner came to us in isolation and wanted advice about PFR we would normally advise an independant survey to be done at first place as opposed to going straight out and buying off the shelf. This is the because each individual property is different and A one size fits all approach is rarely going to work. we have had property In the past that have some level of protection already applied to them, some will be perfectly appropriate and meets the bill others will be lacking, may not have addressed all the points of entry and we will have gone in and updated or added to the levels of protection. One thing we've found with properties with PFR the common one is the service action or lack of non return return valves, so even when there is intervention its always worth making sure the intervention is sufficient for the flooding experience.

Interviewer:
MY last question, If the areas where you started working with the communities before the scheme were people worried about their floor risk or, did they just accept it was a surface water problem and they had to deal with it.

This was before my time, I think the other locations we dealt with have been broadly speaking acceptancing of their risk, the common story is off the highway, in reality its flooding from surrounding agricultural or farmland. We will normally do a modelling exercise to identify those most at risk and the property most at risk and then look to make the community links to say this is what the model shows us, does it represent the real world scenario, and ask are you aware of other properties. Is there anywhere else that we should consider in this, generally speaking that it quite a slow process is quite well accepted. There will be occasions where we have approached people and asked are you aware of the risks and they have said and they said not interested. Its difficult then to try to dis-entangle this conviction there will be cases where that person is reluctant to acknowledge the risk as they fear it will impact house value. They may feel the model is representative of real world.
Model might not be representative of the real-world risk, sometime we are able to disentangle that and work our what's going on but quite abrupt and more difficult to conclude whether or not it's a true reading of the people at flood risk.

Do you think that the people who have PFR now are worried about their risk?
Do you think they could become complacent if they don't have to implement the active measures?

No the vast majority of communities they are openly aware of their risk, you always make the point of saying this is PFR but not centralised.

And if I just go down the list of communities, we have active groups and we are still trying to make positive changes at the community level and trying to better combat the risk. As a whole they are taking a degree of comport that they have PFR type intervention and they are afforded more protection than a lot of these communities are still very hot on issues and still trying to reduce that risk.

End of call

RMA Herefordshire County Council

Start of questions

Interviewer:

What is your role at the council and with the management scheme?

I'm Herefordshire councils natural flood management project officer. Initially employed to manage the defra funded pilot project, now ended, so now I'm in process of collating all the work done on project and reporting back to defra and now working with the EA securing funding for the next 6 year as part of the 6 year environment programme.

Interviewer:

About the scheme in general, why was this chosen?

Herefordshire is widely affected by flooding, over the past 18 months 5 significant flood events on varying scales. Oct and Nov 2019 and Feb 2020 had to give grants to several hundred properties to aid recovery after properties had flooded internally. So flooding is widespread problem across county - very rural and some typical hard engineered schemes are not suitable so we were looking at different more appropriate schemes. So decided to look at alternative method, i.e NFM project as a pilot scheme which is being trialled in 7 sub catchments across county. The catchments vary, some very rural and one that is south of Hereford and more city located, so they were picked base on location and fact that a lot of properties at flood risk and the fact they were not necessarily suitable for a bigger scheme. Looking now at expanding the project into new catchment areas as some of the principles improving land management can be done across the whole county. Huge benefits involved in reduced nutrient losses, climate change etc

Interviewer:

Limited evidence on Natural flood management, so how did you implement it?

The problem is no evidence of how effective, so as a pilot project, it was a pilot project to gather evidence to develop understanding of the knowledge gaps, we developed a monitoring scheme to explain the project delivery we had catchment advisors that went out, and engaged with land owners and gave them tailored advice about free tailored nfm opportunities on their land so as part of the visit landowner and they would walk around their farm and do some free soil testing, talk about how the farmer manages the land what they do with it, if they use sign maps, erosion risk maps, look at the where the high risk locations are for runoff and from that they would produce a recommendation report with funding opportunities through countryside stewardship or grant schemes etc. As part of those visits we collected soil to have a base line soil data set for the catchment to look at organic content, filtration, worm counts, and some of them looked at nutrient content. We then re-tested some sites to see if any changes as a result of the NFM implemented, it was difficult to prove in a short time scale and we needed more data. Some sites were directly linked and an improvement in organic matter content, this has a huge impact on water holding capacity of the soil. We focused on research as we had catchment authority to do pre-soil tests and we set up a more detailed soil monitoring programme, so now we have 12 sites where we have soil moisture probes monitoring so comparing scenarios. So for an example I'm comparing two (comp)arable fields one with a current crop on and one that is bare to see how the moisture content varies at depth (10cm to 40cm). We might not have the answers now, but we're gathering evidence and this is how we are doing it, other projects before us they have lots of examples i.e national projects like stroud project, they have lots of anecdotes and evidence To show nfm does make a different. We have put in rainfall monitoring stations in the catchments which has a public accessible log in. Good way to engage with the Communities, they liked this aspect to be able to look at the data, we've also done a habitat survey, before and after the leaky dams were installed but because of covid we haven't been able to do the post install surveys. The 6 year project will include more research, river monitoring for the next 3 years but we definitely need to keep this, also end of project stuff some consultants commissioned to quantify the benefits and find out how much more NFM would be needed. Also set up the citizen science volunteer scheme and had volunteers for 6 point photography and hoping to train volunteers to do river morph surveys. We are doing all this research as we don't currently have hard evidence of NFM benefits. Nationally it's a proven way of reducing flood risk, we just have to quantify it, land owners' willing to get involved and appreciated the fact that it was something they couldn't do themselves, a lot of the land owners were keen to help out as they could see that it affected neighbours and wanted to prevent this happening. Also, the measures benefited them such as the soil improvements works, helps with the agricultural business and the yield, because we set up the grant scheme to cover costs because of the inconvenience to the landowner. The leaky dams were no benefit to the landowner so we gave them grants for 100% but the soil improvements were beneficial so we asked for a contribution. 50% grant rate for example.

Interviewer:
What measures have you used, as you didn't use the leaky dams, was it just the soil improvements?

That was just at the habitat site. We have installed a lot of nfm measures, we installed 137 leaky dams but also seepage barriers, sensing, tree planting, hedge planting, some management works, ponds, also land owner innovations such as direct drilling and helped to pay for rain water harvesting systems and helped to buy some equipment such as under sowing maize drill, so the field wasn't left bare. What we have done, have you heard of the Argyl web site? I'll send the link.
Defra projects website managed by the rivers trust, you can go on it and can see all of the NFM projects, theres a tab on it, and can zoom in across the country, and see the projects with details. Could be useful. Click on the different ones and it has the different benefits for each one.

Interviewer:
Is it an ARC GIS online map? – you have sent it already. But will check.

With all the measures, and with the landowners being willing to get involved, were there any options that they preferred, or did they prefer structural protection or did they understand that his was not an option?

I think that they understood that this was the only option offered, so because we wanted to involve communities we did launch events in the catchments we worked in publicly open events and talked about what we were doing and people could ask questions, mostly they were supportive and positive, after this they set up community groups in the catchment areas so they could find out about the projects and could tell us about their local knowledge of floodings, we had plans that people could annotate what had flooded and where, they appreciated being involved. A lot of the people that attended were more residents and didn't own the land so it could become difficult, a lot of the those parish councils attended the meetings and elected ward representatives showed up. So a mix of people, because of Covid we stopped these meeting as it wasn't feasible but looking to restart in the future. They definitely appreciated being able to tell us what they were interested in but at the time we only had funding for this one approach. But currently as a council we are managing another scheme to do with property flood resilience grants so if people were flooded in the feb 2020 flood they are eligible for up to £5000 for flood barriers and doors etc so when we are engaging people we can ask this, some of the catchments are also linked to environment agency schemes so the agency have the scheme in Leominster to improve the flood defences there. That is at the bottom of one of our catchment so the nfm scheme would benefit this. We will help with this scheme, in the dulas brook catchment the environment agency has a flood defence fund already there, so the nfm is supporting other schemes.

Interviewer:
You mentioned you had had some of the data on the soil, there have been bits of improvements, have you had any for reducing the flood peaks? I suppose not. Since its implementation, perhaps 2021?

I'm still looking through all of this, if you read guidance from defra or environment agencies on improving you ideally needed 10 years back data which we don't have. We couldn't collect that and implement the NFM we had to do both at the same time so I think it will be tricky to fully link the two but one of the catchments did have their own river level gauge so that one area we can look at and see what the differences have been.

Interviewer:
If they had a gauge then they already knew about their flood risk before the implementation?

Yes, that's in Bodmin, they have a really active flood group, from looking at their minutes they filled out your survey last time, they're really active and have recently changed Chair, they had national press as they were badly flooded in 2007 and then set up the flood group which meets regularly to coordinate maintaining the brook as it comes through the village. Also set up a buddy system, neighbours look after each other, if an alert gets issued it goes to certain people and then they pass the message on or put flood barriers up for them if they're not in.

Interviewer:
Is this the only community that really implemented these things prior to your scheme?

There's also Brimfield and Little Hereford flood groups, they were active before the project they don't run in the same way but have done previous projects. They realised early on that one of the things was a bridge on a farmer's land that was acting as a pinch point so they raised funds and did some improvement work to the bridge, that helps the conveyance underneath it, they have been involved with the NFM project so I have been invited to meetings, they have also shared key information to residents who do flood with info like who the key contacts are, what to do in a flood and what to do about flood insurance.

Interviewer:
So quite a few catchments are active in trying to reduce their flood risk by themselves?

Yes, even the group in the community even the catchments that don't have a formal flood group, they have residents in them that were very interested and aware of flooding, the Dulus brook catchment has an elderly gentleman that used to be a highways engineer. There was some modelling done by the environment agency that was contested by the locals and they drew up their own maps and did surveys to challenge the modelling. So groups like that, with local residents, do definitely let you know about it.

Interviewer:
Do you think they are still worried about their flood risk with the natural flood risk management being implemented and they're still interested to see the benefits and the evidence?

Yes, last year had quite significant flooding, natural flood management isn't going to stop the massive floods and this is a hard message to get across, people want to know they are never going to flood again. So I think there is always going to be concern from residents, looking at since the project came about we have been approached by other residents and areas of the parish where they have experienced flooding issues, or they see farmers land with water running off it and they want to sort it out to reduce the flood risk, so there has definitely been a link between big flood events and people wanting to see action. Its always going to be playing on their minds until there are no floods.

Interviewer:
But they might be more aware with the schemes in the communities, or do you think the level of awareness has stayed the same?

I think it has definitely increased because, for example when we did the launch event, we had a lot of people attend to start off with; we had roughly 140 people attend because of all the catchments; and then in the catchments the people attending the first community group meeting varied from 1, though lots of farmers in

the catchment were interested they just didn't attend the meeting; whereas the two catchments with the flood group one had 13 people attend and one had 12. 11 in the others. But then in the 2nd meetings, Brimfield Brook foe example, had 13 in its first and 18 in the second so picking up momentum, in Cheatham Brook catchment they had 11 first meeting and 17 second meeting;, then covid impacted so didn't manage to do second meetings in some catchments but if were to re do it, given the big floods that happened, I think more people will show up.
I think if you were to re-do it given the big floods that have happened I think you would see more show up to the events.

Last week I was invited to an event ran by a farmer who had decided he wanted to show the brook that ran through his last and invited neighbours, land owners, residents to all come along and invited the catchment adviser and the whole evening was talking about the river the Brook and the flood risk, and what they can do to manage the land and how to protect it and what people should be doing, he gave the impression that there was more people but they couldn't cope with the numbers due to covid restrictions, so little groups getting together themselves to talk about it.

Interviewer:
To talk about getting in contact with some of these people, do you have any contact details you could pass on? I would like to talk to them just a phone call, any interested people such as from groups or residents, easier for you if you could ask in a flood group. So maybe still have the survey but if you know any good areas I can talk the survey to or if you could ask flood groups to contact me?

More to see their perception to their flood risks, their responsibility towards their flood risk, people more interested now, and to see if their perception towards flood risk in general. PhD based on the levy effect. It would be beneficial if I could speak to people that had flooded. If you have groups I could contact that would be really helpful. Mobile and email is fine.

I'll see what I can do, maybe Bodnam flood group as they're proactive. Brimfield, changes going on between people so not necessarily good option, they have been promised things that haven't happened. Their flood group was set up on the Parish boundary but NFM different and gone in another parish as boundary bigger, so had to share documents with them so they can see what has been delivered. Flood group supportive but lots of politics going on. Do you just want NFM pilot projects or anything in general?

Interviewer:
How you are working with property flood resilience is interesting, so flood risk in general really. But anything on flood risk in areas. And if you can identify any areas for leaflets. Large maps that people had drawn on, if you had any copies I could look at. If it's not too difficult.
On project webs site we have put case studies, one for a charity in the Dulus Brook catchment called Jamie's Farm, they invite inner city kids etc, they have done NFM on their grounds so they could be a good one to approach and give you some thoughts on it.

Interviewer:
So, part of the survey there was a sketch map where respondents drew where they are at risk, we then compare to EA flood maps and then a map we produced that tried to take into account exposure and vulnerabilities, so I though if there were any drawn in a community group it might help, but if anything you could share would be helpful?

One thing you could look for, we have to do section 19 reports and the council did a survey and approached different people to ask what their account of the study was, the outputs are still in draft but do include some things that some people said in the survey which might be of use.

Interviewer:
Are they on line?
Once finalised will be made public. Other councils might have done something like this.

Interviewer:
Have you tried speaking to parish councils?

Yes, but I didn't get a very good response.

There's a parish council in Loufton and they approached us to ask for their own river level gauge to be installed, so we have paid for a gauge board and put it in for 6 point photography, lot of interest in the flooding, the primary school floods so they might be good people to talk to, I can see if they are happy to talk to you.
Interviewer:
That would be helpful thank you.

All my questions done, thank you. You have been really helpful.
End of call

SPS – Resident

Interviewer:
How long have you lived in Selly Park?
Since November 2017, in rented to start.

Interviewer:
So you were around for last flood event in 2018?
House I now live in did flood but I didn't live there at the time of the 2018 flood.

Purchased the house after it had flooded but there had been alleviation works nearby, not actually sure if it does make a difference.

Interviewer:
Did you know about the flood risk in the area before you moved in? Guessing you did?
Yes.
I've got a degree in some sciences and worked in flood risk modelling so am aware of these things.

Interviewer:
What do you think of the Selly Park Schemes.

They don't seem to have worked, that one in the south other residents seem to think… the one in the south that is the one that's tied into a bridge and didn't use wall, this seems to have worked –

Interviewer:
Are you a member of Selly Park South neighbourhood association?

Yes, so Chris who you've spoken to, he answers the emails as the comms person but I am also on the management committee so am aware of a little bit of history.
There's someone called John Clayton – you spoke to him last year, I recommend speaking to him for historical info.

Interviewer:
Have you spoken to the residents of the Selly Park Scheme, so you know how they feel about it?

I think most people are aware it happened but I don't think it has been tested in anger yet. I think there is still a concern but it's mainly around surface water flooding.
As regards the Selly Park North one, I think its called the Bourn Brook, underneath the road, I'm not sure it this has been tested enough, it may have been more because we have had heavy rainfall and it seems to have done the job. When I know that it had in terms of impact on the traffic and I know it took a long time for that to happen.

Interviewer:
As you are on the management committee can you share a questionnaire on the perceptions?
I don't see a problem, we could put it on the web site and send it out to the distribution list. Unsure what the response rate will be. I don't have a problem but will check with the rest of the management committee. Have you given it to John? He has lived here a long time and knows people.

Interviewer:
John previously did this when we did the paper version, due to covid this has moved online. Door knocking didn't work.

I have a management committee tomorrow night so can raise it.

Interviewer:
I can send posters and leaflets.

Send the link or attachment. How have you done his before?

Interviewer:
It's a link or a bar code and we have info with the Q R code.

We can send it out as a news post on web site.

Interviewer:
We are still considering, we did leaflets through doors previously, now university letting us go back out for field work. So hopefully we can push some leaflets through. I spoke to one the EA team members that did Selly Park irrigation scheme and they said that they go for leaflets as well but there isn't really a very good response rate unless someone in your position maybe has informed people they may be having a leaflet through.

It does help to have local relationship building for these things, given that there is a group in the area so good idea to use them. I don't mind spending a few minutes doing this.

Interviewer:
In terms pf community engagement, you work on the engaging environments? I've seen some things about it but not that much.

It's funded by NERC, so it started as a 3 year project coming up to two year but might be an extension due to covid, its across the country, Reading, Newcastle Universities. Manchester both unis, and the OU and University College London, it's a collaboration. Different unis play a different role, our focus is on – a fairly local approach instead of trying to engage on a national basis we try to have a community approach, a range of community partners to try and understand where their work overlaps with the research that NERC formed in its broadest dimension. It came in about, pilot project a year before had a ten month project, that particular community focus - we worked with citizens UK, who do a lot of work around social justice low pay, poor housing etc, and use their methodology called community organising which is where you build an alliance of individuals and organisations to try and build change. Our rationale for that was that quite often environmental changes have a neighbourhood level or action that was needed, the clean air zone is a classic in Birmingham, as a policy response to breaking the law. For some people that feels to them they are being singled out and there is always a social as well as an economic issue we're trying to understand community responses and actions and where is the environment in it. Low carbon homes for example. Concern about flooding is around insurance rather than the extent of it. Or causes. So that's the approach we take, social justice element and green space not equitably distributed across the country, some groups have green space more than others if your going to improve those areas how are you going to do it. So, it's based on this idea of community organising. You want to build those connections beforehand, before writing the proposal. So this can take a while to develop.

Interviewer:
From your work how closely would you say engaging with neighbourhood and communities are to their perception to environmental problems? As in how closely engagement and perceptions are linked?

I don't think there is very good engagements, one or two people do some good work but to others it seems a burden or a chore. Your project seems to be different, if you're looking at mantle dynamics hard to get an angle on this but if you are looking at all the stuff that happens, forestry research and the role around clean air. Its very strong in Birmingham it does have a community element to it but quite often my opinion is that community engagement is an afterthought, not up there with business and policy engagement. My opinion.

Interviewer:
So how many communities have you worked in to try and get community engagements?

Where I live Selly Park and also Hay mills, east of Birmingham bit in Hull with one group and Lozelles. And maybe one or two areas in Handsworth, they are quite connected.

Interviewer:
What sort of projects do you do?

We take community organising to things, storytelling is led by people in Manchester and season science is mainly in Newcastle, the bit here is why people use green space and why the volunteer to help out and growing schemes public and corporate spaces, working with them to find out why they do it. The intentions was there to take the seasoned science approach but fundamentally people are interested in the natural work but they don't want to be counting sparrows or a particular type of moth. They often come at it from a perspective of working alongside other people as an social element, they want to feel that they have contributing but might not be that interested in contributing to the science because they want to take action and do something positive. Quite often we will go in as scientist with a project and say we want to measure this or that and it's not devised by communities, so what we are looking to do it to look at how we develop, they want the university because they have access to the training and skills that you can build on as a strong and stable partner that can give attributes to community focused project but not necessarily ....

Interviewer:
Have you seen a lot of responsibility in the communities in Birmingham about this, I'm not sure what it's like in other environmental issues, but for flooding it's very much like wanting someone else to take actions?

Yes, your right in the areas I work in it's about hate crime and poor housing, so their priorities for those who have the time and energy to do this it's about coming home safe and things like that, that's why you have to understand this perspective.

Interviewer:
In your idea, more engagement is needed, I recognised I'm biased but would say that yes it is if you think about the government want us to plant lots of trees some of them will be in urban areas, who wants those trees who will manage them in the future?

The impact of those trees good and bad are felt at community level but the people are rarely asked about how they want to do it or where they could go, things like that. So I would say read that engagement thing, would be very important, also there is a shift the NHS for example are engaging much more with public about health concerns other public institutions are putting engagement right at the top of their agenda because they recognise its part of the solution, you need to do these at neighbourhood level but how do you match what neighbourhoods want and environmental things want to change and the only way to do this is to build relationships and gain that trust, to understand why people are concerned and what they are concerned about.

Interviewer:
So what's the next steps for your project now?

We have done projects, a colleague called Rob as well as academic partners and citizens Uk there is another developing, how you do work in green space? That's working with groups and developing a small diverse site, the idea is to keep working together and then continue writing the stuff I have around air quality and things of engagement that wouldn't normally be seen as engagement. I've had a number of student placements, in really small community organisations doing small projects with them, so writing those ups sometimes theyalso things around educational resources, playground is another one, they are not directly environmental but they have an environmental impact I suppose to the people who host the students. Some people do different things for different reasons, I'm always keen to develop new things as well, university have bought a bank called the exchange which is public facing building.
(can't hear)
Lots of academic colleagues supporting but I will be proving more resource. Really continue this work there is a real desire to work alongside the university. My role is developing a network of people trying to be a resource to keep this network going so people can communicate with each other but fundamentally it's to power them.

End of call

Selly Park North – resident

Interviewer:
I have questions about you living in Selly Park and your flood experience and the scheme.

Did you see the email, I regularly take people to see the floor alleviation scheme, so if you wanted to see it I can show you why it's happened,

Interviewer:
If that's ok with you that would be really helpful thank you

Yes, I'm retired so any time, will take about an hour.

Interviewer:
First how long have you lived in Selly Park North?
Since November 79. I finished my degree I moved back to Birmingham to do my postgrad and I used to go to school on my bike.
I've lived here since age of 5 and now I'm 68.

Interviewer:
So, you experienced the big floods?

Our road only flooded in 2008, 2016, and 2018. A slight scare in 2012. I've got a picture of this road that did flood in 1924 and I've got it on canvas
But that was the river Ray that flooded, after that they did some work on the River Ray and put it in a deep channel now it runs through Cannon Hill park. All experiences to do with the Bourne Brook.

Interviewer:
Did your property flood in 2008?
No but bloody close! right up to the threshold of the door. Some of my neighbours did flood. But we did flood in 2016 and 2018 and it got to a height of about 16/17 cms so above the skirting board, water came into the house and up through the floorboards and basically the flooding was marginally worse each time. I've got photos and videos of all this.

Interviewer:
Did you already know your flood risk before?

After the 2008 it was a shocker and it was after this that the environment agency started to do their planning, and it should finish after we flooded again in 2018. I have a timeline of the building of that flood alleviation scheme. Bit of a sore point that the Environment agency took such a long to build it, it became massively delayed.

Interviewer:
Now I'm interested in the community perspectives towards it as well?

It was deeply, deeply upsetting .
Flooding is massively upsetting and until you have experienced it it's difficult to explain the upset it causes to your life.

Anyway we have an alleviation scheme now so I'm dead happy

Interviewer:
Are you positive about it?

I am yes and when I get the chance to show you I can explain why I feel confident about it, because they changed the landscape in such a way that I can't conceive how we can flood again in the same way, as long as it works, they have done lots of testing on computers as long as it works we should be fine.

Interviewer:
Do you prefer that the scheme is more natural because you have the flood storage as well?

I wouldn't be able to show you that but I have been to look and it's significant and a lovely walk the Bourne Brook walkway goes to Woodgate valley. I feel positive about it.

Interviewer:
Do you prefer the fact that it has a natural element to it and not just a culvert, I think you have an embankment as well?

The way that they have built it, it was constructed the way it has been to do with funding, the area that flooded was the former sight of a BBC former social club, football pitches and hocket pitches and that ground was there then the BBC moved off the Pebble MIll sight, so the area was left, the people who owned the land Calth….Estates, which is an ancient family in Birmingham who own vast tracks of Edgbaston; they knocked down what was BBC Pebble Mill were developing the whole of this site, I can explain when I show you, they never built on the land because it was sludge, it was climate change that pushed that flooding to an extreme, where it got so deep it flooded onto the Road and always trying to get to the River Ray, it came down our road we were hit with a lakes worth of water in a short space of time. As part of the development of the Pebble Mill site which is where the flood alleviation scheme is they've raised the level of the land massively so that now can't flood same way again because there's no where for that amount of water to ever gather again. They changed the landscape so thats why I'm confident. Calthop estates put up a huge amount of money for the flood scheme but I'll never feel guilty about that because they can basically develop the land now because it won't flood. It was win win for them.

Interviewer:
Are you still worried about the flood risk?

The scheme was completed a couple of years ago it hasn't been needed yet, but one day we will be more confident when we see it work, I'm am still a bit touchy about it. But I am confident that if we flood it wont be from the Bourne Brook again it will be from something else.

Interviewer:
Did you have to move out in 2016?

We did in 2016, because I'd had the house rewired after the 2016, when it got to the 2018 the water, because of the way we flooded it was basically this low lying land that filled up with water and then it came down our road. So we got a large amount of water in a short space of time, once the rain stopped the flooding eased off so we weren't under water for days and days we were under water for hours. So, in 2018 because we had the house rewired and the sockets higher in the wall and we got a consumer unit that tripped out it made a big difference that we had power, we turned it off when it flooded but the next day it was safe to turn the power back on. When i had the house rewired there's no wiring under the ground floor so it all comes down from above, because we had power I felt ok about staying in the house. The insurance company would have funded it but I deliberately handled my claim more personally the second time round so I had wanted to stay at home because the repair, dealing with insurance is a whole separate thing and not quick so you end up being involved in lengthy negotiation, so that what I chose to do but other neighbours moved out.

Interviewer:
Have you found it easier to get insurance now because of the scheme?

The scheme itself has helped but basically it was when the government introduce the flood re scheme, we live 200 yards of the river Ray, when you make your statement about risk you have to say this, so the flood re thing helped to stay insured.

Interviewer:
So, with the re-wiring had you done any other things with the property before the EA finished with the plans and started implementing the scheme?

No I hadn't and I still regret when the walls were re-plaster after 2016. I was casual about it in in 2016 because I thought they would finish the alleviation scheme soon, so I allowed builders to use plaster board again, so in 2018 when the alleviation scheme was massively over due and we flooded again if I'd had walls replastered with the traditional render we wouldn't have had to have the plastering done again. So I wished I had instructed builders to use more traditions methods so that's my stupidity.

Interviewer:
Are you part of the Action Group in Selly Park?

Yes, I was instrumental in writing the reports that went to the council I have had two involvements with the flood action group, first time 2012 I was involved then and running it, I stood down because I was modelling it on Selly Park South, down the road, I bit off more than I could chew, I didn't know the people down there very well and it was run by a guy called John Clayton . He had a bunch of volunteers who were very keen and I modelled our plans on their plans, actually when it came down to it in 2016 I realised that we couldn't possibly do that so I stood down. And because I didn't do it no one else would do it so we didn't have a flood action group then. In 2018 we realised that we needed a flood action group again so I got involved again and now we are much more… we only do what we can do and it's very doable.

Interviewer:
So, there was no like, sandbags or things dispersed like in Selly Oak?

We did have those in 2016 because I copied them so we got sandbags delivered from the council and hydro snakes I had delivered to the houses. To the ones most likely to flood but the nature of the flooding was so severe and it was flash flooding and serious. When I was trying to take some of those hydro snakes to a neighbour I was nearly washed off my feet as I tried to cross the road, I was in water up to my waist, it was like a Welsh mountain stream. I can show you the videos, I took them so there was a record of the volume of the water. Because the water came up into the house through the floorboards having those sand bags trapped the water inside the house, so useless. It was a weird this when the water is coming up and it's like the house is sinking. All of a sudden your up to your knees. The water was deep.

Interviewer:
So, your glad the EA has gone with this alleviation scheme rather than property resilience and property level protection?

Oh yes absolutely! We really needed that scheme, really, really. In a terraced house I could get self-sealing air bricks and do all that stuff but if my neighbour doesn't we've had it, I can't control what happens so it would be the same. So that flood thing was great. The other thing you should be aware of is that Bourne Brook which has caused our most recent flooding there was no monitoring system on the Bourne brook and that was the, in all the stuff we have done, there was a monitoring in place, Visionlink monitoring system, which you could log onto if you wanted to and you can look at it, so I can look at the area where the flooding originated from, it's not very good in the dark, so I can look at stuff. With the Bourne Brook it responds to heavy rain incredibly quickly so it can go from nothing to full on within half an hour, we do look at the floodline warning scheme, the national scheme which I'm registered for, but for instance in 2016 and 2018 I'd got the phone text message that there was a risk of flooding when I was standing in my kitchen up to my knees in it. We have a separate monitoring system which is unusual but God am I grateful for that.
And that's through the environment agency there's no monitoring on the Bourne brook, but in the end they did, they are well meaning people but they are so slow. And you know they started a scheme said it would be 8 months and it took 2 and a half years, such pathetic planning really. Basically it was under the Percil Road, The Eland Valley water, and water for Birmingham comes from Wales in a pipe and they were tunnelling under that pipe I couldn't believe it when they said they couldn't tunnel as fast as they though. I knew that pipe was there so I got angry. But there you go I'm over it now.

Interviewer:
So you had quite a lot of engagement with the EA, lots of meetings?

Loads yes, and we still meet with them (couldn't make out the names) meetings and the flood action group we acted as an interface, basically our flood action group is part of our residential association so we were able to give people progress reports and represent our views.

Interviewer:
Do you agree that the responsibility for the alleviation scheme should fall within the government and the EA?

Yes, and the land owner because council estates must have know that that area flooded, I didn't know because I couldn't see it, and the BBC should have known because a certain amount just decided to look the other way, and with climate change the amount of rainwater has increased dramatically so anyone who gets climate change needs their head looking at, it reached the tipping point in 2008 and it was only then that this flood scheme was first talked about but that area must have experienced it but as it was s sports field it didn't matter it got flooded.
The only way we were going to get an alleviation scheme but it meant they could develop the area. 1 350 bed student block, costa coffee and behind the dental hospital, so they come across as being benevolent and stuff but its big business. They are property developers, and they know what they are doing. Where Pebble Mill used to stand, it was a large regional broadcasting centre a very big building 7/8 storeys high where they broadcasted from. I don't know why they left but having left it that presented Cal… Estates, there two private hospitals, student accommodation, costa coffee, eye hospital, and they've got everything. I'll show you on our walk.

Interviewer:
So the rest of the flood action group that you talk to, do you think that everyone in the area has become more aware since the scheme or do you think it was just the flood events that everyone already knew?

I like to think that we made them more aware by producing leaflets and distributing them, we communicate with residents by the resident's association and face book page, but I have to say all my neighbours fear about is house prices but it hasn't made any difference, they sell really quickly, when I'm aware of people moving into the area I go and tell them about it. I say you need to know you live in an area which is a meeting point of two waterways, and it has a history of flooding and I give them some leaflets and historical information a list of web sites but when I explain to them they look at me like I'm mad, but it can't do that any more because of the alleviation scheme.

Interviewer:
Do you think some residents have experienced it are still worried about it?

Yes, quite a few were severely traumatised and even now, I try to reassure them, when we get heavy cloud burst people get jumpy. I contact them and say look this scheme hasn't yet been required, but even so they can get jumpy.

Interviewer:
Do you know what the return level is for the flood level defence scheme?

I do have all this information. The EA reclassified all the figures, and that was two years ago and but John is still looking into it, has an impact on some people's insurance. He's looking into it.
But are so slow.

Interviewer:
So, you think that people moving into the area are more complacent than those who have already been flooded?

Yes, those I am aware of, I can explain what happened in the past, but they have never taken me up on my offer of taking them on a tour.
With our flood action group, the way we run it now compared to back in the day is I'd got this amazing plan, we don't do that anymore and we only do what we can do. I've told them how to get onto the vision link so can check the levels of the Bourn Brook and all the information they need, and national flood forum so they can discuss any modification they can make to their houses, but basically I can only point them in the right direction, I can't do it for them. I've still got it in my house, it's a very simple flood plan and I've got it in such a way that I could clear the decks in my house in half an hour, thank God in 2018 I wasn't in the house when it flooded, my children were and my wife and they managed to save everything but in 2016 we lost a load, we don't have fitted carpets we have rugs on wooded floors, roll them up quick and I've got a supply of plastic creates so we can get it off the floor in minutes and my valuable stuff is all upstairs such as paperwork. Makes me feel ok.

Interviewer:
Thank you, Howard.

I'll Happily give you a tour, I can send you pictures but the videos are too big, if you want them you are welcome to it but there are quite a lot that the BBC had so you can probably get access to it.
So you can see how much worse it was in 2016 and 18 compared to 2008. If you look on youtube it was on Midland News the water was strong enough to pick up a car and was left hanging over a wall, then it dropped so the car was stuck across a wall.
I'll take you for a walk to look, bring a camera

Interviewer:

We have done an online questionnaire but we've shared it in a few groups in Selly Park but not had a very good response to it. If I send you a link could you share it with the flood action group maybe?

There's only 4 or 5 of us, but do sent it to me. Do you want me to start sending you information by email? I've got lots.

Interviewer:
Yes please anything you have please send it.

I've even got a timeline with key points

Give me an indication of a good time for you, preferably when it's not raining.

Interviewer:
Thank you

End of call