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Working Paper 03: Strengthening insurance partnerships in the face of climate change – insights from an agent-based model of flood insurance in the UK.

Authors: Florence Crick (The Grantham Research Institute on Climate Change and the Environment, London School of Economics), Katie

Jenkins (Environmental Change Institute (ECI), University of Oxford), Swenja Surminski (The Grantham Research Institute on Climate Change and the Environment, London School of Economics)

Title	STRENGTHENING INSURANCE PARTNERSHIPS IN THE FACE OF CLIMATE CHANGE – INSIGHTS FROM AN AGENT-BASED MODEL OF FLOOD INSURANCE IN THE UK.
Author(s)	Florence Crick, Katie Jenkins and Swenja Surminski
Organization	The Grantham Research Institute, London School of Economics, and Environmental Change Institute, University of Oxford

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Executive summary

Multisectoral partnerships are increasingly being mentioned as a mechanism to deliver and improve disaster risk management. Yet, partnerships are not a panacea and more research is required to understand the role that they can play in disaster risk management and particularly in disaster risk reduction. In this paper, we investigate how partnerships can incentivise flood risk reduction by focusing on the UK public-private partnership on flood insurance. Developing the right flood insurance arrangements to incentivise flood risk reduction and adaptation to climate change is a key challenge. While expectations of the insurance industry have traditionally been high when it comes to flood risk management, the insurance industry alone will not provide the solution to the management of rising flood risks due to climate change and socio-economic development. In addition, faced with these risks insurance partnerships can no longer afford to focus only on the risk transfer function. The case of flood insurance in the UK illustrates these challenges: even national government and industry together cannot fully address these risks and other actors need to be involved to create strong incentives for risk reduction. Our paper investigates this for the specific issue of surface water flood risk in London. Using an agent-based model we investigate how other agents could strengthen the insurance partnership by maintaining affordable insurance premiums and reducing flood risk and test this for the new Flood Re scheme. Our findings are relevant for wider discussions on the potential of insurance schemes to incentivise flood risk management and climate adaptation not just in the UK but also internationally.

Contents

1 Introduction

The risk of climate-related disasters and the economic losses arising from these has been increasing across the world in the last few decades and will continue to do so as a result of climate change and socio-economic development (IPCC, 2012). To manage these risks and improve society's ability to prepare for, respond to and recover from disasters, there have been growing calls for greater collaboration and partnerships between the public, private and civil society sectors. While disaster risk management has traditionally involved the activities of multiple actors across different sectors, the last couple of decades have seen a shift towards a greater diversity of actors being involved and the development of stronger and more formal collaborations and partnerships (Meijerink & Dicke, 2008; Walker et al, 2010).

These multi sector partnerships (MSPs) are increasingly seen as critical for the delivery of sustainable development goals and improved disaster risk management. For example, the UNISDR's 2011 Global Assessment Report on disaster risk reduction identified fostering partnerships as a key element for successful disaster risk management across governance scales and development sectors (UNISDR, 2011). That report recommends adopting innovative local partnerships between civil society, private sector and local and central governments to ensure that land use management policies and building regulations do not increase risk but instead reduce it (UNISDR, 2011). The recent Sendai Framework for Disaster Risk Reduction 2015-2030 highlights that disaster risk reduction requires the engagement of a variety of actors across sectors, partnerships between different stakeholders and across governance levels, and a clearer definition of responsibilities across public and private stakeholders (UN, 2015). In addition, in 2015 the Disaster Risk Reduction Private Sector Partnership adopted five visions for a resilient future, one of which specifically focuses on strong public private partnerships to drive disaster risk reduction at local and national levels (UNISDR, 2015).

Despite the growing calls for partnerships in disaster risk management, there has been little research examining how effectively they can help reduce the risk from disasters and there remains a lack of clarity around the roles of public, private and civil society actors, and how they can act together. Indeed, a critical issue is how to bring together those actors that can really bring about change. Furthermore, partnerships for disaster risk management are usually not static and may evolve over time, as they will be affected by a range of factors, including population growth, development trends and changing climate risks. This can have implications for the membership as new or different partners may be needed to fulfil the aims of a partnership. Partnerships and disaster risk management activities also often operate at different scales, with many partnerships formed at the national level while many risk management activities are implemented locally.

In this paper, we investigate the role that partnerships can play in incentivising flood risk reduction by focusing on the arrangements between the UK government and the insurance industry. This partnership was first established in 2000 (known as the Statement of Principles (SoP)), reviewed in 2007 following major flooding throughout the UK and finally modified into a new partnership in 2016 with the creation of Flood Re. The flood insurance partnership is coordinated at the national level and represents a compensation measure to households in response to any flood loss, including river, coastal, and surface water flooding. While Flood Re is presented by industry and government as an innovative way of securing future affordability and availability of flood insurance, there are concerns about its ability to achieve its aim of providing a transition to a market with risk reflective pricing where insurance remains affordable and widely available (Hjalmarsson and Davey, 2016), especially because in its current set-up it does not provide any direct means to encourage risk reducing behaviour. Although risk reduction was identified as one of the design principles for future flood insurance at the start of the negotiations for a renewed partnership (Defra, 2011b), it is no longer a central aim of the new insurance partnership, which represents a missed opportunity (Surminski and Eldridge, 2015). Indeed, a recent study by Jenkins et al (2016) finds that in its current format the partnership does not incentivise flood risk reduction and will therefore face the key issue of how to address and manage over time the increasing gap between levels of premium paid by high risk properties and the risk based value they would face outside this scheme. In addition, the UK Committee on Climate Change find that in its current design Flood Re is likely to be counter-productive to the long-term management of flood risk as it does not provide enough incentives for high-risk households to put measures in place to avoid or reduce flood damage (Committee on Climate Change, 2015). Recognising its lack of potential to directly influence risk reduction, Flood Re identifies in its transition plan the need to build strong partnerships with a range of actors from the public, private and civil society sectors as a key strategy to ensure a successful transition phase (Flood Re, 2016).

We explore how the flood insurance partnership could be strengthened by using an agent-based model (ABM) to test how to best incentivise surface water (SW) flood risk reduction. Surface water is the least understood of the flooding risks and yet represents one of the biggest potential impacts of climate change on the UK (Defra, 2012). In fact, the 2007 floods across the UK, which differed in scale and type from previous floods as a much higher proportion of flooding than normal came from SW flooding (EA, 2007), were a major trigger for the proposed changes to the insurance partnership and eventually led to the development of Flood Re. SW flood risk management has also been assessed by the UK's Committee on Climate Change as a key adaptation priority where insufficient progress has been made in managing vulnerability and providing a plan of action (Committee on Climate Change, 2015). Using the ABM, we investigate how the inclusion of other agents, namely property developers and local government, could enhance the risk reduction potential of insurance and test this for the new Flood Re scheme. In addition, this novel approach allows us to examine whether there may be trade-offs between the goals of maintaining affordable insurance premiums and reducing SW flood risk, as well as the complexities of identifying the most appropriate balance in the role of different actors to incentivise SW flood risk reduction.

2. The role of insurance partnerships in disaster risk reduction

In general terms, partnerships can be defined as "collaborative arrangements in which actors from two or more spheres of society (state, market and civil society) are involved in a non-hierarchical process, and through which these actors strive for a sustainability goal" (Van Huijstee et al, 2007: 77). Collaborative partnerships focus on the "fulfilment of an agreed common goal, the sharing both of responsibilities and of risks and the transfer of skills and know-how between partners" (Castan Broto et al, 2015: 573). Within the context of natural disasters, the overall shared goal for partnerships would be a reduction of risks and an increase in resilience. Examples include retrofitting of buildings to new standards, delivery and dissemination of extreme weather warnings, raising risk awareness, sharing risk information, improved risk mapping tools, provision of disaster related services in disaster response and recovery phases, and the use of improved risk information for the development of risk financing schemes that cover large losses after catastrophic events (CEA, 2007; Stewart et al, 2009; Tompkins and Hurlston, 2010; NRC, 2011; Chen et al, 2013; Bajracharya and Hastings, 2015). These partnerships offer several benefits, including bringing together a range of expertise and resources, the ability to link actors operating at different scales, and a decentralised and flexible structure that can deal with uncertain futures and changing development demands (Sherlock et al, 2004; Forsyth, 2007; Morsink et al, 2011; Pinkse and Kolk, 2012; Castan Broto et al, 2015; McAllister and Taylor, 2015). Yet, partnerships also face key challenges including the need to reconcile diverging interests and expectations, align incentives and maintain trust between the different partners (Chen et al, 2013; Bajracharya and Hastings, 2015).

Flood insurance partnerships offer important insights, as they highlight the difficulties in moving from a narrow insurance approach to a much more holistic and joint-up flood risk management strategy. The European Insurance industry views partnerships as vital for reasons of insurability, risk transfer and ensuring the use of appropriate adaptation and prevention measures (CEA, 2007). In the wake of recent natural disasters there has been growing interest from policy makers, practitioners and academics in the use of insurance as an economic disaster risk management tool to encourage prevention efforts and reduce physical flood risk (Crichton, 2008a and 2008b; IPCC, 2012; Surminski, 2014; Surminski et al, 2015). In theory, when the premium is priced in line with the risk, insurance can act in two fundamental ways: first it can prevent settlement in an area of high flood risk if the premium is high enough to act as a deterrent; and secondly, it can encourage adoption and installation of mitigation measures if these lead to an insurance discount (Filatova, 2013; Kunreuther and Michel-Kerjan, 2009). There are many flood risk management options in different sectors that flood insurance may incentivise, including flood proofing of buildings and property, retrofitting of houses, local flood protection measures, and building larger scale flood protection schemes (Bräuninger et al., 2011).

Yet, there is to date limited evidence in practice of the success of insurance in encouraging risk reduction behaviour at the household level (Thieken et al, 2006; Treby et al, 2006; Crichton, 2008; Botzen et al, 2009; Lamond et al, 2009; McAneney et al, 2013). A range of barriers have been identified, including the absence of adequate risk-based pricing due to its conflict with affordability of cover (Kunreuther, 1996), mismatch between required prevention investment by policy holders and the premium savings, prevailing uncertainty about the benefits of risk reduction measures due to lack of standardised assessment methods, and the need for active involvement of policy holders to put in place and operate those mitigation measures (Bräuninger et al., 2011).

2.1 From the Statement of Principles to Flood Re: The evolving UK flood insurance partnership

The UK flood insurance partnership between the UK government and the Association of British Insurers (ABI) known as the Statement of Principles (SoP) was set up in 2000 in the wake of growing flood losses and set commitments from both the insurance industry and government to establish flood insurance provision (see Crick et al (2013) for further details on the SoP). In 2008, this agreement was extended for a final five-year period until 2013 and committed the government and insurance industry to a transition to a free market for flood insurance. However, sparked by concern about rising risk costs, the frequency of high loss events and the belief by the insurance industry that a free market might leave around 200,000 high risk homes struggling to afford cover (Committee on Climate Change, 2015) a modified version of the partnership was agreed in 2013 with the creation of Flood Re (see Figure 1), which started operations in 2016. Designed to secure affordable cover for properties at high risk of flooding, Flood Re complements the current insurance market, where private insurers are offering cover against flood damage as part of standard home insurance policies. The not-for-profit scheme offers flood insurance cover for households, with fixed premiums (ranging from £210 to £1200) dependent on council tax banding. In addition to these premiums, the scheme is funded by an annual levy taken from all insurance policy-holders, independent of their flood risk exposure, which is currently expected to be around £10.50 per policy, and will be imposed on insurers according to their market share. Premiums and levies will be reviewed every five years, with changes requiring the approval of the Secretary of the State. The scheme will be additionally 'topped up' through ad hoc contributions from insurers and will also be covered through reinsurance purchased to minimise large loss in any given year. New properties built after 2009 are excluded (Defra, 2013).

The UK government and insurance industry present Flood Re as a roadmap to future affordability and availability of flood insurance. Yet, there are already concerns that it does not sufficiently consider rising flood risks due to climate change and incentivise flood risk reduction or the improvement of the flood resilience of properties (Horn and McShane, 2013; Surminski and Eldridge, 2015; Hjalmarsson and Davey, 2016; Jenkins et al, 2016). This raises the question as to whether in its current format this new insurance partnership will achieve its aim of moving towards risk reflective pricing while maintaining insurance affordability in the face of rising SW flood risks and what role other actors could play to enhance the risk reduction potential of insurance.

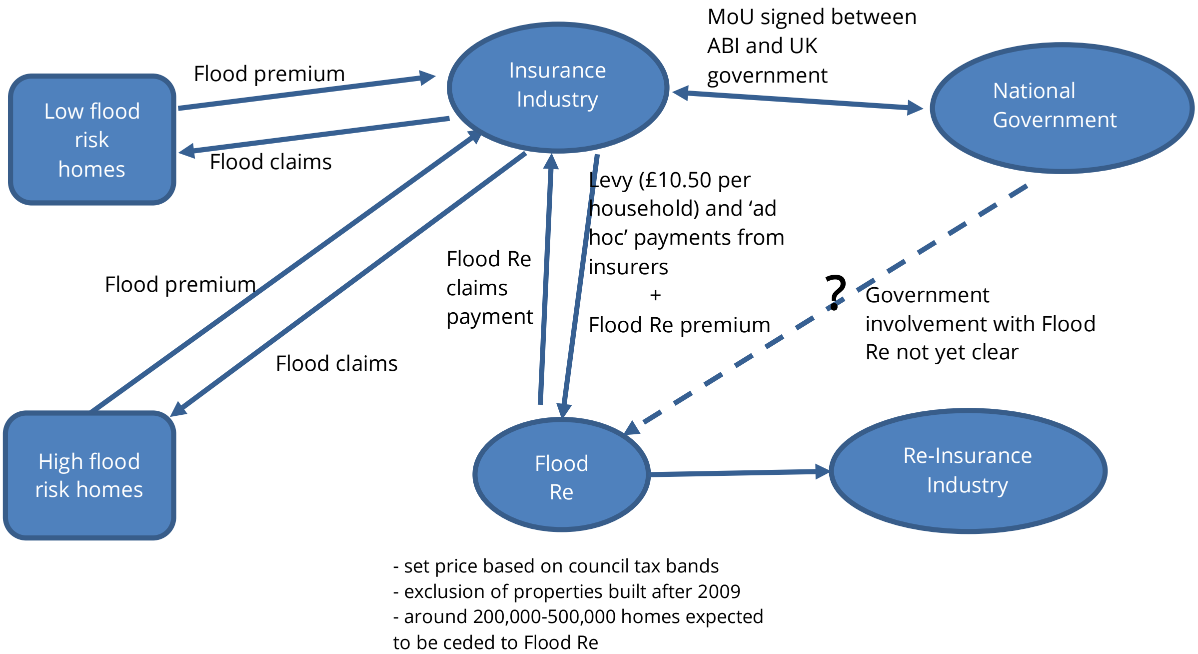

Figure 1. The new insurance partnership – Flood Re

2.2 Strengthening the insurance partnership by involving more actors?

The main aim of any insurance scheme is the compensation for damages and the funding of recovery efforts. In addition, there is scope to go beyond this basic principle and use insurance also to incentivise risk reduction and promote broader flood risk management activities. Yet, while expectations of the insurance industry have traditionally always been particularly high when it comes to flood risk management (cf. Kunreuther, 1996; Botzen and Van den Bergh, 2008; EEA, 2013), the insurance industry alone will not provide the solution to the management of rising flood risks. Private stakeholders beyond insurers have a critical role to play in incorporating flood risk reduction considerations into urban developments (Bosher et al, 2009; Bosher, 2012). In Figure 2, we identify the range of public and private stakeholders in England who are involved in the development process, from the concept of a building to actually delivering it on the ground. Nevertheless, many of the actors identified have not so far been actively involved in the management of flood risk and in particular SW flood risk. Indeed, there is a lack of clarity around how to engage these different actors for SW flood risk reduction and what actions they could take independently or in collaboration with the government. Figure 2 also highlights the key legislation and policies regulating and guiding the different actors during the different stages and the stages at which key flood risk aspects and potential flood risk reduction measures come into play. Bosher et al (2009) identified the pre-construction phase of a development as the most critical stage where key stakeholders should adopt flood risk reduction and prevention measures. Indeed, as shown in figure 2, this phase is the target of key planning and flood regulations (e.g. The Building Regulations 2010, Flood Risk Regulations 2009 and Flood and Water Management Act 2010) that require key actors to evaluate flood risk and integrate flood risk reduction measures. Property developers and local government are identified as critical actors in this stage. By contrast, figure 2 shows that insurers are only involved at the end of the development process, with limited ability to influence the initial phases.

In this paper, we specifically focus on property developers and local government, as key actors who make decisions about future flood risk levels. In the UK, while flood management responsibility, policy and legislation for England are determined by the national government, local governments are the ones with lead responsibility for managing local flood risk, which includes surface water runoff, and are designated as Lead Local Flood Authorities (LLFA). Under the National Planning Policy Framework, local authorities have to produce a Strategic Flood Risk Assessment (SFRA) that contributes to the Sustainability Appraisal of their development plans and their corporate approach to flooding. In addition, local governments have to produce Surface Water Management Plans (SWMPs) and Preliminary Flood Risk Assessments (PFRAs), which together with the SFRA and associated flood and hazard risk maps provide the necessary evidence base to support the development of their Local Flood Risk Management (LFRM) Strategies. Local governments are also the approving body for Sustainable drainage systems (SUDS). With regards to property developers, their role in flood risk reduction is generally mentioned in relation to the implementation of SUDS but rarely more broadly in terms of their role and responsibility when building in high flood risk areas and how they could engage with other actors, including insurers and local government, to reduce flood risk. Yet, the role of property developers in reducing flood risk and how they could collaborate with local governments to achieve this and in the longer term promote climate change adaptation is a key emerging area of research with important implications for policy (e.g. Handmer, 2008; Taylor et al, 2012; Taylor and Harman, 2015).

Property developers are involved right at the start of the development process (see Figure 2) and therefore have the potential to play a greater role in reducing and managing SW flood risks for new developments. Developing in the correct way and in the correct location will minimise current and future risks to both the development itself and the area surrounding the development. Only appropriate development can be located in the designated flood zones, with a preference for developments towards the lowest flood risk zone. Nevertheless, unless required by building regulations and planning policy there seems little incentive for these private sector actors to consider future risk levels. Indeed, Wynn (2005) found that the availability of land for development on a floodplain, and therefore at risk of flooding, did not deter developers from seeking planning permission. Both the old and new version of the insurance partnership do not apply to new buildings built since January 2009 based on the assumption that the planning system as well as increased awareness of developers should deliver and prevent new high risk properties from being built. How this is playing out in reality is less clear, as the burden of flood risk does not remain with developers, designers or planners. There is limited evidence if this 'disincentive' has worked. The effectiveness of the planning system remains a cause of debate, with around 12% of all new residential development in England between 2001 and 2014 occurring in floodplains, and around 25% of that floodplain development has been in areas at medium or high levels of flood risk (Committee on Climate Change, 2015). In addition, the annual rate of development on the floodplain is also higher than for areas outside of the floodplain and the annual rate of development in areas of high flood risk is higher than the average for the floodplain as a whole (Committee on Climate Change, 2015). The issue is problematic as property developers have only a limited interest in the insurability of the new homes, not beyond the point of sale.

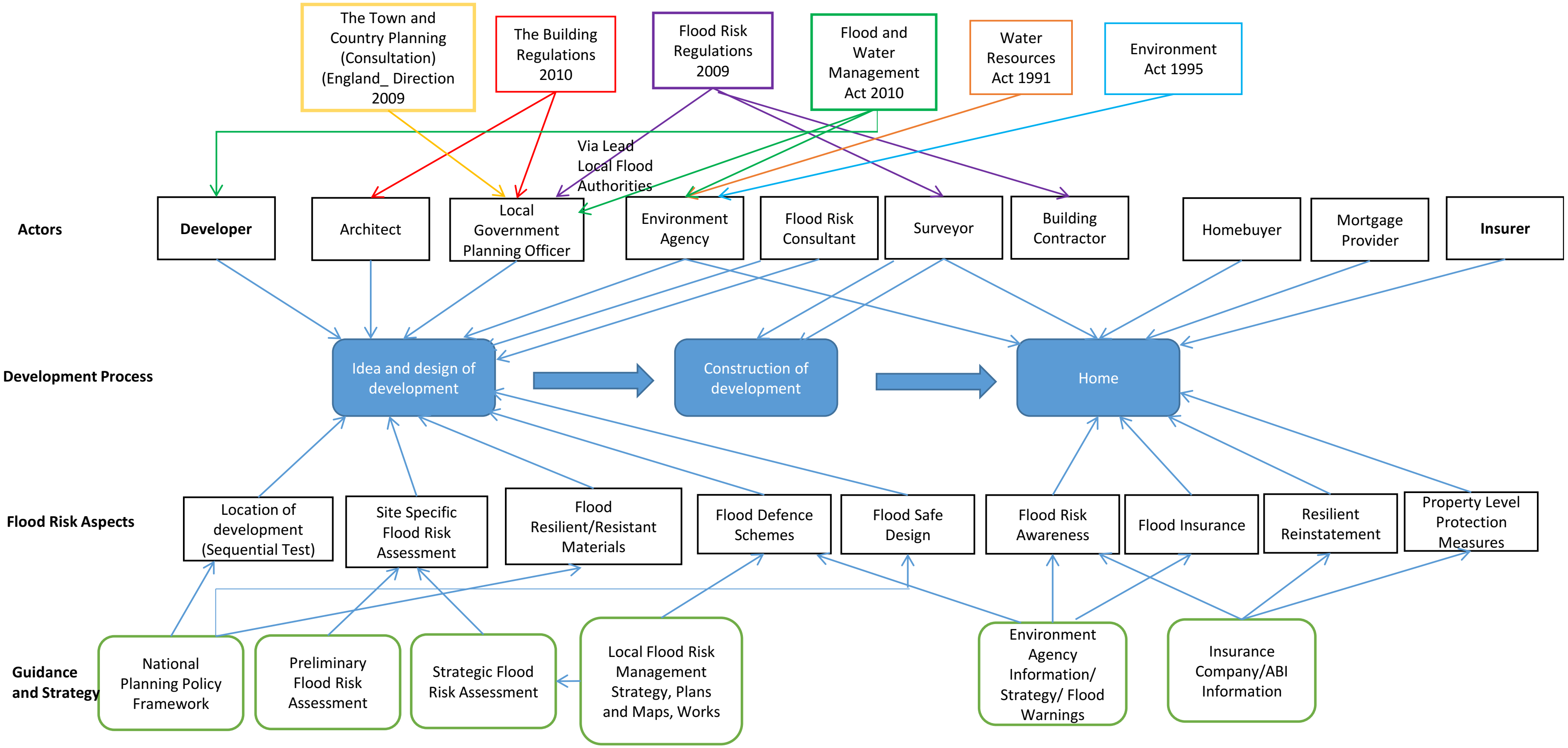

Figure 2. Key actors and stages at which flood risk considerations can be incorporated in the progress of the development: from initial concept to delivering a home (Adapted from Surminski et al, 2014).

3. Applying an Agent Based Model to investigate resilience options for the UK flood insurance partnership

ABMs provide a bottom-up approach for understanding the dynamic interactions between different agents in complex systems. They can provide an improved understanding of systems by simulating these systems and their evolution. In addition, by adjusting certain model parameters ABMs can be used to investigate key drivers and the scope and limits for future evolution of these systems, and visualise possible strategies and evolutionary pathways. As such they have a number of advantages as support tools for policy making, including their accessibility and flexibility for testing different conditions and behavioural rules (van Dam et al., 2012).

In this paper, we use an ABM developed for London, and in particular the London Borough of Camden, which has a high risk of SW flooding and a historic precedent for events due to the nature of summer thunderstorms and the topography of the area (Drain London, 2011). Nevertheless, the approach is transferable to other regions and localities and offers insights for the UK flood insurance arrangement. This ABM is novel in its application to SW flood risk and its incorporation of the insurance partnership, key actors outside the partnership and implications of climate change in Greater London.

The ABM was developed to capture essential features of the UK flood insurance partnership, with the overall patterns of behaviour shown by the ABM in line with available literature, real world data for London and Camden, and expert opinions (Dubbelboer et al., In Review). The parameterisation of the ABM reflects empirical data and expert opinion, and was developed around GIS data to allow a realistic representation of residential buildings and SW flood risk. Such grounding is essential if ABMs are to be applied for policy analysis and be seen as robust when exploring future changes in systems (Filatova, 2015). Also, while in many cases the ABM results reflect the model design, assumptions and parameters used, the advantage of using such a model here is the ability to integrate different agents and strategies, and investigate potentially unexpected interactions and trade-offs between strategies, how these strategies and trade-offs evolve over time, and resultant implications for SW flood risk reduction.

A summary of key components of the ABM reflected in this analysis is presented below and key assumptions underlying the behaviour of the different agents within the ABM detailed further in Appendix 1. Further information on the model is available in Jenkins et al. (2016) and a copy of the model and full documentation, including the ODD protocol, tables of parameters, data values and sources, decision trees, validation of the model and significance testing is available in Dubbelboer (2015), and online at https://www.openabm.org/model/4647/version/1/view.

To represent the role that the partnership could play in incentivising SW flood risk reduction the ABM includes three key agents: i) local government, which has a key role in managing local flood risk and approving new developments; ii) insurer committed under the SoP to the provision of flood risk insurance and under the new flood insurance partnership to the running of Flood Re; and iii) developer as a key private sector actor beyond the insurer who could play a greater role in reducing SW flood risk. In addition, the ABM represents another two agents critical to the functioning of the model: i) people who can own, buy and sell houses in the model, require flood risk insurance, and whom the local government ultimately aims to protect from flood risk; and ii) a bank agent that can repossess properties if homeowners default on mortgage payments. Within the model, these agents have individual properties and behaviours and interact with each other resulting in patterns on which insight can be gained to help inform the investigation into the multi-sectoral partnership. Figure 3 provides an overview of the ABM with its key agents, processes and interactions.

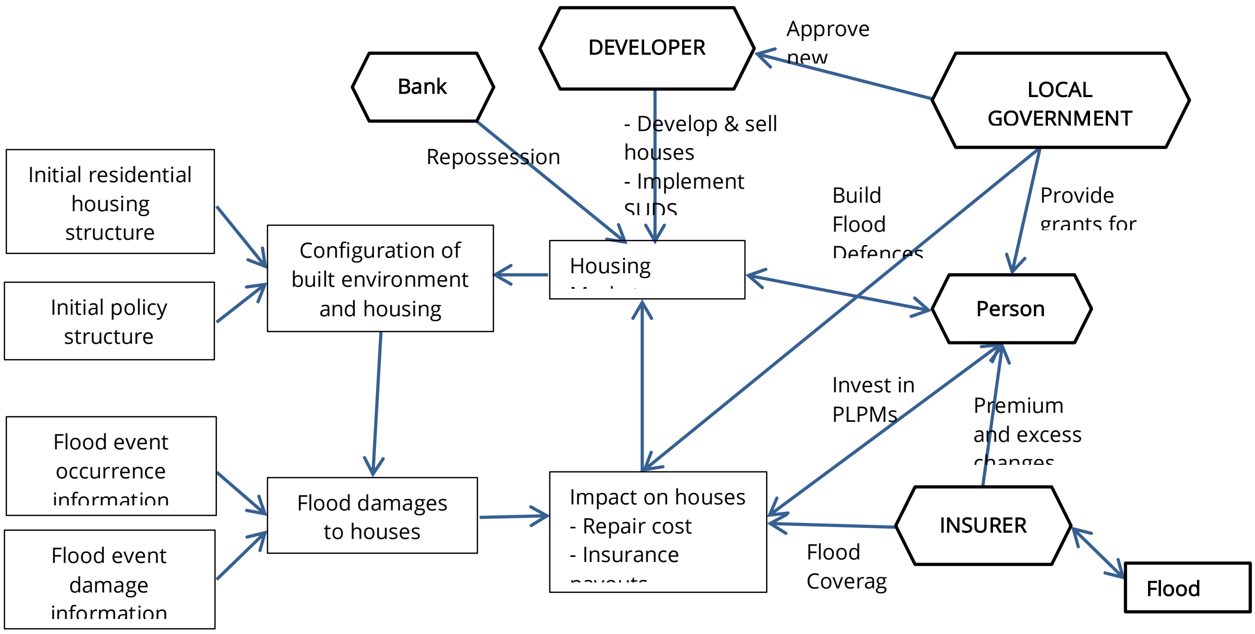

Figure 3. Overview of the agent based model for Greater London, including the key agents with a role to play in SW flood risk reduction

Using the ABM we investigate if and how property developers and local government could strengthen the insurance partnership. First, we test the impact that different requirements and restrictions placed on developers have on reducing SW flood risk and maintaining the affordability of insurance. Specifically, we explore the following measures that developers could take: contributing to government flood defence investment, paying flood risk insurance for a set number of years of a new property and building all new properties with SUDS. We also examine the impact of limiting the number of houses developers can build as well as removing building restrictions on developers. Second, we change the criteria that local governments use to approve new developments and examine the impact of these changes on SW flood risk and insurance premiums. Specifically, we explore the following options for local governments: i) a more stringent development approval ratio, which represents the profitability made from selling land for development and the additional level of flood the development will add to the area; ii) setting a lower maximum acceptable flood risk level; and iii) ensuring that flood risk and approval ratios are examined for every development proposal. Finally, we examine the impact that changes to and restrictions on both developer and local government behaviour has on SW flood risk reduction and insurance affordability to explore whether there may be trade-offs or counter-active effects that occur when constraints on both sets of actors are combined (see Table 1 for a summary of the different experiments run by the ABM).

Each experiment setting was run using SW flood event time series data for a baseline (1961–1990) and future high emission climate change scenarios for the 2030s (2030H) and 2050s (2050H) (equivalent to the IPCC SRES B1 and A1FI scenarios and comparable to Representative Concentration Pathways 4.5 and 8.5 respectively). 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 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. While Flood Re is intended to be a transitional scheme to be phased out over a 25-year period, in the interests of simplicity we have tested a steady state version of Flood Re over a 30-year simulation period.

Table 1. Experiments developed to test the role of the developer and local government in strengthening the insurance partnership

Experiment Number	Developer contributes 10% to government Flood Defence Investment	Developer pays flood risk insurance for first 5 years of new property[1]	Developer must build all new properties with SUDS in place	Limited number of houses developer can build[2]	No Developer Restrictions – (i.e. no government approval needed to	Local Government sets a more stringent development approval ratio[3]	Local Government sets lower maximum acceptable flood risk level	Local Government must look at flood risk and approval ratio for every

[1] This is currently only used to test the decision making of the developer whether a property is economically viable if they had to cover the insurance for 5 years. Premiums are not deducted from assets although the developer does pay insurance until the property is sold. Once it is sold the premium is paid by the homeowner as normal.

					build)			proposal[4]
1 (Baseline)	NO	NO	NO	NO	NO	NO	NO	NO
2	YES	NO	NO	NO	NO	NO	NO	NO
3	NO	YES	NO	NO	NO	NO	NO	NO
4	NO	NO	YES	NO	NO	NO	NO	NO
5	NO	NO	NO	YES	NO	NO	NO	NO
6	NO	NO	NO	NO	YES	NO	NO	NO
7	YES	YES	YES	YES	NO	NO	NO	NO
8	NO	NO	NO	NO	NO	YES	NO	NO
9	NO	NO	NO	NO	NO	NO	YES	NO
10	NO	NO	NO	NO	NO	NO	NO	YES
11	NO	NO	NO	NO	NO	YES	YES	YES
12	YES	YES	NO	YES	NO	YES	YES	YES
13	YES	YES	YES	YES	NO	YES	YES	YES
14	NO	NO	YES	NO	NO	NO	YES	YES

[2] The number of developments allowed reflects the annual Camden development trajectories. In this scenario, the number of properties which can be built is reduced by 50% annually (this can be altered but provides a first example).

[3] The development approval ratio is increased from 1 (i.e. profits from selling land must be ≥ to the additional level of flood risk added to the local area by the development) to 1.25 (i.e. the profit made from selling land for development will need to be at least 25% higher than the additional level of flood risk added to the local area for the development to be approved). These initial assumptions are based on the premise that demand for housing as well as potential economic benefits both could provide a case for developers to continue to build on high flood risk land, and for local authorities to approve such developments. While the EA is able to oppose developments at high levels of flood risk it is ultimately down to the local authority 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.

[4] In comparison to the baseline set up where 75% of proposals are randomly approved by the local government straightaway

4. Strengthening the partnership: Role of property developers and local government

4.1 Role of property developers – implementing SUDS and investing in flood defence schemes

Using the ABM we focus on the role of the developer and hypothetical changes to regulations which would impact upon their decision-making and development of new homes in the model and the effects these have on SW flood risk reduction and insurance premiums. We find that SW flood risk is highest when no developer restrictions are in place (experiment 6) (Figure 4a). In contrast, SW flood risk is lowest when the developer is required to build all properties with SUDS (experiment 4) and where this is imposed in combination with other restrictions (experiment 7). This reflects the assumption that SUDS reduce flood damage by 35% (Defra 2011) in the model, and will lower but not totally remove SW flood risk for protected properties. The experiments where additional financial costs would be imposed on the developer (experiments 2 and 3) have no noticeable effect on the overall level of risk compared to the base case (experiment 1), suggesting that they do not lead to a change in behaviour of the developer or provide enough incentive for the developer to build in areas of lower SW flood risk. For example, requiring the developer to cover insurance premium costs for five years did not act as a strong disincentive to them building in areas of flood risk, as the profitability of developments far exceed these additional costs. This remained the case assuming that the developer had to cover insurance premium costs for 10 years (results not presented here), with only marginal effects under the 2030H and 2050H climate scenarios, where increasing SW flood risk and insurance premiums for new developments inflict higher costs on the developer. Reducing the number of properties that the developer can build also has very limited effect in terms of overall SW flood risk (Experiment 5). This suggests that the more profitable developments may well be in areas of higher flood risk in Camden. Similar trends are seen for the 2030H and 2050H climate scenarios, albeit at a higher level of flood risk (Appendix Fig. A1).

For flood insurance premiums the greatest reductions in average household flood insurance premiums are seen under experiments 4 and 7 (Fig. 4b). Average flood insurance premiums become slightly higher under experiment 6, where there are no developer restrictions, as these new builds are excluded from the Flood Re scheme. When development is not regulated and does not follow the proposed housing trajectory around 5000 more homes are built by year 30, with a higher number of properties built in flood risk. However, building 50% less properties annually (experiment 5) has limited impact in terms of reducing risk and average household premiums. Whilst the number of properties built annually declines, the overall number of properties built by year 30 is very similar. This is because the local developer focuses the majority of new developments in Opportunity Areas (OAs) designated by the local council for large development, and with a maximum limit on total houses (Camden Council, 2015). The OAs begin to be full by around year 22 in the base case and so the trajectory begins to slow and converges with that of experiment 5 which continues to increase steadily over 30 years (Appendix Fig. A2). Similar trends in average household flood insurance premiums are seen under the climate change scenarios (Appendix Fig. A1). However, there is greater divergence in the results between experiments 4 and 7 and 6, and greater impacts on average premiums of the different experiments.

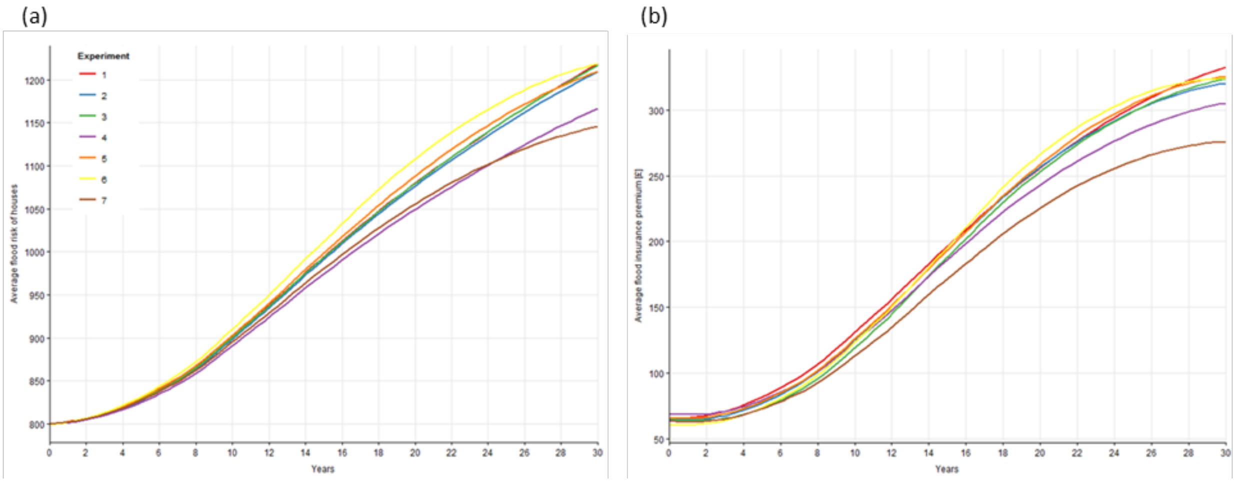

Figure 4. a) Average household SW flood risk and b) average flood insurance premium of all houses in flood risk estimated under experiments 1-7.

The model also allows us to examine the effects of increased investment in flood defences by the developer. Under experiments 4 and 7 (which both require all new developments to have SUDS installed) a larger proportion of homes are protected from SW flooding by SUDS over the 30-year period (Figure 5). These results underlie the trends highlighted in Figure 4 with experiments 4 and 7 resulting in the lowest level of average household flood risk and insurance premiums.

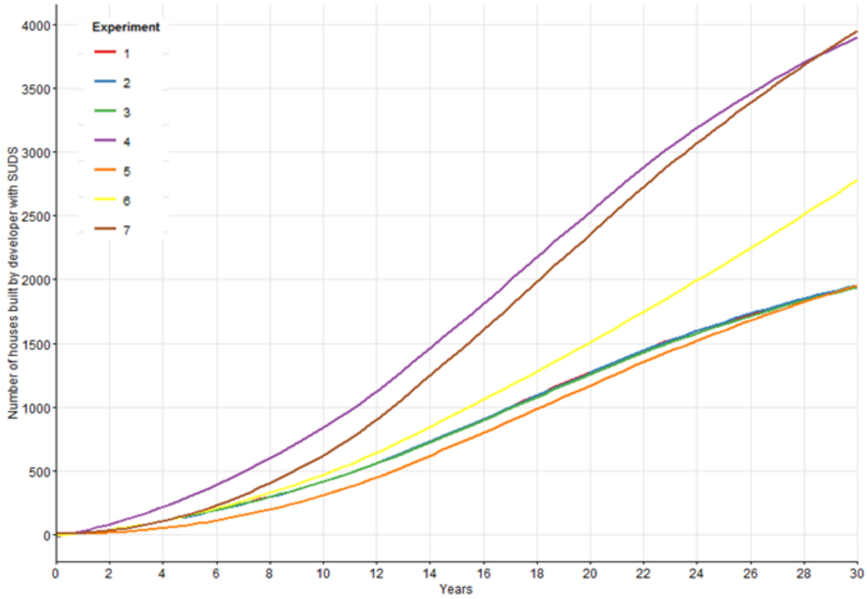

Figure 5. The number of new build houses in the model simulation built with SUDS in place

Interestingly, one positive outcome of experiment 6, where there are no developer restrictions, is when looking at property foreclosures. The number of cases where mortgage payments become unaffordable and houses are foreclosed by the bank are 3% lower by year 30 compared to the other scenarios, with a reduction in foreclosures of properties both in and out of flood risk[5] (see Appendix Fig. A3). In addition, under experiment 6 average house prices of properties in and out of flood risk become lower than the base case scenario (Appendix Fig. A4). This is because where there are no developer limitations supply is able to keep pace with demand allowing homebuyers to find more affordable housing which keeps average house prices lower in the simulated housing market. Similarly, it makes it easier for homeowners who cannot afford their housing costs to move to a cheaper property at a quicker rate. These trade-offs show on the one hand benefits of a stringent SW flood risk management programme, and on the other hand benefits of more relaxed planning policies for the property market and affordability of homes.

[5] 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. In reality many factors can play a role in the resulting foreclosure of a property, the number of repossessions can fluctuate largely across years, the process for repossession is more complex, and arrangements can be made with lenders to avoid repossession.

4.2 Role of local government - investing in flood protection measures (PLPMs and SUDS) and approving new developments

The ABM allows us to examine the impact that local government investment in flood protection measures would have on the affordability of insurance and SW flood risk reduction. Figure 6 presents the effect of local government investment in PLPMs and SUDS on the average SW flood risk and levels of premiums of both existing houses and new developments. The dotted lines reflect the baseline experiment 1, whilst the solid lines reflect a modified version of this where it is assumed there is no government investment in SUDS or grants for PLPMs. While the average SW flood risk of existing and new build properties are similar, the benefits of government investment in flood protection measures are larger for the new build houses (which are only built from year 4 of the model run), as these include properties in some of the higher flood risk areas, which are targeted for SUDS projects based on their favourable cost-benefit ratio. In contrast, for existing houses in the model, the benefits are smaller and increase gradually as households mainly invest in government funded PLPMs in a reactive way after floods. Figure 6b highlights the positive impact that flood protection measures have on flood insurance premiums. Premiums remain much higher for new build houses, as they are excluded from Flood Re. The beneficial implications of investment in PLPMs and SUDS by the local government are evident. The government reduces risk in the area, the insurer's risk portfolio is reduced, and households benefit from lower premiums, as it is assumed that the insurer takes into consideration these investments when setting premiums and repair costs if flooded.

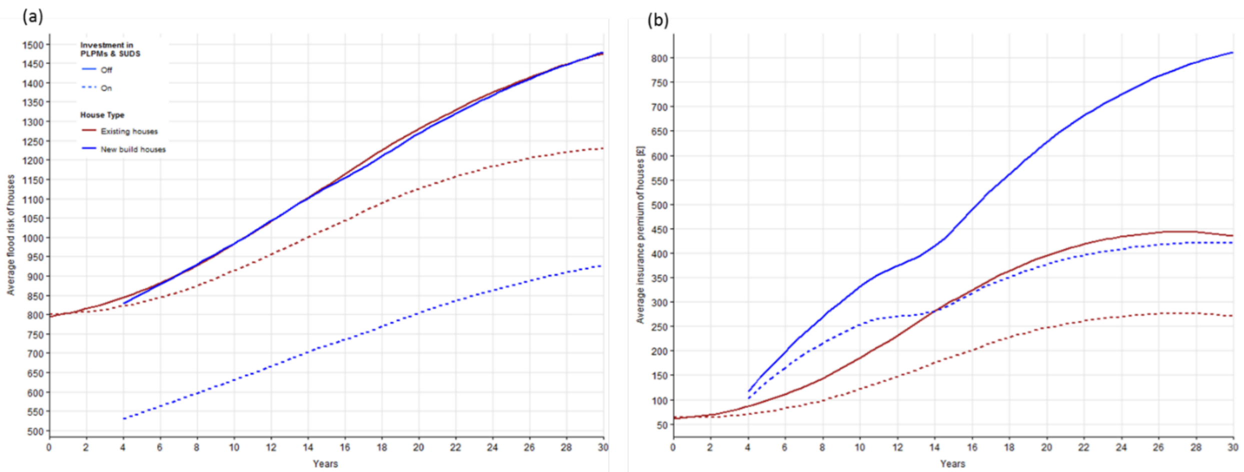

Figure 6 (a) The effect of different flood protection measures on average household SW flood risk for existing and new build houses; and (b) the effects of these flood protection measures on average flood insurance premiums. Baseline Climate scenario.

The next set of results focuses more on the role of the local government (experiments 8-11) when it comes to approving new developments, and consequences for flood risk and insurance premiums.

Under the current model set up simply reducing the maximum level of flood risk acceptable for new properties (experiment 9) or requiring the government to assess all proposals based on flood risk and the level of profit (experiment 10) has little effect on the average SW flood risk of new build properties (Figure 7). The results follow the same trajectory as seen under the baseline (experiment 1, not shown on the graph). This is because proposals for new properties in flood risk areas will still be approved by the government if the sale of land is valued higher than the additional level of flood risk that will be added to the Borough. In the case study of Camden this is always the case given the exceptionally high value of land and properties. The average SW flood risk of new builds does decline by around 8% by year 30 under experiment 8 where the level of profit to flood risk required if a development is to be approved is increased. More substantial benefits in terms of SW flood risk reduction are seen under experiment 11 (halving the average SW flood risk of new buildings from the baseline by year 30), which combines the above options resulting in less properties being built in flood risk in total.

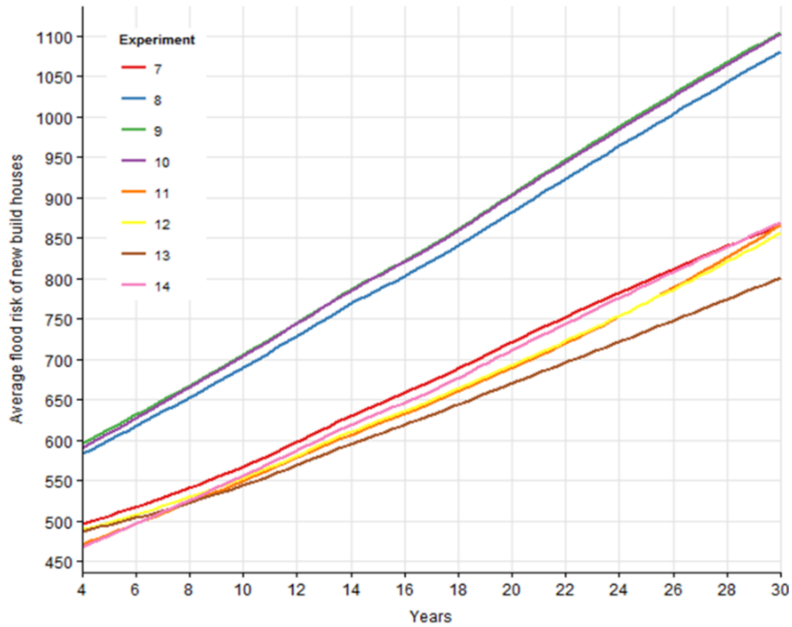

Figure 7. Average household SW flood risk of new builds built in areas of flood risk. Baseline climate scenario.

4.3 Placing joint restrictions on property developer and local government – evidence of trade-offs

We examine the results arising from the combination of restrictions placed on both the property developer and local government (experiments 12 to 14). Similar results to experiment 11 are seen under experiment 12, whereby some conditions are also placed on the developer in parallel. This does not include the need for developers to build all new properties with SUDS, yet the results are slightly more favourable over the 30-year time period than those seen under experiment 7. This reflects the assumption that SUDS reduce flood damage by 35% (Defra 2011) in the model, and lower but not totally remove SW flood risk for these properties. This lowering of flood risk means that more properties are deemed to have an acceptable level of SW flood risk for approval by the government. Therefore, more properties are built in areas of SW flood risk overall, contributing to a higher level of risk to the wider study area of Camden (as highlighted in Figure 8).

The most beneficial results are seen when the full range of developer and government conditions are implemented together under experiment 13. The average level of SW flood risk to new build properties is reduced by 27% from the baseline by year 30 (Figure 7). The importance of coordinating the developer and local government risk reduction strategies is highlighted by experiment 14. Although the developer builds all new properties with SUDS and the local government reduces the acceptable level of flood risk and must consider this alongside the development approval ratio for all proposals the level of flood risk is very similar to that seen in experiment 7. This is as properties at the highest level of flood risk, even with SUDS in place, can still be approved if they are considered profitable.

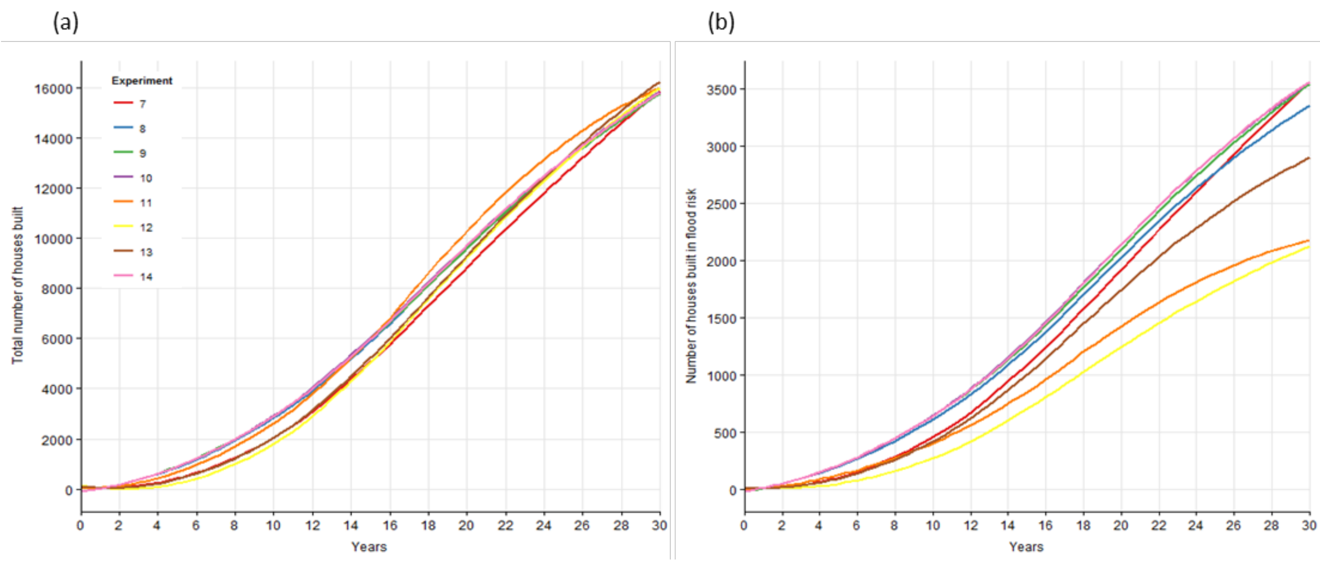

Figure 8. Total number of (a) houses built; and (b) houses built at risk of SW flooding.

Under all experiments the total number of developments follow a very similar trajectory over the 30-year time period (Figure 8a). However, focusing on the number of properties built in areas at risk of SW flooding (Figure 8b) a divergence in trajectories can be seen, highlighting how certain options, such as demonstrated under experiments 11 and 12, act as a strong barrier to the development of properties in areas of high SW flood risk.

Importantly, the results highlight that while options that include investment in SUDS may reduce the level of SW flood risk to houses (e.g. experiments 7 and 14), they inadvertently support continued development of properties in areas of SW flood risk given the experimental conditions in place for the local government. These findings highlight the complexities in identifying the right balance in flood risk reduction actions by developers and local government and shed light on the potential trade-offs which will need to be made between managing flood risk, developing in flood plains and meeting housing targets. However, the results also highlight the need to view such issues of continued development in flood risk areas in a longer-term context given the threat of climate change and negative consequences for flood frequency and intensity (selected results under future scenarios of climate change are provided in Appendix 2).

Finally, figure 9 highlights the upper and lower bounds of the model simulation results, in terms of the average flood insurance premium across existing and new build houses, and across a sub-set of the experiments. All the experiments, with the exception of experiment 6, are beneficial in terms of reducing average premiums from the baseline. Interestingly, results under experiments 7, 13 and 14 are most beneficial in terms of reduced average premiums, compared to the baseline or less stringent conditions as seen under experiment 6. This appears counter intuitive when compared to Figure 8b which highlights that these experiments result in larger number of properties built in areas of flood risk. The reason for this is that in these experiments all new properties are built with SUDS in place, which allows more properties to be approved by the local government and also reduces SW flood risk and premiums.

Therefore, the conditions modelled here that could be viewed as most beneficial for managing and restricting development in areas of flood risk do not necessarily result in the lowest insurance premiums. The potential for counteractive effects when combining constraints and measures targeted to developers and the local government is a key finding of this research and an area that warrants further investigation.

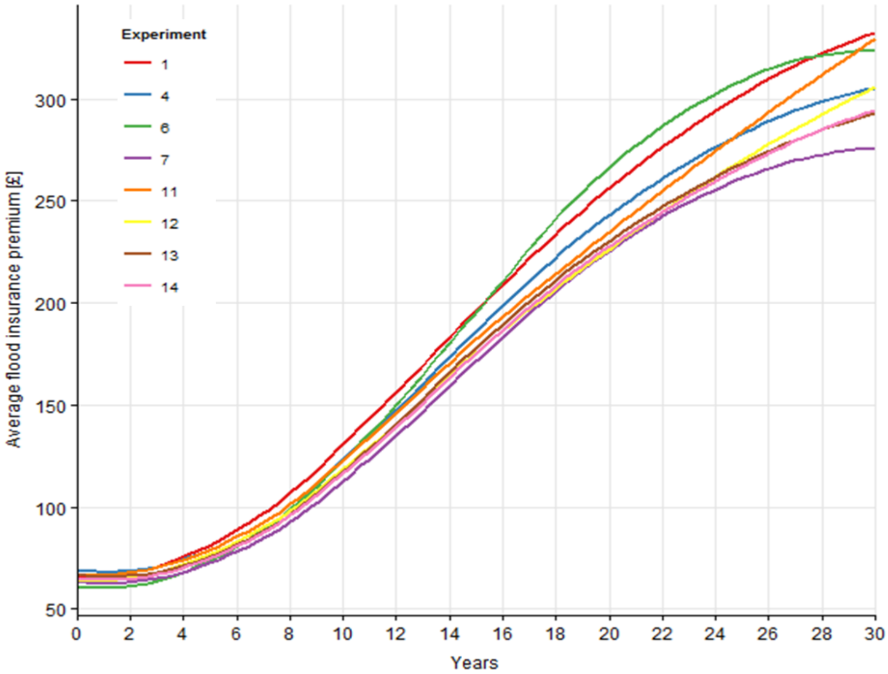

Figure 9. Average flood insurance premium of all houses in flood risk.

Furthermore, the magnitude and trends in average flood premiums also differ largely when future climate change is considered (Appendix Fig. A5). As above, experiment 6 results in premiums higher than the baseline experiment 1, and under all other experiments benefits in terms of reduced premiums are seen. However, as SW flood risk increases under these scenarios the options that are most beneficial change. In the 2030H scenario experiment 11 is the most beneficial, where the onus is on the local government to impose stringent conditions on developers and where SUDS are not required in all new build properties. In the 2050H scenario the most beneficial results are seen under experiment 12 where the onus is on the local government as well as constraints being placed on the developer, including imposing financial costs and limiting the number of new developments allowed.

5. Discussion

Partnerships have been receiving significant attention since the turn of the century within the sustainable development, disaster risk management and climate change fields with multi-sectoral partnership in particular seen as “the paradigm of the 21st century” and the best approach to deal with complex and multi-faceted problems (Pinkse and Kolk, 2012). Yet, despite this positive rhetoric, little research has been done on how partnerships can facilitate and incentivise disaster risk reduction and debates remain with regards to their appropriateness and effectiveness (Sherlock et al, 2004; Tompkins and Hurlston, 2010; Pinkse and Kolk, 2012; Chen et al, 2013). This paper specifically focuses on the UK’s flood insurance partnership in order to investigate if and how the engagement with new actors could strengthen this partnership by incentivising flood risk reduction and maintaining the affordability of insurance, in particular in the face of rising risks due to climate change. Indeed, one of the common criticisms of partnerships is that they often involve the ‘usual suspects’ and thus do not engage with all the relevant actors (Sherlock et al, 2004). While narrow partnerships may be seen as an efficient way of developing a policy or reaching an agreement on a specific issue, this may not offer a holistic understanding of the problem and the solutions (Sherlock et al, 2004). Unless all the relevant actors are engaged with and we move beyond the polarised debate between government and insurers, current and future flood risks will not be effectively managed. As suggested by Horn and McShane (2013) Flood Re is unlikely to encourage adaptation to rising flood risks from climate change if it is not part of a wider strategy that also considers land use planning, investment in structural flood defences, policies to control floodplain development, building regulations and water management. Flood Re itself acknowledges that it does not have strong direct levers to influence flood resilient decisions due to its design (Flood Re 2016). The ABM model allows us to investigate if and how this could be addressed by focusing on local government and property developers and their potential role in the flood insurance partnership. However, our findings highlight the complexities involved in strengthening partnerships. In particular, such a process raises the questions of what role each actor can play and how to engage these different actors.

Our analysis of the UK’s flood insurance partnership suggests a range of options for strengthening the current arrangement in the face of rising SW flood risk. First, we analyse the role of property developers. Although properties built after 2009 are excluded from Flood Re, if and how new developments go ahead in flood risk areas has implications for other houses in the area, and therefore also for Flood Re (Jenkins et.al. 2016). As expected, we find that the requirement for developers to build all properties with SUDS reduces SW flood risk and results in lower average insurance premium. The ABM shows that the increased investment in flood defences by developers, either by contributing to the local government flood defence budget or by directly installing SUDS as standard in all properties, does result in a larger proportion of homes being protected from SW flood risk. While these results ultimately reflect the model design, assumptions and parameters used, the ability to visualise and quantify such effects over time is advantageous in providing a base case on which to compare the effects of alternative strategies. The ABM also allows us to highlight the potential trade-offs between developing stringent flood risk management programmes and the need to maintain affordability of houses, as stricter development requirements lead to higher levels of property foreclosure. Involving property developers in the flood insurance partnership by making them pay for the first five years of insurance premiums does not seem to lead to greater flood resilience at the point of designing and building a development. This finding is somewhat surprising and points towards the need for future research to better understand if concern about not securing affordable flood insurance for a new development might lead to greater flood resilience at point of design and building.

Second, our analysis examines the role of local governments. The existing insurance partnership is between the insurance industry and the national government, yet local governments have lead responsibility for managing local flood risk, including from SW runoff. Local governments receive subsidies from the national government to invest in flood defence and PLPMs. In addition, they are responsible for approving new developments and have to manage the often conflicting aims of restricting development in flood plains and meeting housing targets. The benefits of local government investing in flood protection measures (SUDS and PLPMs) are clearly shown in the results from the ABM: it reduces risk levels as well as insurance premiums. Local government investment in these measures therefore appears to be beneficial to the insurer as the risk portfolio is reduced and to households whose premiums are reduced. The ABM also shows that a stricter approval process for new development, with a greater weight given to flood risk, does have a clear impact on the overall flood risk, but also leads to trade-offs for the local government in terms of generating income from new developments, meeting housing targets and reducing flood risks.

Third, a particularly interesting aspect of our ABM is the ability to investigate different restrictions placed on developer and local government and the impact that this can have on insurance premiums and the trade-offs with developing in flood risk areas. The ABM results suggest that while a stricter local government stance on the approval of developments in flood risk areas does reduce insurance premiums, the strategies which result in the lowest premiums also lead to a larger number of developments in areas of flood risk. In this example, this reflects the requirement for the developer to build all properties with SUDS in place. This reduces the level of SW flood risk to the property (and the insurance premium), often below the local governments maximum acceptable flood risk level, which along with the revenue these developments generate for the local government facilitates continued development in such areas. There is evidence that such trade-offs are already occurring, with local authorities encouraging developers to build in flood plains as the revenue stream this provides is one of a few ways in which they can finance large flood protection or resilience projects. Yet, such strategies leading to flood plain development will not be sustainable in the long-term. Whilst developments may benefit from initial site-level flood protection the consequences for future flood insurance, given properties are not eligible for Flood Re, the potential implications of climate change on the level of flood risk, and the lack of clarity over responsibility for maintaining flood infrastructure in the future are critical issues. The ABM allows such trade-offs to be identified and investigated, and highlights how different aspects of flood management, the Flood Re scheme, and planning policies may cause conflicting outcomes for certain partners. Indeed, our results suggest that a more stringent flood risk management programme that seeks to limit development in flood risk areas does not maximise benefits in terms of the levels of insurance premiums, potentially conflicting with Flood Re's aim of maintaining the affordability of flood insurance for households at risk of flooding. A better understanding of these trade-offs is an area that warrants further investigation.

One important point highlighted by our ABM analysis is the impact of climate change and other risk drivers on insurance premiums. We find that over time current strategies for maintaining low insurance premiums and managing flood risk may become less effective, unless adjusted to the new risk trends. This highlights the importance of engaging with multiple actors to strengthen the partnership, and allowing a flexible framework that can be modified over time as different risk thresholds are passed. Here a pathways approach is widely advocated by climate adaptation experts: this would involve sequencing the implementation of actions over time to ensure the system adapts to the changing social, institutional, environmental and economic conditions, and would act to build flexibility into the overall flood risk management strategy (Ranger et al, 2010; Haasnoot et al, 2012; Wise et al, 2014).

The study highlights the potential of using an ABM approach to inform and support the development of enhanced flood insurance partnerships to incentivise flood risk reduction and adaptation to climate change. In particular, we build on the analysis of Jenkins et al., (2016) to highlight how the behaviour of different actors could affect future SW flood risk, development in flood risk areas and insurance premiums, the trade-offs between these different goals and how optimal strategies for achieving these goals can change with future climate change. 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). However, to enhance the policy relevance of these findings a move from a conceptual ABM experiment towards the simulation of a real life situation in an ABM would be beneficial (Filatova, 2015). For Flood Re this would only be possible once the first few years of claims and premium data are available, as well as more information on behaviour of the actors emerge.

Finally, 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, and certain behaviours such as how insurers consider the implementation of SUDS and PLPMs are simplified. In addition, our model is designed around those actors deemed most relevant in this context, but we acknowledge that other key actors, such as water companies and mortgage providers, may have a critical role to play in providing a more holistic approach to flood risk management (Kunreuther and Michel-Kerjan, 2009; Sargent et al, 2009). How to better integrate these actors in flood risk management decision-making to better incentivise flood risk reduction is a critical issue for further research.

6. Conclusion

Insurers are seen as a key private actor who can play a greater role in reducing flood risks (Kunreuther and Michel-Kerjan, 2009; Surminski, 2014; Surminski et al, 2015). Yet, developing the right flood insurance arrangements to incentivise flood risk reduction and adaptation to climate change remains a key challenge, not just in the UK. Indeed, at a European level the European Commission Green Paper on the 'Insurance of Natural and Man-made Disasters' (EC, 2013) questioned the appropriateness and availability of current insurance options in the context of rising risk, and asked if and how the provision of insurance could be reformed.

In response, our investigation provides insights on the importance of multi-sectoral collaboration in order to utilise insurance for flood risk reduction. Our ABM-analysis reveals how different policy options and actions from local government and property developers could reduce SW flood risk and help to maintain affordable insurance premiums and thus strengthen the current flood insurance partnership. Yet, our findings also show the many trade-offs that actors may face: finding the optimal strategy for reducing SW flood risk, maintaining low insurance premiums, constraining development in flood plains, meeting housing targets and maintaining the affordability of homes is challenging under current conditions, let alone in the face of rising risks over time.

With regards to the role of government it is important to highlight that different governance layers are relevant for the flood insurance partnership. Public policy is shaping the way insurance is designed and provided: 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, planning regulations and better flood risk data provisions.

Therefore, a stronger policy approach to flood risk management (planning, defence, resilience measures, data etc.) would make the insurance partnership more viable. For this, collaboration between the national and local authorities, planners, and developers is crucial. In our case 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 local authorities to approve such developments. While the Environment Agency is able to oppose developments at high levels of flood risk it is ultimately down to the local authority to make the decision. The Adaptation Sub-Committee (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 Environment Agency's recommendations is not sufficiently transparent or accountable.

We therefore note that the engagement with those other actors could take many different forms. This is especially apparent in the case of property development. Flood Re explicitly excludes new build in order to avoid moral hazard from property developers. However, this position could in future come under pressure. If new property developments in high risk areas were to continue, as current trends suggest (Committee on Climate Change, 2015), this could create political pressure on Flood Re to expand its remit and to offer cover to those new build properties. In the context of our assessment this would not strengthen the partnership, but remove the only risk reduction incentive that Flood Re has. Instead, engaging with property developers could be more effective beyond the core risk transfer: The insurance industry itself, as the world's largest institutional investor, clearly has a role to play. Ironically, investment decisions by insurers do not usually consider the climate risk knowledge gained on the underwriting side. Far too often property and infrastructure investment decisions go ahead without any reflection on climate risks (Surminski et al., 2016). A closer reflection on flood resilience when making investment decisions could therefore have positive implication for the flood insurance provision.

In a similar way it would be important to investigate the options for collaboration between insurance and local government. One recent example, that may lead to more resilience, is the Resilience Zone concept (Ceres et al, 2013a and b), currently tested by some insurers and local governments. Resilience zones are urban areas, specifically vulnerable to climate change risks, which are earmarked for regeneration via comprehensive risk management and upgrading – a process that brings together insurers, developers and local governments. While this is at an explorative phase, our ABM could be applied and provide useful insights into how different actors and policy options may influence risk levels.

While our ABM focuses on the case study of Camden, our modelling approach and findings are highly relevant for wider discussions on the potential of insurance schemes to incentivise flood risk management and climate adaptation in the UK and internationally. There is a clear current momentum at international level to use insurance to incentivise risk prevention and adaptation, as highlighted by the increased efforts to design new insurance schemes in developing countries through the new G7 'InsuResilience' initiative, and underpinned by the UNFCCC's Paris Agreement (see Surminski et al., 2016). The engagement of multi-sectoral partners and the clarification of their roles and responsibilities will determine if and how those new schemes can support climate resilience.

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APPENDIX 1

Overview of Agent Based Model and key assumptions

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 SW flood risk in the London Borough of Camden[6]. 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 full in Jenkins et al., forthcoming). The frequency, extent and spatial heterogeneity in SW 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).

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 SW 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 (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

[6] 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 under the GLA Drain London Project (Greater London Authority, 2015a).

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 SW 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 properties built prior to 2009 into Flood Re. 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, 2011a) 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 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.

In England, the use of SUDS was recommended by the Pitt Review (2008) and since April 2015 SUDS are a requirement for all new developments of ten or more properties at risk of flooding under amended planning guidance (DCLG, 2014). The Pitt Review (2008) also highlighted the potential for PLPMs to minimise damage from floodwater and recommended that local authorities extend eligibility for home improvement grants and loans to include flood resistance and resilience products for properties in high flood risk. PLPMs are applicable across flooding types, including SW flooding. Defra and the Environment Agency ran grant schemes installing this equipment in over 2000 homes between 2007 and 2011, and following winter flooding in 2013-2014 the government introduced a repair and renew grant scheme to help affected homes implement PLPMs. PLPMs are increasingly considered as an alternative or complement to other flood defence activities.

In the ABM the local government will proactively search for SUDS projects to invest in every year. 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 selects an area to build based on available land with the highest economic value of surrounding houses and profitability. Based on the development plans of Camden specific Opportunity Areas (OAs) are outlined where the developer can build as many houses as optimal per year, with a maximum limit on total houses (Camden Council, 2015). Outside of the development areas the developer is limited by a maximum number of houses it can build per year (150-200) reflecting the planned housing trajectory of Camden (Camden Council, 2013). It is initially assumed that 50% of all new properties are built with SUDS in place[7].

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.

[7] 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.

APPENDIX 2

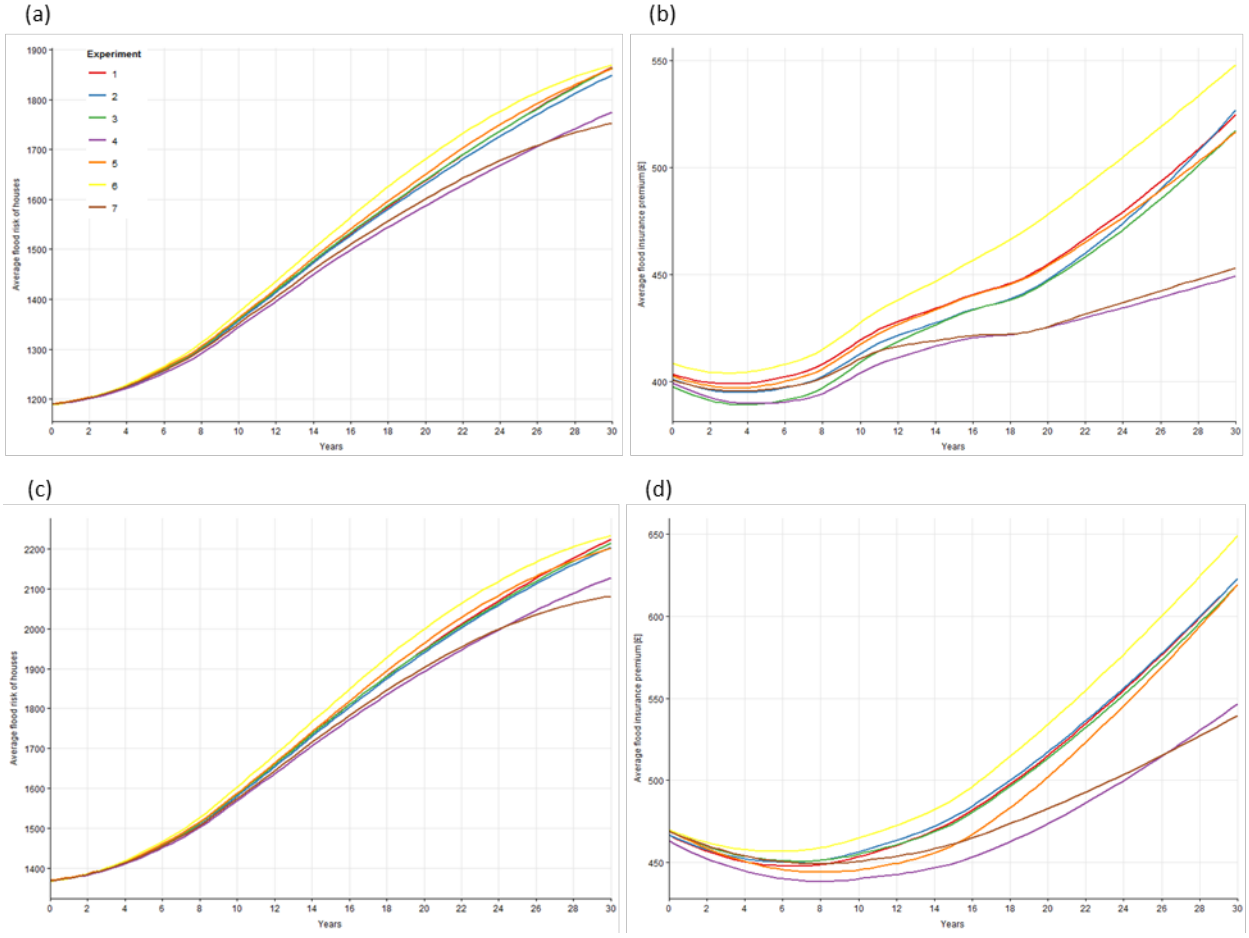

Figure A1: The effect of experiments 1-7 on the average household flood risk estimated under (a) 2030H and (c) 2050H climate scenarios, and the average flood insurance premium estimated under (b) 2030H and (d) 2050H climate scenarios.

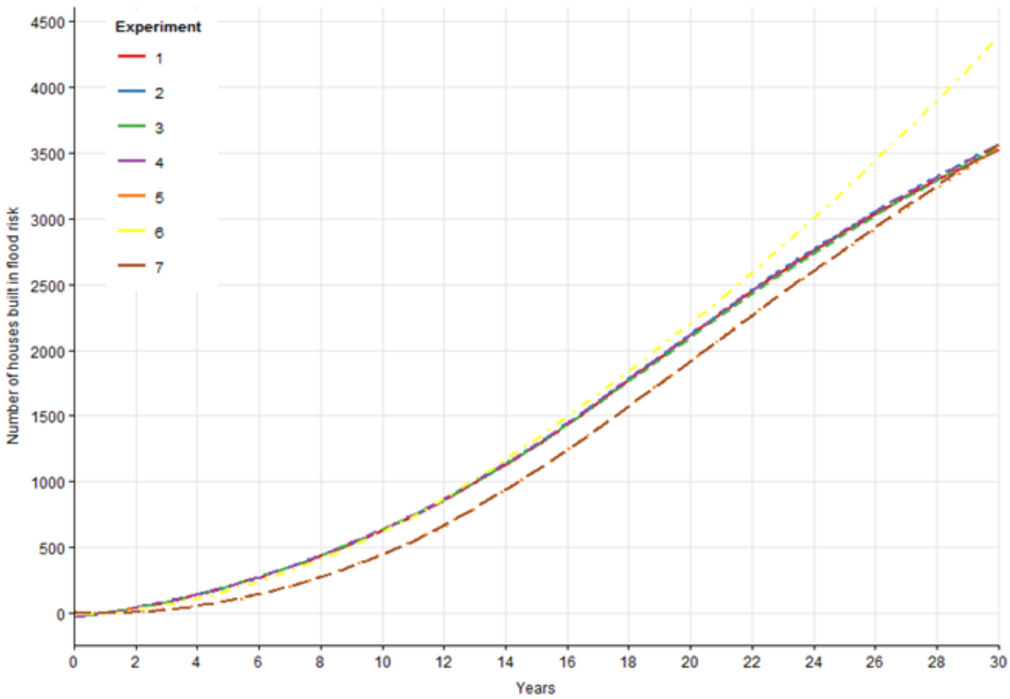

Fig A2: The total number of houses built in areas at risk of SW flooding. Baseline Climate scenario

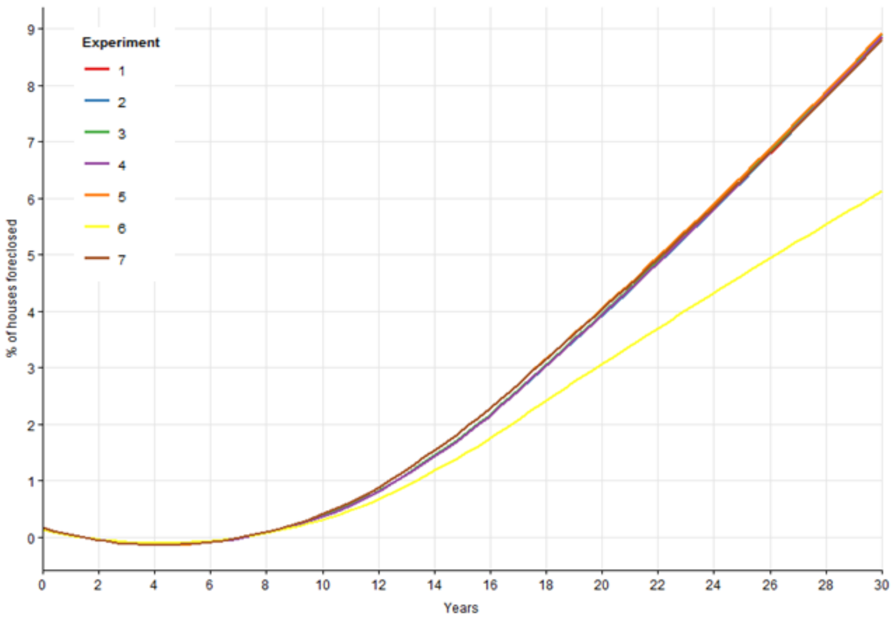

Fig. A3: The percentage of houses foreclosed in the model simulation. Baseline climate scenario

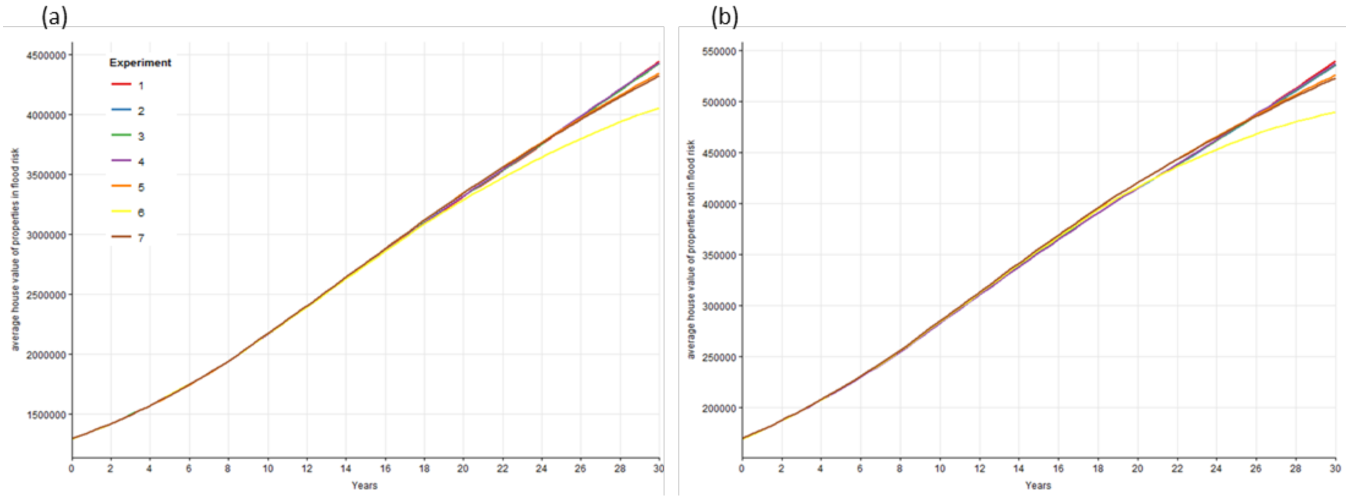

Fig. A4: The average house value of properties in the model simulation in (a) flood risk and (b) not in flood risk[8]. Baseline climate scenario. Under experiment 6 average house prices of properties in and out of flood risk become lower than the base case scenario. This trend becomes prominent around year 20 as in the other scenarios this is when development begins to slow as space and capacity for new builds is reached in line with Camden's development targets.

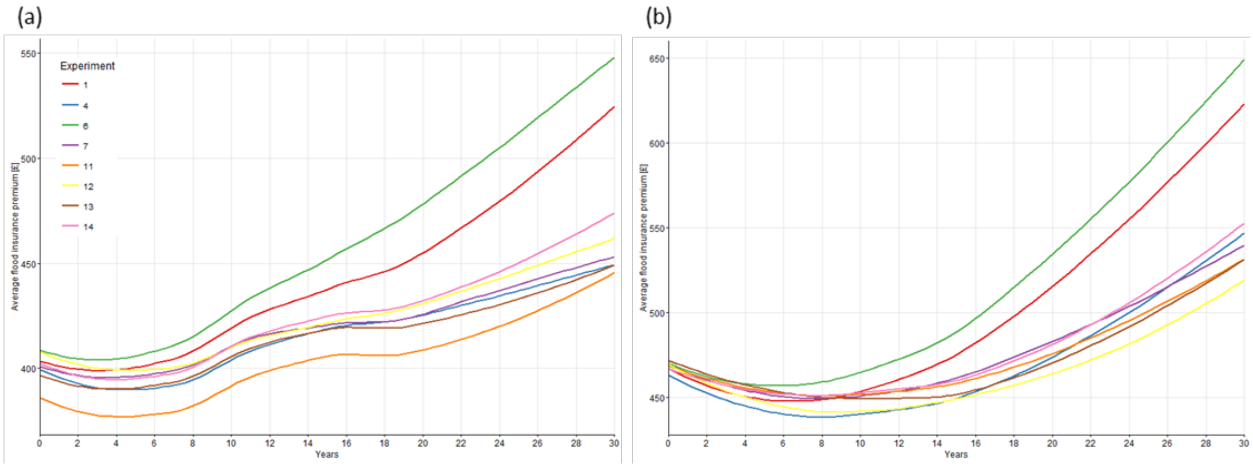

Figure A5: Average flood insurance premiums of houses in flood risk under (a) 2030H and (b) 2050H climate scenarios. Note that under these future climate scenarios a large

[8] Note the differing y-axis values on Figure 8a and Figure 8b highlight that the average value of houses in flood risk is much higher than that seen for houses not in flood risk. This is as 1st floor and above flats make up a large proportion of properties not in flood risk, and these properties tend to have the lowest values in Camden. In contrast, 58% of detached houses, the most expensive property type, are located in areas of flood risk.

proportion of existing houses are covered under the Flood Re scheme (results of which are presented in Jenkins et al., (2016)). This results in average premiums being relatively stable over the first 10 years of the model simulation. The increasing premiums in the latter years are due to increasing numbers of new build properties which are not eligible for Flood Re, and which are often built in areas of high SW flood risk.