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Working Paper

Assessing surface water flood risk and management strategies under future climate change: An Agent-Based Model approach

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Abstract

Flooding is the costliest natural disaster worldwide. In the UK flooding is listed as a major risk on the National Risk Register with surface water flooding the most likely cause of damage to properties. Climate change and increasing urbanisation are both projected to result in an increase in surface water flood events and their associated damages in the future. In this paper we present an Agent Based Model (ABM), applied to a London case study of surface water flood risk, designed to assess the interplay between different adaptation options; how risk reduction could be achieved by homeowners and government; and the role of flood insurance and the recently launched flood insurance pool, Flood Re, in the context of climate change. The ABM is novel in its coverage of different combinations of flood risk management options, insurance, and Flood Re, and its ability to model changing behaviour, decision making, surface water flood events, and surface water flood risk in a dynamic manner.

The analysis highlights that while combined investment in property-level protection measures and sustainable urban drainage systems reduce surface water flood risk, benefits can be outweighed by continued development in high risk areas and the effects of climate change. Flood Re is beneficial in its function to provide affordable insurance, even under climate change, and is shown to have some positive effects on the housing market in the model. However, in our simulations Flood Re does face increasing pressure due to rising surface water flood risk, which highlights the importance of forward looking flood risk management interventions, that utilize insurance incentives, limit new development, and support resilience measures. Our findings are highly relevant for the ongoing regulatory and political approval process for Flood Re as well as the wider flood risk management discussion in the UK.

Keywords
Surface water flooding; risk; insurance; climate change; adaptation

1. Introduction

Flooding is the costliest natural disaster worldwide, and the effective management of long-term flood risk is an increasingly critical issue for many governments across the world, especially in light of climate change. The OECD's Environment Outlook revealed that nearly 20% of the world's population could be exposed to floods by 2050 and the economic value of assets at risk could rise to US$45 trillion even before the potential effects of climate change on flood risk are considered (OECD, 2012). Flooding across Europe was estimated to cost €4.2 billion annually for the period 2000 to 2012, with the potential to rise to €23.5 billion by 2050 (Jongman et al., 2014). These growing losses are putting pressure on affordability and availability of flood insurance – a challenge that is expected to increase, due to socio-economic drivers and climate change.

Flooding can occur in various forms, such as coastal, river and surface water flooding (sometimes known as 'urban' or 'storm water' flooding). Surface water flooding occurs due to a complex interplay of factors, including the precise location, intensity and duration of rainfall, the characteristics of urban land surfaces and the engineering design of the surface drainage and sewer system. Surface water flooding tends to be most severe during intense rainfall downpours, which are often, but not exclusively, associated with convective rainfall events.

Surface water flood risk emerges from the interplay between biophysical and human factors (Hall et al., 2003b). Biophysical factors determine the frequency, duration and intensity of rainfall, and the runoff that occurs when rain hits the ground. Rainfall may be infiltrated into the ground, but in urban areas with impermeable surfaces rain water will flow on the surface in directions modified by the form of buildings and streets and will accumulate at locations with low topographical elevation. These processes are modified by drains that are designed to convey water away from urban areas on the surface or in pipes (Blanc et al., 2012). Risk will also be dependent on the vulnerability of the area and population exposed to the event (Hall et al., 2005) and, where in place, the effectiveness of surface water management interventions.

In England the consequences of surface water flooding were brought to the forefront by the summer floods of 2007, which caused the country's largest peacetime emergency since World War II. The country suffered its wettest summer since records began, with periods of intense rainfall: 55,000 properties were flooded; there was a loss of essential services including half a million people without mains water or electricity; transport networks failed; and emergency facilities were put out of action (Pitt, 2008). The total economic cost of the floods were estimated to be £3.2 billion (2007 prices), with £2.5 billion borne by households at a cost of £1.8 billion to insurers (Environment Agency, 2010).

These floods differed in scale and type from recent floods in that a much higher proportion of flooding than normal came from surface water flooding rather than rivers. According to the Environment Agency (EA) (2007a) "two-thirds of the 55,000 homes and businesses affected were flooded because drains, culverts, sewers and ditches were overwhelmed. (…) In London, virtually all of the 1,400 properties flooded were due to surface water flooding. In the South-East and Yorkshire and Humberside regions, around 70 per cent of the properties flooded were from surface water. Just over half the properties flooded in the East and West Midlands and South-West regions were from surface water flooding". This water then accumulated in rivers to extend the impact to the floodplain. The Pitt Review (Pitt, 2008), which was conducted to provide lessons and recommendations in the aftermath of the 2007 summer floods, highlighted major gaps in the understanding and management of risks from surface water flooding. Similar concerns have also been raised across Europe with some member states in the past giving a much lower priority to this type of flood risk meaning that vulnerability has crept upwards (European Water Association, 2009). The need for further attention to this type of risk is apparent given that the UK National Risk Register lists surface water flooding as the most likely cause of damage to properties, with estimated annual costs of £1.3bn to £2.2bn (Defra 2011).

The Pitt Review also emphasised the need for urgent and fundamental changes in the way the UK is adapting to the likelihood of more frequent and intense periods of heavy rainfall, particularly given the impact that climate change would have on the probability of similar events in the future. Findings presented in the UK Climate Projections (UKCP09) show that as a result of climate change the UK weather in the upcoming century will be characterized by more days of extreme precipitation during the winter and summer period (IPCC 2013). These changing precipitation patterns are expected to result in an increase in surface water flood events in the UK (Ramsbottom, Sayers, & Panzeri 2012). Combined with an increasing pattern of urbanisation Defra estimated that damages from surface water flooding could increase by 60-220% over the next 50 years (Adaptation Sub-Committee 2012). Recent estimates also suggest the Expected Annual Damage (EAD) from surface water flooding could increase by 135% in England by the 2080s, rising from an EAD of £200 million to £470 million under a 4°C climate scenario (Sayers et al., 2015).

The combination of biophysical and human factors influencing surface water flood risk means that it is extremely challenging to predict the occurrence and extent of events, limiting the ability to warn and plan for future risks (Houston et al., 2011). This and the large number of stakeholders involved make surface water flooding a very complex issue. One area where this is particularly apparent is flood insurance. While insurers traditionally insure against all types of flooding in the UK, over the last decade the concerns about surface water flooding have contributed to a review of existing insurance practices.

Flood insurance across the United Kingdom is unique amongst most other national schemes as under the so-called Statement of Principles (SoP) it is provided entirely by the private market. Under the SoP insurers provide the financial risk transfer while responsibility for flood risk reduction is primarily placed on the government (national and local) who commits to flood risk management activities such as the construction of flood defences and the regulation of water utilities who construct and maintain sewers.

However, the 2007 UK summer floods triggered a review of this arrangement, with a renewed version of the SoP being put in place from 2009 but excluding newly build properties. Government and industry then started lengthy negotiations about a new approach to flood insurance, which eventually concluded with the development of Flood Re, a new pool solution for high-risk properties, due to be in operation from Spring 2016. Households under low to normal flood risk will still be provided with insurance as standard, whilst the flood element of the home insurance policy for the 1-2% of highest risk properties can be passed to Flood Re by insurers. The premiums offered for high risk households are fixed dependent on council tax banding (ranging from £210 - £540). Flood Re will be funded by these premiums and an annual levy taken from all policyholders, on average £10.50 per policy, and imposed on insurers according to their market share (Surminski & Eldridge 2015). Premiums and levies will be reviewed every 5 years, with changes requiring the approval of the Secretary of the State. The proposed Flood Re scheme is designed by Government and industry as a transitional solution, with an anticipated run time of 20-25 years, aimed at helping to smooth the transition to more risk-based pricing in a competitive insurance market in the future, while securing affordability and availability of flood insurance (Defra, 2013).

While the change in the flood insurance scheme has been triggered by concerns about the rising flood losses it remains unclear if and how Flood Re will be able to cope with future risks and fulfil its tasks. Rising losses and increased volatility can affect the fine balance between affordability and profitability. In extreme cases this could lead to insurers withdrawing from certain markets and regions, as highlighted by the UK's insurance regulator PRA (Prudential Regulation Authority, 2015). While the recent flood loss trends in the UK are largely due to socio-economic factors, such as more development in exposed areas, climate change is expected to exacerbate these impacts (IPCC, 2012, 2014). One important aspect therefore is if and how insurance can be integrated into overall risk management and climate change adaptation efforts.

Throughout the Flood Re consultations concerns have arisen over the financial sustainability of Flood Re given that costs will remain higher than benefits delivered (Defra, 2013, p.30). Another area of criticism is the lack of incorporating climate change into the Flood Re risk modelling despite its 25 year outlook (Surminski & Eldridge 2015). The new system has the sole objective of keeping flood insurance affordable over the next 20-25 years. It is not designed with risk reduction in mind, and it offers no incentives or formal mechanisms to encourage household level flood risk reduction (*ibid*.). Similarly, implications of the scheme, and potential negative and positive feedbacks, have not been considered in parallel with other flood risk management interventions, including those targeted at surface water flooding.

This gap is the starting point of our investigation. We propose a methodology for assessing different adaptation options for surface water flood risk, including structural (e.g. urban drainage) and non-structural (e.g. regulatory) measures. We investigate if and how these measures affect local surface water flood risk in the context of different climate change scenarios. We apply this to a London-based case study and analyse how risk reduction could be achieved by homeowners and government and what role flood insurance can play. Our model allows us to analyse how the current and future proposals for flood insurance could influence London's resilience to surface water flood risk today and in the future under various scenarios of climate change.

The analysis presented here is novel in two respects. Firstly, different combinations of surface water flood risk management options are modelled, to include structural adaptation options, the role of insurance, and the specific case of Flood Re. Secondly, typically flood risk is calculated using static data on properties at risk and the damage that will occur during a flood (Hall et al., 2003a). This approach does not address the distribution of losses across different households and the role of adaptation options or insurance in redistributing those losses. Nor does it address the dynamics of householders' locational choices and the ways in which those choices may be modified by flood risk and insurance availability (Dawson et al., 2011).

The above issues are addressed through the application of a novel agent based model (ABM) to capture and model the dynamics of surface water flooding, changing surface water flood risk, and how adaptation and insurance decisions could affect future surface water flood risk in that dynamic (Dubbelboer et al., Forthcoming; Jenkins et al., 2015a). The ABM benefits from the incorporation of a surface water flood event dataset, for present and future climate scenarios, developed by combining probabilistic precipitation projections with broad scale surface water flood modelling and mapping (Jenkins et al., Forthcoming; Jenkins et al., 2015b).

While the ABM presented here is advantageous for visualising the effects of changing behaviours and emergent properties of complex adaptive systems, as with any model, it is based on a range of assumptions, which often simplify inherently complex processes (see table 1 below). Results presented below are interpreted and discussed in light of the underlying assumptions which are necessary given this complexity, availability of literature, data sources, and model limitations.

Section 2 provides some further context on the current management of surface water flooding in the UK and London and options to address risk. Section 3 presents the core study area and methodological approach. Section 4 presents the main findings of the study and discussion of results. The implications of these findings for surface water flood risk are presented in Section 5, and conclusions in Section 6.

2. Context

2.1 Challenges in managing surface water flood risk in the UK and London

Overall flood management responsibility, policy and legislation for England are determined by the Department for Environment, Food and Rural Affairs (Defra) with national flood and coastal erosion management delivered by the EA. Local authorities have lead responsibility for managing local flood risk, which includes surface water runoff, groundwater and ordinary watercourses, and are designated as Lead Local Flood Authorities (LLFA) (see Crick et al., (2013) for further description). The LLFAs are also responsible for the production of Surface Water Management Plans (SWMPs). These aim to improve and optimise coordination between relevant stakeholders; provide the vehicle for local organisations to develop a shared understanding of local surface water flood risk; set out priorities for action, maintenance needs; and link into local development frameworks and emergency plans. The development of SWMPs as the basis for managing all local flood risk, and the lead role of local authorities was a clear recommendation of the Pitt Review (2008). These recommendations were further supported by a 2009 report on urban surface water management planning commissioned by the ABI (Sargent et al., 2009), which highlighted the need for new legislation to clearly identify local authorities as the lead agency for surface water management planning and for surface water flooding to be fully considered in Strategic Flood Risk Assessments to inform planners and the local development framework.

The Pitt Review and ABI report also shed light on the many barriers to effective surface water management planning, including a lack of suitably skilled staff and funding for the LLFA; the complexity of surface water flooding and number of stakeholders who are involved and require input; and the large data requirements which are often constrained by commercial, confidential or licensing issues. Some of these barriers remain today. For example, the management of flood risks in London cuts across the responsibilities of many organisations, including the EA, the Greater London Authority and the London Boroughs.

In conjunction with the EA and the London Boroughs, the Greater London Authority is involved in flood risk management through the identification of flood risks, of communities and infrastructure susceptible to flooding, of attenuation areas and areas to protect from flooding, and of critical drainage areas and the permeability of surfaces in regards to surface water. This role is particularly important for development in London as the Mayor consults on all planning applications of strategic importance to London.

While there are several plans relevant for the management of flood risks in London[1] the need for further quantification of surface water flood risk and information to support adaptation options is often highlighted (Greater London Authority, 2011b). In response to the London Regional Flood Risk Appraisal (RFRA), the Drain London[2] project was established to improve knowledge of the surface water drainage system and areas at most risk of flooding, including the provision of detailed surface water flood depth and hazard maps. Flood risk modelling through Drain London has so far helped London's boroughs to better understand their level of risk and produce SWMPs.

Given the future climate projections for the UK, a crucial component of surface water flood risk management should also focus on understanding changing risk due to climate change. The overarching policy for climate change adaptation in the UK is the National Adaptation Programme (NAP) based on the UK Climate Change Risk Assessment (CCRA). The CCRA identified the management of flood risk as one of the key areas for action over the next five years (Defra, 2012). The need for action on flood risk management was also highlighted in the UK's Adaptation Sub-Committee 2012 report on flooding and water scarcity, calling for key decisions on levels of funding and approaches to flood risk management to be made by 2020 to ensure the UK is prepared for climate change-related flood risks (Adaptation Sub-Committee, 2012). Based on the CCRA findings, the NAP recognises flood risk as a key cross-cutting risk and in particular for the built environment sector. Embedded within this is the need to embed evolving understanding of surface water flooding in policy and delivery approaches.

Recent projections of future flood risk in the UK undertaken on behalf of the Committee on Climate Change (Sayers et al., 2015) highlight that EAD from flooding will increase significantly by the 2080s if current levels of adaptation continue. Delivering enhanced levels of adaptation was projected to offset almost all additional risk under a 2°C climate change and low population growth projection, and almost all additional risk under the high population growth projection. However, for the 4°C climate change and high growth projection only 70% of the additional risk was offset by enhanced adaptation, with this ambitious level of adaptation requiring significant investment and concerted action across stakeholders to implement.

Surface water flooding is acknowledged as a challenge in the London Climate Change Adaptation Strategy (Greater London Authority, 2011a). Within the SWMPs for each of the London boroughs (and other local authorities), climate change is taken into account by increasing rainfall intensity by 30% in the modelled results that feed into spatial planning

[1] Including the London Plan which is the overall strategic plan for London, setting out a fully integrated economic, environmental, transport and social framework for the development of the capital to 2036.
[2] Led by the Greater London Authority, who are due to publish a Drain London interim report shortly. Drain London includes a partnership of 33 London boroughs, the EA, Thames Water, Transport for London, and other bodies that have drainage responsibilities in London. See: http://www.london.gov.uk/drain-london.

requirements, and impacts of climate change are incorporated into groundwater risk assessments. In justifying this uplift rate Defra comment that there is no standardised methodology for determining the impact that climate change will have on surface water flooding. However, besides limitations of focusing on a single climate response within the SWMPs, this method does not facilitate the quantification of uncertainties for Governments and policy makers to help support the design and implementation of robust and economical adaptation options.

2.2 Options to address surface water flood risk

SWMPs provide a tool to improve understanding of the causes, probability, and consequences of surface water flooding. They outline the duties and responsibilities of different partners and stakeholders for risk management and ultimately aim to provide a co-ordinated action plan to mitigate future flood risk in a cost effective manner.

This includes the role of Sustainable Drainage Systems (SUDS) in managing surface water flood risk. SUDS aim to reduce surface water flooding by minimising runoff (by reducing impermeable surfaces in urban areas) and store or convey surface water so that it does not cause harm and, as far as possible, does not enter sewers. In England, the use of SUDS was recommended by the Pitt Review (2008) and since April 2015 are a requirement for all new developments of ten or more properties at risk of flooding under amended planning guidance (DCLG, 2014). However, the recent uptake of SUDS has been insufficient to mitigate increasing flood risk from surface runoff and the risk of sewer overload (Defra, 2011). Incorporating SUDS into new developments will only be part of the solution and retrofitting SUDS within existing developments will be important for managing future flood risk (Environment Agency, 2007b). Ongoing concerns include the technical expertise and capacity of local planning authorities and the guarantee of long-term maintenance funding and clarity over who is responsible for maintenance (Defra and DCLG, 2014).

A second option increasingly considered as an alternative or complement to other flood defence activities is property-level protection measures (PLPMs), used by property owners aimed at either flood resistance (preventing or reducing the amount of water that gets inside the house) or flood resilience (reducing the damage water causes when water gets inside a house). PLPMs are applicable across flooding types, including surface water flooding, and are most cost-beneficial for frequent low-level flooding (Adaptation Sub-Committee, 2011). The Pitt Review highlighted the potential for PLPMs to minimise damage from flood water and recommended that local authorities should extend eligibility for home improvement grants and loans to include flood resistance and resilience products for properties in high flood risk (Pitt, 2008). Defra and the EA ran grant schemes installing this equipment in over 2000 homes between 2007 and 2011 and following winter flooding in 2013-2014 in the UK the government introduced a repair and renew grant scheme to help homes affected to implement PLPMs. It is estimated that up to 330,000 properties in England could benefit from PLPMs by 2035 (Adaptation Sub-Committee, 2011).

However, known challenges include the underestimation of flood risk by many residents, poor understanding about flood protection responsibilities, and the costs and aesthetics of PLPMs (Thurston et al., 2008). Recent efforts to address these challenges include Defra's new surveying protocols for PLPM technologies and Innovate UK's project to develop a Property Flood Resistance Database for the insurance industry (White et al., 2015).

3. Methodology

3.1 Study Area

Whilst the storms of summer 2007 were not centred on London the enormity of the damage, disruption, and recovery times that could occur following such an event were apparent. Increased population and reduced urban surface permeability due to densifying development mean that London's aging drainage systems are under pressure, and the risk of surface water flooding is acute. Around 680,000 properties are estimated to be at risk with 140,000 Londoners at high risk, and another 230,000 at medium risk (Greater London Authority, 2014). The number of residential properties prone to surface water flooding has been increasing from 2001 to 2011, as has the proportion of urban land covered with manmade surfaces (>70% in many London boroughs) (HR Wallingford, 2012). Because of the scarcity of undeveloped land which is not otherwise protected for recreational or environmental purposes, over 96% of new developments in London in recent years have been on brownfield sites. However, many of the remaining brownfield sites for development are in flood risk zones (Greater London Authority, 2009). Developments in areas prone to surface water flooding have also been increasing by 0.5 to 0.7% per year from 2008 (Adaptation Sub-Committee, 2012).

The ABM presented here has been developed for Greater London and is transferable to other regions. This analysis focuses on a case study of surface water flood risk in the London Borough of Camden (Fig.1). This encompasses an area of 21.8km^2 and a population of approximately 228,400 people (Greater London Authority, 2015). Surface water flooding poses a large risk to Camden due to the nature of summer thunderstorms and the topography of the area, with a historic precedent for such events (Drain London, 2011).The area is not at risk of flooding from the River Thames or any other open rivers.

Figure 1: The boundary of Greater London study and the London Borough of Camden and the location in England (inset)

3.2 Agent Based Model

ABMs provide a bottom-up approach for understanding the dynamic interactions between different intentional agents in complex systems. They are particularly advantageous for visualising the effects of changing behaviours and emergent properties of complex adaptive systems. They have a number of advantages as a support for policy making such as their accessibility and flexibility for testing different conditions and behavioural rules (van Dam et al., 2012). Figure 2 provides an overview of the ABM with its key processes and interactions (for a full description of the model, agents, process and validation see Dubbelboer *et al.,*(Forthcoming)).

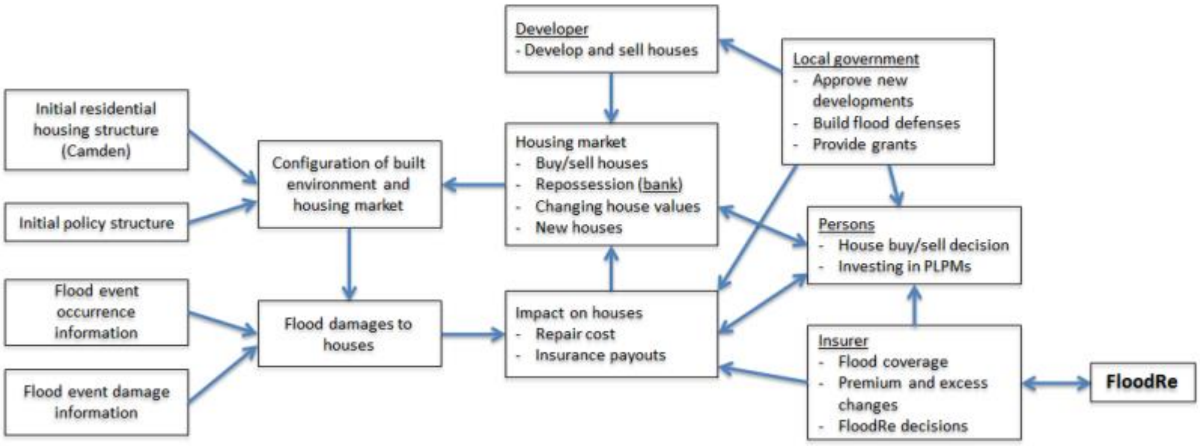

Figure 2: An overview of the key processes and interactions in the surface water flood risk ABM

The ABM has been parameterised based on a large array of data sources and developed around GIS data to allow a realistic representation of residential buildings and surface water flood risk in the London Borough of Camden[3]. A key input to the ABM is a probabilistic flood event set developed by linking the Drain London surface water flood depth maps to residential building data, with potential economic damage to properties in each simulated flood estimated using established flood depth-damage functions (Penning-Rowsell et al. 2010) (described in Jenkins et al., Forthcoming). The frequency, extent and spatial heterogeneity in surface water flood events was captured by rescaling these homogenous maps for each simulated flood event through the use of an hourly Weather Generator (WG), conditioned upon the UK's probabilistic climate projections (UKCP09).

The ABM includes six different agents[4]: people, houses, an insurer, a bank, a developer and a local government, each with their own behaviour (summarised in Table 1 and outlined below). Based on the estimated economic damage to houses for given flood return periods, every house in the model has a level of surface water flood risk assigned to it, which is the expected annual flood damage (Bevan and Hall, 2014, p.17). This level of surface water flood risk is recalculated every year to reflect the dynamic changes in the model and the creation of new houses by the developer. Initial houses in the model are also assigned a surface water flood history. The length of the flood history is dependent on the build year of

[3] The study used GIS data from the London Datastore (Greater London Authority 2015b) and residential building data from Landmap (2014). Derived data on the economic damage to properties at risk from surface water flooding is estimated using the UK Buildings Residential Building Class Dataset (The GeoInformation group data ® copyright by The GeoInformation® Group, 2014 Licence No. 3786) and surface water flood depth maps generated for the GLA Drain London Project (Greater London Authority 2015a).

[4] An agent is defined as the software representation of some entity that completes an action or takes a decision, by which it effectively interacts with its environment.

the property, and reflects a random time slice from the baseline flood event time series. The household damage for given return periods do not change under the future climate scenarios (just the frequency of events of this magnitude). To illustrate the effect of climate change the change in probability of surface water flood events of a given magnitude are estimated and accounted for in the probability damage curves and subsequent estimates of risk.

In the ABM we assume that an insurer has detailed information that provides an estimate of surface water flood risk. Based on that risk estimate and a flat administration cost a fair insurance premium and excess can be calculated for each household. In this analysis we only model the technical side of flood insurance and not the commercial side (i.e. competition between insurers which might modify the offered premium). As we are focussing on surface water flooding we limit the insurer's attention to the surface water flood history of a house and the estimated surface water flood risk.

The insurer first sets the flood insurance excess for all houses. The assumption is made that the flood insurance excess amount is non-negotiable and will initially be equal to £200 per household per year. Houses hit during a surface water flood event will see their insurance excesses increase by 1/3rd, to a maximum of £2500, as normally the excess would not be more than that as homeowners would not be able to get a mortgage (House of Commons Environment, Food and Rural Affairs Committee, 2013).

The surface water flood risk estimates are summed across all affected houses in the model representing the insurers expected annual loss. The insurer deducts from this the total value of excesses paid and the total base flood insurance premium paid by all households in the model, assumed to be of £50 per house per year. The remaining loss that has to be covered is spread across the households at risk of surface water flooding, by increasing their flood insurance premium proportionally to the flood risk they are in. In this way people owning a house in surface water flood risk will receive a higher flood insurance premium.

Insurers typically pass on risks above a set threshold by purchasing reinsurance on the global market. In this case study the Flood Re scheme represents a government designed reinsurance entity to ensure continued insurance coverage for high flood risk properties in the UK. When switched on in the ABM the insurer has the option to re-insure eligible properties into Flood Re[5]. The insurer will have to pay to re-insure a household into Flood Re with a fixed premium per policy to the insurer dependent on the property value (approximated according to the local property council tax rate ranging from £210 to £540 in the study area). The household flood insurance premiums are capped to these amounts if reinsured in Flood Re.

In addition, the local government aims to reduce flood risk through investment in PLPMs (implemented by homeowners and linked to government funded grants) and surface water flood reduction projects in the form of SUDS. Based on available literature it is initially assumed that these measures will reduce household flood damage by 75% (Thurston et al. 2008) and 35% (Defra 2011) respectively. The amount of assets the local government can spend on SUDS and PLPM grants every year is equal to the annual subsidy they receive from the national government and a small percentage of their income from selling land to the

[5] High risk properties are only eligible if built prior to 2009. The exclusion of new floodplain properties was introduced following the review of the Statement of Principles in 2009.

developer and collecting property taxes from home owners. Initially it is assumed that up to 80% of this budget can be spent annually on SUDS and 20% for PLPM grants.

Every year the local government will proactively search for SUDS projects to invest in. Every project consists of a minimum of 100 houses that are in close proximity to each other. The projects are selected based on the flood risk of houses and the benefit-cost ratio that the local government would achieve for each project. From the 10 projects the local government will try to build as many as it can with the budget it has, starting with the projects with the highest benefit-cost ratio.

The second task of the local government is the evaluation of development proposals. The developer will establish the number of houses it wishes to build based on the current unmet demand for housing in the model. The developer will locate land for development based on the estimated land value and the number of properties which can be built annually within allocated development areas. Land value, the type of house to build, and the house price once completed are calculated based on the characteristics and values of the surrounding houses. It is initially assumed that 50% of all new properties are built with SUDS in place[6].

In the initial model set up a development proposal will be approved by the local government in 75% of the cases. Although regulation on approving development proposals states that local governments should consider flood risk, figures indicate that in 75% of cases flood risk is not looked at (Wynn 2005). In remaining cases the development proposal will be approved if the proposed flood risk of the development is lower than the governments acceptable maximum flood risk. If this is not the case the development proposal can still be approved based on the profitability of the land sale to the local government. This reasoning reflects the current pressure local governments are put under by central government to develop more houses within their borough (Camden Council 2013; Greater London Authority 2011b), and highlights trade-offs which must be made when addressing flood risk and housing shortages.

Table 1 summarizes the underlying assumptions that fed into the model.

[6] Defra (2011) report that on average 38% of minor developments and 58% of major developments are now being built by developers with SUDS systems. It is not clear to what standards they are being built to. It is assumed that 40% of build was accounted for by Minor Development with the remaining 60% accounted for by Major Development. This implies that 50% of build does not have SUDS.

Agent	Main Behaviours
Homeowner	Decide to buy or sell properties Required to renew flood insurance annually Pay household fees Decide whether to invest in PLPMs (assumed that 1% of homeowners invest proactively per year, while 34% invest reactively following a flood) May consider flood risk when considering to purchase a new property
Insurer	Estimates household surface water flood risk for every property in model (it is assumed that where in place they account for PLPMs and SUDs in these estimates) Sets insurance premiums and excess levels for every property in model Provides all households with flood insurance Decide whether it is cost effective to place high risk properties into Flood Re Provide compensation, minus the excess, to properties following a flood event
Local Government	Invest up to 80% of their local flood defence budget (or more in the year of a flood event) in SUDS projects which protect houses at highest risk of flooding and provide a cost-benefit ratio of 1:5 or greater Invest up to 20% of their local flood defence budget to provide £5000 grants to households investing in PLPMs Evaluate and approve/reject property development plans based on their financial benefits and flood risk Sell land to developers for approved property developments
Developer	If demand for new properties outstrips available properties on the market propose to build new properties to meet demand Identify optimal land to maximise profits from developments, within allocated development areas and the local governments planned development trajectory Submit development proposal to be approved by the local government Build new houses (initially assumed that 50% of all houses built will have SUDS) and sell on the market
Bank	Reposes houses if the owners are unable to afford household fees for three consecutive years Sell houses on market

Table 1: Summary table of main agent behaviours

The role of Flood Re, PLPMs and SUDS in managing surface water flood risk were tested individually and in combination for 8 different experiments (Table 2). Each experiment setting was run using flood event time series data for a baseline (1961–1990) and future high emission climate change scenarios for the 2030s (2030H) and 2050s (2050H). These climate scenarios were translated into simulated rainfall series using a Weather Generator (Jones et al., 2009). The experiments were run at a yearly time-step for 100 simulations of the 30-year time series data corresponding to the baseline, 2030s and 2050s so as to sample stochastic variability in the rainfall series. These repeated simulations are each driven by a new resampling of the uncertainties in the climate scenarios, so the statistical results also reflect these uncertainties.

Experiment Number	Experiment Name	Current Insurance Scheme	Flood Re system	Investment in SUDS	Investment in PLPMs
1	Insurance	ON	Off	Off	Off
2	Insurance+Flood Re	ON	ON	Off	Off
3	Insurance+SUDs	ON	Off	ON	Off
4	Insurance+PLPMs	ON	Off	Off	ON
5	Insurance+FloodRe+PLPMs	ON	ON	Off	ON
6	Insurance+FloodRe+SUDs	ON	ON	ON	Off
7	Insurance+FloodRe+SUDs+PLPMs	ON	ON	ON	ON
8	Insurance+SUDs+PLPMs	ON	Off	ON	ON

Table 2: Combination of management options included for each different experiment

4. Results

4.1. Surface water flood risk analysis

The simulation results presented below for surface water flood risk are reflective of the modelled trends seen in the surface water flood event data set of Jenkins et al., (Forthcoming), which highlighted that for Greater London the frequency of events exceeding present day 1/30yr return levels increased by 61% and 56% under the 2030H and 2050H climate change scenarios respectively. The smaller change in frequency of events between the 2030s and 2050s is in line with other studies. For example, the study by Sanderson (2010) for London used UKCP09 data to illustrate that rainfall events are likely to become more frequent in the future, particularly between the present and 2040s. Sanderson postulated that this could be because the extreme rainfall events, especially those for the higher return periods (which have larger return levels) are already near to their maximum possible return levels. Although the atmosphere can hold more water vapour as it warms, the incremental change in these extreme events as the climate warms could become progressively smaller. The results may also reflect seasonal variations in precipitation extremes. Fowler and Wilby (2010) report an increase in extreme rainfall events in winter in Southeast England (including London), but little change in autumn and an increasing decline in summer for the 2020s and 2050s.

Based on the original Drain London surface water flood depth maps and residential building data it was estimated that 11,854 of the initial 95,561 houses in Camden were at risk of surface water flooding. Applying the flood depth-damage functions highlighted that the total damage to all properties at risk of surface water flooding could reach £204 million.

4.2 Surface water flood risk of houses modelled in the ABM

Figure 3 highlights how the level of surface water flood risk to properties changes over time under experiment 1 (see Table 2), and provides a baseline case on which to compare the other experiments. The points reflect the annual results for each of the 100 model runs for each climate scenario (and illustrate an increase in variability between the runs over time), with a smoothed line of best fit. We test these 30 year simulations against the three climate scenarios mentioned above: baseline, 2030s and 2050s. Note that these scenarios are stationary so the climate is not simulated to change during any given simulation. The changing flood risk therefore reflects the dynamics of changing flood vulnerability in the ABM.

The key driver of the upward trend in surface water flood risk seen is the development of new properties over time, often in areas of high flood risk (the number of properties at risk of flooding increase to around 16,250 houses by the end of the 30 year period), which drives up the overall flood risk of the area. Comparing across the climate scenarios the average surface water flood risk of properties increases, by up to 80% by year 30 in the 2050H scenario.

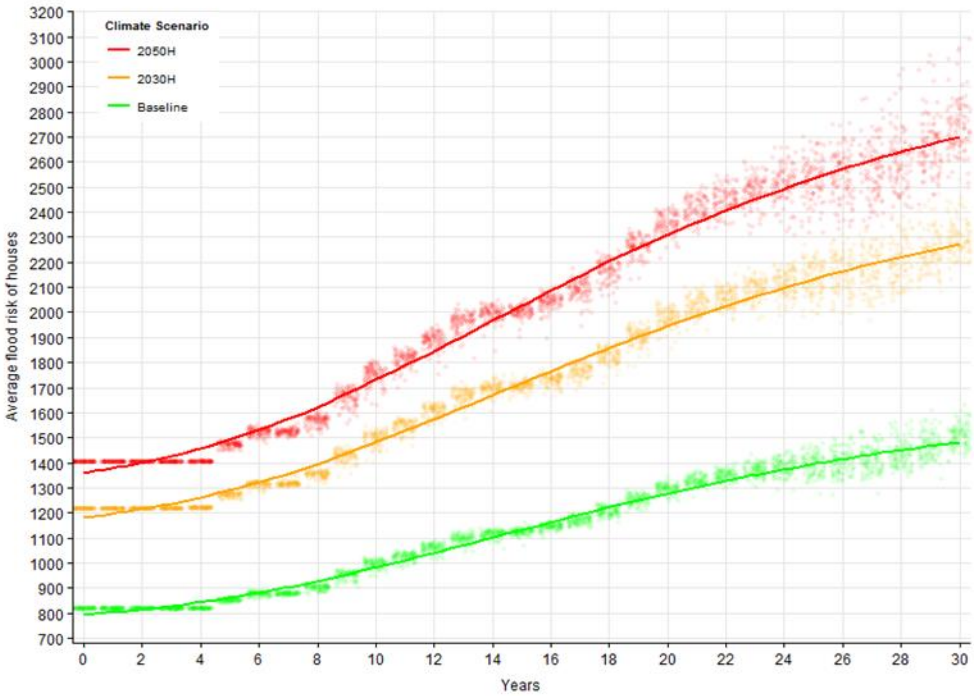

Figure 3: The average annual flood risk of houses susceptible to surface water flooding.

4.3 Modelling the effect of surface water flood risk management options

The ABM was used to test the role of different structural adaptation options and insurance for influencing surface water flood risk levels (table 2). The results illustrate the upper and lower bounds of the different options modelled, and potential benefits and limitations of different combinations of options.

For the baseline climate scenario, figure 4 highlights how the implementation of PLPMs (experiment 4) or SUDS (experiment 3) in the model acts to reduce the trend in the average surface water flood risk of houses over time, by around 10% and 15% respectively by year 30. The effectiveness of investment in SUDS and PLPMs are initially very similar even though installation of SUDS is assumed to reduce the potential flood damage by 35%, whilst installation of PLPMs are assumed to reduce the potential flood damage by 75%. And secondly, given that annually a larger number of properties are protected by PLPMs than SUDS (reflecting the underlying model assumptions outlined in section 3.2). This reflects the rationale of the local government in the model to build surface water flood defence projects in areas at highest risk of surface water flooding where the economic benefits and level of risk reduction will be the greatest (figure 5). This is compared to people who are assumed to invest in PLPMs in a less rational manner in the model, reflecting broader anxiety and emotions (Harries 2012).

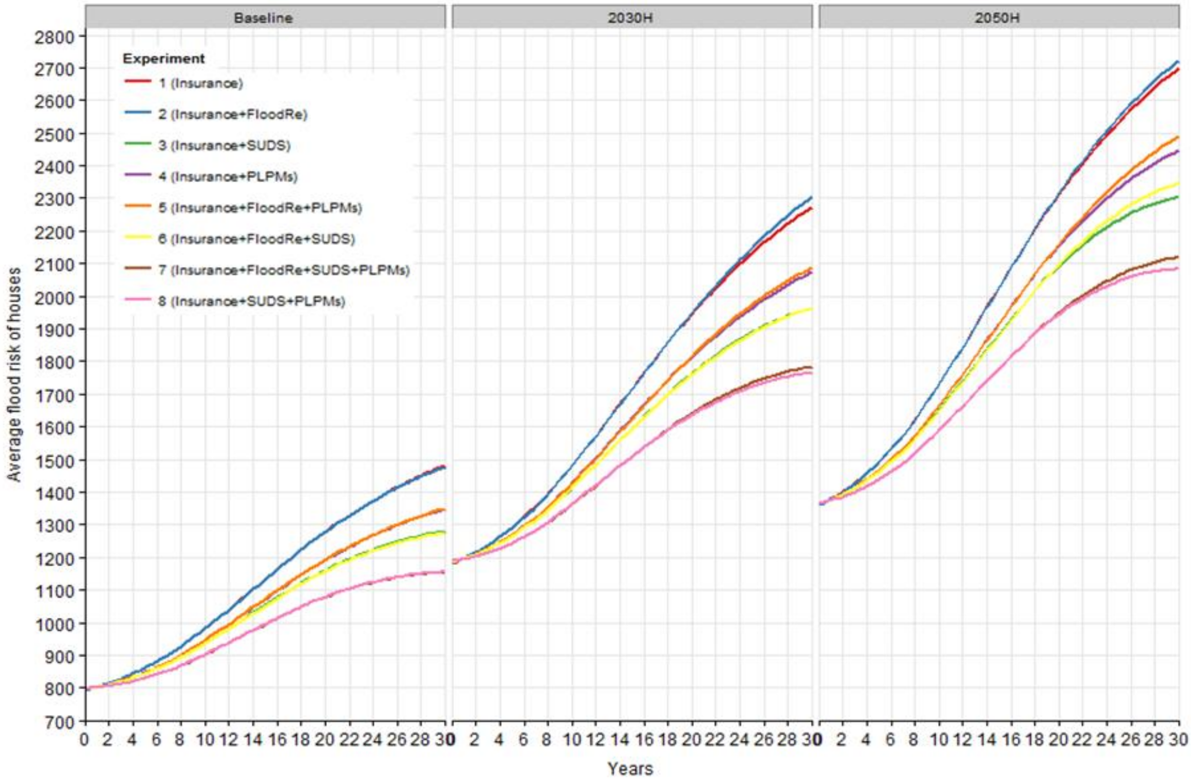

Fig. 4: The average surface water flood risk calculated for each of the experiments under the baseline, 2030H and 2050H climate scenarios.

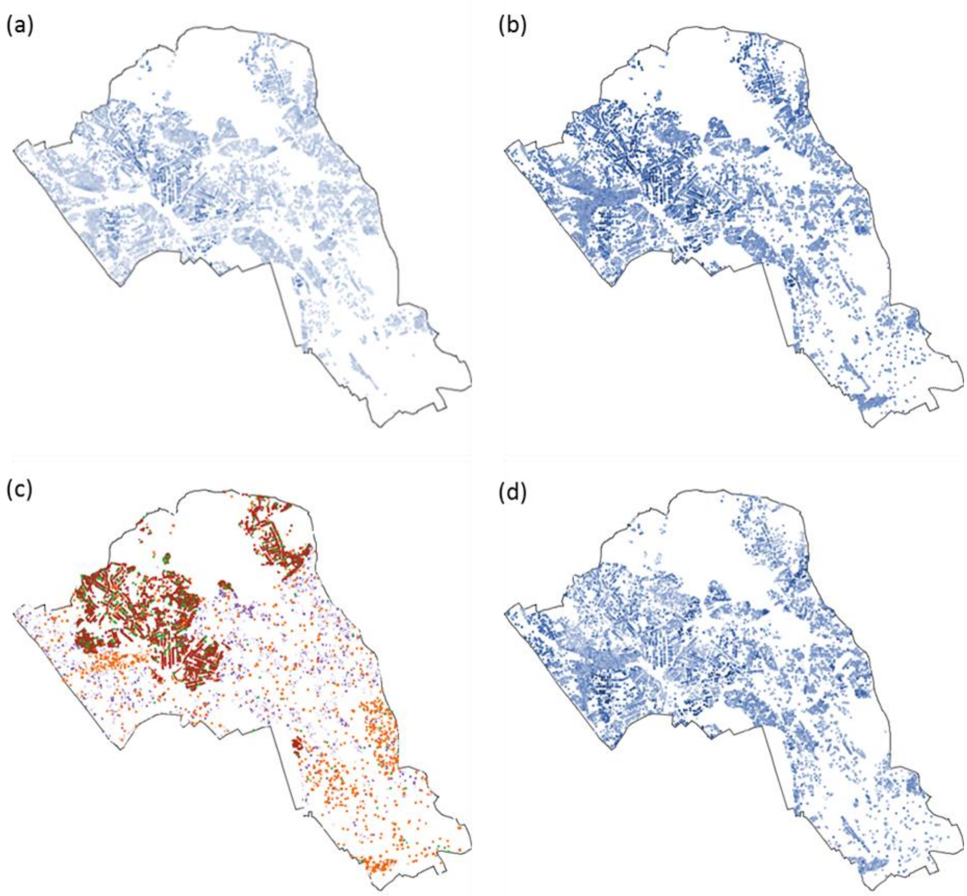

Figure 5: Image (a) shows the initial surface water flood risk to houses in Camden at the start of a single model run for the 2050H climate scenario (darker blue indicates higher flood risk); (b) shows the surface water flood risk in year 30 under experiment 1. In comparison, (c) shows the spatial pattern of investment in flood protection (red reflects investments in flood defences by the local government; purple shows PLPM investments; and green reflects properties that have both) under experiment 7; (d) highlights the related level of surface water flood risk for experiment 7.

The greatest benefits are seen in Experiments 7 and 8 where investments are made in both SUDS and PLPMs options, with a 23% decline in risk by year 30 compared to the insurance only experiment for all three climate scenarios. In comparison the experiments which include Flood Re suggests that this has no benefit in terms of overall risk reduction. In fact, in the 2030H and 2050H climate scenarios the opposite effect is seen with slightly higher levels of overall flood risk emerging by year 30. This trend is an indirect result of the positive effects of Flood Re on the broader housing market in terms of house prices and the number of foreclosures (see Section 4.4). Within the model annual house sales and developments fluctuate in a single model run. In the years where a lot of trade is seen between homebuyers and sellers, the developer is not as active in the market. However, after several years of growing house sales the related increase in house prices means that home buyers start to search for different more affordable options, at which point the developer addresses this demand by developing more properties (Dubbelboer et al., Forthcoming). This fluctuation repeats itself several times during most model runs. Consequently, as house prices rise so does the investment in new developments, often in high flood risk areas, and consequently overall flood risk rises.

Figure 4 also highlights how the average household surface water flood risk continues to increase over time regardless of investment in risk reduction measures due to continued development of properties in flood prone areas. Whilst more stringent controls on the developer would reduce this risk it highlights the real pressure local governments are put under by central government to develop more houses, and trade-offs which must be made when addressing flood risk and housing shortages.

The results also highlight the role of climate change in driving surface water flood risk. In the worst case (experiments 1 and 2) average flood risk of susceptible houses in year 30 increases by 53% and 80% from the baseline in the 2030H and 2050H scenarios. Even in the best case (experiments 7 and 8) where there is combined investment in flood risk management options the level of risk continues to increases above the worst case baseline scenario, being 13% higher under the 2030H scenario and 33% higher under the 2050H scenario. This highlights the imperative to design surface water flood risk management strategies with climate change and future levels of risk in mind if impacts and costs are to stay at or below present levels.

Figure 6 highlights that Flood Re does achieve its purpose of keeping insurance premiums affordable for high risk properties, however we also find that the current insurance set up and the Flood Re scheme does not enhance surface water flood risk reduction (figure 4). Under the baseline climate scenario household flood premiums initially remain below the thresholds where it would become economical to pass properties into Flood Re, and as such this has limited effect on average flood premiums in the first 8 years. However, as premiums increase (reflecting the increased risk highlighted in figure 4), the potential benefits of PLPMs and SUDS for risk reduction and premiums are emphasised. The inclusion of Flood Re further reduces average premiums, from approximately £650 to £280 in the baseline scenario. Even under future climate change scenarios average premiums are limited to £450 - £550 by year 30[7], with a clear divergence in results which include/exclude Flood Re. The experiments without Flood Re illustrate much higher and steeper increases in average flood insurance premiums, upwards to £1700 under the 2050 high scenario. The implications of this in terms of the solvency of the Flood Re scheme are discussed below.

An interesting observation is that the investment in SUDS or a combination of SUDS and PLPMs can stabilise insurance premiums over time – a clear indicator that surface water risk management is essential in maintain the viability of flood insurance.

[7] It should be noted that the results of the model simulation are run for 30 year time-slices which represent the stationary flood event time series data, centred on the baseline, 2030H and 2050H time-periods, so as to sample stochastic variability in this time series. As such in these examples it is assumed that Flood Re is operational for this period of time and the transition to risk based pricing is not represented here. Further research not presented here focuses explicitly on modelling different mechanisms for this transition, and associated consequences.

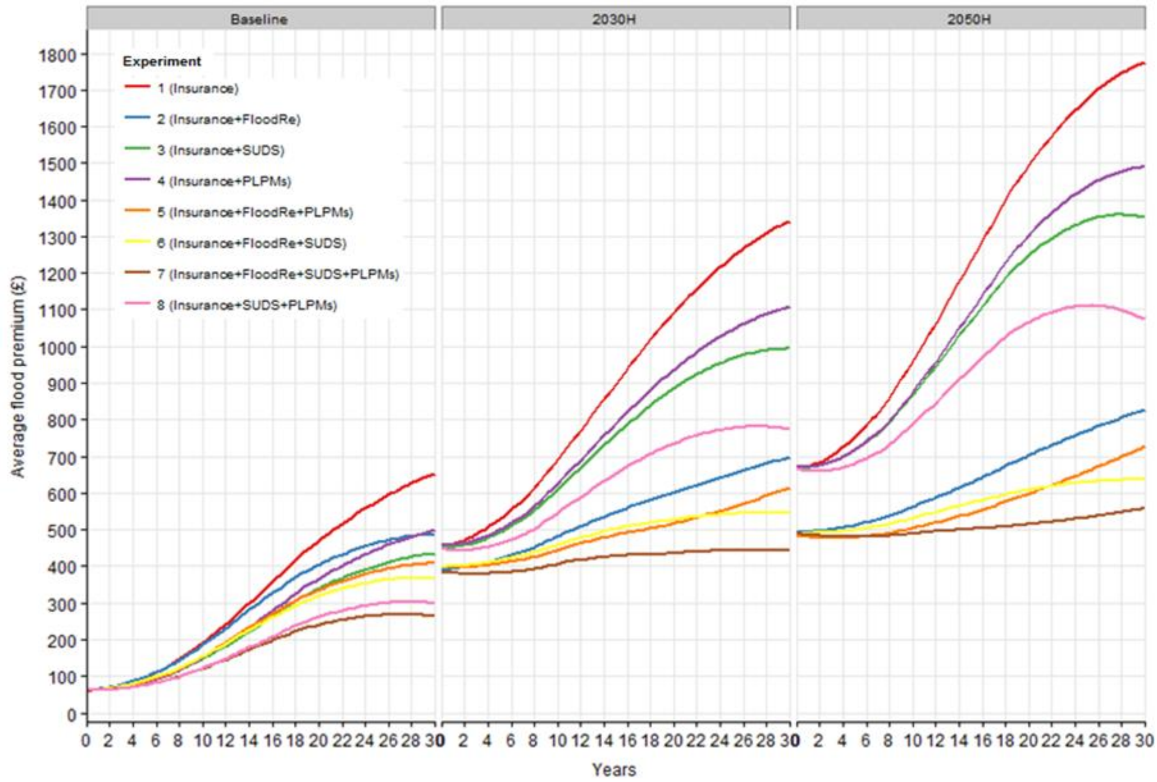

Fig. 6: Average flood premiums of houses in risk for each of the experiments under different climate scenarios.

Importantly, Flood Re has been designed to be as a transitional solution, with an anticipated life of 25 years, over which time the scheme will transition to more risk-based pricing in a competitive insurance market. A key issue is how the scheme will cope with the increasing gap between subsidised and risk based premiums given urbanisation and climate change. The potential gap is highlighted through the comparison of experiments with and without Flood Re, with increasing divergence over time and across the climate scenarios. In the baseline scenario the gap by year 30 between the best and worst estimates of average premiums is £375, and under the 2050H scenario £1210.

Furthermore, while our simulations indicate that Flood Re could ensure the affordability of insurance to homeowners, even under future climate change, this is modelled here without constraint on the number of properties which can be placed into Flood Re. An extension of Flood Re could have significant consequences for Flood Re's funds and reinsurance cover, with affordable cover becoming harder to sustain under the future scenarios. Figure 7 demonstrates that in the baseline scenario there is initially limited demand for Flood Re. Coinciding with the rise in surface water flood risk and premiums in the study area there is a sharp increase in properties eligible for the scheme, ranging from 20-75%, depending on the climate change scenario. The declining trend seen towards the end of the 30 year period reflects the increasing proportion of new build houses in flood risk which are not eligible for inclusion in Flood Re as they were built after 2009.

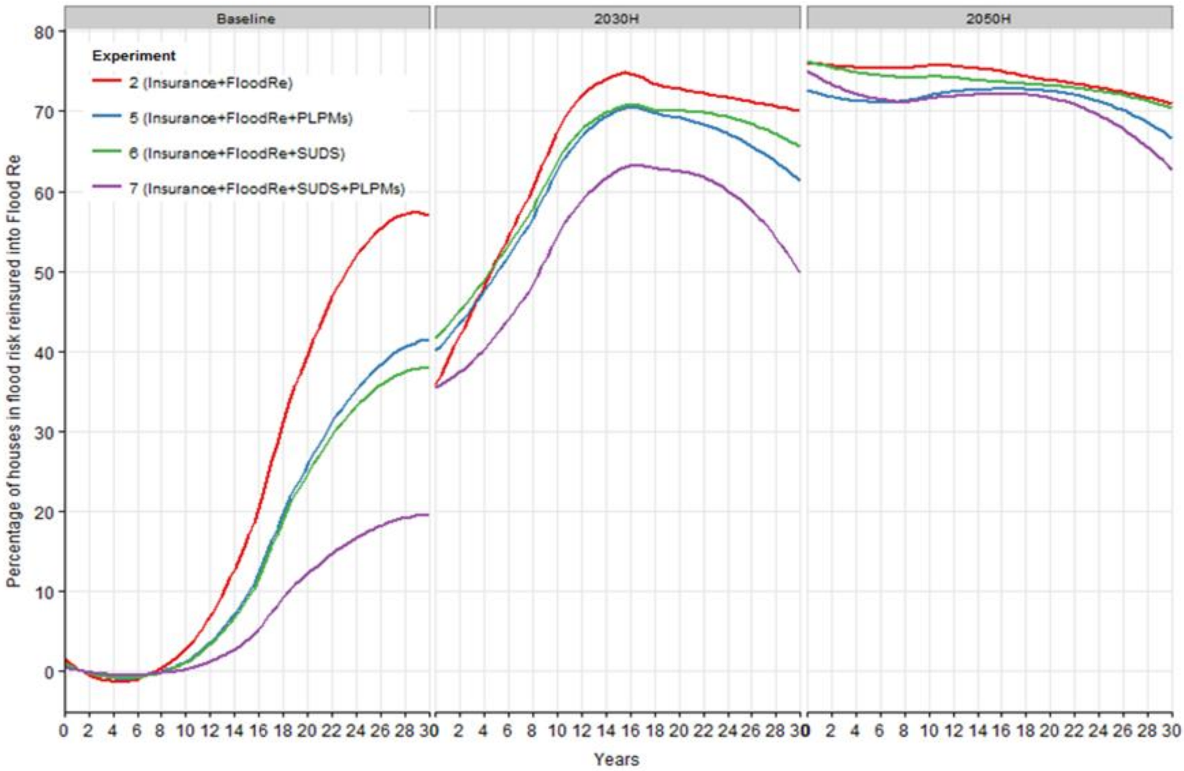

Fig. 7: The percentage of properties at risk of surface water flooding reinsured into Flood Re

Finally, while Flood Re does not directly incentivise investment in PLPMs or SUDS, a positive feedback is seen in that fewer properties are re-insured into Flood Re when such flood risk reduction measures are in place. This is as PLPMs and/or SUDS are accounted for when estimating the potential damage to properties affected by flooding, and consequently lowers the insurers estimate of flood risk of protected properties and in some cases the need to place the property into Flood Re. In these simulations a combination of insurance, SUDS, and PLPMs are shown to be most beneficial in terms of reducing the number of properties which are placed into Flood Re.

4.4 Surface water flood risk management and the local housing market

In addition to the proposed benefits of Flood Re on the continued affordability and insurability of houses, Defra also highlighted that the success of the scheme should be visible in terms of stability in local housing markets (Defra, 2014a). In the model simulations the Flood Re scheme is shown to alleviate unaffordable insurance premiums which has a marginal effect on the number of instances in which mortgage payments become unaffordable and houses are repossessed (foreclosed) by the bank. Figure 8 highlights the upper and lower bounds seen for the number of mortgage foreclosures of houses at risk of surface water flooding with Flood Re and risk management options (experiment 7) and without (experiment 1).

Initially mortgage foreclosures are extremely low in the case study area and reflect the real situation in Camden where mortgage based repossessions were estimated to be around 1% in 2014 (Shelter, 2014). However, in the model a steep increase in foreclosures is seen from around year 8, rising to around 14% by year 30 coinciding with the rise in surface water flood risk and premiums. In addition, the increasing insurance excess costs of houses affected by surface water flooding means that homeowners affected by flooding will have reduced savings to cover house fees and maintenance costs. In reality many factors can play a role in the resulting foreclosure of a property, the number of repossessions can fluctuate largely across years (*ibid.*), the process for repossession is more complex, and arrangements can be made with lenders to avoid repossession. In contrast, the model results reflect the simplified assumption that homeowners will always foreclose on their properties if they are unable to afford housing costs (including mortgage repayments and insurance) for three consecutive years.

The percentage of mortgage foreclosures declines from 13.8%-14.5% (dependent on the climate scenario) to around 13.5% by year 30. The effects are noticeable although slight, and Flood Re mitigates the additional risk seen under the future climate change scenarios.

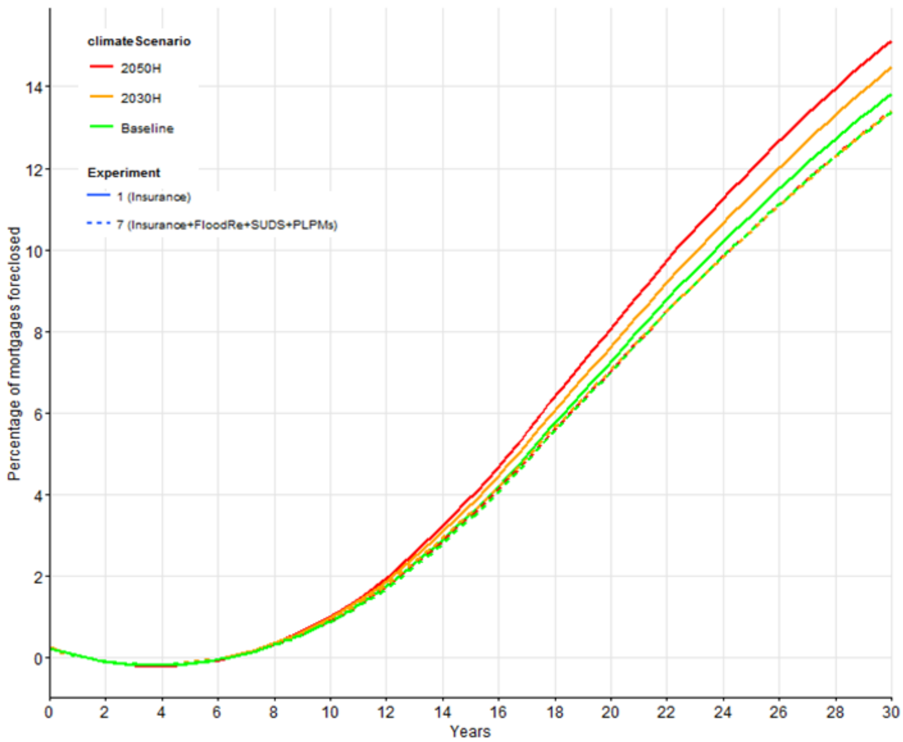

Fig. 8: The percentage of houses at risk of surface water flooding that are foreclosed as annual fees become too high

In comparison, for houses not at risk of surface water flooding around 5% are foreclosed by year 30. This difference reflects assumptions within the model on the risk perception of homebuyers, whereby 57% are assumed to consider a property's flood history and events which have occurred within three years when deciding on purchasing a property (Lamond et al., 2009). This can mean that houses at risk of surface water flooding remain on the market longer and the homeowner is at greater risk of foreclosing on the property.

Figure 9 shows the average house values of properties at risk of surface water flooding for experiments 1 and 7, highlighting the limited effect of overall flood risk (illustrated by the climate scenarios) on the broader housing market. From around year 18 a small, but positive, effect can be seen where Flood Re is implemented alongside investment in PLPMs and SUDS. This is primarily due to a lower number of properties being foreclosed and subsequently sold by the bank at a lower value than would otherwise be the case. In all cases average house prices continue to rise in the model. Across all houses in the model, both in and out of flood risk, average house values are estimated to increase steadily on average of 4.5% a year. The 5 year forecast 2015-2019 of Savills (2014) projects an expected annual growth of 5% in Central London. Even though the house values estimated internally are a result of the emergent behaviours of agents buying and selling houses in the ABM, the model does shows plausible dynamics of future house prices in line with this forecast data.

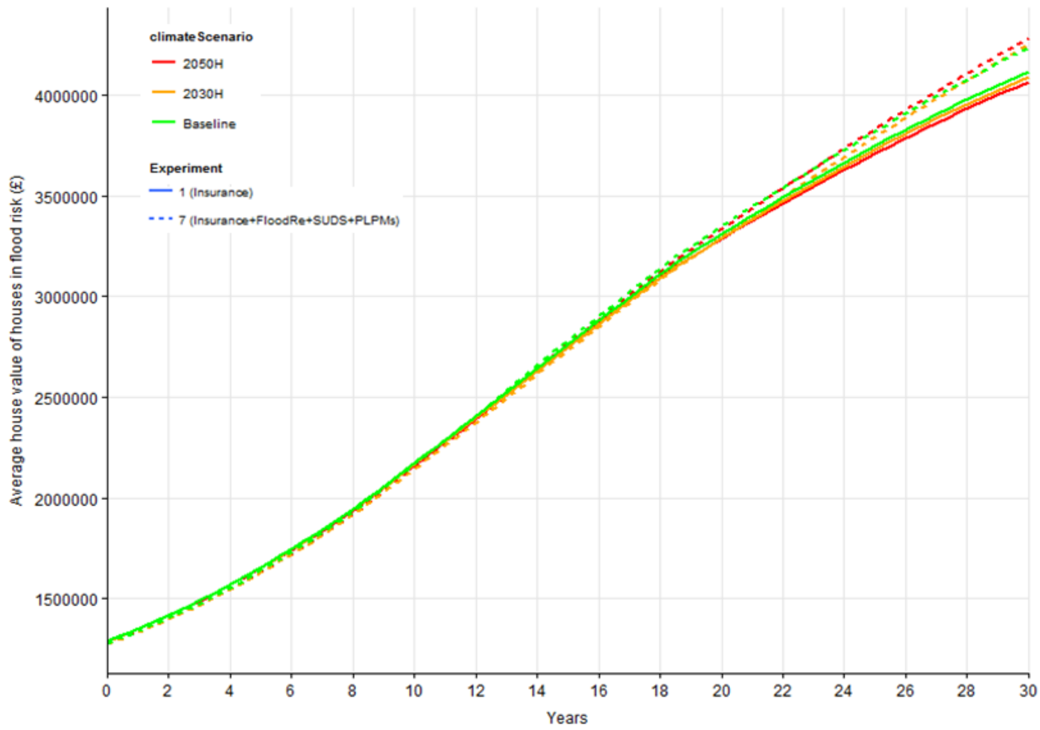

Figure. 9: The estimated average value of houses at risk of surface water flooding in Camden

5. Discussion

The paper presents an ABM developed to model the dynamics of surface water flooding, changing surface water flood risk, and how adaptation and insurance decisions could affect future surface water flood risk in that dynamic. While the focus of this paper is a case study of Camden the modelling approach is applicable to the broader situation in Greater London and could be extended to other areas in the UK or specific situations in other countries (dependent on availability of relevant data and computational resources). The analysis is novel due to its dynamic nature and as different combinations of surface water flood risk management options can be modelled, to include structural adaptation options, insurance, and the specific case of Flood Re.

The potential of using an ABM to support policy making and testing different conditions has been shown. Filatova (2015) highlights the need to move from conceptual modelling experiments to simulating real life situations through the use of available data if an ABM is to be applied for policy analysis and seen as robust by relevant stakeholders. In this example, the model has been parameterised based on a large array of data sources, developed around GIS data to allow a realistic representation of residential buildings and surface water flood risk, and repeated simulations carried out to provide an assessment of uncertainty.

However, a limitation of this design is that the ABM inevitability becomes more complex and as with all ABMs the results must be carefully interpreted given the underlying assumptions which are necessary given this complexity, availability of literature, and data sources. For example, in the version presented it is assumed that SUDS and PLPMs do not fully mitigate flood risk but reduce damage homogenously across the study area; there are no constraints on the number of properties ceded into Flood Re or the available assets of the scheme; and certain behaviours such as the process of mortgage foreclosures and how insurers consider the implementation of SUDs and PLPMs are simplified.

Nevertheless, the ability of the framework to incorporate different agents with their own behaviours; flexibility for testing different conditions and behavioural rules; flexibility to test and evaluate different policies and options; and the ability to visualise and quantify this in a spatial and dynamic manner, highlights the potential benefits of such an approach to support and inform decision making with regard to surface water flood risk and management strategies. The flexibility of this approach will benefit from future stakeholder engagement, input, and evaluation.

Overall, the ABM highlights how climate change and socio-economic development can exacerbate current levels of surface water flood risk in Camden, with an increase in the average risk to properties of up to 80% by year 30 under the 2050H scenario. Surface water flood risk also increases over time under each climate scenario, reflecting the continued development of properties in areas of flood risk in the model.

Our analysis of different response mechanisms and interventions indicates that the implementation of SUDS and PLPMs, as recommended by the government in its National Adaptation Programme (HM Government, 2013) are beneficial for reducing surface water flood risk. In the model, investment in SUDS reduced the trend in the average surface water flood risk of houses by 15% by year 30.

The most beneficial result for surface water flood risk reduction was a combination of investment in both PLPMs and SUDS. This highlights the need for further investment and provision of grants for PLPMS and adds support to the current reviews and government led pilot schemes into PLPMs being undertaken in the UK. However, Ball et al. (2013) found that the insurance industry remained doubtful that PLPMs provide a foundation for lowering policy costs or excesses: how PLPMs can actually be assessed consistently and accurately once in place remains an issue, but recent cost-effectiveness results paint a more positive picture (Defra, 2014b).

In our model even with SUDS and PLPMs in place the average surface water flood risk continued to increase over time, and under no experiment did it stabilise or decline in the model. Given the implications of climate change on surface water flood risk this illustrates the danger of further trade-offs between future development plans and flood risk management.

For insurance our model shows that Flood Re would achieve its aim of securing affordable flood insurance premiums, while potentially having positive feedbacks to the stability of the broader housing market by marginally enhancing the value of properties in surface water flood risk areas and reducing mortgage foreclosure levels. However, our findings also clearly highlight that the new pool would be placed under increased strain if challenged with increasing risk as highlighted by the future climate change projections.

In our model, Flood Re has no additional benefits in terms of overall risk reduction. This supports concerns that the new scheme is missing an opportunity to contribute to risk reduction, which is important to its own resilience under future climate change. It also raises concerns about issues of moral hazard as it could de-incentivise flood risk reduction at a household level and dissuade homeowners from investing in PLPMs while in place (Surminski and Eldridge, 2015). However, for incentives to reduce surface water flooding to be successful, they need to target those who can take action. This goes beyond homeowner and government – and needs to include all those who determine if, where and how houses are being built, refurbished or repaired, including property developers, mortgage providers and local planning officials (the analysis and discussion of which will be presented in a parallel working paper).

This is a key design issue for Flood Re – in its current format there is no remit and no funding to foster such a resilience-enhancing role. This is particularly important as Flood Re has been designed to be a transitional solution, with an anticipated duration of 20-25 years, smoothing the way to risk-based pricing in a competitive insurance market in the future.

Several of the questions addressed in our analysis have particular relevance for Flood Re's transition process, which will determine if and how the new scheme operates over time. Overall flood risk trends, including surface water, provide the backdrop against which Flood Re needs to fulfil its legal obligation of providing affordable flood insurance over its 25 year life-time. Our analysis provides insights on the different pathways and measures available in response to rising risk levels, and the implications on pricing and scale of Flood Re. A key issue will be how the increasing gap between the level of premiums paid by high risk properties and the risk based value they would face outside this scheme is addressed and managed over time. The potential gap is highlighted through the comparison of experiments with and without Flood Re, with increasing divergence over time and across the climate scenarios (figure 6).

The ABM also provides a framework to further investigate how changes to regulatory measures and the roles and behaviour of stakeholders could be enhanced to support surface water flood risk reduction under future climate change. Collaboration between the national and local authorities, planners, and developers is crucial. Planning guidelines have been tightened under the National Planning Policy Framework (DCLG, 2012) and subsequent amendments for inclusion of SUDS in developments of 10 or more properties in 2015 (DCLG, 2014). However, the economic benefits of developments and demand for housing provide a case for developers to continue to build on high flood risk land, and for LAs to approve such developments. While the EA is able to oppose developments at high levels of flood risk it is ultimately down to the LA to make the decision. The ASC (2012) has raised concerns that there is still limited consideration of future risk under climate change within the approval process, and the actual levels of uptake of the EAs recommendations is not sufficiently transparent or accountable.

6. Conclusion

Whilst there is extensive literature on fluvial and coastal flood risk, surface water flood risk has received less attention both nationally and internationally. In the UK there are still major gaps in the understanding and management of risks from surface water flooding, and the need for fundamental changes in how we adapt to such challenges in the future. The number of stakeholders involved, and varying degrees of responsibility across government and other agents further complicates the ability to manage risk in an integrated manner. The example of flood insurance highlights this. One the one hand there is the (political) quest to keep flood insurance affordable, while improved risk data and a growing recognition of the challenge of surface water flooding suggest that the technical price of insurance should be rising. This then requires some form of subsidy –either indirect as seen under the SoP arrangement, or direct, as proposed through Flood Re, to make insurance more economical for those at higher risk.

Our particular interest in the interactions between flood insurance in the UK and surface water flood risk management stems from the current changes facing the industry with the introduction of the new Flood Re pool expected in 2016. Our analysis suggests that the efforts to reform the insurance arrangements have been predominantly focused on dealing with the affordability of insurance, without considering the implications of alternative mechanisms for managing and reducing the underlying risks. Reflecting on evidence emerging from other European and international flood insurance schemes, we notice that this is not an exception, but rather the norm (Surminski and Eldridge, 2015).

The provision of flood insurance is influenced by public policy – directly through regulation such as mandating cover or instigating the development of new schemes. And indirectly by providing the enabling infrastructure and environment, for example through a broad risk reduction framework, including building codes and better flood risk data provisions. This point is particularly relevant in the context of surface water flooding. Depending on its design and implementation, an insurance scheme can send signals to policy makers in support of flood risk management policies, which would address risk levels, for example through changes in the planning system and building regulations. Our investigation finds that the new Flood Re scheme does not enhance this policy link nor the incentivisation of home resilience, which is a missed opportunity. Until now this issue has not received sufficient attention due to lack of data or analysis.

The ABM and analysis presented reflects on current policy in terms of planning, national and local adaptation, and flood risk management. However, it highlights that there is still discord between these. The potential of integrating these options and using Flood Re along with other measures such as grants for PLPMs and enhanced planning policy can be investigated through the ABM and results quantified to account for the role of different actors, changing risk under future climate change, and potential uncertainties.

Our findings directly feed into the question of transition planning, which is a fundamental pillar of Flood Re. This analysis suggests further policy on planning developments, increased investment in SUDS for new and existing properties, and investment in PLPMS is required. The forthcoming Flood Re scheme could help with this transition if it were able to incentivise such measures. These issues are likely to become more apparent under climate change and urbanisation and need to be considered within the framework if areas like Camden are to become more resilient to surface water flood events in the future.

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