Delft University of Technology

Graduation Thesis

Structuring flood insurance in the UK
An assessment of the London market using Agent Based Modelling

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“Even with all our technology and the inventions that make modern life so much easier than it once was, it takes just one big natural disaster to wipe all that away and remind us that, here on Earth, we’re still at the mercy of nature”

Neil deGrasse Tyson

“There is a 20 percent chance we are living in a computer simulation”

Nick Bostrom, philosopher at Oxford University
Acknowledgement

This thesis is my final deliverable as a student of the Master of Science in Systems Engineering, Policy Analysis and Management (MSc. SEPAM) at the Delft University of Technology. I am very happy that I got the chance to work on an amazing project that not just taught me a lot, but also gave me an amazing month of working in Oxford and the possibility of going back to Oxford for 3 months to continue doing research. I would like to express my gratitude to the people who have contributed to my graduation thesis.

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Jan Dubbelboer
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In the winter of 2013-2014 the south of the UK (London, Oxford) experienced the heaviest rainfall since 1767. It has seen its wettest winter on record, with January 2014 being especially wet. Research done at the University of Oxford in April 2014 concluded that global warming has a small, but significant effect on these extreme rainfalls and floods resulting from it. At the recently held European Geosciences Union meeting in Vienna Professor Myles Allen presented his evidence of a link between the recent floods in the UK and climate change. Extreme types of weather that cause floods like those in January 2014 have increased by a small, but measurable, amount.

A project that is currently investigating this pressing issue of surface water flooding is the ENHANCE project. This is a large project that aims to enhance risk management partnerships for catastrophic natural disasters in Europe. A specific part of this project is a project performed at Oxford University, where a specific focus is put on examining the way economic instruments, like flood insurances, may support risk management in flooding. Insurances can be used as a tool of flood risk management which reduces the economic impact and facilitates recovery after a flood event. A well-designed flood insurance system has the potential to reduce risky behaviour, promote risk-awareness, and encourage flood proofing. A specific case within the ENHANCE project, the Oxford-LSE London flooding case, will focus on the potential of insurance based mechanisms to incentivise flood risk management in a specific part of London that is prone to flooding.

One of these potential insured based mechanisms that can be used to incentivise flood risk management is the FloodRe system. As a reaction to the flooding in the south of the UK, the UK government and the Association of British Insurers came to a principle agreement on the layout of this new FloodRe system in May 2014. Within this system a non-profit flood fund will be set up that ensures that flood insurance remains affordable and available to homeowners at high flood risk. This system allows insurers to transfer the flood insurance premium part of the homeowners insurance into a separate insurance; FloodRe. In return FloodRe will reimburse the insurers for flood claims they pay to their customers.

In its current form the FloodRe system does nothing more than plugging a hole. Insures re-insure their high risk policies that are not profitable into FloodRe, and FloodRe will be a non-solvent system. However, with the adaptation of risk incentive measures to the FloodRe system, a potential system can be created that provides a solution for the current flood problematic, but also work towards a more risk aware future in which more houses are protected against flooding and the FloodRe system will not be needed any more.

In this thesis research is performed that contributes to the research done within the Oxford-LSE London flooding case by looking into the FloodRe system. For this purpose an agent-based model is created on the basis of which data can be gathered that provides insight into the potential of insurance based mechanisms to incentivise flood risk management in a specific part of London that is prone to flooding. Within this thesis an agent-based model is conceptualized, coded, verified, validated and used to answer a specific question of interest for the larger research done in the case. The specific research question that will be answered in this thesis is:
What are the effects of the FloodRe system on an UK housing market area prone to flooding and how can the FloodRe system be better structured to incentivise flood risk management?

To answer the research question above, an agent-based model with following specification was made:

- The London district of Camden was chosen as location to model.
- The area can be hit by 3 different kinds of modelled surface water floods.
- Within the model 5 different actors will behave and interact. These actors are:
  - Persons that own, sell and buy houses. They can insure their house against floods. And they can invest in property level protection measures to make their house more flood resistant and resilient. It is compulsory for every person to take flood insurance for their house.
  - An insurer that sells flood insurances to actors owning houses. It also decides to re-insure houses it insures into FloodRe. In the model the technical flood insurance risk will be modelled, not the commercial flood insurance risk.
  - A bank that forecloses houses of persons that default on their mortgage. The bank then sell these houses on the market again.
  - A developer that develops new houses and sells these on the market.
  - A local government that builds flood defences, gives out grants to persons for investing in property level protection measures and evaluates development proposals from developers.

![Figure 1: Overview of the agent-based model structure](image-url)

Figure 1 provides an overview of the model structure. To gain insight into the effect of FloodRe on a housing market prone to flooding and how FloodRe can be adapted to incentivise flood risk management, experiments were run on the agent-based model. Within these experiments the influence three separate behaviours have on a large set of output parameters was checked. The three behaviours that were investigated are:

- The FloodRe system in its current form
- The investing in property level protection measures by persons
- The building of flood defences by the local government

In running these experiment insights were gained not only on the working of the FloodRe system, but also on the working of the two modelled flood protection measures to see how they can be influenced by adaptations that can be made to the FloodRe system to
better incentivise flood risk management.

An analysis on the data gathered from the experiments that were run has shown that the FloodRe system is successful in fulfilling its task of making flood insurances affordable, by decreasing flood insurance premiums, but only has a very limited affect on the housing market beyond that. The flood risk houses are in and the flood insurances excesses that persons have to pay are not at all affected by the FloodRe system in its current form.

The FloodRe system also does not have any effect on the current state of flood risk management among persons and the local government. However flood protection measures do show their potential in effecting the flood risk houses are in. This in turn does not only effect the housing market, but also effects the number of houses that need to be re-insured in FloodRe. Because of this it can be concluded that a system, in which the current FloodRe system is adapted with ways of incentivizing flood risk management, will result in a system that succeeds in keeping flood prone areas affordable and liveable by providing protection to houses and offering affordable flood insurance premiums and excesses.

The question that remains is how the FloodRe system can be structured so that it incentivises flood risk management. Although this specific question is not answered in the research done in this thesis, the research has been a step towards finding an answer. Not only have the results of the research given confidence in the created agent-based model to use it for further research, it also has provided insights into the housing market and FloodRe system as a whole, based on which direction for promising further research on the FloodRe system can be formulated.

One of the most promising aspects in which further research can be done is how FloodRe can provide persons with information that would incentivise them to invest in property level protection measures. This could either be information about the specific things they can do to protect their house, or can focus on incentivizing them to protect their house by showing them it will be financially beneficial for them in the long run. Besides this further research should also be done in how the FloodRe system can work together with local government to realize the building of flood defences by sharing risk information and co-finance projects. Finally the way FloodRe will be scaled down over the upcoming 30 years can also provide a very strong incentive for persons to invest in protecting their house, as long as the right method for scaling down in chosen. On this topic further research with the created agent-based model can also provide promising results.
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Abbreviations

ABI  Association of British Insurers
ABM  Agent-Based Modelling
DEFRA  Department for Environment, Food and Rural Affairs
EDA  Exploratory Data Analysis
GIS  Geographic Information System
LSE  London School of Economics
PLPM  Property Level Protection Measure
SUDS  Sustainable Urban Drainage System
Terminology

Given the different uses of technical terms within the broad risk assessment industry, precise definitions of the thesis concepts need to be clear for everyone to correctly follow the reasoning given in this thesis [FLOODsite, 2005]. To provide a clear terminology of the concepts used in this thesis the 'language of risk' as it is defined by FLOODsite [2005] will be used. The following concepts are used in this thesis with the following definitions:

- **Flood**: "A temporary covering of land by water outside its normal confines" [FLOODsite, 2005]. In this case only surface water flooding will be investigated which "happens when rainwater does not drain away through the normal drainage systems or soak into the ground, but lies on or flows over the ground instead" [Environment Agency, 2013].

- **Risk**: "Risk is a function of probability, exposure and vulnerability. Often, in practice, exposure is incorporated in the assessment of consequences, therefore risk can be considered as having two components - the probability that an event will occur and the impact (or consequence) associated with that event" [FLOODsite, 2005]. So in the case of 'flood risk' which will be talked about in this thesis it is about the probability of a surface water flood occurring and the impact this has.

- **Flood Risk Management**: "The complete process of risk assessment, option appraisal and risk mitigation" [FLOODsite, 2005]. The specific action in which flood risk can be mitigated will from here on out be referred to as 'flood protection measures'.
1. Introduction

In the winter of 2013-2014 the south of the UK (London, Oxford) experienced the heaviest rainfall since 1767. It has seen its wettest winter on record, with January 2014 being especially wet [Redfern, 2014]. Research concluded at the University of Oxford in April 2014 shows that global warming has a small, but significant effect on these extreme rainfalls and floods resulting from it [University of Oxford, 2014]. At the recently held European Geosciences Union meeting in Vienna Prof Myles Allen presented his evidence of a link between the recent floods in the UK and climate change [Allen, 2014]. Extreme types of weather that cause floods like those in January 2014 have increased by a small, but measurable, amount.

The problem of flooding in the southern part of the UK can no longer be ignored and a plan needs to be made for the future to deal with floods. A project that currently investigates this pressing issue is the ENHANCE project. This is a large project that aims to enhance risk management partnerships for catastrophic natural disasters in Europe [ENHANCE, 2014]. A specific part of this project is a project that runs at Oxford University, where a specific focus is put on examining the way economic instruments may support flood risk management in flooding. An important economic instrument in this is flood insurances. Insurances can be used as a tool of flood risk management that reduces the economic impact and facilitates recovery after a flood event. A well-designed flood
insurance system has the potential to reduce risky behaviour, promote risk-awareness, and encourage flood proofing. A specific case within the ENHANCE project, the Oxford-LSE London flooding case, will focus on the potential of insurance based mechanisms to incentivise flood risk management in a specific part of London that is flood prone. Within this case an agent-based model will be created that will represent a specific part of London that is prone to flooding on which different insurance based mechanisms to incentivise flood risk management can be studied [Igor Nikolic, 2014].

1.1 Problem background

1.1.1 The difficulty of flood insurance

For insurers floods often form a problematic case. In normal insurance cases insurers can spread the risk, and payouts are gradual. Take for instance theft insurance. This is something everybody can come in contact with and is something that happens on quite a constant basis. For insurers this is a fairly easy thing to cover. But when looking at flood insurances the opposite is true. Floods are volatile and do not effect everyone. Floods are extreme, peaky and very costly events. Insurers can not predict the costs for the next years. They have to hold extra capital in order to deal with uncertainty. On top of this there is the media attention when dealing with claims. The sudden rush of claims often results into a lack of hotel rooms, lack of builders, etc., which increase the difficulty for insurers to handle the situation. [Igor Nikolic, 2014].

Besides this there is the problem of ‘moral hazard’. The risk of a flood is hard to spread. Why should someone living on top of a hill pay for the flood damage of someone living next to the river? The persons that live in flood plains take higher risk by living there and they have to be ’bailed out’ by the people that do not live in flood plains. Because this is unwanted the burden shifts towards the persons living in high flood risk areas, making their flood insurance unaffordable.

1.1.2 Flood insurance in the UK

Besides flooding being an interesting and difficult case for insurers in general, the UK flood insurance system is of particular interest. In the UK there is a gentlemen’s agreement between the government and insurers representing a public-private partnership.
The government reduces risk through investment in defences and insurers cover damages in the case of floods. Insurance against risk is provided in almost all homeowners’ house insurances which bundles flood insurance within it (even for properties considered at significant risk of flooding). This is compulsory as mortgages are only given where full household insurance coverage is purchased. However, as the frequency and extent of floods and damages rise there is the need for a continued but redefined public-private partnership, and the government needs to take action to make sure flood cover remains widely available [Igor Nikolic, 2014].

If the situation does not change homes located in areas in the UK that are prone to flooding and have inadequate defences are facing flood damage excess levels more than 40 times higher than low-risk properties, as well as sharply higher premiums. According to AA insurance some households are already enduring flood insurance excess levels of as much as £20,000 compared with £250 for low-risk peers. Households across the UK are facing premium increases of between 3-5% next year, according to Deloitte, but brokers said homes in at-risk areas could endure rises of as much as 10 times these levels [Gray, 2012].

The FloodRe system

In May 2014 the UK government and the Association of British Insurers (ABI) came to a principle agreement on the layout of a new system, called FloodRe\(^1\). Within this system a non-profit flood fund will be set up which ensures that flood insurance remains affordable and available to homeowners at high flood risk. This system allows insurers to transfer the flood insurance premium part of the homeowners insurance into a separate insurance; FloodRe. In return FloodRe will reimburse the insurers for flood claims they pay to their customers. A cap is put on the premiums that have to be paid for flood insurance to make sure it will stay affordable for everyone. This cap is based on the council tax band the consumer is in and can range from £210 for homes in tax band A to £540 for homes in tax band H.

The FloodRe system will be paid out of two sources. The first source is the money insurers pay for putting one of its policy holders into FloodRe. The amount of money insurers have to pay equals the capped flood insurance premium they will offer their

\(^1\)Because the definite FloodRe system is still being created it can change at any moment. The analysis in this paragraph on what the FloodRe system currently looks like is made in December 2014 and based on the following sources; [Association of British Insurers, 2014] & [Department for Environment, Food and Rural Affairs, 2013] and by talking to experts within the ENHANCE project
policy holder. For insurers this means their balance for a person they re-insure into FloodRe will be 0 (the premium they receive from the policy holder has to be paid to the FloodRe system). The second source is from a levy that will be put on all consumers. According to ABI this will be equivalent to the already existing cross-subsidy in the market and will be around 2.2% of a persons insurance premium, which will average to £10.50 per consumer. Because consumers already pay this levy for cross-subsidizing high flood risk properties, ABI highlights that this levy will not be an extra cost for consumers.

To have the FloodRe system focus on helping the persons that need it the most and not have it give the wrong incentivise, the following demarcations are set in the system:

- Houses built after 1 January 2009 will not be covered in FloodRe. According to ABI this is done because this would otherwise incentivise unwise building in flood risk areas.
- The FloodRe system is not designed to cover ‘catastrophic’ (1 in 200 year) flood events. In such a situation the UK government will have the primary responsibility to effectively respond to the situation.
- The FloodRe system is designed to help those that need it most. Initially this meant that homes in the highest Council Tax band H would not be covered by the scheme. However in December 2014 FloodRe was changed to also include tax band H.
- Commercial buildings are also not covered by FloodRe.

With this principle agreement on a FloodRe system a first step is taken, but there are still a lot of details that need to be worked out. The aim of ABI and the government is to have the system up and running in the summer of 2015 [Association of British Insurers, 2014] & [Department for Environment, Food and Rural Affairs, 2013]. Recently the EU got involved because in the way FloodRe seems to be structured now it can be seen as disguised state aid [Department for Environment, Food and Rural Affairs, 2013]. Problems like this make it even harder to predict what the end result of FloodRe will be and if the deadline of the summer of 2015 will be reached.

The above gives an insight into the official working of the FloodRe system as it is proposed now. However, the most interesting part of the FloodRe system is the part
that is not talked about in official publication. The FloodRe system as described now is just a system to plug a hole. High risk insurances that are not deemed profitable by the insurer will be re-insured in FloodRe, shifting the risk towards the FloodRe system and away from the insurer or uninsured person. It does not provide a constructive solution to the problem of flooding.

The makers of FloodRe also realize this and want to structure it in a way that it does form this constructive solution. With the introduction of FloodRe the insurance market should be changed in a way that in 20-30 year FloodRe can be phased out again and flood insurances will still be affordable and available. For this to happen the FloodRe system should be designed to incentivise flood risk management among homeowners and governments. However no decision so far has been made in how FloodRe can be designed to make this happen.

1.2 Research problem

To restructure the FloodRe system from a system that plugs a hole to a system that incentivises flood risk management and can be phased out in the long run, research into different possible FloodRe structures is needed. To help in finding a FloodRe structure that will be successful in incentivizing flood risk management an agent-based model will be created on the basis of which different FloodRe structures and the effects they have can be tested.

To be able to create an agent-based model in which the consequences of different structures can be captured, the full complexity of the system and its surroundings will have to be understood. Given the structure of the flood insurance market in the UK and the newly created FloodRe system, there are more knowledge gaps that need answering than just looking at how the FloodRe system can be structured to incentivise flood risk management.

First the effects of the FloodRe system as it is proposed now are not yet known and need to be researched. The FloodRe system is a system that does not yet exist and so also does not have measurable effects yet. What in theory sounds good can maybe not work in reality. It will be important to first look into the effects the currently proposed FloodRe system has on a housing market, before already looking into how the system can be structured to do more.
Second the current working of the housing market and the way flood risk is managed within it needs to become clear. If the FloodRe system wants to be structured in a way that it keeps flood insurances in a flood prone housing market affordable and also incentivises flood risk management, it first needs to become clear how flood risk is managed currently under normal circumstances. Only if the current state of affairs is clear, FloodRe structures can be sought out to influence it in a positive way.

Given the complexity of the working of a housing market with flood risk management in it and the complexity of a flood insurance system to which a FloodRe system gets added, the limited time frame in which the research in this thesis has to be done is not enough to research everything. But this research being placed in a larger project in which further research will be done gives the possibility to keep the research done in this thesis limited. Therefore the goal of the research that will be done in this thesis will be limited to creating a strong basis on which further research can be done. With the insights gained in the creation of the model and the experiments that will be run on it, insights will be gained on promising aspects to do further research on.

1.3 Research objective and deliverables

The objective of the research that will be done in this thesis can be formulated as follows:

To develop an agent-based model on the basis of which insights can be derived regarding the effect of the FloodRe system on an UK housing market prone to flooding, with specific interest in flood risk management.

The main deliverable of this thesis will be an agent-based model that tries to capture the complexity of the insurance system and housing market in the UK. It will be important that a thoroughly thought out agent-based model is delivered on basis of which significant results can be gathered.

This agent-based model should initially be able to provide insights into how the current proposed FloodRe system affects an UK housing market area prone to flooding. In addition it should also provide the possibilities to research different FloodRe set-ups to see how flood risk management can properly be incentivised.

The final deliverable of this research will be insights on the effects the current FloodRe system has on an UK housing market prone to flooding and how it affects
flood risk management. Besides this recommendations will be given on what further research can be done with the model to gain more insights into how the FloodRe system can potentially be structured to incentivise flood risk management.

1.4 Research question

To provide the deliverables as mentioned above, the following main research question is set up:

What are the effects of the FloodRe system on an UK housing market area prone to flooding and how can the FloodRe system be better structured to incentivise flood risk management?

To answer this question an agent-based model will have to be created. For the creation of the agent-based model the following sub-research questions are formulated:

1. What does an agent-based model that represents a simplified UK housing market in an area prone to flooding look like?
2. In what way can the FloodRe systems be implemented in this agent-based model of a housing market?

With further research in mind it will be important that the division between these two sub-research question stays visible in the model. Where the behaviour of the UK housing market will most likely not change any time soon, the setup of the FloodRe system is bound to change, seeing it is still being created. By keeping these two aspect separate in the model conceptualisation and creation, the FloodRe system can easily be changed when doing further research, without having to search in all the housing market conceptualisation and model code.

\footnote{In this context 'simplified' means that the housing market that will be modelled should be demarcated to the behaviours that are of interest and should not be overburdened by detail}
2. Research approach and methodology

Based on the problem that will be researched in this thesis and the research questions that are formulated, the research approach and the methods that will be used to answer the research questions can be structured. The research approach will first be made clear, after which the methods, specified in the research approach, will be elaborated on in further detail. When the research approach and methodology are clear the social and scientific relevance of the research can be elaborated on, to end with the structure the remainder of the report will have.

2.1 Research Approach

A flow diagram of the research approach that will be used in this research can be found in figure 2.1.

The main complexity the approach of this thesis faces is the fact that the thesis will be situated within a case that is situated within a large project, the ENHANCE project. To make a thesis that works well within this project and also to make it add knowledge, close collaboration will be needed with persons who have been longer involved in this project. In the case of this thesis this will mainly mean close collaboration with Dr. Ir. Nikolic who has been working with the ENHANCE project for the last half year and has gained a lot of knowledge on the agent-based model that will be created. In the approach of this thesis a clear distinction between work done in collaboration and work done alone will be made.

The approach of this thesis can theoretically be separated into two parts. The first part of the thesis will focus on creating an agent-based model that can provide insight into how the FloodRe system affects an UK housing market area prone to flooding (answering the sub-research questions). The main collaborative aspect of the thesis will mostly lie in this first part of the thesis.

The second part of the thesis approach will start after a working experimental device has been created. This second part will focus on answering the main research question. Insights gained from analysing data gathered from experiments run on the model can be used to conclude on the effects the FloodRe system has on a housing market area prone to flooding and to give recommendations on promising directions for further research to find a FloodRe system that properly incentivises flood risk management.
Because the main focus of this thesis lies in creating an agent-based model and using this model to gather data on a problem, the overlying theory that will be used to approach this research will be the 10 steps of agent-based modelling (ABM) as presented in the book 'Agent-based modelling of socio-technical systems' [van Dam, Nikolic & Lukszo 2012]. This book presents a clear 10 step guide that starts at formulating the problem the model has to tackle, to concluding on the insights gained with the created model. Within this thesis these 10 steps will be followed to create the wanted agent-based model and to get proper results from it. Appendix A, provides a more detailed
look into the 10 steps of ABM that will be used.

2.1.1 First part of the thesis

To create an agent-based model on basis of which insight can be gained into the FloodRe system and a flood prone housing market, a very step-by-step and iterative process will be used. This part of the thesis will be approached in this way because a range of expertise from different fields of study is needed to enable the agent-based model to capture the complexity of the situation it will represent.

The creation of the model will start by making a clear conceptualisation of the envisioned model. This conceptualisation will be made based on documents and expertise provided from within the ENHANCE project. After a conceptualisation, that is agreed upon within the ENHANCE project, is created, it will be used to create an agent-based model. This model needs to be verified to make sure the model is built in the right way.

This first part of the thesis encompasses the first 6 steps of the 10 steps of agent-based modelling that will be followed.

2.1.2 Second part of the thesis

When a working and representative agent-based model is created, the second part of the thesis can be started. The created agent-based model will be used to gather data on the effects of the FloodRe system and the way it can possibly be used to incentivise flood risk management. By analysing the patterns in the gathered data, the outcome of the model can be analysed to make sure the model is able to provide significant insights into the effect of FloodRe and to make sure the model is valid; it represents the situation it tries to model. Using the results from the analysed data the main research question can be answered and recommendations can be given.

2.2 Methodology

Following the 10 steps of ABM there are four moments identifiable in which specific methods need to be used to gain results. In the first 4 steps the modelling problem is formulated and the model is conceptualised. In these steps there is a clear need for knowledge on which the problem formulation and conceptualisation can be built. In step 5 the conceptualisation needs to be transferred into creating an actual model using a modelling method. For step 6 (verification) and step 7 (experimenting) the just
created model and the theory behind these steps as presented in the book are needed, but no specific methods are needed. In step 8 the output gathered in the previous step needs to be analysed. For this a method on **analysing model output** needs to be used. In step 9 a method will be needed for **validation** of the model and the results coming from the model. Step 10 focuses on presenting gathered results, for which no specific method is needed.

The choice of methods that will be used at the four identified places within the research approach will now be elaborated on. By analysing the situation a method is placed in and what support it needs to provide within the research, a choice in method will be made. This will be based on the advantages the method has over similar methods, given the situation. But because every method also comes with its limitations, these will also be outlined to make sure they will not form a problem in executing the research.

### 2.2.1 Need for knowledge

Because this research will build on research already done within the bigger ENHANCE project, no elaborate knowledge gathering will be needed. Most of the knowledge that is needed will be gathered from documentation available within the project and by talking to experts within the project.

**The limitations in using expert knowledge**

The main limitation to consider using expert knowledge is that information and knowledge is biased. "Individuals create their own 'subjective social reality' from their perception of the input" [Bless et al., 2004]. For using expert knowledge the consequence is that knowledge should never be trusted just because it comes from an expert. It will be key to also use own judgement when using knowledge provided by experts.

Because a lot of documentation and knowledge provided for the making of the conceptualisation will come from one person; Mr. Nikolic, this limitation is something that needs close attention within the making of the conceptualisation. Seeing a model is created of which there is no model alike, many assumptions will have to be made to try to capture reality within a model. To tackle the pitfall of depending too much on assumptions made by Nikolic, every assumption made needs to be thought through to make sure it makes sense. To make sure this happens properly not only the modeller
(me) will look closely at this, but also other experts will be highly involved in the creating of the model conceptualisation. For the main part these other experts are; Jim Hall (Director of the Environmental Change Institute at Oxford University), Katie Jenkins (Urban Systems Modeller at the Environmental Change Institute at Oxford University) and Swenja Surminski (Senior Research Fellow at the London School of Economics). From outside of the ENHANCE project Jill Slinger (associate professor of Policy Analysis at the TU Delft and second supervisor of this thesis) also provided knowledge for the model. Besides these experts, a range of other experts, connected to the ENHANCE project (among others, experts within Willis Group, the London School of Economics (LSE) and the Department for Environment, Food and Rural Affairs (DEFRA)), will be used on a less specific bases (teleconferences and document exchanges about the ENHANCE project in whole and not just the creation of this model) to gain knowledge that can be used in the model creation.

Guides/Tools for using expert knowledge

In gaining expert knowledge no specific guides or tools will be used. Before and during the creation of the model many conversations will be held with experts. Because almost all of these conversations will be held with experts within the ENHANCE project who will be talked to more than once, a very open form of communication is chosen. The conversations will be semi-structured, guided by questions set up in advance and parts of code that can be shown. If specific questions have to be asked to an expert, they will be asked. Besides this the conversation will be very open to have room to discuss the full extend of the model.

2.2.2 Modelling method

As already made clear agent-based modelling will be used to create the wanted model on the basis of which insights can be gained on the effect of the FloodRe system on flood risk management in an UK housing area prone to flooding.

The limitations in using agent-based modelling

When using agent-based modelling there are two clear limitations that have to be taken into account during the modelling effort. Because players in the model have information on all previous events that occurred, they have ‘perfect information’, and are rational
in their decision making, being able to calculate the result of every action they perform, decision making in the model can be sub-optimal. This limitation has to be accounted for and clearly stated, seeing the results of the model will be subject to this limitation. A second limitation of using agent-based modelling is in the detail that can be put in a model. The model can always be improved to have it 'better' represent the real world. This tendency often results in too large and too complex models that go beyond their goal of what they wanted to represent.

A limitation that has to be tackled outside the done modelling effort is the computational power that is needed to run agent-based models. The wanted agent-based model is of such complexity and size that a lot of computational power will be needed to run the model. By running the model on a cluster at the TU Delft this computational power limitation will be tackled.

The interesting thing about agent-based modelling however is that, although its limitations, it is mainly the advantages that it has, that make it a good modelling technique to use for this research. The main advantage of agent-based models is the way they can represent themselves. If properly set up the interface of an agent-based model is very well equipped to give a simple view on the behaviours that are modelled. This is especially true for the spatial aspect that is modelled when looking at a housing market that is affected by floods. Within the ENHANCE project this interface can be used very well in quickly showing interested persons in what the model can do and what behaviours resulted in the conclusions that are drawn up based on the output of the model.

If these advantages are not properly used in the creation and use of the model, they can also be seen as limitations, because the used modelling technique will then not be used to its fullest. Therefore both the advantages and limitations will have to be accounted for. Appendix B elaborates further on the advantages and limitations of ABM by comparing it to an approach that uses a hybrid of system dynamics and game theory to gain the wanted insights into the UK housing market system.

Guides/tools for using agent-based modelling

As already specified the 10 steps of agent based modelling will be used as guide to construct the wanted agent-based model. The programming tool that will be used to execute the modelling will be Netlogo [Netlogo]. This modelling program is chosen for
two reasons. First it is one of the modelling programs that is suggested within the theory on agent-based modelling that is used to build this research on. And second because I (the modeller) have gained expertise in working with this program in the two courses I took on agent-based modelling at the TU Delft. In these two courses I have found Netlogo to be a complete program in which an agent-based model can be created that not only works well but is also already visualised in a very good way within the interface of the program.

2.2.3 Analysing model output

To analyse the data that will be gathered by running experiments on the created model, a method needs to be chosen that can deal with the data that is gathered. Because research will be done on a system that does not exist yet, the type of research that will be done will be very exploratory. There will not be specific hypotheses for which specific results will be generated to see if the hypothesis is true. The optimal solution is not clear. Large experiments with a wide range of values that will be tracked will have to be run to gather a lot of data on a wide solution space.

Given the range of data to look at and the end goal of gaining insight into a system that does not exist yet, the method that will be used is exploratory data analysis (EDA). EDA is an approach in which large data sets can be summarized, often using visual methods [Seltman, 2014]. By presenting the large sets of data in clear and understandable graphs, patterns can be found that can be used to build conclusions and recommendations on.

The limitations in using exploratory data analysis

EDA will give us the ability to gain some insight into the effects of FloodRe. However it also has its limitations. EDA is, as the name says, an exploratory method. This means it will never give definite answers [UC Santa Barbara Department of Geography]. The role of the person executing the analysis is large. The executor decides which data will be analysed, in what way it will be analysed and how the analysed data will be interpreted. This leaves a lot to the judgement of persons. Answer can not be cook-booked. It will be important to keep these limitations in mind because persons make mistakes and base what they do on their own biased knowledge and information (as discussed in the need for knowledge section).
This can especially be true if it is the same person that creates the model and analyses the data, as is true in this case. During the creation of the model the modeller has already been pushed into thinking in a direction. In analysing the data he will search for confirmation that his way of thinking is correct. For this reason it will especially be important that during the creation of the model experts are often consulted, but also that the results, gathered from exploring the model output, are run by experts to see if these are logical (see next section; validate results).

**Guides/tools for using exploratory data analysis**

The tool, that will be used to do exploratory data analysis with, is 'R’ [R-project, 2015]. R is a free and open source program that is good in representing large sets of data in understandable graphs. R can be used on a very basic level, by just making simple graphs, but can also be used on a more advanced level, by using additional packages available for R. In this way the range of data that will come from the experiment can be made clear and understandable and patterns can be found on which conclusions and recommendations can be build. One of the main advantages of R and also the reason why it is chosen is the way it works together with Netlogo in a very simple way. Another advantage of R is that it has a large and active user group that provides guidance and help in using R.

**2.2.4 Validation**

The model and the resulting data will need to be validated to make sure the right model is build and the results form it are convincing. A problem for the validating of the results is that the problem investigated is of a system (FloodRe) that does not exist yet. This makes the model hard to compare to a real-world situation. There is also no model alike that can be used to compare the model with to validate it. However, this research being placed within a larger project does provide the possibilities of using experts. In the creation of the model a lot of expert knowledge is already being used. This already validates the model to a certain extent, but only validates the actions that are coded, not the results they bring. So, to make sure a valid model is created that also provides valid results, expert knowledge can be used.

Where the use of expert knowledge in the creating and validating of the model will be done on a more unstructured basis, as described in the section on the need for
knowledge, the validating of results can be done on a more structured basis. By asking a set of pre-made questions based on the data that is gathered from the agent-based model, a specifically selected expert can be interviewed to validate the results of the model.

The limitations in using expert interviews

Just as with expert knowledge that will be used in the gathering of knowledge, the limitations in the use of expert knowledge in the validation of the model is the same; information and knowledge is biased, individuals create their own ’subjective social reality’ from their perception of the input. This is also why it would be wise not to ask an expert that has already been too involved in the conceptualisation of the model, to also validate the output of the model. For this reason an expert, that also has knowledge on the modelled situation but has not been too involved in the model so far, will be chosen to do an expert interview with on the output of the model.

Guides/tools for expert interviews

Just as with the gaining of knowledge for creating the agent based model, no specific guides or tools will be used for the expert interview that will be held. This conversation will however be more guided by having a pre-made set of questions that will be asked to the person who is interviewed.

Additional validating

In this thesis the validation effort will be limited to validating the model mechanics and output. Seeing this model will be build with the use of further research in mind, validation on the usability of the model can also be an option. If the model that is created will only be usable for the person that created the model, the usefulness of the model for further research is not big. However as modeller I will be the main person doing further research with the model. The other person who will most likely work with the model Katie Jenkins. Together we already got a good understanding of the model. Therefore this validation will not be done for now. When it becomes clear persons that have no prior knowledge on the model will want to start using the model to do research with, a validation on the usability of the model will be useful.
2.3 Research relevance

The societal relevance of this thesis lies in the contribution it will try to make in finding a solution for the on-going flood insurance problem in the UK. The current flood insurance situation in the UK is a real problem that does not have a complete solution yet. To keep flood insurances affordable and available in flood prone areas research needs to be done to find an insurance system that works. This research will contribute in finding this working system by creating a model on the basis of which the effects of FloodRe on an UK housing market area prone to flooding can be investigated and insights can be gained on how the FloodRe system can be structured to incentivise flood risk management.

The scientific relevance of this thesis lies in the new insights that will be created into the flood insurance system of the UK. In the insurance world economic models are the prevailing methods and the use of agent-based modelling is new. By combining financial aspects, policy aspects, land usage geophysics and a flood hydrology into a single model, novel insights can be obtained into the working of the UK flood insurance system. By reflecting on the working of the model after it has been created, what it can and can not do, knowledge can be gained on how successful ABM can be in providing novel insights into a market in which economic models prevail.

Although this model will be focused on the UK situation, the model can have a wider relevance. Because the concept of flood insurance and housing markets is to a large extent quite generic, the model could in theory also be used to investigate situations in other countries. Appendix C provides an overview of how the model that will be created can be used in other countries.

2.4 Report structure

In the structure of the remainder of the report a clear line following the steps of ABM can be found.

In chapter 3 the model will be created using agent-based modelling and knowledge from documents and experts within the ENHANCE project. In this chapter the first 6 steps of the 10 steps of ABM are worked out.

Chapter 4 elaborates on how experiments are set up, that can be run on the agent-based model, to collect data to gain insight in the effects of the FloodRe system. In this chapter step 7 of the 10 steps of ABM is worked out.
Chapter 5 focuses on analysing the just gathered data. First patterns will tried to be found in the gathered data by using exploratory data analysis. The results of this will be validated by interviewing an expert within the ENHANCE project. In this chapter step 8 and 9 of the 10 steps of ABM are worked out.

In Chapter 6 the conclusions and recommendations that come from the research that is done are presented. In this chapter the main research question will be answered. A reflection chapter, chapter 7, follows the conclusion and recommendation chapter.
3. Creating the model

Following the problem formulation an agent-based model can now be created that represents an UK housing market that is flood prone in which the FloodRe system is introduced. By running experiments on this model data can be gathered that can be analysed to find patterns based on which insights can be gained. However, because the data that is gathered from the model will be subject to the choices and assumptions that are made in creating the model, these choices and assumptions will have to be understood if the insights gained in this research also properly want to be understood.

A detailed elaboration of the execution of the modelling effort, in which the first 6 steps of the 10 steps of ABM as presented in the book 'Agent-based modelling of socio-technical systems' [van Dam, et al., 2012] will be executed, can be found in appendix D.

3.1 General modelling choices

- The specific housing market that will be modelled and on which research will be done in this thesis is Camden, a district of London. Appendix F elaborates on this choice.
- Only the residential housing market will be modelled, no commercial buildings will be modelled. Because commercial buildings are not eligible for FloodRe this will not have a big impact in the model and the research that is done with it.
- The model will run with a time step of a year. This means every run through of actions will entail a year. Results can be gathered on a year-by-year basis. Paragraph D.2.3 in the model creation appendix elaborates on this choice.
- The modelled area of Camden can be affected by three different flood events of flood return periods 1 in 30 years, 1 in 100 years and 1 in 200 years. Appendix H elaborated on this choice and the data that is used to model these floods.
- The focus of the model will lie on the effects of flood risk mitigation and the drive of persons and the local government to mitigate flood risk. That is why the options to mitigate risk in the model will be limited and the complex reasoning of appraising different options to manage flood risk will not be modelled. The flood protection measures that will be modelled are investments in property level protection measures (PLPMs) for persons and the building of flood defences for the local government. Appendix J gives a short overview of the types of flood
protection measures that will be modelled. These flood protection measures will lower the damages done by floods by an equal percentage over all modelled flood return periods. Appendix K elaborates on this choice.

3.2 General modelling assumptions

- Perfect information: Each player, when making any decision, is perfectly informed of all the events that have previously occurred [Osborne, 1994]. Agent within the FloodRe model save all information that has previously been provided to them and they make decisions based on this.
- Rational decision making: Every agent always maximizes his utility, thus being able to perfectly calculate the result of every action [Game theory.net]. For the model this has a consequence that all agents will act in a very rational way. In the real world agents often don’t act in a rational way because they simply can not consider all events when making a decision and irrational factors, like emotions, play a large part.

3.3 Modelled agents and their behaviour

Within the model six agents will be modelled that behave individually and interact with each other. The aggregate of their behaviours and interactions will result in patterns on the basis of which insight can be gained in the working of the modelled housing market and the FloodRe system.

Persons   Persons are the main agents within the model. They own, sell and buy houses. They insure their house against floods and can invest in PLPMs to make their house more flood resistant and resilient. The most important assumptions made in modelling persons are:
- It is compulsory for persons to take flood insurance for their house
- Persons select a house to buy only on the criterion that it is the most expensive house they can afford given their income
- Most homeowners will decide on a reactive basis, after their house is hit by a flood, to invest in PLPMs. Only a small percentage will invest in PLPMs on a proactive basis, not based on a flood event but on flood risk
• All persons that think about investing in PLPM reactively will do so because PLPM investing is subsidized

**Houses**  Houses receive information, compute it and pass it on to the agent owning the house. The most important assumptions made in modelling houses are:

• The value of a house won’t directly be affected by being hit by a flood
• All houses in the model are houses for sale. House renting is not modelled

**Insurer**  The insurer sells flood insurances to agents owning houses. He also decides to re-insure houses into FloodRe. The most important assumptions made in modelling the insurer are:

• Only a single insurer will be modelled
• An insurance market will not be modelled
• The technical flood insurance risk will be modelled, not the commercial flood insurance risk
• Insurer will not have the option to deny people an insurance
• The insurer will never go bankrupt and leave the model
• Insurers will not provide FloodRe information to third parties, meaning other agents do not get information about houses being re-insured in FloodRe. D.2.5

**Bank**  The bank forecloses houses of persons that default on their mortgage and sell these houses on the market. The most important assumptions made in modelling the bank are:

• Only a single bank agent will be modelled
• The bank sells the houses they foreclosed for market value and will not lower the asking price if the house will not be sold

**Developer**  The developer will build new houses and sell them on the market. The most important assumptions made in modelling the developer are:

• Only a single developer will be modelled
• The development of new houses has no effect on the flood risk of surrounding houses
• The developer does not account for flood risk when choosing the location to build
• 50% of all new developed houses will be build with flood defences already in place
• The developer sells the houses he has developed for market value and will not lower the asking price if a house will not be sold

**Local government**  The local government will build flood defences, give out grants to persons for investing in PLPMs and evaluates development proposals from the developer. The most important assumptions made in modelling the local government are:

• Only a single local government will be modelled that governs over the whole modelled area
• All land in the model without a house on it belongs to the local government
• The local government decides on building flood defences in a proactive way; looks for beneficial flood defence project to build without having to be triggered by a flood event
• The approving of development proposals only depends on the flood risk and the financial values of the given development proposal

### 3.4 Overview of the conceptualisation

Figure 3.1 provides an overview of the model structure and design following the behaviours of the modelled agents.

![Overview of the agent-based model](image)

**Figure 3.1:** Overview of the agent-based model

### 3.5 The created model

As specified in the methodology, the created conceptualisation will be translated into an agent-based model by coding it into the agent-based modelling program Netlogo. Figure
3.2 shows the Netlogo interface of the model that followed from the made conceptualisation, of which the main points are elaborated on above. The layout of the modelled area of Camden can be seen in the middle, parameter options can be seen on the left and counters on the right. This model will be used to gain insights into the working of the FloodRe system and how it can incentivise flood risk management.

### 3.6 Model verification

In the last step of model creation the model will be verified to make sure the conceptualisation is correctly translated into the model code and the model can be used to start doing experiments on. Details of the verification step can be found in appendix D.

The model has first been verified by making explicit predictions of what we theoretically expect an agent to do when provided with well-defined inputs, to see if the behaviour of the model coheres with the hypothesis of how the model should logically behave. These hypothesis can be formulated following from the made conceptualisation. This test looks if the agents behave well under normal inputs. To also test the edges of the normal behaviour, the agents in the model are tried to be 'broken' by providing
them with extreme value inputs and see how they behave under it. Both test have been executed extensively and both have resulted in showing the model is correctly translated from the made conceptualisation.

The last verification test that is done is to check the variability between single model runs of the model. A single run of a Netlogo model can not be trusted because agent-based models are often chaotic, results can vary quite a lot between runs. Within the variability test the model will be tested under normal model settings, but with different amounts of repetitions. In this way the variability between runs can be seen. With this testing the number of repetitions that should be used for experimenting with the model can be determined.

Figure 3.3 shows a compilation of the box-plots that show the variability between several runs with different repetitions. Because the model is computational heavy the smallest amount of repetitions wants to be found on the basis of which a good sample of results can be gathered. The choice is made to run with 50 repetitions because the deviation between the medians and ranges of the 50 and 100 repetition runs are not as large as can be seen for the lower amount of repetition runs.
Figure 3.3: Compilation of variability boxplots
4. Experimenting

In the previous chapter a verified agent-based model is built that can be used to gain insight into the effects the FloodRe system has on a flood prone housing market. In this chapter the experiments that will be run on the model to get the data on basis of which these insights can be gained will be set up. For this step 7 of the 10 steps of agent-based modelling will be used to set up and execute experiments with the FloodRe model.

In this chapter the hypotheses that will be checked by running experiments will first be made clear. After this the time frame in which the experiments will be run is set. Last the experimental design is set up in which the inputs, parameters and output of the experiments that will be run are defined. These experiments will provide large sets of data that will be analysed in the next chapter.

4.1 Hypothesis

The created FloodRe model is made to explore the effects of FloodRe on an UK housing market and to get insights into possible ways for the FloodRe system to incentivise flood risk management. The way the current FloodRe system is set up is supposed to already make flood insurance premium affordable in flood prone areas by putting a cap on the maximum insurance premiums persons have to pay. The hypothesis that can be checked to see if this is indeed the case is: The number of persons that have to sell their house because they can not afford it any more will decrease with the introduction of FloodRe.

Because research will be done on a system that does not exist yet and the effects of it are therefore not yet known, the research that will be done will be of an exploratory kind. The model does not try to replicate an exact real world situation that can be validated by seeing if it matches the real world. This means that there are no hypothesis that can be made to which experiments can be tailored to recreate. To gain insight, large experiments will have to be run with many output variables to get an idea on how FloodRe effects the housing market and the way flood risk is managed in the modelled area. This is also the reason that no specific hypothesis will be set up next to the single hypothesis on decreasing forced house sales.
4.2 Time frame

The first important aspect that needs to be decided is the time frame in which the experiments will be run. In this case: for how many years will the model run? In choosing the amount of years for which the model will be run, a consideration needs to be made between on the one hand the minimum amount of years needed to research the emergent patterns of interest, and on the other hands what relevance running more years would bring. A larger time frame means that experimenting will take longer (a run of the model takes longer) and that changing external factors (Government policies on the housing market for instance) start having a bigger influence.

An interesting changing external factor in the context of the model is climate change. The model is intended to be able to do research on the effect of climate change (making floods happen more often). However for this thesis the focus will not lie on climate change and therefore a minimal time frame will be chosen.

The choice in time frame is set to 10 years. In the way the model is coded it takes 3 years for the housing market to fully start up. In the choice of how flooding will be modelled a flood will occur after 5 years. After this the model will run another 5 years to see how everything reacts to the flood.

4.3 Experimental design

In this section the input variables that will be fed into the model, the parameters that will be changed over the different runs and the output that will be measured to gain insight into the effects of the different parameter settings, will be elaborated on.

4.3.1 Inputs

The external variables that will be fed into the model will be kept limited. The main goal of the model is to provide insight into the effects of a FloodRe system on a housing market prone to flooding. For this the housing market that is modelled will actually have to be affected by flooding to see how FloodRe system handles this. Geographical Information Systems (GIS) data provides information on three floods of different flood return periods (1 in 30, 1 in 100 and 1 in 200 year flood events). Because the choice is made to only have a single flood occur during a single experiment and because 'no flood’ is also an option there are in total four different input settings under which the
model can run. In this way the consequences of a large range of flood events, from no flood, to a small flood (1 in 30 year) up to a large flood (1 in 200 years), are accounted for in the model.

Besides feeding flood event in the model there are also other external factors to look at. Take for instance the financial picture of flood protection subsidizing, or the general interest (political and among persons) there is for flooding. These are also important factors that influence the behaviour in the model. However because of the recent floods in the UK it is assumed the interest, and with this also the amount of money available for subsidies, is currently quite high in the UK and will most likely not change much in the 10 years the model will run. Because of this the changing of these factors is not something that will be accounted for in the experiments that will be run for the research in this thesis. When doing further research these factors can however be important if robust results want to be gathered on a longer time frame. For this reason these factors are elaborated on in the recommendation on further research that can be done with the model.

4.3.2 Parameters

The experiments that will be run should provide insights in the effect the FloodRe system has on an UK housing market area prone to flooding and should provide insight in how FloodRe can be structured to incentivise flood risk management better. The created agent-based model represents an UK housing market area prone to flooding. So by running experiments with both the FloodRe system turned on and off the effect the FloodRe system has on an UK housing market area prone to flooding can be measured.

When looking at the goal of gaining insight into how the FloodRe system can be used to incentivise flood risk management the behaviours to look at are the flood protection measures that are modelled into the agent-based model; the investing in PLPMs by persons and the building of flood defences by the local government. To get an idea on how these behaviours can be incentivised it will not be enough to just look at the effect FloodRe has on these behaviours and how these behaviours affect FloodRe. In order to form an idea on how a behaviour can be influenced, the behaviour itself should also be fully understood. In the coding of these behaviours, the choices and assumptions that are made for it, insights are already gained that can be used to form an idea on how these behaviours can be incentivised. However the actual effect these behaviours
### Table 4.1: Experimentation setup

<table>
<thead>
<tr>
<th>#</th>
<th>FloodRe system</th>
<th>PLPM investing</th>
<th>Flood defence building</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Off</td>
<td>Off</td>
<td>Off</td>
</tr>
<tr>
<td>2</td>
<td>On</td>
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<tr>
<td>3</td>
<td>Off</td>
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<td>5</td>
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<td>6</td>
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<td>7</td>
<td>On</td>
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</tr>
</tbody>
</table>

The experimental setup that this gives is shown in figure 4.1. By identifying patterns of interest in data coming from experiments in which the parameters are turned on separate from each other (experiments 2-4) but also in which they influence each other (experiment 5-7), the full range of effects the parameters have can be researched.

Because of the simplicity of the parameter setting that will be used the most straightforward manner of performing a parameter sweep is chosen, the full factorial design. Every parameter has a parameter sweep of 2 full factorial samples (on and off).

#### 4.3.3 Output

This just leaves the question which values will be tracked to gather output data from. The output that will be looked at can be divided into general output that provide insights into the housing market and the effect the parameters have on it, and specific output that look at the three separate parameters. The choice in output is directed at gaining the insights that are wanted within the ENHANCE project.

### General output

First a general insight on the housing market can be gained by tracking how the **house values** and the **number of houses that are put on sale**, with the reasoning behind the selling choice, evolve every year. Besides this the effect of flooding on the housing market wants to specifically be looked at. For this the **flood risk** houses are in, the
flood insurance premiums and excesses persons have to pay and the flood repair fees persons have to pay when their house is hit by a flood will be tracked.

Specific output

- **FloodRe**: To gain insight into the FloodRe system the number of houses re-insured in FloodRe will be tracked. Besides this the FloodRe assets will be tracked to get an idea on the money going in and out of the FloodRe system.
- **PLPM investing**: The investments in PLPMs can be tracked by looking at the number of persons that invest in PLPMs every year.
- **Flood defence building**: The building of flood defences can be tracked by looking at the number of houses for which flood defences are build.

4.3.4 Experimental design setup

The chosen experiment settings result in the following setup of the experimental design:

**General setup**

- **Ticks [10]**: each tick = 1 year. 10 years is long enough to explore the behaving of the housing market and the consequences different parameter settings have
- **Repetitions [50]**: As determined in the variability testing in the verification step D.6.3.

**Inputs**

One of the following flood events will occur in year 5 of the model run:

- No flood
- A flood event with a 1 in 30 year flood return period
- A flood event with a 1 in 100 year flood return period
- A flood event with a 1 in 200 year flood return period

**Parameter setting**

- **FloodRe system**: parameter sweep using 2 full factorial samples [on/off]
- **PLPM investing**: parameter sweep using 2 full factorial samples [on/off]
- **Flood defence building**: parameter sweep using 2 full factorial samples [on/off]

**Output at each tick**

- House values
- Number of houses put on sale
- Flood risk houses are in
Experimenting

- Flood insurance premiums
- Flood insurance excesses
- Flood repair fees persons have to pay
- Number of uninsurable houses
- Number of houses re-insured in FloodRe
- FloodRe assets
- Number of PLPM investments
- Number of houses for which flood defences are built

In total this will give 28 experiment settings (4 different input values over 7 parameter settings) in which 11 values are tracked for every year the model runs. Figure 4.1 visualizes the design space.

![Figure 4.1: The design space](image)

4.4 Additional experiments

Although the choices made for the experiments that will be run are clear and thought through, it can not be denied that the choices will have a large effect on the outcomes. Just running the model for 10 years with a limited representation of flood events will provide the wanted output for the research done in this thesis. However additional experimenting can be done to see if the patterns found in the experiments run with the setup as specified above are also present under different settings.

To do this an additional set of runs will be done in which the time frame is extended to running 30 years, the time frame in which FloodRe should be phased out again, and the input is changed to a single setting in which all three events occur; in year 8 a 1 in
30 year flood will occur, in year 15 a 1 in 100 year flood will occur and in year 22 a 1 in 200 year flood.

Because of time limitations these experiments will be run and for the output it will only be checked if the same patterns are found as with the experiments done so far. No extensive data analyses to find new/more patterns will be done on the output of these experiments.
5. Analysing results

In this chapter the data will be analysed and validated. By running the experiments as presented in the previous chapter a lot of data is generated. The first goal will be to get insight into this data by analysing it and making it understandable by presenting it in graphs. From these graphs patterns can be found that can be used to build conclusion and recommendation on. However these patterns will first be validated to increase the confidence in the data on which conclusion and recommendation will be build. This validating will, among other methods, be done by analysing the found pattern to see if they show logical behaviour.

5.1 Data analysis

In the experiments three different parameters, the FloodRe system, investing in property level protection measures and the building of flood defences, are run separate and together, as specified in 4.1. The complete data analysis that is done on the data generated by running these experiments can be found in appendix R. Here only the most relevant results will be represented on which the main conclusion and recommendations are based.

Following the set research question: 'What are the effects of the FloodRe system on an UK housing market area prone to flooding and how can the FloodRe system be better structured to incentivise flood risk management?', the effects of FloodRe on the housing market will first be looked at. After this the effects of the protection measures have on the housing market is looked at. Last the effects the FloodRe system and the flood protection measures have on each other will be looked at so that insights can be gained on how the FloodRe system can be structured to incentivise these protection measures.
5.1.1 Effect of FloodRe on the housing market

When looking at the effects FloodRe has on the housing market there are a few interesting patterns to see. As graph 5.1\(^1\) shows the hypothesis that is set, proofs to be correct. The FloodRe system lowers the number of sales because of too high annual fees and makes it that just as many persons with a house in flood risk as persons with a house that is not in flood risk are forced to sell their house. This indicates that FloodRe is successful in lowering the flood insurance premiums of persons, as can be seen in graph 5.2, and unaffordable flood insurance premiums that have to be paid on houses in high flood risk no longer form a reason for persons having to sell their house.

Because less persons are forces to sell their house the house values are also influenced positively by the FloodRe system. Besides these effects FloodRe shows no effects on the rest of the housing market. Flood risks are not lowered and the insurance excesses are also not affected.

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\(^1\)For this graph it has to be noted that although it shows absolute numbers the in and out of flood risk lines can be compared seeing 51% of houses are in and 49% of houses are out of flood risk in the model.
5.1.2 Effect of protection measures on the housing market

To understand the effects the flood protection measures have, their investment pattern first need to be clear. What can be seen in graph 5.3 is that the most flood defences are build in the first few years because in these few year all best projects that have the most effect are build. The investing in PLPM goes gradually in the first few years when proactive investors invest, but sky-rockets after a flood event occurs and the reactive investors also invest in PLPMs.

The main effect that flood protection measures have on the housing market is that they, as expected, lower the flood risk houses are in. As can be seen in graph 5.4 the protection measures have quite a good effect on the flood risk. Because the flood risk a house is in is connected to the flood insurance premiums and excesses it has to pay, the flood protection measures also have a positive effect on these factors.

Besides these effects, the flood protection measures do not influence the housing market. They do not affect the average house values and only have a very small effect on the number of forced house sales.
5.1.3 How FloodRe and flood protection measures effect each other

When looking at the effects FloodRe and the flood protection measures have on each other there are a few interesting insights gained from the data that is analysed. First it can be concluded that FloodRe does not have any effect on both the flood protection measures. Whether the FloodRe system is active or not the amount of investments in flood protection measures is the same. Looking the other way around it can be seen that the flood protection measures have a positive effect on the FloodRe system, as shown in graph 5.5.

Another interesting insight that is gained is that if all parameters affect each other the protection measures only have a limited effect on the average flood insurance premium.

As already could be seen in 5.2 the FloodRe system has a very positive effect on the average flood insurance premium, lowering it by an average of around £300. The flood protection measures without FloodRe being active, also have a positive effect on the average flood insurance premium, together lowering it by an average of around £150. But when adding the effect of the flood protection measures to the
effect that FloodRe system already provides, the effect is quite small, as can be seen in 5.6. This is because the flood protection measures affect the flood risk a house is in, which lowers the flood insurance premium of the person living in the house would have without FloodRe, but not the flood insurance premium they get with FloodRe. The effect that can still be seen is for the most part from flood protection measures influencing the premiums of houses that are not eligible for FloodRe, houses build after 2009.

5.2 Model validation

Now that the data is analysed the last modelling step, before concluding on the research, needs to be executed; the model validation. In the verification step it already became clear the model was built right. In this step the question; did we build the right model? is answered.

The validation of the model can be separated in three parts. The data that is fed into the model needs to be validated, the behaviours that are coded in the model need to be validated and the output coming from the model needs to be validated. Both the validation of the input and behaviours are done during the conceptualisation of the model, before experiments were run on the model. Validation of the output is based on the data that is generated from running experiments on the model.

As already specified in the methodology, validation on the usability of the model will not be done. The validation in this thesis will be restricted to validating the working and results of the model to make sure the model that is created can be used to get proper results for the research that is done.

5.2.1 Input validation

The input that is used in the model is validated by both working close together with experts and by only using reliable sources to take input values from. In appendix L all input that is used in the model is presented with the source it originates from. For all input values for which clear sources could be found the input is double checked by both me, the modeller, and Katie Jenkins, of the ENHANCE project. However reliable sources could not be found for all needed input values. Because of this, several assumptions on input values were made. Although these assumptions were made in collaboration with experts (Katie Jenkins, but also others) it is still hard to predict what effect these
assumptions have on the model. Two of these assumptions will be elaborated on here because they are of key importance to understanding the patterns that have been found in the analysing of the data coming from the model.

- **Housing ratio increase**: This value determines the ratio of minimal income to housing value a person needs to reach in order to have to sell his house because of too high annual fees. This value is important for the number of persons that have to sell their house because they can not afford it any more. The housing ratio increase value is now set in a way that in every run it is very likely there will be persons that are forced to sell their house and that small value changes, in for instance house values, can cause large differences in the number of persons that are forced into selling their house. This assumption results in the exact number of person that are forced to sell their house not being representative, but that changes in the pattern of forced house sales coming from changing parameters can clearly be tracked, which is the goal of the research done in this thesis.

- **Base flood insurance premium**: This value indicates the base flood insurance premium that every person in the model will pay. No real data on this value could be found, but the consequences of the choice in the height of this value are important. If this value would be increased, the insurer will be able to cover more risk with the base insurance premium and the persons in flood risk would not see a big increase in premium. If this value is set lower, less risk is covered and the insurer has to increase the premiums of persons in flood risk more to cover their part of the flood risk. The way flood insurances excesses are set connected with the value of base flood insurance premium that is now set at £50, an average of around 50% of houses will be placed in FloodRe. This is not representable for the real world seeing only 1-2% of houses are expected to be placed in FloodRe according to DEFRA (personal communication, 17-12-2014, London). But just as with the number of forced house sales it is about gaining insight into the patterns that can be seen and not the specific values. To gain these insights a value of 50% is good.

### 5.2.2 Behaviour validation

The final behaviours that have been coded into the model are a result of a constant iteration of creating and improving behaviours based on conversations held with many
experts on the expectation they have of what the behaviours should do. Within the conceptualisation of the model, appendix D, the specific aspects that have been influenced are clearly marked as personal communications. To create a better understanding of the reasoning behind all important behaviours in the model that have resulted in the data that is analysed, the contributions of the main experts that are spoke with will be elaborated on here.

**Katie Jenkins**

Katie Jenkins works as an urban systems modeller at the Environmental Change Institute at Oxford University. Because Mrs. Jenkins will be one of the main persons that will keep on working with the created model in the future, she has developed a good understanding of the model by being highly involved in the creation of the conceptualisation of the agent based model. The specific information/assumptions coming from Mrs. Jenkins important for the model behaviour are:

- The reasoning that all reactive persons will invest in PLPMs. While data suggest only a small part of persons that take action after a flood actually invest in PLPMs (most look at information), the coding of this process would have been based on many assumption. Together with Mrs. Jenkins the choice was made to introduce PLPM grants into the model in which reactive people would be convinced to invest in PLPMs, seeing the cost part of it would not be the problem any more.
- The simplified representation of flooding in the model. Although the model is equipped to provide a better, more complex representation of flood events, the limited time frame this research is placed in made it impossible to properly use this flood representation in the experimentation. In coherence with Mrs. Jenkins and Mr. Hall (see expert below) the choice was made to simplify the representation of flooding for the research done in this thesis.

**Jim Hall**

Jim Hall is the director of the Environmental Change Institute at Oxford University. Mr. Hall provided feedback on the conceptualisation of the model throughout the creation, especially during the time the model creation took place in Oxford (from end of November to the end of December). The specific information/assumptions coming from Mr. Hall important for the model behaviour are:
• The way flood risk is calculated is based on the way that is described in the book 'Applied uncertainty analysis for flood risk management' [Beven & Hall, 2014, p. 17]. With the help of Mr. Hall the formulas to calculate flood risk as presented in this book were applied to the specifics of this model.

• In a Skype meeting with Mr. Hall on 6-10-2014 the wish for a proactive insurer came forward. This resulted in the insurer being coded in the model in a way that it calculated insurance premiums and excesses in a proactive way and does not wait for a house to be actually hit by a flood to look at the flood risk the house is in.

• In a meeting on 28-11-2014 Mr. Hall made clear that persons should stay in the model to try and sell their house. Originally, as taken from the Putra model, persons would abandon their house after 3 years of not being able to sell it. However, Mr. Hall specified that for the UK situation, and the insight that want to be gained with the model, it would be better if persons would just stay and keep trying to sell their house for a lower and lower price.

• Another point discussed in the meeting on 28-11-2014 was the way investing in PLPMs was done in the model. Mr. Hall suggested to look at proactive and reactive persons and keep the investing in PLPMs fairly simple. Persons do not make difficult cost-benefit analysis to determine if they would invest in PLPMs, it is mainly an emotional decision, as research suggests.

• The last thing that was discussed in the meeting on 28-11-2014 was the way flood defences would be build and what their effect would be. Mr. Hall suggested to look at SUDS as a possible interesting flood defence method. He commented that for now the way flood defences have affect on the flood risk of a house can be modelled linear, same percentage of risk reduction over all flood return periods, but that in further research defence mechanism that for instance focuses on small floods and do not much against large floods can be an interesting options.

• In a meeting in London on 17-12-2014 Mr. Hall and Mr. Nikolic (see expert below) specified that in selecting a flood defence project to build the choice of the local government should be based on a portfolio of different projects from which it selects the projects with the highest benefit-cost ratio that it can afford.

• In the same meeting Mr. Hall and Mr. Nikolic specified the way flood risk aware home buyers behave on the market, based on the occurrence of flood events. With
5 Analysing results

this important adaptation to the model the consequences of flooding are made more important.

Igor Nikolic

Igor Nikolic is an assistant professor at the Technical Policy Management faculty at the TU Delft, specialised in agent-based modelling. The conceptualisation, on which the model that is created is based, came from Mr. Nikolic. In this conceptualisation a lot of information on the behaviours that should be coded into the model was already given but many behaviours have been added/changed compared to what was in his conceptualisation. In changing these behaviours the feedback of Nikolic was constantly used.

Jill Slinger

Jill Slinger is an associate professor of Policy Analysis at the TU Delft and is also the second supervisor of this thesis. Based on her knowledge in flood modelling the choice was made to look at a simplified way of modelling flooding, given the goal of the research done in this thesis.

Swenja Surminski

The last specific expert that provided information and feedback on the model was Swenja Surminski. She is a senior research fellow at the London School of Economics. Her specific knowledge in what is going on with FloodRe and her knowledge on insurers was specifically interesting for the model conceptualisation. The specific information/assumptions important for the model behaviour that came from Mrs. Surminski are:

- She gave advise on how the FloodRe system is coded in the model. This model should just stick to the basics of what is known on the FloodRe system up till now and should provide room to do research on possible adaptations to the system.
- She also gave advise on how the insurer should work. Because we specifically focus on the technical side of the insurer the focus should lie on him reacting to flood risk. This knowledge is used in a way that the insurance premiums are based on flood risks and the insurer calculates a loss ratio. This loss ratio however is currently not yet used in the model, but can for further research be implemented in the model to make it represent the situation it tries to model better.
On 5-11-2014 Mrs. Surminksi answered questions that were send to her. In these answers she suggested to set the insurance excess of a person to a set percentage of the building value of the persons house, with it increasing with a set percentage every time a house was hit by a flood. This was used in the conceptualisation of the model.

5.2.3 Output validation

A lot of effort has gone into creating a valid conceptualisation of the model. This however does not guarantee the output of the model will also be valid. To also validate the output of the model an expert interview is held with Swenja Surminski. Because of her expertise in the modelled situation and because she only has been involved in the modelling efforts in a more general sense she is the perfect expert to interview about the output of the model. She knows enough about the project to understand the background of the shown patterns, but has not been so involved that she will be biased in her opinion on the results.

Within the expert interview that was held the results as presented in appendix R were discussed. The interview was guided by the following questions:

1. What do you think of the choice in data output that is looked at?
2. What did you think of the output in general? Do all patterns and explanations of the pattern seem logic?
3. Did you see any unexpected results?
4. What are your suggestions for improvements?

Concluding on the interview it could be said that Mrs. Surminski agreed with the choices made in output data to look at. The main thing she was concerned about was the way the effects of FloodRe were presented in the data analysis. The aspect of having persons that are not flood insured is important to the FloodRe system, seeing a goal of FloodRe is to also provide these persons with flood insurance. With the assumption of mandatory insurance this cannot be researched. However what can be researched with the model is the high flood insurance premiums and excesses of persons that normally would not be insured but are now insured only because of the made assumption of mandatory insurances. If FloodRe successfully lowers the flood insurance premium these persons would also get insurance in the real world. For this reason an output variable is added
to data analysis that is done to get a better idea of how FloodRe deals with uninsured persons (see R.4.7).

Other than this concern all pattern shown in the data analysis seemed logical to Mrs. Surminski and also no unexpected results were seen. The data can therefore be seen as valid and can be used with more confidence to built conclusions and recommendations on.
6. Conclusion and recommendations

The current flood insurance situation in the UK is in need of change. The proposed system to make this change is FloodRe. However at the moment it is still unclear what exactly this FloodRe system will look like and what its effects will be. The research done in this thesis has been focused on gaining insights into the effects the current proposed FloodRe system has on an UK housing market area that is prone to flooding. A model has been made in which the effect of the FloodRe system on a housing market can be investigated. This model has been created in collaboration with the ENHANCE project. The goal of the created model is to be used in further research to better structure the future FloodRe system. Now this model has been created, verified and validated, it will be used to answer the main research question: What are the effects of the FloodRe system on an UK housing market area prone to flooding and how can the FloodRe system be better structured to incentivise flood risk management?

First conclusions can be drawn up on the insights that are gained in the research that is done on how FloodRe effects a flood prone housing market and flood risk management in it. After this recommendations can be drawn up on what further research can be done with the model to gain a better understanding of the FloodRe system and how it can incentivise flood risk management.

6.1 Conclusion

The effects the FloodRe system has on the housing market are effective, but limited. The simple goal of the FloodRe system as it is currently set up, is to make flood insurance premiums affordable again for persons that currently have unaffordable flood insurance premiums. FloodRe succeeds in doing this. The hypothesis that was set up is that the number of persons that have to sell their house because they have to pay a too high annual fees will decrease with the introduction of FloodRe. Data has shown that this is indeed the case. With FloodRe active the number of persons that have to sell their house because of too high annual fee is not different for persons living in a house with flood risk than person living in a house that is not in flood risk. This means that FloodRe achieves the wanted result, making flood insurance premiums for persons living in high flood risk houses affordable again.

Because less persons are forced to sell their house the house values in the market are influenced positively. This is however the only side effect the FloodRe system has on
the housing market. It does not do anything to lower the flood risk in the model or to lower the unaffordable flood insurance excesses persons have to pay.

The tools for flood risk management that are researched, the flood protection measures, do however influence the flood risk and high excesses currently present in the housing market. Although the FloodRe system in its current form does not influence the management of flood risk in any way, it does not make more persons invest in PLPM or the local government build more flood defences, the potential is there.

Both flood protection measures influence the flood risk houses are in: lowering premiums and excesses person have to pay and lowering the damage floods do to the houses. This influences the FloodRe system positively in two ways. It lowers the number of persons that have to be re-insured in the FloodRe system because they have a too high flood insurance premium. They also lower the damage flooding does to houses of persons that are re-insured in FloodRe, which lower the payouts that have to come from the FloodRe system to repair these houses.

When looking at both flood protection measures, money can be an incentive. Persons are more likely to invest in PLPMs when they do not have to fully pay for it themselves and the local government will be more likely to invest in building flood defences if they get money from the national government with the specific task to build flood defences. By investing money in flood protection measures the FloodRe system will 'save' money. This money can then be invested again into more flood protection measures, and so on, and so on (positive feedback loop). This is however still a theoretical idea and is not yet researched. For this purpose further research can be done. But there are probably also other, non-financial ways to incentivise flood risk management better through the FloodRe system, by giving persons information for instance. The effect of such measures can also be investigated further.

Overall it can be concluded that the FloodRe system in its current form is successful in what it sets out to do, but does not incentivise flood risk management in any way yet. However there is potential to structure FloodRe in a way that it does incentivise flood risk management. This topic will be further elaborated on in the recommendations.

6.2 Recommendations for further research

With the research that is done in this thesis an extensive agent-based model is created in which insights are gained on the working and effects of the FloodRe system and flood
protection measures. Based on the gained insights and the fact that the created model is not yet used to its full potential, further research topics can be formulated.

The main further research that can be done with the model will focus on ways the FloodRe system can be adapted to incentivise flood risk management better. This is however not the only topic the research performed in this thesis, has provide insights on. The current proposed FloodRe system is successful in its task to make flood insurance premiums affordable, given the experimental settings that are used. However how successful the same system would be on a longer time frame under different circumstances is not sure. In order to test the rigour of the current FloodRe system under different circumstances, further research can also be done. Appendix T elaborated on the way this research could be performed.

Furthermore the research done in this thesis also provides insights into ways the model is not optimally coded yet or sheds light on aspects that should be included in the model to make it better represent the situation it models. The further research that can be done based on these insights to improve the model is explained in appendix U.

The main focus of the recommendations however is to use the insights gained in the research to create a list of promising adaptations that can be made to the FloodRe system to make it incentive flood risk management better. A list of recommendations for promising adaptation to further research is made and ordered from most promising to least promising. For every adaptation the changes in the agent-based model that will be needed to properly do research on the adaptation will be elaborated on

1. Providing persons with information: Persons can be provided with information on the possibilities of investing in PLPMs. A small percentage of persons invests in PLPMs pro-actively. These persons are most likely well informed and therefore choose to properly protect their house. With the proper information reactive persons might also be able to be convinced to start acting pro-actively in protecting their house. Furthermore there are also persons that are neither, not pro- or re-active. They simply do not know about the possibilities of protecting their house. Here providing persons with the right information can most likely also go a long way into getting them to at least think about protecting their house, maybe becoming a reactive investor. Within the current idea box of the FloodRe creators there is an idea about how persons can be incentivised to invest in PLPMs. "If a property under FloodRe is inundated then a survey proposing PLPMs is carried out. After a second flood these resilience measures should be implemented. If the
property floods a third time without these measures in place then the property is removed from the Flood Re scheme. Who will pay for the survey and resilience measures has yet to be discussed” (personal communication DEFRA, 17-12-2014). Although the idea is good to go visit flooded persons, the way it is done is not optimal. When a person is put into FloodRe the information is there that the person is in flood risk. A flood is not needed to show that he actually is. When a person is put into FloodRe he should already be provided with information on PLPMs and it should not take 3 flood events to make a person act. If more proactive PLPM investors can be created, the effects floods have can be lowered pro-actively, a flood event will not be needed for this. A flood event however will help in mobilizing people to act. Most likely persons already informed before a flood happens will act sooner if a flood event actually occurs. To investigate this by using the model, better research will have to be done in how influential exactly the role of information is in the choice of PLPM investing and what a person would drive to become a proactive investor. If this research can be implemented in the model the role of providing information and how successful it would be in connection with the FloodRe system can be researched.

2. Move to risk reflective pricing: Instead of changing the investment behaviour of persons by giving them the proper information, as described in the adaptation above, their behaviour can also be influenced by giving them incentivises to lower their annual fees on their house. Currently flood insurance premium and excesses are based for a large part on the soft side of insurances and less on the technical side that is modelled. However on the technical side the link between the flood risk the house of a person is in and the pricing of insurances is quite strong. Because in the model the technical side of insurances is modelled this connection is already present. The persons however do nothing with the information. With the introduction of FloodRe a step can be made to more risk reflective pricing. Connected to this, persons can get more information on how much flood insurance premium they pay and how they can influence it by investing in protecting their house. Investing in flood protection is currently a mainly emotional decision for persons. If they can be provided with the right information and get the right incentivises for lowering their fixed cost for insurances they may be more inclined to invest in protection measures. To do research on this with the model, more research will be needed on how inclined persons are to actually put effort into lowering their
annual fees and what they will do if provided with such information. It can for instance be researched how the results of the model and the effects of FloodRe will change if it will get persons to perform cost-benefit analysis on protecting their house against floods. An interesting adaptation to this research can be to look at how persons in different tax bands react different to such financial incentives. Person in the highest tax band are most likely less incentivised by financial gains than person in the lower tax bands.

3. Breaking the information asymmetry: Where in the previous two adaptations information under the guise of FloodRe was given to persons, it is not yet certain persons will even know it when they are placed in FloodRe. The FloodRe system is set up in a way that it only communicates with the insurer. This is done so that the insurance system on the level of homeowners does not change. However the insurer does not have the legal obligation to inform it’s policy holders of this information (DEFRA, personal communication, December 17, 2014). This forms a situation of asymmetric information in which the insurer has information on the risk and situation of its policy holder, but the policy holder is kept in the dark. So if the FloodRe system wants persons to manage their flood risk better they should be provided with information on being placed in FloodRe, what this means for them and especially what happens to them if FloodRe ends or if they are not included in FloodRe in the future any more. This might trigger persons to start managing their flood risk better. To do research on this with the model, more research is needed into finding out what exactly the information of being placed in FloodRe would do to a person and what the fear of maybe being excluded from it again will do to him. These two topics are discussed in appendix U as topic 4 and 5. If this can be added to the model the FloodRe system itself and the demarcations that are put on it, see appendix T, especially with a proper transition mechanism put in the FloodRe system, see adaptation 5, can result in some very interesting results.

4. Make FloodRe and the local government work together: next to providing persons with the right information and incentives, the local government is also an important player that should be incentivised to manage the flood risk in its municipality better. In the current model the assumption is made that the local government invests in flood defences in a proactive way and has perfect information about the flood risk houses are in and the consequences of building flood
defences. That this is not completely realistic is logical, but in working together with FloodRe this can become more realistic. Information from the FloodRe system can be shared with local government so that they have better information on which areas in their municipality are at high flood risk. This information can also trigger them to invest in flood defences. Besides, the aspect of cost can also be influenced when working together. Results show that proper building of flood defences will lower the cost of FloodRe, money that can be invested in the building of flood defences. Seeing both the FloodRe system and the building of flood defences is financed from government bodies money should be able to be redirected from FloodRe to the building of flood defences. To see if this is a valid strategy more research will have to be done though. This will be fairly easy to investigate using the model seeing assumptions for the aspects above are made in the model now and can easily be changed a bit to research different settings under which the local government builds flood defences. Where a standard budget to build flood defences is now assumed this can easily be increased by just changing a single value in the model code to see what this would do to the building of flood defences.

5. Transition mechanisms: The idea behind the current FloodRe system is to incentivise flood risk management in a way that FloodRe can slowly be scaled down so that it is not necessary any more in 20-30 years because the market mechanism have taken over the flood risk management by than. However the current FloodRe system does not have such a system in it yet. In conversation with DEFRA on the 17th of December 2014 it became clear that there also was no good idea yet how this transition mechanism would be structured in the FloodRe system. Several ideas where mentioned that can all be further researched. These mechanism are also ordered from most to least promising.

(a) Flood risk: The most promising transition mechanism mentioned by DEFRA was a mechanism in which every 5 years 10% of the houses with the highest flood risk would be excluded from FloodRe. Assuming persons will be provided with the proper information, this will give persons, that live in high flood risk houses, the choice of investing in protecting their house or possibly getting excluded form FloodRe, which would make their flood insurance premium sky-rocket again. Besides needing information on what being excluded form FloodRe would mean to a person, as discussed in adaptation
3 already, the excluding of the top 10% houses in flood risk every 5 years is very easy to code into the model.

(b) **FloodRe insurer cost**: Instead of excluding persons from FloodRe every 5 years this transition mechanism excludes persons from FloodRe by increasing the flood insurer cost\(^1\) for insurers over all tax bands. Only if a person has a higher flood insurance premium than the set flood insurer cost of the tax band his house is in, the insurer will decide to re-insure this person in FloodRe. By increasing the flood insurer costs more and more persons will have a lower insurance premium than the set cost and the insurer should decide on re-insuring less persons into FloodRe. The effect this transition mechanism will have will depend on how the rest of the FloodRe system will be set up. Only if negative consequences are connected to being placed in FloodRe, persons will not have any incentive to manage their flood risk, seeing they will only be excluded from FloodRe the moment their flood insurance premiums is lower than the insurer cost anyway. *Besides needing information on what being excluded from FloodRe would mean to a person, as discussed in adaptation 3 already, the increasing of the FloodRe insurer cost every 5 years is very easy to code into the model.*

(c) **Tax band**: The least promising idea for a transition mechanism that was mentioned was based on tax bands. By excluding a tax bands from the FloodRe system every 5 years less and less persons will be placed in FloodRe. Because persons can not control in which tax band they are placed they can not control being excluded form FloodRe, which does not really provide persons with any incentive. It can however still be interesting to look at the effects this will have, seeing it is not hard to implement in the model together with the other mentioned transition mechanisms. *Besides needing information on what being excluded from FloodRe would mean to a person, as discussed in adaptation 3 already, the excluding of a tax band every 5 years is very easy to code into the model.*

6. Connecting FloodRe with flood insurance excesses: Although results show that a combination of the FloodRe system with the proper incentivizing of flood risk management will already give a system in which both high flood insurance premiums and high flood excess are decreased, a system can also be constructed in which

\(^1\) the cost an insurer has to pay to the FloodRe system when he wants to re-insure a person in it
FloodRe also affects the flood insurance excesses. Just like FloodRe does with flood insurance premiums, a cap can be placed on the amount of flood insurance excesses that have to be paid. In such a system everyone will have an affordable flood insurance, but the FloodRe system will lose even more money and flood risk management is still not incentivised in any way. It can however be an interesting aspect to look at in combination with the transition mechanisms. If a person will no longer be re-insured in the FloodRe system and both his flood insurance premium and excess shoot up, he might be very inclined to invest in protecting his house. *Besides needing information on what being excluded from FloodRe would mean to a person, as discussed in adaptation 3 already, also putting an insurance excesses cap in the model will be easy to code seeing it can work the same way the flood insurance cap is already coded.*

7. Risk reduction at the developer side: Within the current FloodRe system a demarcation is set that houses build after 2009 are not included. This is done to not give developers the wrong incentive to build in high flood risk areas. However because of the current pressure on the UK housing market, both developer and local government do not have much attention for flood risk when building/approving new housing developments. This causes for many housing projects to still be build in flood risk areas. Instead of ignoring these houses more stringent build regulations can be made for new housing projects. Although maybe this stands too far from FloodRe, seeing it is not connected to flood insurances, it would be a waste to have the positive effect of the FloodRe system being undermined by many new houses being build in flood risk areas. Given that sources state that building houses with SUDS is just as expensive as without, enforcing the building of new houses with SUDS could be a simple starting point in making new build houses also protected against flooding. *This will be an easy thing to code into the model seeing now already 50% of new houses are build with SUDS installed. This number can easily be put to 100% to test this adaptation and to see its effects.*
7. Reflection

This final chapter reflects on the research that is done within this thesis. First a reflection on the problem formulation and research approach is given. This will be followed by a reflection on the research process. Because one of the main things this thesis has done is the creation of an agent-based model, the created model will be reflected on as well. After this the research results and relevance are reflected upon, to end with a personal reflection.

As a guide for the reflection effort the paper of Slinger, et al. [2008] is used. This paper addresses the role of reflective skills in the development and training of new System Dynamics modellers (which is transferable to agent-based modellers) at the tertiary education level. To properly reflect, both the own perspective and the external perspective should be used so that the full range of reflecting is covered. Especially in the goal this thesis had, creating a model to be used by other researchers, it is important to look at the external factor.

7.1 Reflection on the problem formulation

First I would like to reflect on the problem formulation. Although from the start it seemed I was given a quite straightforward problem to investigate, it turned out in the end this was not as easy as I thought. The exact problem formulation to be used has given me quite some problem throughout the whole writing of my thesis, and this is definitely something I learned from.

Although I started my thesis by creating a problem formulation, my final problem formulation and with this my final research question was only finalized 3 weeks before I had to hand in my draft thesis for green light. Although this may cause big problems in many project this was not the case in my thesis seeing I could just keep working on the model I was creating. It however did give me more ‘headache’ than necessary.

One of the main things done in this thesis is creating an agent-based model in which research could be done on how the FloodRe system influences an UK housing market area prone to flooding. This is also what the first months of thesis execution have been focused on. The model that I created has the possibility to research many FloodRe related aspects. At the start my idea was that I would investigate several forms of FloodRe to see what things could work. In the end the making of a good model took so much time, the research I have done with it is quite limited.
I regret that I could not have done so much research with my model. I put a lot of effort into creating an extensive model with many possibilities, and in the end I only used a small part of its possibilities. I am however very pleased that Oxford also saw the potential in the model and me and invited me to come and work for them as a researcher for 3 months so that I could do more research using the model I created.

In the end not having a clear model formulation from the start has caused me to continue modelling too long. Because my final research goal was not clear, I stuck too long to the safe haven of modelling, were I knew exactly what to do. I did not want to make the step into the unknown, the research I had to do with the model. I think having a better problem formulation from the start would have helped me into better making the transition from modelling into researching.

7.2 Reflection on the research approach

The structure of the research approach was to a certain extent already set when I started this research. Because a start of a conceptualisation for an agent-based model to research the topic I have researched now was already created by Nikolic, the choice to use agent-based modelling was already set from the start. Given that I wanted to do something with agent-based modelling in my master thesis this was perfect for me.

Reflecting back on the choice in modelling technique I must say I still 100% agree with the choice in agent-based modelling. The final model has not just provided very nice results on the effects of the FloodRe system, it also still has a lot of options to do further research with. On top of this the very nice interface of the model has been used several times to give different experts a quick glimpse into what the model did and what its possibilities were. The way agent-based modelling was used could have been done better though.

From the start my focus has been with agent-based modelling and only when Jill Slinger suggested that I should also look into other techniques to learn about the strength and weaknesses of ABM compared to other techniques I started to better see the weaknesses of ABM. As specified in appendix B a hybrid of system dynamics and game theory could have also been an option. Especially looking into game theory has opened my eyes for the possibilities of looking better into the decision making process of persons. In the current ABM model a lot of assumptions had to be made to represent the way persons, companies and the government make decisions. With the recommendation for further
7 Reflection

research also looking further into mainly the decision making of persons I think looking at how maybe game theory could be used for this can be interesting.

In the end the only real problem I have had with agent-based modelling is the computational power that was needed to run my large model and this is something I should have thought about earlier. Only when wanted to start to do experiments on my model I started looking at how much computational power and time it would cost to run all the experiments I wanted to do. Since this was not achievable on a normal computer setup I had to go on the cluster of TU Delft to get my results. Getting my model to properly run on this cluster took me 2 weeks because I constantly needed help from other people who did not have much time to help me and who I did not want to bother too much. This meant I had the results of my experiment 2 weeks later than I would have wanted, which also caused me some headache. In the future when working with models the running of them and what is needed for this is something I definitely will start thinking about earlier.

Besides the modelling method, the other methods used in my thesis were also set pretty much from the start. Because a model would be made within a project in which a lot of experts would work and because the model would be made of a system that did not exist yet, it was clear expert knowledge would be the backbone of this research.

In the end I think this worked out really well. Literature research is not my strong suit, so I was happy this was already done to a certain extent by Mr. Nikolic in the conceptualization and literature he provided. By talking with a lot of expert I quickly got a good idea of the system that would be modelled. The insurance world, and even more the UK flood insurance world, was something completely new for me. So I think it helped me really well that I already got quite an extensive layout of the idea to be modelled from the start and I was immediately placed in a situation in which I was surrounded by experts. This helped me a lot in focusing my effort on creating an extensive agent-based model that could be used for different FloodRe related research goals.

7.3 Reflection on the research process

When it comes to the actual research process that followed from the research approach there are several interesting points to reflect upon.
7 Reflection

First I would like to reflect on my modelling efforts and how this process went. When it comes to the idea of what a graduation project at the TU Delft is, I think I put too much effort into the modelling part and too little in everything surrounding it. When I started this project and Nikolic told me it would be a lot of modelling, I was happy, seeing I liked modelling, but I was also concerned, knowing I would have to restrain myself from modelling too much and too long. In the end I was not able to stop myself completely and maybe put too much effort into my model. This has given me a nice model to work with and on the basis of which further research can be done. It however has limited the amount of time I actually spend on doing research. In the end I am quite satisfied from my own standpoint on what I did. From a TU graduation stand point I could have gotten more out of it. I think the lesson to learn here is that I have to try even harder to prevent myself from making this mistake. I think that having a better end goal in mind when starting with the modelling will already help quite a bit in this.

The only thing I regret is how the expert validation of the output has gone. Experts have contributed a lot in the conceptualisation of the model, but because of time pressure they did not look much at the results. This is something I wish I had more time for. It would however not made my research results much better, I think. The results presented now are based on a very extensively validated model that is subject to many assumptions that are also validated. Output validation only looks at the patterns that result from the aggregated behaviour of the model. If a pattern seems not-logical it will most likely not be an easy task to find out where in the model this weird pattern originates from. Because the validation of the conceptualisation is done very extensively I still feel very confident about the results the model show. More output validation however could have provided me with a few more discussion points to which could be looked at in further research. Seeing the model will be continued to work on in Oxford where several people will for sure look at it, I think this aspect will be taken care of in Oxford.

When it comes to the rest of the process of the thesis, I am satisfied. The main thing I learnt is to not be afraid to be wrong. I had to work with a lot of experts in creating my model. Always when doing projects at my university the teachers in charge of the project knew a lot more than me as a student. This is of course logical, but it gave me maybe a bit of a wrong perspective on experts. When starting the project I almost instantly accepted everything an expert told me. But the further I got into the project, the more I learned and read about the topic, the more I started to realize I myself
was also becoming an 'expert' on the FloodRe topic. This gave me the feeling I was communicating more on the same level. Where initially I was afraid to say stupid things, afraid the experts would thing I am dumb, this feeling faded more and more the further I got into my projects.

One of the things that helped me a lot in this is the month I spent in Oxford. This month has been very good for the process of my research. When I initially heard I would do a project that was situated in Oxford I was impressed and so were family/friends around me. Oxford University is a big name, but in the end it are also just persons working there. In the month I worked in Oxford I was surrounded by very smart researchers. The funny thing however was that they saw me as just one of them, also valuing the things I said. This helped me a lot in gaining confidence in the project I was working on, in judging the value of my own work and also made the results of my research better in the end, seeing I was less afraid to talk about everything with experts, also about the things I was unsure about and might make me look dumb.

7.4 Reflection on the created model

Where in most research the results may be the most important part of the research, this is not entirely the case in my research. If the results would be the most important, a simpler model could have been constructed to gain the same results. However because this research was situated within a bigger project, the intention was to create a model that could not only be used to gain some results for my own research, but could after that also be used in further research to get a lot more insight into the FloodRe system and how it can be structured in the future. For reflecting back on the modelling efforts and the final model that is delivered it will therefore be important to not only look at the strength and weaknesses of the model, but so alto look at it from an external perspective. Have I delivered the model that can be used for further research and in what way have I added value for the client (the ENHANCE project)?

7.4.1 Strengths

The strength of the model lies in the approach that is used to created it. As already discussed this is done in collaboration with many experts and is done very extensively. This has provided a model that is well worked out and documented in detail. A model is never perfect, which also counts for this model. However because in the way it is created
and the way it is worked out in detail, many imperfections of the model are visible. The model is based on many assumptions. All these assumptions are documented well and clear for everyone. So the accessibility of the model is high which is, I think, a very important aspect for a model created in this kind a situation (within a larger project).

Another important strong point of the model is the easy adaptability of it. The housing market and FloodRe system are conceptualised separate and this can also be found in the model. If more research needs to be done on the FloodRe system, for instance by adding restrictions to it, a very limited Netlogo coding skill is needed to be able to quickly add this in the code and do experiments on.

7.4.2 Weaknesses

However there are also weaknesses in the created model. When looking at it from the research perspective, the main weakness of the model is the size of it. It takes a lot of computational power and time to run experiments. However this is not something that can easily be fixed. It is a big model and it needs to be a big model to do everything it should do.

Another weakness is, that the amount of assumptions that had to be made to create this model, is quite high. As already discussed in the validation of the model, there are quite some assumptions that are important to the behaviour of the model. Although all these important assumptions are discussed with experts, they are still assumptions based on the knowledge and judgement of persons. I think this is a weakness that is maybe inherent to modelling, but is something I maybe should have addressed and discussed with experts even better to really get a clear idea. Some assumptions are for instance only discussed with a single expert. A view from multiple experts is needed, I think, to get a proper assumption that holds.

When looking at the assumptions made, I think the biggest weakness when it comes to the model itself is that flood insurances are compulsory. Because FloodRe is to a certain extent meant to insure the people that are not insured, a model in which persons could have also been not insured could have been very interesting. This said, I still agree 100% with the choice made not to model the insurance decision, given that the reasoning behind such a decision can be quite complex. It can however be interesting to look into collaboration with another agent-based model being made within the ENHANCE project that looks into this decision mechanism behind flood insurances. I think this is
something that could make the model better for sure and will give a better idea of what actually FloodRe does.

7.4.3 Usefulness for further research

Simply stated, I think the usefulness of the model for future research is good. The model is extensively documented, making it very open to be used by other persons. And it is easily adaptable to do research with. As discussed in the recommendations for further research there are many possibilities in testing policies/adaptation on the model, most of which are quite easy to put in the model.

7.4.4 Added value for the client

I think the model provides good added value to the client, the ENHANCE project. This added value comes for the main part in the approach that is used to create the model. It is created by working together with the persons that will continue to do research with it. This already gives them an understanding of the model and will make the step from me doing my own research to them doing their own research a lot smoother.

It is however hard to judge the added value the model I created adds for the client. I think me being invited back to Oxford to be a researcher there already sends a positive message. Also getting much positive feedback of persons that actually saw my model and saw the behaviour it showed in its interface and the graphs resulting from it gave me a positive feeling about the added value this model will have.

When it comes to the added value of the result, I don’t think that is very big yet, seeing the results are still basic. However seeing the model is done to a large extent now I am sure the added value in results will be there when I get another 3 months in Oxford to do more research with it.

7.5 Reflection on the research results

Given the fact that the model was the main important thing coming out of this thesis, the question that should be asked is: Was the model needed for the research results that were gained? When looking at the research question of this thesis the simple answer is no. The insights gained on the effects of FloodRe and the effects of the flood protection measures have not been unexpected. Specific results from the model were
not necessarily needed to find out the FloodRe system lowers flood insurance premiums and flood protection measures lower flood risk.

That only expected behaviour came out of the model is however not a bad thing. Given the situation the model is created in it can even be a very good thing. The model is created with future research in mind. If the model would have provided all kinds of weird and unexpected results the conclusion of this research might have been more interesting, but the confidence this would have given in the model to use it for further research would be less. The results that came out of the model now have provided a consistency check for the assumptions that are used in the model. The combined results of all made assumptions shows expected behaviour. This gives good confidence in the model for using it for further research.

When looking at the '30 year multiple flood' experiments that are run the same pattern could be seen as in the '10 year single flood' experimental runs, which also gives confidence in the model. However there runs also showed some unexpected behaviour that does not logically follow from the behaviours. This is something that definitely has to be looked into if the model will be used for further research with longer time frame experiments. Given that I will be the person that will continue working with this model in further research, I know these strange pattern now and will look into them when I continue my research.

Besides this, I think the process of creating the model has also provided a lot of insights that would otherwise not have been gained. Only by constantly iterating on behaviours of agents and the assumptions that were made, not only me, but all experts thought about the FloodRe system and everything surrounding it. This has not just given a very nice basis to build further research upon but has also provided clear ideas on what direction the further research should go in.

So in the end I think that in this research the actual results coming from the model have not been the interesting aspect. The confidence the idea behind the results give and the path towards getting the results have been the most interesting and most valuable results of my thesis.
7.6 Reflection on the relevance of the research

When it comes to the relevance of the research I did, I think most relevance lies in the agent-based model and the further research that can be done with it. No specific solutions are found yet to solve the flood insurance problem in the UK. Results show that the FloodRe system in its current form makes insurance premiums affordable but is not yet a structural solution to the problem. However I think the insights gained so far and the possibilities for a lot more further research will provide a better idea of what this structural solution can be.

Furthermore I also think that there is an added value to using agent-based modelling to investigate a system, the insurance system, in which economic models prevail. When looking at the system that is researched the financial picture is of course important. Proving persons with financial incentives, by subsidising investment in protection measures for instance, can already go a long way to getting them to manage their food risk better. But as I already discussed in the recommendations for further research, I think providing them with the right information is also a very important aspect. For this an agent-based model can very well be used to see how the behaviour of persons can be affected.

So when looking at the whole spectra of what can be done to incentivise flood risk management better I think an agent-based model can definitely provide novel insights that could never be gathered with economic models. On the other hand the amount of assumption that had to be made for the agent-based model does not make it a very suitable tool to specifically look into what different measures will financially mean. An agent-based model will be well suited to find behavioural pattern on how economic behaviours can be influenced, but if economic research on specific methods is needed an agent-based models will not most suitable, I think.

7.7 Personal reflection

I am very happy I got the chance to do this project. Initially I came to Mr. Nikolic with the simple idea of wanting to do something with agent-based modelling because I liked the modelling technique and I see potential in it. I could never have imagined I would learn so much from this project. Not only did I learn things on a research level, I also learned a lot of skills surrounding it. I learned to write my thesis using the text editing
program LaTeX instead of using Word. I learned better to work with the data analysis program R. And I learned to work with the operating system Linux and how to work from the terminal on my computer to make my model run on a cluster.

Although learning all these new skills has cost me quite a lot of time, more than I sometimes liked, I think it is really good I learned them and I think they can benefit me in my future work. In the end, for instance, I really did not use LaTeX to its fullest. I probably could have gotten the same, or even better, results using Word in the same time frame. This is mainly because the research I did is not so extensive. However, I now already know that I most likely will keep working in LaTeX in the future. It took me quite along time to get used to it, but I really start to see the benefits of it now and I think this will also benefit me a lot if I will continue my work on this research.

So in the end the learning of new skills and going abroad might have caused a bit of delay in my project, but I am still very happy I did it. Not only did it broaden my way of thinking and the skill set I have, it also gave me a possibility to become a researcher in Oxford for three months, which I am really looking forward to.
Appendix A. The 10 steps of agent-based modelling

The approach that is used in this thesis to create an agent-based model and get results from it is based on the 10 steps of ABM as presented in the book 'Agent-based modelling of socio-technical systems' [van Dam, et al. 2012]. This appendix shortly explains what each of the 10 steps are and what is done within each step.

1. Step 1 Problem formulation and actor identification: In the first step the problem gets formulated and the actors get identified. This step focuses on the question:
   (a) What is the problem?
      i. What is the lack of insight we are addressing
      ii. What are the observed emergent patterns of interest to us
   (b) Whose problem are we addressing?
   (c) Which actors are involved?
   (d) What is our role?

2. Step 2 System identification and decomposition: In the second step of the ABM modelling approach the system gets identified and decomposed. This step identifies and outlines the behaviour of the agents (actors) that were identified in step 1. By describing the states (values), action and interactions of these agents the first step in getting clear how the model will look is taken.

3. Step 3 Concept formalization: In this step the states and actions of agents that were described in step 2 will be formalized to get a more context free idea of them. This is done because computers do not deal well with context. The concepts identified in the step 2 need to be converted into computer understandable analogues.

4. Step 4 Model formalization: The steps up till now have showed the 'what' and 'who' of the model. This step will focus on the 'who does what and when' question. This will be done by first getting clear what assumptions are made to set up a representative model. After this a the concept formalization of step 4 will be translated into a model formalization in the form of a 'model narrative'. The model narrative tells the 'story' of how the agents behaviour will be modelled. With this the model conceptualization will again be made more precise for it to be implemented in an actual modelling program.
5. Step 5 Software implementation: In this step the created model conceptualization will be implemented in an agent-based modelling program.

6. Step 6 Model verification: Now that a working model is created the following question should be answered: did we correctly translate the conceptualisation into the model code? In this step it is made sure the model is created right by verifying it. The verification consists of four main parts:
   (a) Recording and tracking agent behaviour
   (b) Single-agent testing
   (c) Interaction testing in minimal model
   (d) Multi-agent testing

7. Step 7 Experimentation: In step 7 the now verified model will be used to run experiments with. In this step it is important that it is clear what exactly will be investigated. Which parameters in the model will be varied in different model runs and which output will be tracked.

8. Step 8 Data analysis: Now that experiments are done, the output that is tracked in these experiments will be analysed in this step. The data analysis tool to be used should be tailored to the results that want to be gathered with it and the output that is gathered from the model. In this step it is important to find patterns in the gathered output. The pattern in data can be used to gain insight in the problem that is formulated in step 1.

9. Step 9 Model validation: But before the answer to the problem is formulated it must be made sure that the right thing is build. Where in the verification step it should have become clear that the model was build right, it is now important to see if the actual right model is build. Now that the data is analysed to patterns that are found can be checked to see if the results actually are as expected. To do this 4 methods are specified:
   (a) Historic replay
   (b) Face validation through expert consultation
   (c) Literature validation
   (d) Model replication

10. Step 10 Model use: In this last step the results of the model and hopefully an answer to the question set up in step 1 can be formulated. This step also focuses on the aspects surrounding this. How do you present your findings and how do you continue after having presented your findings.
Appendix B. Agent-based modelling as method

The choice that is made in using agent-based modelling as modelling technique in this thesis does not mean that no other choices could have been made. When looking at the modelling aspect of what is to be modelled, system dynamics could also do the job. This will however not fully capture complexity of the decision making that should be in the model. For this game theory can be used. Together, using a hybrid of system dynamics and game theory, could be used to gain the wanted insight into the UK housing market system. By comparing ABM to a this hybrid modelling theory the strength and weaknesses of ABM will become clear. These strengths, but mostly the weaknesses (limitations), will have to be accounted for during the modelling efforts that will be done.

B.1 Advantages of agent-based modelling

When looking at agent-based modelling compared to a hybrid of system dynamics and game theory, there are a few clear advantages to using ABM. The first advantage lies in the the way an agent-based model can represent itself. The model that is to be created will be used in a large research setting, the ENHANCE project, in which many different persons will look at the model and try to understand it. To gain this understanding in the complex system that is modelled it will be important that people not just understand the output coming from the model, but also understand the aggregate of behaviours that result in these output. Unlike system dynamics and game theory, that are both more abstract in showing what leads up to the provided results, the interface of an agent-based model is really good at providing a simple insight into behaviours and how they together results in the output that can be seen.

The second advantage lies in the spatial aspect of the model. Because the effect of flooding on a housing market is modelled, the spatial aspect is an important aspect. Different spatial areas, housing areas, are affected in different ways by a flood event which causes for different reactions of persons in different areas of the model. Both system dynamics and game theory are not very capable in accounting for this spatial aspect. With agent-based modelling this spatial aspect can not only be modelled well, it can also be presented in a very nice way. The interface of the model will be able to
provide a clear view of the housing market that is modelled in which a flood is simulated, different regions are hit with a flood and persons reacts in different ways.

**B.2 Limitations of agent-based modelling**

However there are also weaknesses to using agent-based modelling compared to using a hybrid of system dynamics and game theory. The first weakness lies in the assumptions of perfect information and rational decision making (which are often assumed when modelling). Each player, when making any decision, is perfectly informed of all the events that have previously occurred [Osborne, 1994]. On top of this every player always maximizes his utility, thus being able to perfectly calculate the result of every action he performs [Game theory.net]. These assumptions together can lead to results that are not conform to the reality. In this case a theory, like game theory, is capable of providing a better insight into what decision making in the real world would lead to.

A second weakness of ABM lies in the modelling effort that is needed to provide a good working model that is able to provide decent results. This can especially be true when creating geo-spatial simulations, as Crooks et al. [2008] discusses. When using system dynamics as modelling technique a model that will provide decent result can be set up quicker. In this way less emphasis can be put on the modelling aspect and more on analysing the results of the model. Because behaviours are modelled in less detail a better demarcation can be made. When modelling large complex agent-based models it is very difficult to set up a clear demarcation. It is very attractive to keep modelling to keep making the model come that little bit more closer to representing the real world situation. This tendency will often end up in creating a too large and complex models that go beyond their goal and end up not being useful. So an important aspect to look at while using agent-based modelling to create a simulation of the real world is to make sure the level of detail is set right. You want a certain level of detail in which the model represents the real-world situation to an extent that significant and useful data can be gathered from it.

The last weakness of agent-based modelling is connected to the limitation above and lies in the computational power that is needed for running agent based model. With agent-based modelling still being a relatively new modelling technique, the emphasis is still mostly put on making the modelling technique work well, and less on making it work efficient. This can lead to large complex agent-based models needing a lot of
computational powers and needing days to run and gather results. To tackle this problem of computational power the model will be run on a cluster of computers at the TU Delft.
Appendix C. The wider relevance of the model

The model that will be created within this thesis has a particular relevance for the UK flooding situation, seeing it will be specially modelled for this situation. But because the concept of the flood insurance system and the housing market that is modelled is to a large extent quite generic, the model can also have relevance for situations outside the UK. In this appendix a short description will be given on how the model can also easily be used outside the UK.

The most important factor which has to be looked at if this model is to be used in a different setting is the data that is used. All data that is used, which all can be found in appendix L, is searched with the specific modelling location in mind. If the model will be used in a new setting, all values that are used as input to the model will have to be reassessed and possibly changed to a setting specific value. The sources and notes given in the data table will already provide a pretty good idea if a value needs to be changed. So are several values for instance assumption made for the model or by Putra that are transferred to the model. These kind of values will have to be reassessed to see if the same assumption is good for the new setting. Quite many values have a source that is specifically from the UK, often gov.uk sources, and will definitely need to be reassessed to see if they can also be used in the new setting.

Besides the data input, the model can largely be split up in 5 different general behaviours: flooding, the housing market, the insurance system, the flood protection measures and the development of new houses. For each of these 5 behaviours a short explanation will be given on their transferability.

- **Flooding**: The way flooding was modelled is done quite straight forward. Different flood return periods hit a different selection of houses with a set amount of flood damage. The houses a flood hits is connected to the layout of the housing grid that is loaded into the model. All this information is based on GIS data that is provided for the model. If the same kind of GIS data was available, the same principal of flood modelling can be used in different settings. This only counts for modelling water surface flooding though. The modelling of river flooding is a totally different form of modelling a flood and can not be modelled based on how flooding is modelled in this model.
Appendix C The wider relevance of the model

- **Housing market**: The housing market that is modelled comes from the Putra model, which models an American housing market. When research was done on what should be changed in the conceptualisation of this market to transfer it from an American housing market to an UK housing market, the conclusion was; not much. The only real change that needed to be made, apart from specific data input, was the way persons foreclose on their house, which is quite different in the UK and America. However the general idea of how persons behave in a housing market was very much alike and could in theory also be transferred to settings that have the same kind of economic and political situation (the western countries). It will most likely be harder to transfer the same idea of how a housing market works to setting that have a different economic and political situation (Large parts of Asia, the middle east, Africa and Latin America).

- **Insurance system**: The insurance market that is modelled is quite straightforward. The assumption is made that everyone has insurance and insurance premiums and excesses are set based on standard technical flood risk calculations. This system is therefore pretty well transferable to other settings.

- **Flood protection methods**: When looking at the flood protection methods that are modelled it can also be concluded that they are quite transferable. The techniques used in property level protection measures and flood defences are worldwide techniques developed by worldwide companies. Although these methods will always have to be adjusted to the specific location they are implemented, these specifics are not modelled. The way the flood protection measures are modelled is straightforward and will not deviate much from how it works in different settings. The only difference which should maybe be accounted for is how exactly the decisions are made to invest in these protection methods. The way the local government does it, according to a benefit-cost analysis, it something that probably can also be seen in many other governments. How the investing in PLPMs happen is in a general sense also transferable. The specific assumption that are made now, renewal and repair grants, that cause all reactive persons to invest in PLPMs is definitely something that is not simply transferable and should be reassessed from setting to setting.

- **Development of new houses**: The way developers develop new housing and how the local government approves these housing developments is something that is UK specific and not transferable. The UK housing market, specifically in the
London area, is way more under pressure than most other housing markets in other countries. In the model this means the developer builds a lot of new houses and that the local government approves almost all development plans.

It can be concluded that the model can definitely provide a wider relevance by using it in different settings. Although a change in setting will always require effort, mainly in the changing of input data, the general behaviour of the model can be used. This however will most likely only really count for settings that are in the same economic/political situation as that of the UK. It will be harder to transfer the model to a setting in a non-western country.
Appendix D. Detailed model creation

In this appendix the creation of the agent-based model is worked out in detail. This is done by executing the first 6 steps of the 10 steps of ABM.

In this appendix it will be elaborated on in detail how an agent-based model is created with the following research question in mind: What are the effects of the FloodRe system on an UK housing market area prone to flooding. To create this agent-based model the first 6 steps of the 10 steps of agent-based modelling as presented in the book 'Agent-based modelling of socio-technical systems' [van Dam, et al., 2012] will be used. By going through these steps a model conceptualisation will be created, on bases of which an agent-based model will be created which will than be verified. From now on the model that will be created will be referred to as the "FloodRe model".

Because this thesis is part of the bigger ENHANCE project it will be important that in creating the agent-based model the bigger picture will be kept in mind. The agent-based model that will be created will not just be used to get results within this thesis, but will after than also be used (and possible expanded) within the ENHANCE project. For the creating of the FloodRe model this will have as a consequence that the conceptualisation already created by the ENHANCE project should be followed and worked out and explained in detail. The people working within the ENHANCE project should not just be able to work with the FloodRe model; they should be able to fully understand it and be able to adjust it in detail.

The following documents are already provided from within the ENHANCE project to base the conceptualisation of the FloodRe model on:

- An agent-based model, made by K. Jenkins of the ENHANCE project. This model originally was planned to be worked out further into the FloodRe model, but was halted when Miss Jenkins went on maternity leave.
- An agent-based model, made by H. C. Putra at the Rutgers University. This is a published model that represents an American housing market in an area prone to floods.
- A written out conceptualisation of the wanted model, made by Nikolic of the TU Delft when he was working for half a year on the ENHANCE project in Oxford.

In the detailed conceptualisation of the FloodRe model it will be made clear when one of the three provided documents is used. From now on the three documents will be
referred to as the "Jenkins model", the "Putra model" and the "Nikolic conceptualisation".

D.1 Step 1: Problem formulation and actor identification

In the first step of the 10 step ABM approach the problem gets formulated and the actors get identified. Because this first step assumes that less research was done on the topic before arriving to this step, the large part of the question posed in step 1 are already answered. The problem that will be addressed is and the insights that are lacking are already made clear. With this the final goal of the model that is to be created is already made clear. The means of reaching this goal, what the actual model that is to be created will look like, is unclear though. The remainder of the question posed in step 1 that still need to be answered focus on making this more clear. These are the following question:

- What are the observed emergent patterns of interest?
- Which actors are involved?

D.1.1 Observed emergent patterns of interest

The goal of creating a model is to "increase our insight into the possible nature of real world system, how they function, and how they may change as a result of intervention or effort to influence the system behaviour" [van Dam, et al., 2012, p. 74-75]. In the specific case of this thesis a model will be made to see how flood risk management can be incentivised in flood prone areas. For this an UK housing market in an area prone to flooding will be modelled.

To guide the creation of this model several emergent patterns are observed that are of specific interest to the situation the model will represent. The following emergent pattern of interest are observed (coming from the conceptualisation of Nikolic):

- Because of high flooding risk and the associated high flood insurance premiums and excesses, ghetto areas will form with houses that are foreclosed or unsellable because they have become uninsurable or too expensive.

- Led by the current housing shortage in the UK, the central UK government has the target to build 3 million new homes, of which many in flood plain areas, by the year 2016 [Wilson, 2010]. This leads to developer being pushed to develop more housing projects. Or For local government it means they will have to find a balance between on the one hand the opportunity cost of preventing development
Appendix D Detailed model creation

on flood plains versus the income generated by housing development and income taxes.

• Increase in housing development can lead to an escalator effect in which "progressively higher levels of flood defences are required to protect against a rising flood damage potential" [Parker, 1995]. The local government has to keep increasing local flood defences if it allows more and more housing development in flood plains in their municipality.

Within the creation and validation of the agent-based model all these observed emergent pattern are important to keep in mind to make sure the model does what is observed.

For the actual focus of this thesis there is no specific interesting emergent pattern that is currently observed that should be changed because the emergent patterns of interest simply does not exist yet. The FloodRe system is not in effect yet. However, by creating a model in which the known emergent patterns and situations are simulated and a FloodRe system is added, emergent patterns regarding the implementation of a FloodRe system can be investigated.

D.1.2 Involved actors

Based on the insight that should be gained with the model and the observed emergent patterns of interest, the following list for actors for the model can be set up:

• Consumers: Consumers form the basis of the housing market. They can own, buy and sell houses. They can also insure and protect their house against flooding
• Bank: Forecloses houses that it than sells on the market again
• Insurer: Insures houses against floods and decides on placing policy holders in the FloodRe system
• Local government: Builds flood defences and approves development proposals of the developer
• Developer: Develops houses and sells these on the market.

Modelling agents

With the actors that we want to model in mind a transformation step should be made from actors to agents. Agents are "the basic units of the model, representing one or more actors in the system. They are recognized by their boundaries, their states, behaviours and ability to interact" [van Dam, et al., 2012, p. 97]. In ABM modelling it is more useful
to talk about agents instead of actors because actors do not show the whole spectrum of possibilities in a model. An agent can for instance also be a building that has values and reacts to things that happen in the model. The term agent is wider than the term actors. For this reason the term agents will be used during the modelling process. The set of actors as set up above is not the same as the set of agents that will be used.

The person will be split up in two separate agents, a person and a house. A person owns, sells and buys houses. Houses need to be seen separate from persons because they are an important part of the model and should also be able to behave without a person. Even if a house has other agent connected to it can still be damage by a flood. When a house is owned it will have 1 person living in it. This one person represents the 'family' living in this house.

Because the bank behaves within the model (forecloses and sells houses), it can be seen as an agent in the model. Because only the interaction between the bank agent and other agents is of interest and not interactions between bank agents, it is assumed that only a single bank agent will be modelled.

The insurer also needs to be an agent in the model because it needs to be able to react to changing risk profiles and interact with its policy holders. Because the insurance market will not be modelled and it can be assumed because of this that insurers will not interact with each other, only 1 insurer agent will be modelled. This will make the data that will be gathered from the model on insurers also easier to comprehend seeing it will come from one single insurer that acts in the housing market.

Because the local government behaves and interacts within the model (builds flood defences and approves development plans of the developer) it should also be an agent in the model. Because initially only a small demarcated area within a single municipality will be investigated a single local government agent will be modelled.

Last the developer should also be seen as an agent because it builds houses and sells these on the market where it interacts with persons that buy the houses. Because the main importance in modelling developers lies in the influencing of behaviour of other agents and a competition between developers is of no interest for the model, it is assumed that there is only 1 developer in the model.

This gives the following set of agents to be modelled:

- Persons
Appendix D Detailed model creation

- Houses
- 1 bank
- 1 insurer
- 1 local government
- 1 developer

D.2 Step 2: System identification and Decomposition

In the second step of the ABM modelling approach the system gets identified and decomposed. This step identifies and outlines the behaviour of the agents that were identified in the previous step.

Because the conceptualisation of agents is already done to a certain extent in the provided documents this step will start with an analysis of how exactly this documentation can be used in creating the conceptualisation for the FloodRe model. Based on the provided documentation and this analysis the behaviour of all agents in the model can be conceptualized. First however a short analysis will be made on the time step in which the model will run. This needs to be done first because input data and behaviour of agents can greatly differ if a time step of an hour is chosen compared to a time step of a year.

The conceptualisation of the agent behaviour will start by writing out the envisioned behaviour of every agent in the model. After this the states (values), actions and interactions they have are written out into more detail to get a clear picture of how exactly every agent behaves and is influenced in the model. Here the environment of the model will also be included since it also performs actions and provides agents with values they need to base their actions on.

In the conceptualisation of the model a distinction can be made between two parts: the current situation (no FloodRe) and the future situation (with FloodRe). The current situation will for a large extent stay the same in the nearby future, a housing market does not rapidly change. The future situation however is bound to change seeing FloodRe is currently still being designed.

Because the model that will be created will be used beyond this research, the conceptualisation that will be made will also be made with the distinction between the 2 parts as specified above. This is done so that a change in the current FloodRe system
and/or other research that will be done on effects of different FloodRe structures can easily be conceptualised without having to look in the large conceptualisation of the housing market.

First a conceptualisation of an UK housing market in an area prone to flooding (sub-sub-research question 1a) will be created. After this a conceptualisation will be made on what behaviour will be changed and added when the current idea of the FloodRe system will be implemented in the conceptualisation of the housing market (sub-sub-research question 1b).

### D.2.1 Using the existing conceptualisation

As already stated three documents were already provided to base the conceptualisation of the model on; two agents based models and a conceptualisation in text. The following conceptualisation for data input and agent behaviour can be taken form these three documents:

- **Jenkins model**: The main thing that can be used from the Jenkins model is the setup of the area that will be investigated. In this model a housing area is set up based on Geographical Information Systems (GIS) data imported into Netlogo. This data provides a set of houses with given locations, house types and general house values. Even thought at this point it is not sure that the GIS data provided here is of the area that will be used to research on, the way this data is loaded in and set in an agent-based model can be used. In theory different data just has to be linked in it when researching a different location.

- **Putra model**: This model models the behaviour of a housing market in an area prone to flooding. Because the models is based on coastal flooding this aspect of the model can not be used seeing the FloodRe model will focus on surge (rain) flooding. The way the housing market behaves can be used and copied to the FloodRe model though. Specifics on the modelling and working of this model can be found in the published article related to the model; Modelling Real Estate Market Responses to Coastal Flooding [Putra, 2013]. Because this model focuses on a housing market in the US, parametrization of values used in the Putra model will be needed to make it represent an UK situation. It will be assumed that the double auction market behaviour that is modelled in the Putra model will also be representative for how an UK housing market works. For the other aspects,
such as the way foreclosing of houses works, a critical look need to be taken at the differences between the US and the UK. In the conceptualization of the model this will be clearly states if changes are made to form the model to the UK situation compared to how Putra modelled it.

- **Nikolic conceptualisation**: The conceptualisation provided by Nikolic gives a lot of background information on the behaviour of all agents to be modelled. It provides specific information on how the person, house and insurer agent should be set up given the conceptualisation of the two given agent-based models. It also sets up the basis on which the behaviour of the local government and the developer can be developed further. Lastly it gives a very general idea of how the current FloodRe system is set up and what kind of FloodRe scenarios can be of interest to investigate.

Given the above, a setup of a housing market in an area prone to flooding can be created by combining the data of the Jenkins model with the behaviour of the Putra model. A more detailed analysis of the two given agent-based model and how these can be combined to create an initial setup of a housing market can be found in E. The setup of a housing market this creates can be richened with the help of the conceptualisation provided by Nikolic. The way the local government and the developer will be modelled and how exactly the current FloodRe system is set up and how it can be used to incentivise flood risk management is something that will need more research.

But before continuing with conceptualising the behaviour of all agents, it will first be important to conclude on the location that will be studies and the time step that will be studied.

### D.2.2 Choice in Location to study

Because a model will be created that will try to represent an UK housing market in area prone to flooding, a location to study needs to be chosen. For this location GIS data can be gather to load into the model. With the use of GIS data an actual location in the UK can be loaded into the model with real life information on a detailed level.

In the model a choice will be able to be made in three areas; the Bromley borough, the Camden District and the Croydon district. The Bromley borough is loaded into the model because it is a small model in which quick test can be done. All GIS information for this area was already included in the original Jenkins model. The areas that will be
studied however will be Camden and Croydon, with specifically Camden to start with. The reasoning for choosing these two areas is made by Katie Jenkins who provided me with all GIS data. Her reasoning behind choosing Camden and Croydon as location to study can be found in appendix F.

For this thesis the main focus will lie on investigating the area of Camden. In appendix G a short report can be found on the impressions Camden had on me, the modeller, when I walked through it.

D.2.3 Time step

To get useful results from the model that will be created, it is important to select a good time step in which the model will run. With the choice in time step there are several factors to account for. Because flood are modelled a time step of an hour can already be very relevant seeing the duration a flood is within an area can greatly affect the damage it does to the area. On the other hand the main research that is done within the model is off a housing market. When looking at housing markets behaviour multiple years need to be looked at to get relevant patterns. Seeing this larger time frame will be needed to get the results wanted from the model, the choice is made to use a time step of a year for the model. This is also the time step that is used within the Jenkins and Putra model. All input data used within the model needs to be specified to the time step of a year. This large time step will need to be accounted for when looking at things like flood damages.

D.2.4 The current situation

As explained the current situation; a housing market without a FloodRe system in it, will first be conceptualized.

Agents and their behaviour

Every agent identified in step 1 will have its own behaviour within the model. The combination of these behaviours will provide a model that represents a simplified UK housing market in an area prone to flooding.

Persons A large part of the behaviour of persons will be the same as in the Putra model. Persons own, sell and buy houses. The main difference in behaviour here comes from the change in housing market focus that comes from the Jenkins model. In the
Putra model the housing market was focused on different types of land. With using the Jenkins model as a starting point for the model, this will change to a housing type focused market. The Putra model also gave persons the ability to built their own house instead of buying one. This behaviour will now be taken over by the developer agent. Persons will just focus on the owning, buying and selling of houses.

In the Putra model persons had the choice to insure their house. The current insurance situation in the UK makes it almost compulsory for people to take an insurance, seeing mortgages are only given where full household insurance coverage is purchased (Nikolic conceptualisation). The only potential persons that do not have flood insurance for their house are the persons that bought a house without needing a mortgage or persons that didn’t renew their insurance after they got approval for a mortgage. **For this reason the assumptions is made that all houses need to be insured against flooding. It will not be possible to not take flood insurance for the house you own**.

Last important behaviour that should be mentioned for the person agent is that he can invest into PLPM for his house to make it more flood resistant and resilient. In looking at incentivizing flood risk management, the ability of persons to invest in PLPMs will be an important behaviour to look at.

**Houses**  The housing agent can be seen as a supporting agent other agents (mainly persons). When it comes to the housing market and the flood hydrology that will be modelled the behaviour of houses is kept the same as in the Putra model. The house receives information (from for instance a flood event), compute this data (damage values to the house) and relays it to the person agent who can then react to it. **An important assumption that is made in the Putra model and will be also assumed for the FloodRe model is that all houses in the model are houses for sale; no house renting will be modelled.**

With the adding of the local government and the developer (that were not in the Putra model), the behaviour of the local government will not be influenced, it will just influence the setting they behave in.

**Bank**  The behaviour the bank in the model will be limited to the buying foreclosed houses and selling these again on the market. This is based on the way Putra modelled
a bank into his model\(^1\). The main reason for having a bank in the model is that persons should have the ability to default on their mortgage and foreclose their house. Because of this banks will be modelled in a simplified way and no research will be done on the values and the behaviour of the bank agent.

**Insurer**  How Putra modelled the behaviour of the insurer will be taken as the base for modelling the behaviour of the insurer agent. Because the UK insurer situation is different from the American situation, the behaviour of the insurer will have to be adjusted to the UK situation.

Seeing the insurer is a company it will focus on staying in business. The main task the insurer has is to sell flood insurance to agents owning houses. For this the insurer will have to calculate flood premiums and excesses on flood insurances. In theory insurers can deny flood insurance to people that live in houses that have a too high flood risk. But because the idea of this model is to gain insights into what FloodRe will do to such high flood risk cases for insurers, it is assumed that the insurer will insure everyone against floods at a price.

Another important assumption that will be made here is that the technical risk will be modelled and not the commercial risk. This will mean the insurer will focus in its calculation on the probability that a flood will damage a particular property. Commercial risk will not be modelled because it "includes decisions across the portfolio of the firm, across multiple types of risk, different markets, overall liabilities and exposure of the firms, decisions based on profitability, market share and stock valuation“ (Nikolic conceptualisation).

**Local government**  Both the Putra model and the Jenkins model did not have a local government coded into the model. The behaviour of this agent will have to be created based on the already given conceptualisation and extra research on the behaviours of a local government given the situation of the model. Given the tasks local governments in the UK are assigned regarding the housing market and flood risk management, the behaviour of the local government can be limited to three tasks; building flood defences, giving grants to persons investing in PLPMs and controlling developers.

\(^1\)The Putra model also had abandoned houses that the bank would buy up. Because the UK housing market is different and people will not simply abandoned their house the choice was made to not model abandoned houses in the FloodRe model
The driving force of the local government in the model will first be to protect the people living in their municipality. But besides this the government also strives to increase the income of its municipality.

To protect the people living in their municipality against floods the local government does two thing. First it give grants to persons that invest into PLPMs. Second they build flood defences. In the current gentlemen’s agreement between the insurers and the government in the UK, the local government reduce risk though investments in flood defences for its municipality and the insurers cover damages in case of floods. With these two measure the government protect its municipality against flooding.

Besides increasing flood protection in its municipality the local government will have the task to evaluate development proposals from developers. The local government can control how and where the developers will build new houses because developers will have to submit a development proposal to the local government if they want to build new houses. The local government can approve or deny these proposals based on for instance the flood risk of the proposed area and the income the project will generate for the local government.

**Developer** Just as with the local government, the developer will have to be created based on the already given conceptualisation and additional research. The idea for the developer agent coming from the provided conceptualisation is that it should mainly be seen as a supporting agent. For this reason its behaviour can be limited to two tasks; building new houses and selling these houses on the market (Nikolic conceptualisation).

The driving force of the developer in the model will be making profit. Just like any other company, developers want to make money with their projects. This effectively means that developers will try to develop profitable housing project, reacting to the housing demand in the model.

To develop profitable housing projects developers first need to locate land to develop houses on. For this opportunity areas in which developers can build are highlighted in the municipality. When they located good land, they will create a development proposal to be approved by the local government. This approving goes according to the guidelines set up by the local government agent. After a proposal is approved, and based on this houses are built, the developer will have to sell these houses on the market to get the money they invested back.
One important modelling assumption that is made for the building of new houses is that they have no effect on the flood risk in the area. The DrainLondon maps that are used to set flood damages are for current land use type/drainage systems etc. which would be modified if development occurred. To model this change is not possible in the current model and therefore an assumption is made to simplify the modelling of new houses.

States, actions and interactions of agents

Based on the general written out behaviour of every agent in the model, a more specific list of values (states), action and interaction that every agent has within the model can be defined. Every agent gets assigned states with a value in the setup of the model. During the running of the model these values of states can change because of actions they perform and interactions they have with other agents. The setup of the model, values of general states within the model and actions that are not specifically linked to an agent will be done within the environment of the model. Therefore will not only the states, actions and interaction of agents be looked at now, but also the states, actions and interactions of the environment of the model.

Within this section all states and actions of all agents and the environment will be elaborated on. When agents perform actions they can base these actions on values of states that are not their own. These are the interactions that occur within the model. These action can occur between classes of agent and the environment (a person interacting with its house for instance) or within agent classes (persons interacting with each other). These interactions is what makes the way the model behaves. Because agents influence the input of each others behaviour the model as a whole will show behavioural patterns. Because interactions happen within actions they won’t be specifically listed, but will be mentioned within the elaboration on actions of agents and the environment below.

Several states will have an initial value set. Some of this data will come from GIS data. All GIS data that is used is outlined in L.1. For values that need initial values for which there is no GIS data another sources are used to set their initial values. Where all these initial values are taken from is outlined in L.2. For some data for which only average values could be found ,distribution are used to make it represent the real world better in which not every person for instance has the exact same income. The distributions
that are used and where they come from is outlined in L.3. All GIS data and many of the sources for the other data inputs are provided by Katie Jenkins of Oxford.

Behind every state and action that will be defined, it will be indicated (between brackets) from where the state/action originated from. The state/action could have originated from 4 sources; the Jenkins model (Jenkins model), the Putra model (Putra model), the conceptualisation of Nikolic (Nikolic conceptualisation) or it originates from neither of these 3 sources (new). Footnotes will indicate if important changes were made to states/actions of the given sources.

**Environment**

**States**

- **Percentage of houses for sale at the start** (New): The number of houses within the model that are on sale at the start of the model run. Seeing persons decide the status of a house, this value will be used in deciding the amount of home sellers that will be created when the model is set up. The percentage of houses for sale at the start will be 2.3% of all houses in Camden L.2 [1].

- **Mortgage interest** (Putra)\(^2\): The annual interest that is charge over a mortgage of the person. The mortgage interest is set to 3% L.2 [2].

- **Mortgage term** (Putra): The number of terms (in years) the mortgage of a person has when taken. The term of a new mortgage is set to 25 years L.2 [3].

- **Average values of houses**: Houses get a house value assigned to them based on an average value given by the environment. For every house type modelled (flat, terraced, semi-detached and detached) an average price is set L.2 [4]:
  - **Average flat value** (Jenkins): The average value for the house type flat is £729,400 pounds.
  - **Average terraced value** (Jenkins): The average value for the house type terraced is £1,327,277 pounds.
  - **Average semi-detached value** (Jenkins): The average value for the house type semi-detached is £1,750,790 pounds.
  - **Average detached value** (Jenkins): The average value for the house type detached is £2,365,034 pounds.

\(^2\)Because no analysing on bank values will be done the mortgage interest (and mortgage term) states are set in the environment seeing they are set values to be used in the model that will not change
• **Owner warning time** (Putra): The number of years a homeowner will pay more on housing fees than what he want to spend on housing fees before he will have to foreclose on his house. The owner warning time is set to 3 years L.2 [5].

• **Number of trade actions** (Putra): This is a state that represents the number of trade actions in the person market run action. In this action a trade round includes a home seller/buyer setting an asking price/bid price and finding a matching bid price/selling price to make a trade agreement for selling/buying a house. Within one of these rounds the number of trade actions indicates the amount of time a homebuyer can set a bid price, or a home seller can set an asking price. The number of trade rounds is set to 30 L.2 [6].

• **Housing ratio increase** (New): The percentage on basis of which the housing ratio is increased compared to the calculated mortgage ratio\(^3\). The housing ratio increase is set to 5% L.2 [7].

• **Average number of incomes as down payment** (New): The average number of incomes a person will pay as a down payment on a house when buying a house. The average number of incomes as down payment is set to 3,05 L.2 [8].

• **Average percentage sell price** (Putra): The average percentage on the basis of which a person will increase the asking price of his house (compared to the house value) when deciding to sell his house. The average percentage sell price is set to 25% L.2 [9].

• **Average profit percentage** (Putra): The average percentage a persons house needs to increase in value before a persons will decide to sell his house for profit. This value is set to 10%, indicating that a persons house needs to increase in 10% in value compared to the price he bought it for to decide on selling his house for profit L.2 [10].

• **Land value** (Putra): This is a specific patch state and represents the value of a patch of land. The land value will be modelled in the same way Putra did it. When a house is placed on a patch of land, the house will have an initial value assigned to it. A part of this initial value will be assigned as the land value and the other part as the building value. The percentage of house value that will be assigned as the land value is indicated by the 'Land value percentage'.

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\(^3\)Putra worked with a given mortgage ratio and housing ratio. However because for this model different data is available the choice is made to calculate mortgage ratio’s based on data that is available and to add a certain percentage to this to get a housing ratio. In this way the goal that Putra had with these values; people having to sell their house if their house fees increase, still works.
• **Land value percentage** (Putra): The percentage of house value that will be assigned as land value. The land value percentage is set to 50% L.2 [11].

• **Flood return period probabilities** (Jenkins): Three flood return periods will be modelled, 1 in 30, 1 in 100 and 1 in 200 years. Because the time step in the model is a year, the probability of a flood event happening is equal to its return period. A flood event with a 1 in 30 year return period will have a probability of occurring once every 30 years (1/30). The same count for the return period of 1 in 100 year flood (chance of 1/100) and 1 in 200 year flood (chance of 1/200).

• **Immigration percentage** (Putra): The percentage of home buyers that will enter the market every year because they want to immigrate to Camden. This immigration percentage is set to 4.7% L.2 [12]. This relatively high number can be explained because the UK is currently in a 'housing crisis' stoked by the shortage of new houses [Osborne, 2014] and because Camden is an attractive place to live in London.

• **Percentage of movers** (Putra): The annual percentage of homeowners that move out of their current house to find a different house within Camden. The percentage of movers is set to 2.7% L.2 [13].

• **House destroy level** (Putra): In the Putra model houses could get destroyed if they took to much flood damage. From the perspective of the research that will be done with this model it is however more interesting to look at how homeowners will behave when their house suffers high damage and they have to pay high repair fees. For this reason the ability for houses to be destroyed is taken out of the model.

• **Flood risk consider probability** (Nikolic conceptualisation): The probability that a person will consider flood risk when buying a house. The flood risk consider probability is set to 57% L.2 [14].

• **No selling decrease value percentage** (Putra): The percentage on the basis of which house values will be decreased when in previous year the house was on sale but not sold. The no selling decrease value percentage is set to 25% L.2 [15].

• **Inflation percentage** (New): The percentage on the basis of which the income of a person will be increased every year. The inflation percentage is set to 2.9% L.2 [16].

• **Percentage of proactive PLPM investors** (New): The percentage of risk aware persons that will decide in a proactive way on investing in PLPMs for their
house. The percentage of proactive PLPM investors is set to 1% L.2 [17]. This means 1% of the risk aware people in the model will act proactive in investing in PLPMs every year.

- **Percentage of reactive PLPM investors** (New): Besides pro-active people, reactive people can also invest in PLPMs. They will only do this after their house has been hit by a flood though. The percentage of reactive PLPM investors is set to 34% L.2 [18]. This figure indicates the percentage of people that would act after their house has been flooded. In theory acting can also mean asking for information on flood insurance, it does not have to mean investing in PLPMs. However the UK government is currently setting up a grant that grants £5000 to person wanting to invest in PLPMs after their house was hit by a flood O). Seeing the cost of PLPMs are between the £3000 and £10000 pounds L.2 [19], it is assumed that all persons that would ’act’ after their house has been hit by a flood will invest in PLPMs.

- **PLPM investment flood protection benefit** (New): Given the above a single cost value for PLPMs has been taken as a one-off investment. This also means the benefit should be reduced to a single value. The benefit was set to be between the 65 and 84% L.2 [20]. An average of this will be taken. This means an investment in PLPM will increase the flood protection of a house by 75%.

- **Flood protection budget** (Nikolic conceptualisation): The local government receives funding from the national government every year to invest in flood protection within their municipality. The flood protection budget for the district of Camden is £220.200 per year L.2 [21].

- **Cost of flood defences** (Nikolic conceptualisation): The costs for local government to invest in the building of flood defences within their municipality. The costs for building flood defences is set to £2000 per house L.2 [22].

- **Flood defence investment flood protection benefit** (New): An investment in flood defences equal to the cost of flood defences will increase the flood protection of a house by 35%. L.2 [23].

**Actions - setup procedures**

The actions of the environment can be split into actions in the setup procedure and action in the go procedure. Actions performed in the setup procedure are only done at the start of the model. Action in the go procedure are performed when the model is running and will be repeated every year (tick) of the
model run. Within the order in which the model will be set up, houses will first have to be set up because persons directly move into houses when set up.

- **Data setup and interface setup**: Before any states of agents and the environment are set, the GIS data that will be used is loaded into the model and based on this data the area outlines in the interface of the model are set up.

- **Setup environment**: Sets up all states along with their initial values as was just specified in the environment states paragraph above.

- **Setup houses**: House agents get created on all locations as specified in the GIS data. All created houses get assigned states along with their initial values as will be specified in the houses states paragraph D.2.4.

- **Setup persons**: A number of persons equal to the total amount of houses in the model gets created. Every person will choose a house to live in within the model at random. A set percentage of these persons will be set as home sellers and start of by selling their house when the model starts running. The rest of the persons will be home owners. After this, all created houses get assigned states along with their initial values as will be specified in the persons states paragraph D.2.4.

- **Setup bank**: Creates 1 bank agent. The created bank gets assigned states along with their initial values as will be specified in the bank states paragraph D.2.4.

- **Setup insurer**: Creates 1 insurer agent. The created insurer gets assigned states along with their initial values as will be specified in the insurer states paragraph D.2.4.

- **Setup local government**: Creates 1 local government agent. The created local government gets assigned states along with their initial values as will be specified in the local government states paragraph D.2.4.

- **Setup developer**: Creates 1 developer agent. The created developer gets assigned states along with their initial values as will be specified in the developer states paragraph D.2.4. It will also assign all patches with a value (surrounding value) that indicates the summed up value of the 10 houses closest to the patch. This value is used in the selection of land to develop on by the developer.

**Actions - go procedures**

- **Flood event** (Jenkins): Represent flooding in the model. Based on the flood that is occurring, houses get flood damage assigned to it.

- **Process market** (Putra): There are 3 agents that sell houses; persons, the bank and the developer. An assumption made by Putra that will also be followed for
this model is that all these markets will be run separately. In this action the three separate markets market will be asked to run. It is assumed that persons prefer newer houses over old houses, meaning the market will be first run for the houses the developer sells. After the developer market is run, the person market runs (home seller to homebuyer) after which the bank market runs.

The 3 markets that will be run will also be split up and run for the 4 separate house types in the model. Following the analyses of E, the order in which the market in the Putra model was run; based on 4 different land types, will now be changed to an ordering according to house types. It is assumed home buyers always look for the best possible house type. So they initially prefer detached houses and if they can not find an affordable detached house they search for a semi-detached house, after which a terraced house, to end at flats. This means the three separate agent markets will also each be run in this house type order (first the market will be run for developer houses of the detached house type, then for person houses of the detached house type, then for bank houses of the detached house type, then for developer houses of the semi-detached house type, etc.. This will give a total of 12 market that are ran with different specification every year.

Based on information on the number of houses on sale and the number of houses sold coming from this action, the values of all houses in the model will be updated.

- **Developer market run** (Nikolic conceptualisation / Putra⁴): The Putra model only modelled a housing market for persons and a bank, but not for a developer. It can be assumed though that developers approach the market in a same way as banks do. Both want to sell the houses they own quickly (although developers do this for a more market conform price). Because of this the behaviour of how the bank sells houses in the Putra model will also be copied to the behaviour of how the developer sells houses.

The developer market runs as follows: Every homebuyer in the model will look at a set amount of developer houses. **An assumption made by Putra is that all homebuyers select the house they will buy only on the criteria that it is the most expensive house they can afford given their income. So from all houses the homebuyer has looked at he will choose the most expensive one he can afford (based on his income) and decides to buy this house.** If all houses are too expensive he will

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⁴The idea comes from the Nikolic conceptualisation, but the way it is worked out comes from the Putra model
not buy any house and will go on to buy houses of a different house type or from a person or the bank that are also selling houses.

To this, and the person and bank market run, the flood risk consideration of a person will be added on top of the Putra code. This adaptation will be explained in the considering flood risk action of persons.

- **Person market run** (Putra): The explanation of the market run action below is taken from the article of Putra on his model [Putra, 2013]. Seeing the double auction market mechanism of Putra is copied to this model, the market run action is build up in the same way.

In modelling the interaction between private home sellers and homebuyers, this model adopts the experimental economics of double auction markets. The goal of this approach is to achieve high levels of market efficiency quickly by running rounds of trading between buyers and sellers. Similar to experiments conducted by Gode [1993], this model provides three choices: bid, ask, and transaction. Whenever a bid and ask cross, the transaction price is equal to the earlier of the two. Thus, there are four possible states: 1) no best ask (lowest ask price) nor a best bid (highest bid price); 2) a best ask and no best bid; 3) no best ask but a best bid; or 4) both a best ask and best bid.

Initially, a homebuyer forms a bid price between his income level, adjusted by an affordability multiplier, and zero. A home seller randomly forms an ask price between the maximum reasonable market price and his buying price of the property. A selected homebuyer then compares his bid with the best ask. If his bid is above the best ask, he accepts the best ask and the transaction occurs at the best ask. If his bid is below the best ask (or there is no best ask) and there is no best bid, it becomes the best bid. If his bid is below the best ask (or there is no best ask) and above the best bid, it overrides the best bid. If his bid is below the best bid, the bid is ignored. The rule also applies to a selected home seller. If his ask is below the best bid, a trade occurs at the best bid. A home seller and a homebuyer that make a successful transaction are removed from future trading for this year.

- **Bank market run** (Putra): The bank market will be run in the same way as the developer market is run, but for bank owned houses.

- **Update house values**: The value of a house is equal to the building value of the house plus the land value of the land under the house. Because of this the house value itself is not updated in the model, but the building and land values are updated. Both the building values of houses and the land values of land under
houses are updated based on the trading that goes on within a year. This is a slight adaptation on the way Putra modelled this. Because in the Putra model land was traded, all updating of values focused on land. Because now houses are traded the values on which the updating is based now are changed from land trade values to house trade values. Because the first action below was solely focused on land values in the Putra model, it was here changed into focussing on building values. The second action focuses on house values (building value + land value) and can therefore keep it’s focus on changing land values. Because there is no consensus in the literature on the effect flooding has on house prices, it is assumed that a house being hit by flood has no direct correlation with a decrease in house value.

- **Building value update** (Putra/new): Based on the number of houses on sale before and after the market is run a ratio can be created for the amount of houses of a given house type that are sold. This ratio is used to in- or decrease the house value of houses of the given house type. The sales ratio that is calculated will be decreased with 0.25 and the ratio that is left will be used to change the building value of the given house type. This deducting of 0.25 means that if less then 25% of houses are sold the building values of the given house type will decrease and if more than 25% of houses are sold the building values will increase. *Note: This action will not work the first 3 years of the model run because in these first 3 years the market is not yet fully set up (not many homebuyers, no bank houses and not many developer houses).*

- **Land value Update [transaction price]** (Putra): Besides the building values that are updated, the land values under the houses that were traded are also updated. This is done by calculating the average price for which houses of the house type that currently is being traded were traded. When a house is sold this code is run and the land value under the house gets updated by deducting the building value of the just sold house from the average price that was just calculated. *Note: Just as the building value update, this action will not work the first 3 years (ticks) of the model run because in these first 3 years the market is not yet fully set up.*
• **Person status** (Putra): A person will have a status assigned to him based on the situation he is in. If the person is looking for a house he will be labelled as a homebuyer. When he owns a house he will be labelled as a homeowner. When he tries to sell the house he owns, he will be labelled as a home seller.

• **Income** (Nikolic conceptualisation): The income a person has. All persons in the model will have an income assigned to them based on GIS data L.1 and a distribution coming from the GIS data L.3.

• **Mortgage ratio** (Putra): A ratio that indicates how much of annual income a person spends on mortgage fee payments. This value is calculated within the model.

• **Housing ratio** (Putra): A ratio that indicates how much of annual income a person spends on house fees. This value is calculated within the model.

• **Number of incomes as down payment** (New): The number of incomes a person can pay as a down payment when buying a house. The value of this number is set based on a distribution L.3 over a set average.

• **Percentage sell price** (Putra): The percentage on the basis of which a person increases their house price when he tries to sell his house for profit. The value of this percentage is set based on a distribution L.3 over a set average.

• **Profit percentage** (Putra): The percentage of profit a person wants to think he can make over selling his house before he decides to sell it for profit. The value of this percentage is set based on a distribution L.3 over a set average.

• **Maximum house price** (Putra): The maximum price a person can pay for a house. This is based on a person's income and the mortgage he can get.

• **Seller ask price** (Putra): The price a home seller asks for his house. This is set based on the value of the home seller's house and the reasoning behind selling his house. People that want to sell their house ask a higher price than people that have to sell their house.

• **Annual Fee** (Putra): The annual fees a person has to pay for the house he owns. The annual fee is equal to the sum of the list of annual fees that are assigned to the house.

• **Flood risk consideration status** (Nikolic conceptualisation): A state indicating if a person does or does not consider flood risk when looking to buy a house. The percentage of persons that will consider flood risk when buying a house is equal to the flood risk consider probability.
Appendix D Detailed model creation

Actions

- **Setup general person states** (Putra): In this action persons get assigned the following states along with their values; income, housing ratio, mortgage ratio, number of incomes as down payment, percentage sell price, profit percentage and flood risk consider status. This action is run for all initial persons in the model and will be run by every person (home buyer) that enters the model.

- **Process persons** (Putra): In this action new homebuyers get created and set up. All home owners are asked to decide on selling their house and to invest in PLPMs. All home sellers are asked to decrease the asking price of their house if they weren’t successful in selling it in the previous year. All persons are asked to correct their income for inflation.

- **House enter** (Putra): Makes persons move into a house (initially or when a home buyer buys a house). The person will take flood insurance for his house and the mortgage the person had to take to buy the house is set.

- **Decide on house selling** (Putra): Persons can have three kinds of motives to decide on selling their house. The first is when they can not afford their house any more (annual fees are higher then the income they can spent on their house). In this case they will have to foreclose their house and sell it to the bank. The second motive is when they think they can make a profit on their house (house value has increased a certain percentage compared to when they bought it). And the third motive is when they decide to move to a different house.

- **House bank sell** (New): When a person has to foreclose his house it is assumed he will sell it the bank and goes on to try to find a rented house (seeing we odn’t model renting, this means the person leaves the model at this point). The house becomes bank owned and the bank can start trying to sell this house on the market again.

- **House market sell** (Putra): When a person decides to sell his house because of profit or moving, he will set the asking price of his house to a higher value than the house value. The person becomes a home seller and his house is set on the market.

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5Even though this action is performed by the environment in the model, it is labelled as a person action because it specifically focuses on the processing of persons  
6To simplify, this also counts for persons that already paid of their mortgage fee  
7In the Putra code this was also selling on the market, but this was changed because selling it to the bank is more logic  
8This is a simplification of how the foreclosure on houses works, but because no research will be done on the bank and its behaviour this is no problem. The main importance is that people can foreclose on their house
Appendix D Detailed model creation

It is assumed that when a person successfully sells his house on the market, he will start looking for a new house to buy within the modelled area (so becoming a home buyer). This is assumed because figures indicate that moves quite often happen within a district [Office for National Statistics, 2014e]. On top of this the model tries to simulate the current pressure on the housing market in the UK. By keeping people in the model this pressure is build up.

- **Set maximum affordable house price** (Putra): When homebuyers search for a house to buy they first have to set a maximum value for the house they can afford to buy. This maximum is based on the homebuyers income, the mortgage he can get and the down payment he can pay on the house. The mortgage the person can get is dependent on his income and mortgage ratio of the person.

- **Considering flood risk** (Nikolic conceptualisation): When buying a house, persons will or will not consider flood risk. When persons considers flood risk they will look at the flood history of the house they wants to buy. A buyer will at a maximum look back 3 years in the history of the house for when it is flooded, as indicated in research by Lamond and Hammond [2009]. All persons that consider flood risk will not look at houses that have been flooded in the current year. When the house was flooded in the previous year only 50% of all considerate persons will not look at it. For flooding 2 years ago this percentage drops to 25%. Floods more than 3 years ago won’t influence the buying behaviour of flood considerate people any more. *Because this action is an adjustment to the buying of houses in the market run codes, it will not be seen as a separate action from here on, but will be included in the market run codes.*

- **Person flood insurance set** (Nikolic conceptualisation): Because its assumed that all persons will need to take flood insurance on their house, all persons will take flood insurance for the house they own.

- **Invest in PLPMs** (New): To protect their house against flooding persons can invest in PLPMs for their house. Investing in PLPMs will increase the flood protection level of the persons house, lowering the damage a flood does to the

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9 Although Putra clearly had the intention to model down payments into his model (the states and everything were in the model), he failed to do so (unknown why). For the FloodRe model down payments are added in

10 Because the mortgage ratio is a value indicating an average mortgage ratio for a person, the calculated mortgage he can get will also be an average mortgage, and not a max mortgage as the max house price would suggest. This still represents the real world well though, seeing banks have become very conservative in giving out mortgages after the financial crisis and won’t give a person a mortgage that will max out the mortgage premium he can pay
house. In the decision to invest in PLPMs, anxiety and insecurity about floods play the most important role [Harries, 2012]. Because of this, most people will initially only decide on investing in PLPMs in a reactive way. This means that the homeowner will decide the year after his house was hit by a flood to invest in PLPMs. However, a small percentage of people will also decide in a proactive way to invest in PLPMs. These people decide regardless of whether they have been flooded or not to invest in PLPMs for their house. PLPMs are considered to be a one-off investment. Once a person has invested in PLPMs he won’t do so again.

- **Income shock** (Putra): In the Putra model, all persons had their income ‘shocked’ every year. This meant that their income would increase by 1% overall and would also be ‘shocked’ by adjusting it with a percentage in the range +/- 5%. Because this does not give a representative view on how the UK housing market works and it provides behaviour (random income loss) that is not wanted in the model, the decision is made not to copy this action from the Putra model to the FloodRe model. However, the income of a person should increase to keep up with the increase in housing prices (inflation). For that reason, the income shock action was replaced with the inflation correction action.

- **Inflation correction** (New): The income of persons will be adjusted for inflation every year. This is simply done by increasing the income of all persons in the model by a given percentage. To keep this simple, it is assumed the inflation correction is for everyone the same and will not change over the years.

**Houses**  

- **House type** (Jenkins): Everyone house in the model is of a certain type. All initial houses in the model will have a house type assigned to them based on GIS data L.1. New houses that will be built by developers will get a house type assigned to them based on the house type the developer chooses to build. There are 4 different house types specified within the GIS data: detached, semi-detached, terraced and flat. Developers will also make a choice between these 4 house types when they build a new house.

- **House value** (Putra): The value of the house on the market. The initial value of houses is set based on a distribution L.3 over set averages per house type. The initial house value is split up in a value of the building that the house is and a land value of the land under the house. These two values are updated while the
model runs and the house value is always equal to the building value plus the land value. This is equal to the building value plus the land value of the ground under the house.

- **Building value** (Putra): The value of the building that the house is.

- **Build year** (New): The year the house is build in. Every house will have a build year assigned to it based on GIS data L.1. GIS data provides categories with build years in which all houses in Camden were build. Houses get a build year assigned at random within these categories. The model start year will be seen as 2014, this means the houses build in the first year will be have a build year of 2014 assigned to them. An important time frame to look at is houses build in the time frame of 2009-2014, because FloodRe does not account for these houses. The build year categories however only provides information that a house is build after 1980, so it is unclear how many houses exactly are built within the 2009-2014 time frame. By assigning houses within the 19080-2014 time frame at random, 1.4% of all initial houses in Camden are assigned in the 2009-2014 time frame.

- **Flood Damage History List** (New): Every house gets a list assigned to it in which the history of flood damage is recorded. For initial houses a history is set from before the model was started based on the flood event GIS data L.1.

- **House status** (New): A house will have a status assigned to it based on the situation it is in. If the house has an owner that just lives in the house (homeowner) it is labelled as person owned. If the house has an owner that tries to sell the house (home seller) it is labelled as person on market. A house is labelled bank owned if the bank owns it. A house is labelled in construction when the developer is building the house and labelled developer owned after construction is finished and the developer owns it.

- **Council tax band** (New): The council tax band in which the house is placed. The placement of houses is done based on the value of the house. See N for more information.

- **Property tax fee** (Putra): The property taxes a person owning a house has to pay over his property annually. The property tax fee of a house is linked to the council tax band it is placed in. See N for more information\footnote{This should maybe be named council tax fee, but because Putra worked with the state property tax fee and within this model the idea to look at council tax fee became only clear in a later stage, the name of property tax fee is kept. This is no problem since it is basically the same thing, in England they more often talk about council taxes though}. 
• **Annual fee list** (Putra): A list of all fees a persons owning a house need to pay on an annual basis.

• **Fee duration list** (Putra): A list of durations of the fees that are in the annual fee list.

• **Mortgage fee** (Putra): The amount a homeowner has to pay annually over the mortgage he took for buying his house. This mortgage will have to be paid for an amount of years that is equal to the mortgage term of his mortgage.

• **Ageing repair fee** (Putra): The annual fee a person owning a house has to spend on repairing his house from ageing. The ageing repair fee is set equal to 1% of a the building value of a persons house

• **House value at buy** (Putra): The value of a house at the moment it is bought by an agent

• **Flood damage list** (Jenkins): A list with flood damages linked to the corresponding possible flood return periods. The flood damages per flood return period are assigned using GIS data L.1.

• **Flood status** (Jenkins): A state indicating the house is flooded within the current year.

• **Flood repair fee** (Putra): When a flood event happens houses get assigned a flood repair fee (taken from the flood damage list). This flood repair fee is added to the annual fees a homeowner has to pay on his house.

• **Flood risk** (Nikolic conceptualisation): The calculated flood risk a house is in. See M for more information. This is a quantification of the flood risk a house is in in pounds

• **Flood insurance status** (Nikolic conceptualisation): If the person living in a house takes flood insurance (currently always, seeing its mandatory), the house will be flood insured. This is done at the house agent because all information on costs and risks is collected in the house agent.

• **Flood insurance premium** (Nikolic conceptualisation): If the person living in a house has flood insurance for the house it means the person will have to pay a flood insurance premium. Just as with all other fees this will be calculated on the house agent linked to the person and the person will receive information on the total of annual fees it has from the house.

• **Flood insurance excess percentage** (New): The percentage of the total flood damage the person owning the damaged house will have to pay in excess on his
flood insurance. Assumed is that excesses are a non-negotiable part of the offered insurance policy. The initial flood insurance excess percentage will be increased for the number of times the house was flooded in the last 10 years. Every time a house is flooded the Flood insurance excess percentage gets increased by a set amount\(^{12}\).

- **Flood insurance excess** (New): The excess amount the owner of the house has to pay when the house is hit by a flood. This is equal to the flood insurance excess percentage times the insured value. The insured value is equal to the building value of the house, capped at £250,000 pounds. Because no good data on insured values for flood insurance in the UK could be found the cap of 250,000 is taken from [Federal Emergency Management Agency], which provides American data on the subject. the value of 350,000 dollar given there is around £250,000 pounds.

- **Compensation amount** (Nikolic conceptualisation): The amount of compensation for flood repairs the house gets from the insurer (insured value - flood insurance excess amount).

- **Flood protection level** (Nikolic conceptualisation): The protection level of the house against floods. When a person invests in PLPMs or the government builds flood defences that affect the house, the protection level of the house will increase. The assumption is made that the flood protection level will be represented by a percentage that will lower the flood damage of every flood return period of the house. If PLPMs protect the house for 50% and flood defences protect the house for 50%, the house will not be protected for 100% but only for 75%. The second protection that will be installed only has effect on the percentage of the house that is not protected yet.

**Actions**

- **Set mortgage fee** (Putra): The mortgage fee will be set based on the following mortgage fee calculation; annual mortgage fee = \(P \times R/(1 - (1 + R)^{-N})\) [HSBC, 2014b]. In this formula \(P\) represents the principle (amount borrow from the bank), \(R\) is the mortgage rate and \(N\) is the mortgage term. The principle is equal to the price a person paid for a house, minus the down payment it could pay on it. When a mortgage is taken the amount of years the mortgage will need to be paid will be set (mortgage term). As long as this term is not 0 the mortgage fee will be added

\(^{12}\)The history insurers look at does not change, meaning that 5 years later the excess percentage is set based on the last 20 years of flood history
to the annual fees of a person. Initially set up persons that move into a house have their mortgage duration set to a random integer between 0 and the mortgage term to symbolize that they have been living in their house for longer than since the model started.

- **Process house** (Putra): In this action the expected flood damage done to a house by a flood will get updated if the value of the house changed and based on possible new protection measures that were installed. The house recalculates its flood risk with the newly given damage data. After this the fees, that the agent owning the house has to pay, are set. For every house a person, the bank or the developer owns, the following fees are set: property tax fee, house ageing repair fee, flood insurance premium and flood repair fee. Each fee gets their own duration in years (set in the fee duration list). When a duration on a fee runs out the agent owning the house no longer has to pay this fee. Because it is assumed these fees get recalculated each year, they get a duration of a year. For persons an extra fee is added that is set when they move into a new house, the mortgage fee. This fee has a set duration (mortgage term) that get decreased with a year every time this action is run. When it reaches zero it gets deleted and a person no longer has to pay mortgage fees. Because the other fees are recalculated every year they will have to be paid for every year the house is owned.

- **Calculate flood risk** (Nikolic conceptualisation): Based on the flood damage and flood return period probabilities, the flood risk for each house can be calculated. The calculation of flood risk of a house is based on the formula outlined in the book 'Applied uncertainty analysis for flood risk management' [Beven & Hall, 2014, p. 17]. Here it is assumed that the value of flood risk of a house only depends on the probability of a flood return period and the damage this flood return period does to the house. An analyses on how exactly flood risks are calculated in the model can be found in M.

- **House flood repair** (Putra): When a house is hit by a flood it will need to be repaired. If the house is insured the flood repair fee will be set equal to the excess value of the insurance. Banks and developers will always repair their houses. Persons will not be able to afford repairing their house if the damage to their house is higher than half of the total money they can spend on house expenditures.

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13 Even though this action is performed by the environment in the model, it is labelled as a house action because it specifically focuses on the processing of houses.
In this case the person won’t repair his house and the flood damage value gets deducted from the value of his house.

- **House dispossess** (Putra): When a house is sold to a new owner this procedure unlinks the house from its previous owner. After this the house is free for the new owner to move into. The previous owner becomes a home buyer.

### Bank States

- **Bank assets** (New): The amount of assets the bank has. **It will initially be set to 0 so that it gives an idea of the bank earning or loosing money. The assets (earning or loosing money) will not have any influence on the banks behaviour.**

### Actions

- **Process Bank**: Ask the bank to perform the 'bank flood insurance set' and 'bank maintain houses' actions

- **Bank house sell** (Putra): Every house the bank owns will be put on the market. Following the way Putra modelled the selling of houses by the bank, **It will be assumed that the bank will sell all houses they own for the actual value of the house and that banks will not adjust prices of houses if they can not sell them. This action will be incorporated in the 'bank market run' action of the environment, therefore it will not be seen as a separate action from here on.**

- **Bank flood insurance set** (Nikolic conceptualisation): Because its assumed that the bank has to insure all its houses against floods, all bank owned houses will be flood insured.

- **Bank maintain houses** (Putra): As long as houses are not sold, the bank will be responsible for maintaining these houses. The costs of this maintaining (set in the annual fees of the house) is deducted from the bank assets.

### Insurer States

- **Insurer assets** (Nikolic conceptualisation): The amount of assets the insurer has. These assets will mainly be used to compensate policy holders for flood damages. **Because only one insurer will be modelled and the main goal is to get information from it, it is assumed the insurer will stay in the market and will not go bankrupt. Because of this reason the initial assets of the insurer will be set to 0 so that exactly can be seen if the insurer makes a profit or loses money during the model run. This will only be based on the premium incomes they get and the amount**
of compensations they have to pay out. To simplify the model working it is also assumed that interest gained on assets (what normally is an important aspect for insurers) will not be taken into account.

- **Initial flood insurance excess percentage** (New): The initial flood insurance excess that a house that has no accountable flood history yet will be assigned. The initial flood insurance excess percentage is set to 1% L.2 [24].

- **Flood excess increase because of flooding** (New): The amount on the basis of which the flood excess percentage of a person increases after being hit by a flood. This increase is set to one-third L.2 [25]. So every time a house is flooded the flood insurance excess of the person living in the house is increase by one-third of the total.

- **Expected average annual loss** (Nikolic conceptualisation): The losses that insurer expects to make from compensating flood damages.

- **Current loss ratio** (Nikolic conceptualisation): The amount of money insurers spent on compensations, compared to the amount of income they get from premium payments.

- **Maximum acceptable loss ratio** (Nikolic conceptualisation): A fraction describing the maximum loss ratio that the insurer wants to have. The maximum acceptable loss ratio is set to 0.6 L.2 [26]

- **Base flood insurance premium** (new): The base flood insurance premium that every person has to pay (also those without flood risk). The base flood insurance premium is set to £50 pounds L.2 [27]

**Actions**

- **Process insurer**\(^{14}\) (New): Asks the insurer to run the following insurer actions: compensate policy holders, calculate current loss ratio and adjust insurer assets.

- **Set flood insurance premium and excess** (Nikolic conceptualisation)\(^{15}\): In this action houses will set a flood insurance premium and excess amount (based on insurer input). Both the flood insurance premium and flood insurance excess amount will reflect the flood risk the house is in. As mentioned earlier, only the technical risk will be modelled and not the commercial risk. It is assumed

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\(^{14}\)Even though this action is performed by the environment in the model, it is labelled as an insurer action because it specifically focuses on the processing of the insurer

\(^{15}\)Although this is an insurer action, its houses that perform this action because in the way the model will be coded they have the flood insurance premium and excess values set to them
persons will not take voluntary higher excesses on their flood insurance for a lower premium.

- **Calculate expected average annual loss** (Nikolic conceptualisation): Insurers calculate the total losses they expect to make from compensating flood damages in the current year.

- **Compensate policy holders** (Nikolic conceptualisation): After a flood event happened the insurer pays out compensations to all damaged houses that are insured. The total compensation they pay out per house are equal to the flood damage done to the house minus the excess the policy holder has to pay himself.

- **Calculate current loss ratio** (Nikolic conceptualisation): The insurer calculates the current loss ratio by dividing the total income from premiums through the total compensations they had to pay out. This current loss ratio can be used to make insurers react to flooding. If more flooding than expected will happen the current loss ratio of the insurer will become higher than the maximum loss ratio they want. Based on this the insurer can increase their insurance prices. However, because there is a lot of vagueness surrounding how insurers deal with these kind of things the choice is made not to include this mechanic in the current model.

- **Adjust insurer assets** (Nikolic conceptualisation): The amount the insurer had to pay in compensations this year will be subtracted from the insurer assets. The flood insurance premiums they receive from all houses will be added to the insurers assets.

**Local government**

- **Local government assets** (Nikolic conceptualisation): The amount of assets the local government has. The local government assets will initially be set to 0 and the local government will not be able to go in debt to invest in flood defences. This means that the local government will only be able to spent the money they receive on building flood defences. They can however go in debt to give out grants to persons, seeing they want to give a grant to everyone that asks for it. Debt will have to be paid back with the incomes they receive.

- **Percentage of land sales used for flood investments** (New): The percentage of income from land sales the local government will use to invest in building flood defences and giving out grants. The percentage of land sales used for flood defences is set to 0.05% L.2 [28].
• **Percentage of property taxes used for flood investments** (new): The percentage of income from property taxes the local government will use to invest in building flood defences and giving out grants. The percentage of property taxes used for flood investments is set to 0.05% L.2 [29].

• **Maximum fraction of value at risk** (Nikolic conceptualisation): The maximum fraction of total building value that will be hit by a 1 in 200 year flood event and for which flood defences are not yet build, before local government considers building flood defences. The maximum fraction of value at risk will be set to 0.45 L.2 [30].

• **Number of projects in flood defence portfolio** (new): The number of flood defence project the local government will have in its flood defence portfolio from which it can choose flood defence projects to build. The number of projects in flood defence portfolio is set to 10 L.2 [31].

• **Minimum houses in flood defence project** (new): The minimum number of houses that should be in a flood defence project. Because these project have scale advantages they should be build for a minimum of houses. The minimum houses in flood defence project is set to 100 L.2 [32].

• **Flood defence portfolio** (new): A list of a set of housing selections with benefit-cost ratios for building flood defences for the housing selection linked to it. From this list the local governments chooses flood defence projects to build.

• **Wanted benefit-cost ratio** (Nikolic conceptualisation): When looking at flood defences the local government can build to increase the flood defences of its governed area, the local government will want to see a benefit cost ratio that is above 5 L.2 [33].

• **Maximum flood risk** (Nikolic conceptualisation): The flood risk that the local government will accept as the maximum risk a house can be in to approve the building of the house by the developer. The maximum flood risk is set equal to the average flood risk of houses that will be hit by a 1 in 100 flood. This value will be recalculated every year.

• **Development approval ratio** (Nikolic conceptualisation): A ratio that indicates when a developer will approve a development based on the extra income it provides although it does not meet the flood safety standards of the local government. The development approval ratio is set to 1 L.2 [34]. So if the income of the development is higher than the quantified risk (flood risk value) it will be approved.
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- **Development proposal status** (New): A state that indicates the status of the development proposal status that the developer send to the local government to be evaluated.

**Actions**

- **Process local government**\(^{16}\) (New): In this action the local government is asked to performs all actions below, except the evaluating of development proposals, which will be done every time a developer sends the local government a development proposal.

- **Collect property taxes** (Nikolic conceptualisation): Each person owning a house (bank, developer or persons) will have to pay property taxes to the local government. The local government will collect these taxes and add a percentage, equal to the percentage of property taxes used for flood investments, of it to their assets to invest in flood defences or give out grants.

- **Collect land selling income** (Nikolic conceptualisation): it is assumed that all land without a house on it in the model belongs to the local government. When a developer decides to build houses they will need to buy the land from the local government. A percentage, equal to the percentage of property taxes used for flood investments, of this money will be added to the local government assets. *This action is incorporated in the developer actions of developing a house. When a developer decides to build a house it buys land from the government and directly pays the land value to the local government.*

- **Collect flood protection investment** (Nikolic conceptualisation): Besides income from property taxes and land selling, the local government also gets a budget from the central government to invest into flood defences and giving out grants. The amount of money they get is equal to the flood protection budget as set in the environment of the model. The local government adds this amount to its assets every year.

- **Decide on building flood defences** (Nikolic conceptualisation): The government will build flood defences to protect the people living in their municipality against flooding. *It is assumed that the local government will decide on building flood defence in a proactive way.* This means that the local government will decide

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\(^{16}\) Even though this action is performed by the environment in the model, it is labelled as a local government action because it specifically focuses on the processing of the local government.
every year again if they will invest in flood defences. If the total value of build-
ings at risk is higher than the maximum fraction of value at risk and if they have
enough assets to actually build a flood defence projects (enough assets to build
defences for the minimum of 100 houses), the local government will be triggered
to invest in flood defences

- **Build flood defences** (Nikolic conceptualisation/New\textsuperscript{17}): When a local govern-
ment has decided to invest in flood defences, the only question left is how much
they will invest. The maximum amount they can invest is equal to the local gov-
ernment assets that are left after they give grants to all homeowners that asked
for a grant on their investment in PLPMs. With these assets the local govern-
ment will want to invest as much as possible in flood defence projects that have
a benefit-cost ratio that is higher than the wanted benefit-cost ratio of the local
government. The local government will create a flood defence portfolio in which
it will select a set of possible flood protection project to build that have a min-
imum number of houses in it and reach the wanted benefit-cost ratio. The local
government will select a flood defence project to build in the following way: To
start it will select the house in its municipality that has the highest flood risk and
for which flood defences has not been build yet. This because, just as PLPMs, it
is assumed flood defences are a one-off investment. The local government won’t
invest twice in flood defences for the same house. It then select the 99 houses clos-
est to this house as the first housing selection. If the local government has enough
assets to build flood defences for this housing selection and the benefit-cost ratio
for building flood defences for this housing selection are equal or higher than the
wanted benefit-cost ratio, the local government will select the 10 houses closest to
the just selected house (that has no flood defences build for it yet) and will again
look if it has enough assets and if there is a good enough benefit-cost ratio to
build flood defences for this new housing selection. If this is also the case it selects
another 10 houses that are closest to the first house and does the same again. It
will continue doing this till it reaches a selection of houses at which point the next
10 houses will cause the local government assets to go negative or the benefit cost
ratio to go below the wanted benefit-cost ratio. It will repeat this 10 times to select
10 projects. Because several project can be build in the same year, houses can’t
be selected for two project. If a house is selected in project 1, it can’t also be in

\textsuperscript{17}The idea came from the Nikolic conceptualisation, how it is worked out is new
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project 2. After the projects are selected the project with the highest cost benefit ratio (of these 10 projects) is chosen and build. After his the project with the second best benefit-cost ratio is looked at. If there are also enough assets to build this project, it will also be build. So all 10 projects are looked at from highest to lowest benefit-cost ratio and as much projects as possible with the money there is will be build. The benefit of building flood defences for the selected houses is equal to the amount of damage that will be avoided by the building of flood defences (calculated over all flood return periods). The cost of building flood defences for the selected houses is equal to the cost of the flood defences times the number of houses selected. For modelling purposes this is a simplification on how the local government builds flood defences. The actual procedures often are larger project for which the decision making takes longer and the local government has to borrow money to be able to afford it.

- Evaluate development proposals (Nikolic conceptualisation): The local government receives development proposals from developers. It is assumed that approving of a development proposal will only depend on the flood risk and financial information of the proposed development. To simplify the model it is assumed that the developer will create a development proposal for each individual house it want to develop. Each development proposal will also be handled on a house by house basis by the local government.

Figures indicate that 75% of all development proposals will be approved regardless the flood risk of the proposed development [Wynn, 2005]. This means that of all development proposals send by the developer, 75% will automatically be approved. For the remaining 25% of proposals the local government will check if the flood risk of the proposed development is lower than the set maximum flood risk. If this is the case the development proposal will also be approved. If this is not the case the local government will look at the financial picture of the proposed development. Based on the ratio between the value at risk that the development will add to the total value of risk of the municipality and the income the local government will see in taxes and land selling from the development, the local government makes a decision on approving or denying the development proposal. If this ratio is lower than the set development approval ratio, meaning the local government taxes extra income over safety of its people, the development proposal will be approved.
Developer States

- **Developer assets** (Nikolic conceptualisation): The amount of assets the developer has. For modelling purposes it is assumed that all assets will be used to fund housing projects. The developer assets will initially be set to 0. It is assumed that for the funding of housing projects the developer has an unlimited amount of money, but it will only build house when there is a demand for them and it is calculated to make a profit. Because of these assumptions the developer assets will show if the developer is gaining or losing money from his housing developments.

- **Proposed land** (New): The land that the developer proposes to develop housing on.

- **Proposed house type** (New): The type of housing that is proposed to develop. Based on the proposed house type the house values of the proposed house can be calculated that can be split in the a proposed land value and a proposed building value.

- **Proposed house value** (New): The house value of the house the developer proposes to develop.

- **Proposed land value** (New): The value of the land that is proposed to develop housing on.

- **Proposed building value** (New): The building value of the house the developer proposes to develop.

- **Proposed council tax band** (New): The council tax band the house the developer proposes to develop is placed in.

- **Proposed property tax fee** (New): The property tax fee of the house the developer proposes to develop.

- **Proposed flood risk** (New): The flood risk of the house the developer proposes to develop.

- **Income-cost ratio for development** (Nikolic conceptualisation): The ratio between income and cost that a housing development should have for the developer to sign off on it. The income-cost ratio for development is set to 1.2, meaning the expected income of a housing development should at least be 20% higher than the costsL.2 [35].

- **Development approval status** (New): A state that indicates if the evaluation of a development proposal by the local government resulted in an approval of denial.
• **Build time** (Nikolic conceptualisation): The time it takes to build a house. In the UK it takes on average 8 months to build a house [36]. Seeing the smallest time step of the model is a year, the build time in the model will be set to 1 year.

**Actions**

• **Process developer**\(^{18}\) (New): In this action all actions of the developer are called upon. First however the local government will be asked to set a value for the maximum flood risk they accept when building flood defences. The local government will use this value in evaluating development proposals. The value of maximum flood risk is set to average flood risk of houses that will be hit by a 1 in 100 year flood. Output of this action is a local government that runs actions and a set maximum flood risk value. After this is set the developer actions are run. As already stated in the evaluate development proposals action of the local government, it is assumed that the development of houses will be done on a house by house basis. This means that his action first asks the developer to perform the following 3 actions: locate land for development, decide to create development proposal and develop housing, as many times as there is a demand for houses (number of homebuyers on the market for which there is no house on the market (number of homebuyer minus all houses on the market or already in construction). It is assumed that the developer will always try to build the exact amount of houses for which there is a demand and will try to build houses every year. After this is done it asks the developer to finish the construction of the houses it has been building for a year and to insure and maintain these houses and all houses it developed and did not sell yet.

• **Locate land for development** (Nikolic conceptualisation): The developer will have to locate land to build a house on. Within the district of Camden the local government has highlighted four opportunity areas, seen in light blue in the interface, for houses to be developed in. These opportunity areas are provided by GIS data [1]. Because of the current pressure on the UK housing market developers assume they will be able to sell the houses they develop in any circumstance, so they don’t account for flood risk when looking for a location to build houses. Because the developer seeks to make as much profit as possible on the building and selling of houses it will choose land based on values of houses surrounding the

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\(^{18}\) Even though this action is performed by the environment in the model, it is labelled as a developer action because it specifically focuses on the processing of the developer.
land. It seeks the patch of land for which the summed up house value of the 10 houses surrounding it will be the highest.

- **Decide to create development proposal** (Nikolic conceptualisation/New\(^{19}\)):
  By weighing the cost of a housing development against the cost, the developer will decide if it wants to develop housing on the located land. The developer will first select a house type that will be build on the located land. For initial houses this house type was set, for now houses here is no information. That’s why the developer will select a house type based on the basic rules that it follows the house type of the houses surrounding it. If there are no houses surrounding it or the types vary too much, it will follow the current house type distribution in the model for selecting a house type. Based on the type of house that will be set, the house value of the house can be set, on bases of which the land value of the land under the house and the building value of the house can be set. Based on these values the expected income (house value of the proposed house) and the total costs (land value + building costs) can be calculated. **As a simplification it is assumed that the building costs are half of the building value of the proposed house and that because houses in the investigated area are on average sold quite fast the possible fees of maintaining a house by the developer till they sell it will not be accounted in the total cost of the development.** If the expected income is higher than the total cost times the income-cost ratio for development the developer wants, the developer will decide positive on developing this house type on the given location and it will create a development proposal to be approved by the local government\(^{20}\). Just as with choosing land to build on, the developer will not account for flood risk when creating a development proposal. Figure indicate that the local government often does not look at flood risk when evaluating flood risk proposals and the developer expects to sell the house even if it is in high flood risk. This means the developer dos not build houses with PLPMs already in place, the person that buys the house is responsible for this. Last it is also assumed that the developer can develop

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\(^{19}\)The idea came from the Nikolic conceptualisation, how it is worked out is new

\(^{20}\)In the current model developers will almost always decide positive because the only difference between the cost and income is that the cost only has half of the building value added to it and the income the full building value. Because half of the building value will almost always be more than what the cost get increased because of the income-cost ratio for development, the developer will almost always decide positive. This behaviour will not be changed since with the current pressure on the housing market it is not weird that the developer will want to build as much as possible. The behaviour will also be kept in the model since it can become important behaviour for the developer if some easy adjustments are made in the future (by for instance adding flood risk to the equation)
housing on land for which previous development proposals were denied, they don’t account for development proposal history.

- **Develop housing** (Nikolic conceptualisation): If the development proposal is approved by the local government, the developers will start executing the proposed housing development. A house will be build and the house gets assigned all its stated, equal to the proposed states as the developer set them in their development proposal it send to the local government. While the house is being build the status of the house is set to in construction. To simplify this process it is assumed is that during the construction of a housing project, floods do not have influence on the house that is developed.

- **Finish house construction** (Nikolic conceptualisation): After a house has been in construction for a year it will be finished. In this action the house will have its remaining states assigned to it and will be set to developer owned so that the developer can start selling the house.

- **Developer house sell** (Putra): The developer will try to sell all houses it developed. Just as with the bank agent, developers will put created houses on the market for an asking price equal to the house value of the developed house. Developer will not lower the asking price if the house does not sell. *This action will be incorporated in the 'developer market run' action of the environment, therefore it will not be seen as a separate action from here on.*

- **Developer flood insurance set** (Nikolic conceptualisation): Because its assumed that the developer has to insure all its houses against floods, all insurer owned houses will be flood insured.

- **Developer maintain houses** (Nikolic conceptualisation): As long as newly developed houses are not sold the developer will be responsible for maintaining these houses. The costs of this maintaining (set in the annual fees of the house) is deducted from the developer assets.

**Schematic model layout**

Figure D.1 shows the states, action and interaction that this step elaborated on in a schematic model layout. This figure gives an overview of the most important state, action and interaction groups for each agent and the environment. A full overview can be found in appendix P.
D.2.5 The future situation

Now that a conceptualization of an UK housing market in an area prone to flooding is set up, a conceptualization can be made of how the FloodRe system as it currently is set up can be added to this conceptualization. This will be done by going through the same steps. How the current FloodRe system will be conceptualized is based on the analysis of it that was made in paragraph 1.1.2.

Agents and their behaviour

Because of the adding in of the FloodRe system some agents can have their behaviour changed. By adding in this behaviour in the already existing conceptualisation a model is conceptualized that represents a simplified UK housing market in an area prone to flooding in which the two insurance systems between which a choice can be made are present (current and FloodRe). Because the FloodRe system has no behaviour that is
of interest within this research the choice is made to not model it as a separate agent, but add it in the existing behaviour of agents already conceptualized.

To keep the flood insurance system simple for the consumer, it is set up in a way that it only interacts with insurers. Its for the insurers to decide on playing through FloodRe information to their policy holders. This has as a consequence that only the behaviour of the insurer agent will change with the adding of the FloodRe system to the model. The behaviours of all other agents will stay the same. Just the setting they behave in (the input values for their behaviour) will change.

For the insurer behaviour in which they choose to put policy holders in to the FloodRe system will have to be added in. Because the insurer wants to provide an insurance at the most cost competitive level to its policy holders, it will always provide its policy holders with the cheapest option for insurance. For the insurer this will mean that he will put one of his policy holders into the FloodRe system when the insurance premium rises above the insurance premium of the FloodRe system.

The gentlemen’s agreement between the local governments and the insurer will still exist with the adding of the FloodRe system. This means local governments will keep investing in flood defences like they currently do.

**States, actions and interactions of agents**

A small set of states, actions and interactions will have to be added or changed to the conceptualization to add the current FloodRe system to it.

**Environment**

**States**

- **FloodRe assets** (Nikolic conceptualisation): The amount of assets the FloodRe system has. It is assumed will be set to 0 so that it gives an idea of the FloodRe system making or loosing money. The assets (making profit or not) will not have any influence on the way the FloodRe system behaves.

- **FloodRe levy**: To help pay for the FloodRe system all flood insured persons need to pay a levy on their flood insurance that goes to FloodRe. This levy will be equal to 2.2% of the persons flood issuance premium $L.2$ [37]. Because ABI assures persons already pay this levy in their current flood insurance premium but it is just labelled differently, it will be assumed that this levy will not be added to annual fees of a person. The levy will however be added to the FloodRe assets.
**Actions** The environment gets no new actions with the adding of the FloodRe system.

**Persons** The person agents get no new states or actions with the adding of the FloodRe system.

**houses** States

- **Re-insured to FloodRe status** (Nikolic conceptualisation): When an insurer decides the risk on a house is too high it will re-insure it into FloodRe. At this moment this state will be set to true, indicating that the house is now re-insured into the FloodRe system.

- **FloodRe insurer cost** (Nikolic conceptualisation): The amount an insurer will have to pay into the FloodRe system when he decides to re-insure a policy holder into FloodRe. The FloodRe insurer cost is linked to the council tax band of a house (and is therefore set as a house state)\[38\] :
  - If the council tax band is A, the FloodRe insurer cost = £210
  - If the council tax band is B, the FloodRe insurer cost = £210
  - If the council tax band is C, the FloodRe insurer cost = £246
  - If the council tax band is D, the FloodRe insurer cost = £276
  - If the council tax band is E, the FloodRe insurer cost = £330
  - If the council tax band is F, the FloodRe insurer cost = £408
  - If the council tax band is G, the FloodRe insurer cost = £540
  - If the council tax band is H, the FloodRe insurer cost = £540

- **Compensation amount** (Nikolic conceptualisation): amount of compensation for flood repairs the house gets from the insurer or **FloodRe system**

**Actions** The house agents gets no new actions with the adding of the FloodRe system.

**Bank** The bank agent gets no new states or actions with the adding of the FloodRe system.

**Insurer** States The insurer agent gets no new states with the adding of the FloodRe system.

**Action**
- **Set flood insurance premium and excess**: With FloodRe added, every person has to pay a levy to help pay for FloodRe. In this action this levy will be set and added to the FloodRe assets. At the end of this action, when the flood insurance premium and excess of a house are set, the action below is run for all houses.

- **Decide on re-insuring in FloodRe** (Nikolic conceptualisation): In this action the insurer will decide on a house-by-house basis if it will re-insure a house into FloodRe. The insurer will decide on re-insuring all house (that are built before 2009) into FloodRe when the insurance premium of the policy holder is higher than his FloodRe insurer cost. In this way the insurer will always provide its policy holders with the cheapest possible insurance policy. The re-insuring into FloodRe will have no consequences for the interaction between the insurer and the house (and person living in it). The insurer will still receive the insurer premium (now capped at the amount equal to the FloodRe insurer cost of the policy holders house) and the house will get compensated in the same way. The insurer however will have to pay a fixed amount equal to the FloodRe insurer cost of the house of his policy holder to the FloodRe system for every house it re-insures in it. And the person will receive the compensations it get from the assets of the FloodRe system and not from the insurer assets. The insurers will not provide FloodRe information to third parties seeing they are not legally obliged to do so and they do not get any gain form sharing the information. This means other agents do not get information about houses being re-insured in FloodRe.

- **Compensate policy holder** (Nikolic conceptualisation): After a flood event happened the insurer pays out compensations to all damaged houses that are insured (and not re-insured in FloodRe). The total compensation they pay out per house is equal to the damage to the house minus the excess the policy holder pays himself. This total compensation will be subtracted form the insurer assets. The same is done for the FloodRe system that pays out compensations and subtracts the total of compensation from the FloodRe assets.

- **Calculate current loss ratio** (Nikolic conceptualisation): The insurer calculates the current loss ratio by dividing the total income from premiums through the total compensations they had to pay out. The total compensation they have to pay out change when the FloodRe system is added. The insurer no longer has to pay the full compensations for policy holders it put in FloodRe. For the policy holders it put in FloodRe they just have to pay the FloodRe insurer cost.
local government  The local government agent gets no new states or actions with the adding of the FloodRe system.

Developer  States

- **Proposed FloodRe insurer cost** (New): The FloodRe insurer cost of the house the developer proposes to develop

Action

- **Decide to create development proposal**: Because the developer needs to set all states of the house he is proposing, he will now also have to set a proposed FloodRe insurer cost for the housing development he is proposing.

Schematic model layout with FloodRe added

Figure D.2 shows the schematic model layout with the states, actions and interactions of FloodRe added. The states, actions and interactions that were added with the adding of the FloodRe system are shown in green. The states action and interaction that were changed are shown in orange. Like before, this figure gives an overview of the most important state, action and interaction groups for each agent and the environment. A full overview can be found in appendix Q.

D.3 Step 3: Concept formalization

The previous step showed the states, actions and interactions that need to be modelled. In this paragraph the states and actions of agents will be formalized to get a more context free idea of them. This is done because computers do not deal well with context. The concepts identified in the previous step need to be converted into computer understandable analogues.

For the states below that have an initial value assigned to them that won’t be changed during the model run only their initial value as how it will be represented in the model is mentioned. For states that have their value assigned during the model run or for which the initial assigned value will change within the model run, the primitive type and the range it can have within the model is mentioned. All states that are used in the formalization of actions are clearly states as input for the actions. Between brackets it is shown which agent the states is coming from (which interaction takes place).
States that will be represented by a boolean (true/false) in the model will get a question mark (?) behind their name. This is done because a state with a ? behind it automatically indicates a boolean within the Netlogo code.

Just as in the previous step a distinction will be made between the current situation and the future situation.

D.3.1 The current situation

First the conceptualization of the current situation will be formalized.

Environment formalization

Environment has

- **Percentage of houses for sale at the start**: 2.3% can be represented by a value of 0.023 in the model

- **Mortgage interest**: 3% can be represented by a value of 0.03 in the model
• **Mortgage term**: 25 years can be represented by a value of 25 in the model

• **Average values of houses**:
  - **Average flat value**: 729,400 pounds can be represented by a value of 729400 in the model
  - **Average terraced value**: 1,327,277 pounds can be represented by a value of 1327277 in the model
  - **Average semi-detached value**: 1,750,790 pounds can be represented by a value of 1750790 in the model
  - **Average detached value**: 2,365,034 pounds can be represented by a value of 2365034 in the model

• **Owner warning time**: 3 years can be represented by a value of 3 in the model

• **Number of trade actions**: 30 trade actions can be represented by a value of 30 in the model

• **Housing ratio increase**: 5% can be represented by a value of 0.05 in the model

• **Average number of incomes as down payment**: 3,05 incomes can be represented by a value of 3.05 in the model

• **Average percentage sell price**: 25% can be represented by a value of 0.25 in the model

• **Average profit percentage**: 10% can be represented by a value of 0.10 in the model

• **Land value**: Floating point $\geq 0$
  The value for land can be represented by a value of 0 (land has no value) or higher. Land can not have a negative value.

• **Land value percentage**: 50% can be represented by a value of 0.5 in the model

• **Flood return period probabilities**: list of Floating point $\geq 0$
  A list of flood return period probabilities (values higher or equal to 0) corresponding to the modelled flood-return periods

• **Immigration percentage**: 4.7% can be represented by a value of 0.47 in the model

• **Percentage of movers**: 2.7% can be represented by a value of 0.027 in the model

• **Flood risk Consider probability**: 57% can be represented by a value of 0.57 in the model

• **No selling decrease value percentage**: 25% can be represented by a value of 0.25 in the model
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- **Inflation percentage**: 2.9% can be represented by a value of 0.029 in the model
- **Percentage of proactive PLPM investors**: 1% can be represented by a value of 0.01 in the model
- **Percentage of reactive PLPM investors**: 34% can be represented by a value of 0.34 in the model
- **PLPM investment flood protection benefit**: 75% can be represented by a value of 0.75 in the model
- **Flood protection budget**: 220,200 pounds can be represented by a value of 220200 in the model
- **Cost of flood defences**: 2000 pounds can be represented by a value of 2000 in the model
- **Flood defence investment flood protection benefit**: 50% can be represented by a value of 0.50 in the model

Environment does Setup procedure

- **Setup environment**: Input for this action are all environment states that have an initial value assigned. In this action these states are assigned and set to their initial value. This is also the output of this action.
- **Setup houses**: Input for this action is the GIS data on houses and all house states that have an initial value assigned. For every location specified in the GIS data a house will be created and given a location. Each created house will get the following states assigned. First each house is given a house value based on the average house values and a distribution. Next this house value is split into a building value and a land value with the help of the land value percentage state. Based on GIS data the houses then get a build year and an income (with a standard deviation) assigned to them. This income will be transferred to the person living in the house when they are created and move in. Also based on GIS data all houses get a flood damage list assigned to them indicating how much damage they take in each flood return period. Houses get flood a flood event dataset assigned to them based on their location and based on this event data they are assigned a flood history that is used to set the initial flood insurance excess percentage (for every year in the last 10 years the house was flooded the initial flood insurance excess is increase by 1/3th). Based on the type of house, every house gets put into a council tax band, as specified in appendix N. Based on this council tax band all
houses get assigned a property tax fee. Output for this action are created houses on every spot assigned by the GIS data with values for all just mentioned states assigned to them.

- **Setup persons**: Input for this action are the percentage of houses for sale at the start (environment) and all person states that have an initial value assigned. In this action a person for every house in the model is created. A percentage equal to the percentage of houses for sale at the start * the number of houses, gets created and assigned as home sellers and are asked to move into an empty house. After this a number of persons equal to the number of houses that are still empty are created and asked to move into an empty house. All created persons get its states assigned with their initial values set and are asked to run the setup general persons states action (persons action). Persons that were assigned to be home sellers are asked to put their house on the market (house market sell action). Output for this action is the creation of persons that have states with initial values assigned and are moved into houses in the model.

- **Setup bank**: Input for this action are all bank states that have an initial value assigned. In this action a single bank agent is created and its states are assigned with their initial values set. This is also the output of this action.

- **Setup insurer**: Input for this action are all insurer states that have an initial value assigned. In this action a single insurer agent is created and its states are assigned with their initial values set. This is also the output of this action.

- **Setup local government**: Input for this action are all local government states that have an initial value assigned. In this action a single local government agent is created and its states are assigned with their initial values set. This is also the output of this action.

- **Setup developer**: Input for this action are all developer states that have an initial value assigned. In this action a single developer agent is created and its states are assigned with their initial values set. This is also the output of this action.

**Go procedure**

- **Flood event**: Input for this action are flood damage lists (houses) and a choice in the way flood events will be modelled. In appendix H this choice is highlighted and concluded here is that for this model one of the 4 flood events (no flood, 1 in 30 years, 1 in 10 years or 1 in 200 years) happens halfway through the model run.
Which flood event happens is based on the input that is chosen for the current run (can be chosen in interface of the model). In this model every house will have assigned a flood return period (equal to 0, 1, 2 or 3 representing the 4 flood return periods, form no flood to a 1 in 200 year flood event) every year of the model run. Most run this will be 0 (no run) but halfway the model run this will become 0, 1, 2 or 3 depending on the input that is chosen. Based on the assigned flood return period a house will set the damage it did to it (set in the house flood repair action of houses). Output of this action is a selected flood return period.

- **Process market**: Input for this action are the 4 house types in the model. In this action the best house type is selected (detached) and the 3 separate markets (for developer, person and bank houses) are run. When these are run the next house type (semi-detached) is selected and the same is done. After semi detached the same is done for the terraced house type and last the flat house type. Before and after the four house type are run in all three markets, data is collected on the amount of houses on sale for the given house type. This output is used in the building value update action (environment action).

- **Developer market run**: Input for this action are all houses that are developer owned, person states (persons), a flood risk consideration status (persons), a flood damage history (houses) and the number of trade actions (environment). This code is repeated in its entirety for the amount of times there are person with a homebuyer status. The code stops when every homebuyer in the model had a chance to look at developer owned houses or when there are no more developer owned houses left.

In the action homebuyers are first asked to set the maximum price they can pay for a house (set maximum affordable house price action of persons). After they have done this they will select a developer owned house at random. If the persons flood risk consideration status is set to false and he can afford the house he will set it as the best house they found so far (they house they will buy). If the persons consideration status is true he will look at the flood damage history of the house. If it took flood damage this year he will not set this house as the best house and moves on to looking at a next house. If the house took damage in the previous year there is a 50% chance he will move on and a 50% chance he will set the house to best house. For damage 2 years ago there is a 25% he will move on and a 75% chance he will set it to his best house.
After a person set a new house as a best house or has chosen not to select the house they visit, they select another developer owned house they have not visited before at random. If this house is affordable (and the same thing with flood consideration and flood damage as above) and higher valued than the earlier selected house, they set this new selected house to the best house. This is repeated for an amount of times equal to the value of the number of trade actions. If after this the person has set a house as the best house (there was a house he wanted and could afford) he will buy this house from the developer. After a successful trade the land value update action for the just set transaction price is performed (environment action). Output of this action can be no buying/selling (no best house selected) or a buying/selling agreement in which the developer that is selling the house hands the ownership of the house over to the homebuyer with who a sale is agreed (the home sellers house performs the house dispossess action (house action) and the homebuyer performs the house enter action (person action)).

- **Person market run**: Input for this action are person states (persons), a seller ask price (persons), the number of trade actions (environment), a flood risk consideration status (persons) and a flood insurance premium (houses). This code is repeated in its entirety for the amount of times there are persons with a home seller status. The code stops when every home seller in the model had a chance to sell his house or when there are no more persons with a home buyer status. In the action homebuyers are first asked to set the maximum price they can pay for a house (set maximum affordable house price action of persons). because home buyers always search for the most expensive house, the best asking price is set to the asking price of the home seller that asks the most for his house. Following this, persons will start bidding up against each other. For a number equal to the number of trade actions home buyers or home sellers are randomly selected to make a bid or set an asking price on the market. When a homebuyer is selected he will put a bid price (a value between his maximum affordable house price and 0) up on the market. If this bid is higher than the best ask price (and the previous flood damage history algorithm as already explained in the 'developer' market run' above is passed) a trade is made between person with the best asking price and the homebuyer that just set a bid price. If this is not the case another homebuyer or home seller is randomly selected to make a bid or set an asking price on the market. If this is a home seller he will set a new asking price for his house (a
value between his previous seller ask price and the best bid from a home buyer on the market. If this new asking price is lower than the best bid a trade is set up (if the previous flood damage history algorithm is passed). This continues till a number of homebuyers or home sellers are selected that is equal to the number of trade actions. If no trade is made in this time this round ends without an unsuccessful trade and nothing happens. If a successful trade is made the land value update action for the just set transaction price is performed (environment action). Output of this action can be no buying/selling (no agreement in asking and bid price is found) or a buying/selling agreement in which the home seller that is selling the house hands the ownership of the house over to the homebuyer with who a sale is agreed (the home sellers house performs the house dispossess action (house action) and the homebuyer performs the house enter action (person action)).

- **Bank market run:** This action is performed in the exact same way as the developer market run is done. The only difference is that it is now the bank agent that is selling bank owned houses instead of the developer agent selling developer owned houses.

- **Building value update:** Input for this action are the amount of houses on sale before and after the market is run per house type (coming from the process market action) and the no selling decrease value percentage (environment). By subtracting the amount of houses of a given house type that are on sale after the market is run from the amount of houses of the same house type that were on sale before the market was run, the number of houses sold of a give house type within a market run can be determined. By dividing this number by the total houses on sale of the given house type after the market run, a sales ratio of the market run this year is calculated for every house type. The sales ratio will be decreased with 0.25. Based on this set sales ratio, the building values of all houses of the same house type as the sales ratio is calculated from will be increased or decreased by the sales ratio.

Note: Houses that are in construction are left out of the calculation done within

\[\text{In the Putra model this best bid was updated every time a home seller wanted to set an asking price. Because this code is asked a lot and made the model slow (around half of model run time was in this code) it was changed to only being set at the start of every trade round. This does not change the model much because in this model the developer market is run before the person market (in Putra the person was first since developer did not exist). Because of this all home buyers have already set a max bid price and the price won’t change much during a trade round. It however does need to be updated every trade round because it is not uncommon that the person with the highest bid is the one that buys a house within a trade round. This bid than disappears from the market.} \]
this action. Output of this action are adjusted building values for all houses in the model that are not in construction.

- **Land Value update**: Input for this action are a successful sale of a house with a transaction price linked to it (environment), previous transacting prices within the same year (environment), house types of sold houses (houses) and a building value (houses). This action is run after an successful sale of a house. In this action an average transaction price per house type is set by adding the transaction price of the just made trade to the total of already made trades of houses with the same house type in the current year. This gives a total of transaction value for the given house type this year. By dividing this number by the total number of transaction done for the same house type in the current year, an average transaction price of houses of the given house type can be calculated. The value of the land under the just traded house gets changed by giving it a new value that is equal to the average transaction price hat was just calculated minus the building value of the just traded house. Output of this action is an update land value for the land under the house that was successfully sold and this action was run for.

**Person formalization**

Persons have

- **Person status**: Booleans

  There are 3 person states. These can best be represented by 3 separate booleans (states that are either true or false) so that persons with a given state can easily be asked to perform an action. These booleans are: homeowner?, home seller? and homebuyer?. A person can only have one off these three states set to true to properly work, the other two have to be set to false.

- **Income**: Floating point $\geq 0$

  The income of a person can be represented by a value higher or equal to 0. A person can not have a negative income.

- **Housing ratio**: Floating point $> 0$

  The housing ratio of a person can be represented by value higher then 0. A housing ratio of 0 or negative is not possible.
• **Mortgage ratio**: Floating point > 0
  The mortgage ratio of a person can be represented by a value higher than 0. A mortgage ratio of 0 or negative is not possible.

• **Number of incomes as down payment**: Floating point > 0
  The number of incomes as down payment of a person is based on a distribution of the average number of incomes as down payment. It can be represented by a value higher than 0. A number of incomes as down payment of 0 or negative is not possible.

• **Percentage sell price**: Floating point > 0
  The percentage sell price of a person is based on a distribution of the average percentage sell price. It can be represented by a value higher than 0. A percentage sell price of 0 or negative is not possible.

• **Profit percentage**: Floating point > 0
  The profit percentage of a person is based on a distribution of the average profit percentage. It can be represented by a value higher than 0. A profit percentage of 0 or negative is not possible.

• **Maximum house price**: Floating point >= 0
  The maximum house price can be represented by a value higher or equal to 0. Persons cannot have a negative value as the maximum price they can pay for a house.

• **Seller ask price**: Floating point >= 0
  The maximum seller ask price can be represented by a value higher or equal to 0. Persons cannot ask a negative value for their house.

• **Annual Fee**: Floating point >= 0
  The annual fees can be represented by a value higher or equal to 0. Persons will never have to pay a negative amount of fees.

• **Flood risk consideration status?**: Boolean
  The flood risk consideration status can be represented by a boolean because a person either does (true) or does not (false) consider flood risk when buying a house.

**Persons do**

• **Setup general person states**: Input for this action are person states (persons), a mortgage fee (persons), an income attached to houses (houses), the housing
ratio increase (environment), the average number of incomes as down payment (environment), the average percentage sell price (environment), the average profit percentage (environment) and the flood risk consider probability (environment). This action will be both run for persons initially created and persons that get created during the model run.

In the setting up of houses all houses had an average income and standard deviation set to them. Initial created persons (persons that have a status of homeowners or home sellers assigned to them) first get their income set to them based on a normal distribution over the average income and standard deviation set to the house they move into. After this the persons get their mortgage fee set equal to the mortgage fee of their house divided by their income. Their housing ratio is than set to their mortgage fee + the housing ratio increase.

Person that enter the model while it is running (persons that have a status of homebuyer assigned to them) will first set their income equal to a random chosen person in the model. The mortgage ratio of these new persons is set equal to the mortgage ratio of a different random person in the model and the housing ratio is again set by adding the housing ratio increase to the mortgage ratio. After this, all persons, initial or new, have the following states set based on distributions around their averages set in the environment (as specified here L.3). These states are; number of incomes as down payment, percentage sell price and profit percentage. All persons also get assigned whether they do or do not consider flood risk when buying a house. An amount of persons equal to the flood risk consider probability get their flood risk status set to true, the other stay false. Output for this action are a set value for the following person states for every person in the model: income, housing ratio, mortgage ratio, number of incomes as down payment, percentage sell price, profit percentage and flood risk consideration status.

- **Process persons**: Input for this action are the immigration percentage (environment), the annual fee list (houses) and the no selling decrease value percentage (environment). In this action a number of persons equal to the immigration percentage times the number of houses in the model will be created and labelled as homebuyers. They will be asked to set up their initial states with their values (setup general person states action of persons). Besides creating new persons, all existing persons are also asked to perform tasks. All persons labelled homeowners are asked to set their annual fee as the sum of the annual fee list. They are also
asked to decide on selling their house (decide on house selling action of persons) and to invest in PLPMs (invest in PLPMs action of persons). All persons labelled home sellers will decrease their house asking price by a percentage equal to the no selling decrease value percentage if they failed to sell their house last year. Home sellers will keep doing this till they sell their house (or just never sell their house). All persons are asked to adjust their income for inflation (inflation correction action of persons). Outcome of this action are newly created persons (homebuyers) that have states assigned, homeowners that are asked to perform actions (house selling and investing in PLPMs), home sellers that change the asking price of their house and all persons that are asked to correct their income for inflation.

- **House enter**: The input for this action are a person status (persons) and a house status (houses). In this action all persons that move into a house (at model setup or when they bought a house) will have their status set to homeowner. The house the person moves into will have its status set to person owned. This house gets asked to set the mortgage fee (and duration) the persons owning the house will have to pay on it (set mortgage fee action of houses). The person that just moved into his new house is asked to get flood insurance for his new house (person flood insurance set action of persons). Output of this action are a person that moved into a new house with both the person and the house having a new status.

- **Decide on house selling**: Input of this action are an annual fee (persons) an income (persons) a housing ratio (persons), the owner warning time (environment), a house value (houses), a house value at buy (houses), a profit percentage (persons) and the percentage of movers (environment). In this action all homeowners will decide if they sell their house. If a homeowner has an annual fee that is higher than his income times his housing ratio, and this occurs for a number of years equal to the owner warning time, he will be forced to foreclose his house and sell it to the bank (house bank sell action of persons). If this is not the case a homeowner will check if the house value of his house is higher than the house value at buy of his house times the homeowners profit percentage. If this is the case he will decide on selling his house on the market (house market sell action of persons). In the Putra model all persons in the model did this. Because the creating of houses and setting of house values is done different in this model (already done for the main part in the setup based on GIS data and not during the model run as done in the Putra model) this code can cause for huge selling spikes because there are more houses
and house prices are closer to each other. Seeing it is not a logical situation that within a single year 50% all people sell their house (which sometimes happened), this code was changed a bit. The assumption is made that only 10% of all people in the model would sell their house for profit. In this way the model will still show sell spikes as was seen in the Putra model, but the size of the spikes are closer to what also in the Putra model happened. If a person also did not decide to sell his house because of profit, there is a chance, equal to the percentage of movers, that the person will decide on selling his house (house market sell action of persons) because he want to move to a different house. Output of this action is a decision from a homeowner whether he does or does not sell his house.

- **House bank sell**: Input for this action are a house value (houses), a house status (houses) and the bank assets. If a person must foreclose his house and sell it to the bank, the bank will buy this house for its current house value. This house value will be deducted from the bank assets. The status of his house will be changed to bank owned and the person will leave to model to find a rented house (so for the model he will die). Output of this action are a house that is now bank owned, a changed bank asset amount and a persons that left the model.

- **House market sell**: Input for this action are a house value (houses), a percentage sell price (persons), a house status (houses) and a person status (persons). If a person decided to sell his house on the market he will put it on the market for an asking price equal to his house value increased with the percentage sell price. The status of the persons gets changes to home seller and the status of his house to person on market. Output of this action are an asking price for a house that has its state now set to person on market with an owner that has its state set to home seller.

- **Set maximum affordable house price**: Input for this action are a number of incomes as down payment (persons), an income (persons), a mortgage ratio (persons) and the mortgage interest (environment). In this action a homebuyer sets the maximum price he can afford when buying a house. The maximum value is based on the mortgage formula from [HSBC, 2014a] and is as follow: Maximum affordable house price = (((income * mortgage ratio) / (mortgage interest / (1 - (1 + mortgage interest)^(-mortgage term)))) + (number of incomes as down payment * income)).
• **Person flood insurance set**: Input for this action is the assumption that all persons need to take flood insurance for their house and a flood insurance status (houses). In this action persons that own a house set the flood insurance status of their house to true. Output of this action is a flood insurance status that is set to true.

• **Invest in PLPMs**: Input for this action are a flood risk consideration status (persons) the percentage of proactive PLPM investors (environment), the PLPM investment flood protection benefit (environment), a flood protection level (houses), a flood damage history list (houses), the percentage of reactive PLPM investors (environment) and local government assets (local government). In this action persons will decide on investing in PLPMs. Of all the persons that have their flood risk consideration status set to true, a percentage equal to the percentage of proactive PLPM investors, will invest in PLPMs this year, meaning that the flood protection level of their house increases with the PLPM investment flood protection benefit. All persons of which their houses took damage from a flood last year (flood damage history of last year was > 0) a percentage, equal to the percentage of reactive PLPM investors, will invest in PLPMs and increase the flood protection level of their house. It is assumed all these people will ask for a grant from the local government, which means the amount of reactive persons that invested in PLPM times the grant amount (5000) will be deducted from the local government's assets.

• **Inflation correction**: Input for this action are an income (person), the inflation percentage (environment) and the amount of years (ticks) that have passed (environment). In this action the income of all persons gets adjusted for inflation. This is done by increasing the income of all persons with the inflation percentage. Because newly created persons take an income of a person already in the model (that is already corrected for inflation), no extra inflation correction is needed for these persons. The output of this action is an adjusted income for all persons in the model.

**House formalization**

**Houses have**

• **House type**: integer equal to 0, 1, 2 or 3

Based on the 4 house types as presented in the Jenkins model, houses can have
a house type that is equal to the numbers 0 (detached), 1 (semi-detached), 2 (terraced) or 3 (flats)

- **House value**: Floating point \( \geq 0 \)
  A house value can be represented by a value that will always be higher or equal to 0. Houses can not have a negative value.

- **Building value**: Floating point \( \geq 0 \)
  A building value can be represented by a value that will always be higher or equal to 0. Buildings can not have a negative value.

- **Build year**: integer
  The build year can be represented by an integer that is equal to the year the house was build in

- **Flood Damage History List**: List of floating points \( > 0 \)
  A list of flood damage history can be represented by a list of floating points higher than 0, a flood does 0 damage (no flood) or a positive amount of damage, never negative.

- **House status**: Booleans
  Just as with person statuses, houses can have its house statuses translated into booleans. For each house status a boolean will be set. The following booleans can be set to true of false for a house, representing the status they have; person owned?, person on market?, bank owned?, in construction? and developer owned?

- **Council tax band**: string equal to "A", "B", "C", "D", "E", "F", "G" or "H"
  The house can be placed in one of the 8 council tax bands, A, B, C, D, E, F, G or H

- **Property tax fee**: Floating point equal to 880.32, 1027.04, 1173.76, 1320.48, 1613.92, 1907.36, 2200.80 or 2640.96
  The amount of property taxes that has to be paid on the house can be represented by a set of 8 floating points that are linked to the 8 council tax bands a house can be placed in.

- **Annual fee list**: List of floating point \( \geq 0 \)
  The annual fee list can be represented by a list of fees (floating points that are larger than 0).

- **Fee duration list**: List of integers \( \geq 0 \)
  The fee duration list can be represented by a list of integers (durations in years).

- **Mortgage fee**: Floating point \( \geq 0 \)
  The mortgage fee can be represented by a value higher or equal to 0. A negative amount will never have to be paid.
Appendix D Detailed model creation

- **Ageing repair fee**: Floating point $\geq 0$
  
The amount of ageing repair fees that has to be paid on the house can be represented by a value higher or equal to 0. A negative amount will never have to be paid.

- **House value at buy**: Floating point $\geq 0$
  
The house value at buy can be represented by a value higher or equal to 0. Because ask or bid prices can not be negative, this value can also never be negative.

- **Flood damage list**: list of floating points $\geq 0$
  
  Can be represented by a list of floating points that represent flood repair fees per flood return period.

- **Flood status?**: Boolean
  
  Can be represented by a boolean, set to true if a house is flooded and to false otherwise.

- **Flood repair fee**: Floating point $\geq 0$
  
  When a house is not flooded the flood repair fee will be 0. When it is flooded the flood repair fee will be greater than 0.

- **Flood risk**: Floating point $\geq 0$
  
  When a house will not be hit by any of the modelled floods, the flood risk will be 0. If 1 or more of the modelled floods can hit it the flood risk will be greater than 0.

- **Flood insurance status?**: Boolean
  
  Can be represented by a boolean. Set to true if the person owning the house has bought flood insurance. Set to false if the person owning the house has not bought flood insurance.

- **Flood insurance premium**: Floating point $\geq$ base flood insurance premium
  
  The amount of flood insurance premium that has to be paid on the house can be represented by a value higher or equal to the base flood insurance premium set by the insurer. If a house is not in any flood risk it pays the base premiums. If it is in flood risk it will pay a higher premium, never lower.

- **Flood insurance excess percentage**: Floating point $\geq$ initial flood insurance excess percentage and $\leq 1$
  
  In the model run this value can range between the initial flood insurance excess percentage set in the environment and 1. If set to 0 the insurer will pay all damages to the house and the person owning the house would not have to pay any excess.
If set to 1 (100%) the person will have to pay for all damages and the insurer will not pay anything.

- **Flood insurance excess**: Floating point >= 0
  The amount of flood insurance excess that has to be paid on the house can be represented by a value higher or equal to 0. A negative amount will never have to be paid.

- **Compensation amount**: Floating point >= 0
  The amount an flood insurance compensation that is paid out to the house can be represented by a value higher or equal to 0. A compensation amount is not possible.

- **Flood protection level**: Floating point >= 0 and <= 1
  Seeing this represent the percentage a certain flood protection level lowers the flood damage to a house it can be represented by a value between 0 and 1 (0 and 100%).

**Houses do**

- **Set mortgage fee**: Input for this action are a house value (houses), a number of incomes a down payment (persons) an income (persons) the mortgage interest (environment), the mortgage term (environment), an annual fee list (houses) and a fee duration list (houses). In this action the mortgage fee of a house is set according the given mortgage formula of [HSBC, 2014b]: Principle * mortgage interest / (1 - (1 + mortgage interest)^mortgage term). With the principle being equal to the house value - (number of incomes as down payment * income of person owning the house). The mortgage fee gets added to the annual fee list and the corresponding duration (mortgage term) gets added to the fee duration list. Output of this action is a mortgage fee and an adjusted annual fee list and fee duration list.

- **Process house**: Input for this action are a house status (houses) a flood damage list (houses), a flood protection level (houses), an annual fee list (houses), a fee duration list (houses), a house value (houses) and the property tax fee (houses). In this action all houses that are not in construction are first asked to update their flood damage list by adding 10% of the difference between current house value and initial house value to it and by lowering it with the protection level of the house if any protection measures were installed for the house in the previous year. After this the house is asked to calculate its new flood risk (calculated flood risk action
of houses). After this the duration of all items in the fee duration list are decreased with 1. If a duration in the list is equal to 0, the corresponding item in the annual fees list is deleted from this list. The fees that are deleted are calculated again (expect for the mortgage fee). Fees that are set are added to the annual fees list again with the corresponding duration being added to the fee duration list. In this action the following fees are added to the lists: a property tax fee (equal to the property tax fee of the house) with a duration of 1, a house ageing repair fee (1% of building value) with a duration of 1, a flood insurance premium (set flood insurance premium and excess action of insurer), and a flood repair fee (house flood repair action of houses). Output of this action are a possibly updated flood damage list and an updated annual fee and fee duration list.

- **Calculate flood risk**: Input for this action are a flood damage list (houses) and the flood return period probabilities (environment). In this action the flood risk a house is in gets calculated by calculating the space under the damage-probability graph that can be created for each house. How exactly the graph is created, what assumptions are made in creating it and how the flood risk is calculated from it is outlined in appendix M. Output of this action is a flood risk assigned to all houses.

- **House flood repair**: Input for this action are house states (houses), the flood return period (environment), a flood damage list (houses), a building value (houses), a flood insurance status (houses), a flood insurance excess (houses), a housing ratio (persons) an income (persons), an annual fees list (houses) and an fee duration list (houses). This action is performed for all houses that are not in construction. In this action a the flood repair fee that corresponds with the current flood return period gets selected from the flood damage list and set as flood repair fee for the house. The flood repair fee will be set to the flood insurance excess value if the flood insurance status is set to true. If its a person owning the house it might be that he can’t afford to repair his house. If the flood repair fee is higher than half of the persons income times his housing ratio, the flood repair fee will be deducted from the building value of the persons house, indicating that he can not afford the repairs. If he can afford the repairs the flood repair fee will be added to the annual fees list and the corresponding duration (1 year) gets added to the fee duration list. Output of this action is a flood repair fee and a flood repair fee value added to an annual fees list plus duration to fee duration list or a decreased building value of the persons house.
• **House dispossess**: In this action the house gets asked to reset its parameters (unlinking him from the person owning it) and the person owning the house gets asked to reset the parameters that links it to his house and to set his state to home buyer. Output of this action is an unlinked house and person, and a person that changed from home seller to home buyer.

**Bank formalization**

**Bank has**

• **Bank assets**: Floating point

  The bank assets show if the bank is making or loosing money on the market. Because of this it can be represented by any value, positive or negative.

**Bank does**

• **Process bank**: Ask the bank to perform the 2 actions below.

• **Bank flood insurance set**: Input for this action are house states (houses), a flood insurance status (houses) and the assumption that the bank needs to take flood insurance for all its houses. In this action the bank sets the flood insurance status of all houses it owns (houses with status bank owned) to true. Output of this action is a flood insurance status that is set to true for all bank owned houses.

• **Bank maintain houses**: Input for this action are an annual fee lists (houses) and a house status (houses). The sum of all annual fee lists of houses that are bank owned will be deducted form the bank assets. Output of this action is an adjusted bank assets value.

**Insurer formalization**

**Insurer has**

• **Insurer assets**: Floating point

  The insurer assets show if the insurer is making or loosing money by providing flood insurances. Because of this it can be represented by any value, positive or negative.

• **Initial flood insurance excess percentage**: 1% can be represented by a value of 0.01 in the model

• **Flood excess increase because of flooding**: 1/3 can be represented by a value of 0.33 in the model
• **Expected average annual loss**: Floating point $\geq 0$

The expected average annual loss of the insurer can be represented by a value higher or equal to 0. Ranging from no houses in danger (0) to many houses in large danger.

• **Current loss ratio**: Floating point $\geq 0$

The current loss ratio can be represented by a value higher or equal to 0. A value of 0 would mean the insurer did not have to pay any compensation (so no flood). When there is a flood event, a value from 0 to 1 would mean the insurer has to pay less in compensations than that they get from premium incomes. A value of 1 would mean that the insurer would pay all money that comes in on pay-outs. A value above 1 will mean the insurer loses money since he has to pay more on compensation than he gets in from premiums.

• **Maximum acceptable loss ratio**: A fraction of 0.6 can be represented by a value of 0.6 in the model

• **Base flood insurance premium**: 50 pounds can be represented by a value of 50 in the model

**Insurer does**

• **Process insurer**: In this action the insurer is asked to run the following insurer actions: compensate policy holders, calculate current loss ratio and adjust insurer assets.

• **Set flood insurance premium and excess**: Input for this action are house states (houses), a flood insurance status (houses), a flood insurance excess percentage (houses), the flood excess increase because of flooding (insurer), the protection level (houses), the expected average annual loss (insurer), the base flood insurance premium (insurer), the maximum acceptable loss ratio (insurer) and a flood risk (houses). In this action all houses that are not in construction, are flood insured and are hit by a flood this year, are asked to increase their flood insurance excess percentage by the value of flood excess increase because of flooding. For all houses that have installed protection last year the flood insurance excess percentage will be lowered with the new protection level of the house. The flood insurance excess of a house is set to the insured value (building value of house) times the flood insurance excess percentage. After this the insurer calculates its expected average annual loss (calculate expected average annual loss action of insurer). Based on
this value the insurer calculates an average flood risk of houses that are in flood risk (expected average annual loss / number of houses with flood insurance and a flood risk that is higher than 0). The insurer also calculates its average added insurance premium of flood risk houses ((expected average annual loss - (base flood insurance premium * number of flood insured houses) / (maximum acceptable loss ratio)). This is the average premium that will be added to the flood insurance premium of a house in flood risk, on top of the base flood insurance premium. House set their flood insurance premium equal to the base flood insurance premium plus the average added insurance premium of the insurer times the flood risk proportionality of the house (flood risk of the house / average flood risk of flood risk houses). Because the flood risk of non flood risk houses is 0, their proportionality will also be 0 and their insurance premium will be equal to the base premium value. Output of this action are a flood insurance premium and flood insurance excess value set for all insured houses.

- **Calculate expected average annual loss**: Input of this action are flood insurance status (houses), flood damage lists (houses) and flood insurance excesses (houses). In this action the values in the flood damage lists of houses get subtracted with the flood insurance excess of the house. If the flood damage is still higher than 0 after this (damage is higher than excess amount) it gets added to the expected average annual loss of the insurer. This is done for all houses in the model that are flood insured. Output of this action is an expected average annual loss value or the insurer.

- **Compensate policy holders**: Input for this action are a flood insurance status (houses), a flood repair fee (houses) and a flood insurance excess (houses). If a house is flood insured the compensation amount for this house will be set to the flood repair fee of the house minus the flood insurance excess of the house. Output of this action is a compensation amount for all flood insured houses.

- **Calculate current loss ratio**: Input for this action are flood insurance premiums (houses), flood insurance status (houses) and the compensation amounts (houses). In this action the current loss ratio is a calculated by taking the total premium incomes (sum of all flood insurance premiums of flood insured houses) and dividing it by the total compensation payouts (sum of compensation amounts of flood insured houses). Output of this action is a value for the current loss ratio of the insurer, the total premium incomes and the total compensation payouts.
• **Adjust insurer assets**: Input for this action are the insurer assets, the total premium incomes and the total compensation payouts (calculated in the calculate current loss ratio action). In this action the insurer assets get adjusted by adding the total premium incomes to it and deducting the total compensation amounts from it. Output of this action is an adjusted insurer assets value.

**Local government formalization**

**Local government has**

• **Local government assets**: Floating point

  The local government has a certain amount of assets to build flood defences from. Because they can go on debt to give out grants the local government assets are a floating point that can go either way.

• **Percentage of land sales used for flood investments**: 0.05% can be represented by a value of 0.0005 in the model

• **Percentage of property taxes used for flood investments**: 0.05% can be represented by a value of 0.0005 in the model

• **Maximum fraction of value at risk**: a fraction of 0.45 can be represented by a value of 0.45 in the model

• **Number of projects in flood defence portfolio**: 10 projects can be represented by a value of 10 in the model

• **Minimum houses in flood defence project**: a minimum of 100 can be represented by a value of 100 in the model

• **Flood defence portfolio (new)**: a list of integer, floating point combinations

  The flood defence portfolio can be represented by a list of housing selections (integers) with benefit cost ratio’s linked to it (floating points)

• **Wanted benefit-cost ratio**: a ratio of 5 can be represented by a value of 5 in the model

• **Maximum flood risk**: floating point => 0

  Can be represented by a floating point equal or larger then 0, the maximum flood risk can not be negative.

• **Development approval ratio**: a ratio of 1 can be represented by a value of 1 in the model
• **Development proposal status?**: Boolean
  
  Represented as a boolean. Set to true if the developer send a development proposal to the local government to be approved. Set to false otherwise.

**Local government does**

- **Process local government**: In this action the local government is asked to perform the 3 task specified below here; collect property taxes, collect flood protection investment and decide on building flood defences. Output of this action is the local government that performs actions

- **Collect property taxes**: Input for this action are property taxes (houses) and the percentage of property taxes used for flood investments (local government). In this action the sum of all property taxes of houses times the percentage of property taxes used for flood investments gets added to the local government assets. Output of this action is an adjusted local government assets value.

- **Collect flood protection investment**: Input for this action is the flood protection budget (environment). In this action the flood protection budget gets added to the local government assets. Output of this action is an adjusted local government assets value.

- **Decide on building flood defences**: Input for this action are building values (houses), flood damage lists (houses), the maximum fraction of value at risk (local government), the local government assets (local government), the minimum houses in flood defence project (local government) and the cost of flood defences (environment). In this action the local government will decide to build flood defences (perform build flood defences action of local government) if the fraction of value at risk (which is equal to the total value at risk (sum of building values of all houses hit by a 1 in 200 year flood (item 3 of flood damage list > 0)) divided by the total value (sum of building values of all houses in the model)) is higher than the maximum fraction of value at risk and the local government can afford a flood defence project (local government assets is larger than the minimum houses in flood defence project times the cost of flood defences). Output of this action is a decision of the local government if they will or will not build flood defences this year.

- **Build flood defences**: Input for this action are the number of projects in flood defence portfolio (local government), the minimum houses in flood defence
project (local government), the local government assets (local government), the
wanted benefit-cost ratio (local government), flood risks (houses), flood repair lists
(houses), the cost of flood defences (environment) and the flood defence investment
flood protection benefit (environment). In this action the local government per-
forms the following algorithm an amount of times equal to the number of projects
in flood defence portfolio to set up a portfolio of flood defence project from which
they can choose:
The local government selects the house in its municipality with the highest flood
risk for which no flood defences are built and that is not already chosen in a al-
ready made flood defence project selection. It than selects a number of houses
equal to the minimum houses in flood defence project around the house, and for
these houses the local government will calculated the benefit-cost ratio for build-
ing flood defences for this house. Project benefit = sum of flood repair lists of
selected houses - sum of flood repair lists of selected houses with flood protection
of houses increased with a flood defence investment flood protection benefit per-
centage. Project cost = cost of flood defences times the number of selected houses.
If the benefit divided by the cost is equal or higher then the wanted benefit-cost
ratio and the local government assets are higher than the project cost, the local
government will select 10 extra houses (that have no flood defences already build
and were not selected yet this year) and do the same calculation again but now
for the new housing selection. It will repeat this till a set of houses is found for
when a the next 10 houses are added the local government assets will be too low
or the benefit-cost ratio will get too low. It repeats this procedure an amount of
times equal to the number of projects in flood defence portfolio, to set up this
much projects.
This list will be sorted from highest to lowest benefit-cost ratio. the project with
the highest benefit-cost ratio is build first. With the remaining assets that are
left after this more project are tried to be build, starting with the one with the
second highest benefit-cost ratio, going down the list. For the houses that have
been selected in project that are built the flood protection level is increased by the
flood defence investment flood protection benefit and the local government will
lower it’s assets with the cost of all projects that are chosen to be build. Output of
this action is a changed flood protection level for a set of houses and an adjusted
local government asset value.
Evaluate development proposals: Input for this action is the development proposal status (local government), the local government assets (local government), the proposed land value (developer), the percentage of land sales used for flood investments (local government), the proposed flood risk (developer), the maximum flood risk (local government), flood damage lists (houses), the proposed building value (developer), the proposed property tax fee (developer) and the development approval ratio (local government). In this action the local government will decide on approving a development proposal of the developer, if the developer asked them to do that (development proposal status = true). A development proposal will be approved in 75% of the cases without a specific reason. Otherwise the development proposal will be approved if the proposed flood risk of the development is lower than the maximum flood risk. If this is also not the case the development proposal can still be approved if the development value at risk (proposed building value if the house will be hit by a 1 in 200 year flood) divided by the development income (proposed land value + proposed tax fee) is lower than the development approval ratio. When a development proposal is approved the proposed land value times the percentage of land sales used for flood investments will be added to the local government assets (they sell the land to the developer) and the local government will ask the developer to set its development approval status to true. Output of this action is an adjusted local government assets and a development approval status of the developer that is either set to true or false.

Developer formalization

Developer has

- **Developer assets** Floating point
  The developer assets show if the insurer is making or loosing money by developing housing projects. Because of this it can be represented by any value, positive or negative.

- **Proposed land**: patch with x and y coordinate
  The proposed land will be represented by a patch in the model. On this patch the proposed house will be build.

- **Proposed house type**: Integer equal to 0, 1, 2 or 3
  Based on the 4 house types as presented in the Jenkins model, a proposed house
Appendix D Detailed model creation

can have a house type that is equal to the numbers 0 (detached), 1 (semi-detached), 2 (terraced) or 3 (flats)

- **Proposed house value**: Floating point $\geq 0$
  A proposed house value can be represented by a value that will always be higher or equal to 0. The proposed house can not have a negative value.

- **Proposed land value**: Floating point $\geq 0$
  The value for proposed land can be represented by a value of 0 (proposed land has no value) or higher. Proposed land can not have a negative value.

- **Proposed building value**: Floating point $\geq 0$
  A proposed building value can be represented by a value that will always be higher or equal to 0. The proposed building can not have a negative value.

- **Proposed council tax band** (New): string equal to "A", "B", "C", "D", "E", "F", "G" or "H"
  The house can be placed in one of the 8 council tax bands, A, B, C, D, E, F, G or H

- **Proposed property tax fee** (New): Floating point equal to 880.32, 1027.04, 1173.76, 1320.48, 1613.92, 1907.36, 2200.80 or 2640.96
  The amount of property taxes that has to be paid on the house can be represented by a set of 8 floating points that are linked to the 8 council tax bands a house can be placed in.

- **Proposed flood risk**: Floating point $\geq 0$
  When a proposed house will not be hit by any of the modelled floods, the proposed flood risk will be 0. If 1 or more of the modelled floods can hit it the proposed flood risk will be greater than 0.

- **Income-cost ratio for development**: a ratio of 1.2 can be represented by a value of 1.2 in the model

- **Development approval status?**: Boolean
  Represented as a boolean. Set to true if the local government approved the development proposal of the developer. Set to false otherwise.

- **Build time**: a build time of 1 year can be represented by a value of 1 in the model

**Developer does**

- **Process developer**: Input for this action are flood risks (houses), flood damage lists (houses), person states (persons) and house states (houses). In this action the local government first sets a value for its maximum flood risk state. The
maximum flood risk is equal to the sum of flood risk of houses that will be hit by a 1 in 100 flood (this item in the flood damage list is bigger than 0) divided by the sum of houses being hit by a 1 in 100 flood. Output of this action is the local government that performs actions and sets a value for its maximum flood risk. After this the developer sets number of houses it will want to build this year. This is equal to the number of persons that are labelled homebuyer minus the number of houses that are labelled in construction or developer-owned. For this number of times the developer will run the following four actions; locate land for development, decide to create development proposal, ask the local government to evaluate a development proposal (Evaluate development proposals action of local government) and develop housing. After these action are performed the number of times equal to the number of houses the developer wanted to build, the developer will run the finish house construction, developer flood insurance set and developer maintain house actions. Output of this action is a value set for the maximum flood risk of the local government and the developer that will perform all actions it has for the number of times that is set in this action.

- **Locate land for development**: Input for this action are the highlighted opportunity areas in the GIS data, the locations of other houses (houses) and house values (houses). In this action all available patches on which the developer can build will be selected and the developer will choose one of these patches to build on. The available patches are all patches within the highlighted opportunity areas that have no house on them. The developer will choose the patch with the highest surrounding value (as set in the setup of the developer) and set it as the proposed land to develop a house on. Output of this action is a patch that is set as the proposed land.

- **Decide to create development proposal**: Input for this action is the proposed land (developer), possible house types (houses), the land value percentage (environment), the average values of house types (environment), the income-cost ratio for development (developer) and the development proposal status (local government). In this action the needed values for the proposed house are set. The first state that needs to be assigned is the type of houses that will be build. As already mentioned a new way need to be created to set house types for development, seeing initially house types were set based on GIS data. The following algorithm is created to select the house type the developer proposed: The proposed house
type will first tried to be set based on the house types of houses surrounding the location where the house will be build. If in a radius of 20 patches of land (houses next to each other are 2 patches of land apart from each other) there are more then 10 houses of which more then 50% are the same house type, the house type of the proposed house will be set to this house type. If this is not the case the house type will be set based on the initial distribution of house types as set in the GIS data. For Camden this distribution is: 10% detached, 14% semi-detached, 55% terraced and 21% flats. Based on this house type the proposed house value of the house is set. Based on this house value the proposed land value is set equal to the house value times the land value percentage. The proposed building value is set to the house value minus the proposed land value.

Just as with the selecting of the house type we run into a modelling limitation when assigning a council tax and flood damages to the house. For all initial houses there was data that showed in which council tax band the house should be placed and linked to this his property tax fee. There was also data on the damage flood would do to the house and linked to this the flood risk of a house. For newly build houses this data is not available and just as with house types a logical solution will have to be found for this. Because the council tax band is closely linked to the type of house, the council tax band will be assigned based on the house type. it will be done as follows:

⊙ If house type is flat, set council tax band random A or B
⊙ If house type is terraced, set council tax band random C or D
⊙ If house type is semi-detached, set council tax band random E or F
⊙ If house type is detached, set council tax band random G or H

Linked to the council tax band the property tax fee the house can be set in the same way this was done for initial houses.

Now the flood damages need to be set for each flood return period and on basis of this the flood risk of the house can be set. Because floods tend to approximately do the same damage to houses that are in the same area the flood damages of a new build house will be set to the average flood damages op the 10 houses surrounding it. This will mean however that if 1 house of the 10 takes damage on a flood, the proposed house will also take damage (only a tenth of the damage of that house seeing its the average over 10 houses, but the house will still show as flooded). For this reason the following is also assumed; a flood damage will only be set as
the average of the 10 surrounding houses if 5 or more of these houses get damages by the flood. If less than 5 houses would be hit by the selected flood, the flood damage is set to 0. This code is far from optimal for houses that are built far away from any other house, but unfortunately at this time there is no data available for these houses. Based on the set flood repair fees the flood risk of the house can be calculated in the same way the flood risk of an initial house is calculated, based on flood damages and probabilities.

Based on all these propose values the developer will decide if they want to actually build the development they are proposing. If the expected income of the development (proposed house value) is higher than the expected cost of development ((0.5 * building value) + proposed land value) times the income-cost ratio for development, the developer will decide positive on developing the proposed development and they will ask the local government to set their development proposal status to true, indicating that they have a proposal that needs to be evaluated (evaluate development proposals action of local government). Output of this action are values for the states; proposed land value, proposed house type, proposed house value, proposed land value, proposed building value, proposed council tax band, proposed property tax fee, proposed flood damage list, proposed flood risk and a development proposal status of the local government that is either set to true of false.

- **Develop housing**: Input for this action are the development approval status (developer), the proposed land (developer), the proposed house type (developer), the proposed land value (developer), the proposed building value (developer), the proposed council tax band (developer), the proposed property tax fee (developer), the proposed flood damage list (developer) and the proposed flood risk (developer). In this action a developer will develop a house when the development approval status was set to true from the evaluate development proposal action of the local government. It will create a house at the location of the proposed land in the model and it will assigned the house type as the proposed house type, the land value of the proposed land as the proposed land value, the building value as the proposed building value, etc., and will set the house status as in construction. Output of this action is a created house that has states assigned to it and is in construction.
• **Finish house construction**: Input for this action are house states (houses) and build years (houses). In this action houses that have been in construction for a year (build year is last year) have their state set from in construction to developer owned so that the developer can start selling the house. Output of this action are houses with a changed state.

• **Developer flood insurance set**: Input for this action is the assumption that the developer needs to take flood insurance for all its houses. In this action the developer sets the flood insurance status of all houses it owns (houses with status developer owned) to true. Output of this action is a flood insurance status that is set to true.

• **Developer maintain houses**: Input for this action are annual fee lists (houses) and house states (houses). The sum of all annual fee lists of houses that are developer owned will be deducted form the developer assets. Output of this action is an adjusted developer assets value.

### D.3.2 The future situation

Now that the conceptualization of the current situation is formalized, the conceptualization of the future situation can also be formalized.

**Environment formalization**

Environment has States

• **FloodRe assets**: Floating point

  The FloodRe assets show if the FloodRe system is making or loosing money during the model run. Because of this it can be represented by any value, positive or negative and will initially be set to 0.

• **FloodRe levy**: 2.2% can be represented by a value of 0.022 in the model

**House formalization**

Houses have States

• **Re-insured to FloodRe status?**: Boolean

  Represented as a boolean. Set to true if the insurer decided to re-insure this house into FloodRe Set to false if the insurer decided not to re-insure this house into FloodRe
• **FloodRe insurer cost**: integer equal to 210, 246, 276, 330, 408 or 540. The FloodRe insurer cost can be represented by a set of 6 integers that are linked to the 8 council tax bands a house can be placed in (council tax band A and B have a value of 210 and G and H a value of 560).

• **Compensation amount**: The formalization of this state does not change because FloodRe compensations are added to it now

**Insurer formalization**

**Insurer does**  
**Actions**

• **Set flood insurance premium and excess**: Added input to this action is a FloodRe levy (environment). For every person for which a flood insurance premium is set, an amount equal to the FloodRe levy times the persons flood insurance premium will be added to the FloodRe assets. After this the insurer will be asked to decide on re-insuring a house into FloodRe (see action below).

• **Decide on re-insuring in FloodRe**: Input for this action is a build year (houses), a flood insurance premium (houses), a FloodRe insurer cost (houses), the insurer assets (insurer) and the FloodRe assets (environment). In this action, if a house is build before 2009 and the flood insurance premium of a house is higher than the FloodRe insurer cost of the house, the insurer will decide on re-insuring that house into FloodRe (setting Re-insured to FloodRe status to true for that house). If a house is re-insured into FloodRe its insurance premium will be set equal to the FloodRe insurer cost. The FloodRe insurer costs are deducted from the insurer assets, seeing they have to pay this to the FloodRe system for re-insuring one of their policy holders. The FloodRe assets get increased with the FloodRe insurer cost. Output of this action are houses that will be re-insured in FloodRe and an adjusted flood insurance premium for these houses. Also the value of the insurer assets and FloodRe assets are adjusted.

• **Compensate policy holders**: Added input to this action is a re-insured to FloodRe status (houses). If a house is re-insured into FloodRe the compensation amount that is calculated within this action will be deducted from the FloodRe assets and not the insurer assets. Changed output of this action is a possible adjusted FloodRe assets value.
• **Calculate current loss ratio:** In this action the total compensation payout for the insurer are calculated on the basis of which the current loss ratio is calculated. With the adding in of the FloodRe system the total compensation payout will be calculated as follows: \((\text{sum of compensation amounts of flood insured houses that are not re-insured to FloodRe}) \text{ plus } (\text{the sum of FloodRe insurer cost or all houses that are re-insured in FloodRe})\).

### Developer formalization

**Developer does**  
**Actions**

- **Decide to create development proposal:** No new input is needed. The developer just has to set the proposed FloodRe insurer cost of the proposed house based on the proposed council tax band he just assigned.

### D.4 Step 4: Model formalization

The steps up till now have showed the ‘what’ and ‘who’ of the model. This step will focus on the ‘who does what and when’ question. This will be done by first getting clear what assumptions are made to set up a representative model. After this a the concept formalization of the previous step will be translated into a model formalization in the form of a ‘model narrative’. The model narrative tells the ‘story’ of how the agents behaviour will be modelled. With this the model conceptualization will again be made more precise for it to be implemented in an actual modelling program (Netlogo).

Just as in the previous step a distinction will be made between the current situation and the future situation.

### D.4.1 The current situation

First the assumption and the model narrative of the current situation will be created.

**Assumptions**

All assumption mentioned here below are already mentioned in the conceptualisation above of the states, actions and interaction of the environment and the agents. They are mentioned here again in simplified form to get a clear overview of all assumption that were made to create a representative model of an UK housing market in an area prone to flooding.
Environment assumption

- Land/houses are not influenced by a change in flood risk of surrounding land/houses. The developer building houses has no influence on the flood patterns in the rest of the model D.2.4
- The double auction market of Putra properly represents the behaviour of a housing market in the UK D.2.1
- The market is run separately for the developer, persons and bank D.2.4
- Homebuyers will first try to buy houses from the developer before buying from private sellers and the bank D.2.4
- The market is run for each house type separately, starting with most expensive houses; detached houses, before running it for the semi-detached, terraced and flat house types. D.2.4
- The developer market is run the same way as the bank market D.2.4
- The value of a house won’t directly be affected by being hit by a flood D.2.4

Person-agent assumption

- It is compulsory for persons to take flood insurance for their house D.2.4
- It is impossible for persons to take voluntary higher excesses on their flood insurance for a lower premium D.2.4
- If the flood damage to a persons house is higher than half of the total amount of income he can spend on housing fees, the person will not be able to afford repairing his house and the flood damage will be deducted form the house value D.2.4
- Homebuyers select a house to buy only on the criteria that it is the most expensive house they can afford given their income D.2.4
- Persons that have to foreclose on their house will leave the model D.2.4
- Persons that sell their house on the market will stay in the model to buy a new house D.2.4
- 10% of all persons in the model would think about selling their house for profit D.3.1
- The income of persons will be increased by the inflation percentage every year. The inflation percentage is for everyone the same and will stay the same over the years D.2.4
- Most homeowners will decide on a reactive basis, after they have been hit by a flood, to invest in PLPMs D.2.4
Because reactive persons can get a grant to invest in PLPMs it is assumed all reactive persons that would act in any way after being hit by a flood, will invest in PLPMs D.2.4

PLPMs are a one-off investment. When a person decides to invest in it he will buy the whole package and won't buy any more PLPMs for the remainder of time D.2.4

House-agent assumption

- All houses in the model are houses for sale. House renting is not modelled D.2.4
- The following house fees; property tax fee, house ageing repair fee, flood insurance premium and flood repair fees, are recalculated every year D.2.4
- Investing in flood defences and PLPMs increases the flood protection level of a house which decreases the flood repair fee of every flood return period of the house by a percentage equal to the flood protection level D.2.4
- For calculating the flood risk a house is in the maximum damage a flood will do to a house is set to 20% of its building value M

Bank-agent assumption

- Only a single bank agent will be modelled D.1.2
- The assets of the bank are unlimited and have no influence on its behaviour D.2.4
- The bank sell the houses they foreclosed for market value and will not lower the asking price if the house will not sell D.2.4

Insurer-agent assumption

- An insurance market will not be modelled D.1.2
- Only a single insurer will be modelled D.1.2
- The technical flood insurance risk will be modelled, not the commercial flood insurance risk D.2.4
- Insurer will not have the option to deny people an insurance D.2.4
- Flood insurance excesses are a non-negotiable part of the offered insurance policy D.2.4
- The insurer looks at 10 years of flooding history to base the flood insurance excess percentage of a house on D.2.4
- The insurer will never go bankrupt and leave the model D.2.4
• Interests gained on assets will not be taken into account for the setting of insurance policies by the insurer D.2.4

Local government-agent assumption
• Only a single local government will be modelled that governs over the whole modelled area D.1.2
• All land in the model without a house on it belongs to the local government D.2.4
• The local government will never go in debt to build flood defences. They can however go in debt giving out grants for PLPM investments D.2.4
• All money that the local government receives can be spent on investing in flood defences and giving out grants for PLPMs D.2.4
• The local government decides on building flood defences in a proactive way D.2.4
• The local government will give a PLPM grant to everyone that asks, and will use the remainder of its assets to invest in flood defences. D.2.4
• The benefit of building flood defences is equal to the total damage reduction to all houses in the area that result from the increased flood protection level (calculated over all flood return periods) D.2.4
• Just as PLPMs, flood defences are assumed to be a one-off investment. When the local government has invested in flood defences for a house it won’t do so again D.2.4
• The approving of development proposals only depends on the flood risk and the financial values of the given development proposal D.2.4
• Each development proposal will be judged on a house-by-house basis D.2.4

Developer-agent assumption
• Only a single developer will be modelled D.1.2
• The development of housing has no effect for the flood risk of surrounding houses D.2.4
• Developments will be proposed and built on a house-by-house basis D.2.4
• The developer will try to develop houses every year D.2.4
• The developer will try to develop the same amount of as there is a demand for in the market D.2.4
• The developer do not account for flood risk when searching land to build houses on D.2.4
• The choice in land for development only depend on economic considerations. The land with the highest profit estimation will be chosen to build a house on D.2.4
• The type of house the developer builds is based on on the types of houses surrounding the location the proposed house will be build, or by following the distribution of house types in the municipality D.3.1
• The council tax band the house the developer builds is placed in depends only on the proposed house type D.3.1
• The damages floods do to the developer house when it is done building are set based on the flood damages of the surrounding houses D.3.1
• A decision to developing housing only depends on the calculated profit it makes, not on the amount of assets the developer has D.2.4
• Cost of building a house is equal to half the building value of the house when it is finished D.2.4
• 50% of all new build houses will be build with flood defences already in place J
• The developer will expect to take a year on average to sell the house they created D.2.4
• The developer will not include PLPMs in the houses they build D.2.4
• The developer will not account for its development proposal history D.2.4
• Houses that are being constructed will not be influenced by flooding D.2.4
• The developer sell the houses they have built for market value and will not lower the asking price if the house will not sell D.2.4

Model narrative

A narrative is "an account of a series of events, facts, etc., given in an order and with establishing connection between them" (Oxford English dictionary). For an agent-based model, the behaviour of each of the agents can be captured in a story which explains which agent does what with whom and when [van Dam, et al., 2012].

The model narrative (story) will be told in the form of bullet points. First it will show how the model will be set up. It will do this by showing which values the environment and all agents in the model will set initially. After this the story of what will happen when the model runs will be told. If at any point an agent calls upon an action (of himself or another agent) in the model narrative, it will be shown to which agent the action is linked in italic, like this (persons action). Every time extra explanation is wanted in
the model narrative it will be presented in the **colour orange**. All state changes will be shown in **bold**.

All states and action in the model narrative are written with lines in between them (process-person). This is done because the model narrative forms that last link between the conceptualization and the actual implementation in the modelling program. In the modelling program spaces can’t be used within names of states and actions. For that reason all states and action in the modelling program are named without spaces (processPerson). To search a state or action from the model narrative in the model code, one must simply delete all - in the name. To search for a state or action from the model narrative in the conceptualization above, one must simply put spaces on all positions where there are -.

**Order of actions in the model run** The order the model is run can be split up in a setup and a go section.

**Setup**
In the setup the most important question for the run order is which agent uses input values set by other agents. The environment, insurer, bank and local government only set up their own states with the help of data input. Houses need input from the environment and the insurer. Persons need input from the environment and houses. And the developer needs input from the environment. Taking this together this gives the following run order for the setup

- Setup environment
- Setup insurer
- Setup houses
- Setup persons
- Setup bank
- Setup local government
- Setup developer

**Go**
The go procedure is a bit more complex than the setup procedure and will be explained point by point.

- First the **flood event** action of the environment will be run. This is done first because it provides information on flooding in the current year that is used by all agents
• After this the **process house** action of houses will be run because in this action houses gather and compute data that is used by the persons in the model. Within the action of processing houses the following actions are also run:
  ⊗ Calculate flood risk (house action)
  ⊗ Set flood insurance premium and excess (insurer action)
    ⋆ Calculate expected average annual loss (insurer action)
  ⊗ House flood repair (house action)

• After the houses are processed, the **process person** action of persons will be run. This is run after the houses are processed because this action gives needed information to persons on their house. It is run at this point in the model because it needs to be run before the markets are run because in this action persons gather an compute data that is needed within this market running. Within the action of processing persons the following actions are also run:
  ⊗ Setup general person states (person action)
  ⊗ Decide on house selling (person action)
    ⋆ House bank sell (person action)
    ⋆ House market sell (person action)
  ⊗ Invest in PLPMs (person action)
  ⊗ Inflation correction (person action)

• After the persons are processed the **process insurer** action of the insurer will be run. This is done after the processing of persons because hey need data coming from persons. It is run at this point in the model because new insurer information needs to be clear before the markets are run. Within the action of processing the insurer the following actions are also run:
  ⊗ Compensate policy holders (insurer action)
  ⊗ Calculate current loss ratio (insurer action)
  ⊗ Adjust insurer assets (insurer action)

• Now that the houses, persons and insurer have gathered and computed all needed data the **process market** action of the environment can be run. Within the action of processing the market the following actions are also run:
  ⊗ Developer market run (environment action)
    ⋆ Set maximum affordable house price (person action)
    ⋆ House dispossess (houses action)
    ⋆ House enter (person action)
Person flood insurance set (person action)
Set mortgage fee (house action)
Land value update (environment action)

Person market run (environment action)
Set maximum affordable house price (person action)
House dispossess (houses action)
House enter (person action)
Person flood insurance set (person action)
Set mortgage fee (house action)
Land value update (environment action)

Bank market run (environment action)
Set maximum affordable house price (person action)
House dispossess (houses action)
House enter (person action)
Person flood insurance set (person action)
Set mortgage fee (house action)
Land value update (environment action)
Bank flood insurance set (bank action)
Bank maintain houses (bank action)

Building value update (environment action)

Now that the market is run the **process bank** action of the bank can be run. This needs to be done after the market because the bank needs to process the houses it just bought on the market. Within the action of processing the bank the following actions are run:

- Bank flood insurance set
- Bank maintain house

With the running of the market all action of the environment, persons, houses, the bank and the insurer are run. Now the local government and developer still needs to be run. Because these are more supportive agents of the behaviour of especially persons, the moment at which they are run is not very important. The choice is made to have them run after everything else is run so that especially the developer can act upon what happened in the running of the market in determining how much houses it will want to develop. The **process developer** action of the developer will first be run so that the local government can play into the developing of houses by
the developer. Within the action of processing the developer the following actions are also run:

⊙ Locate land for development (developer action)
⊙ Decide to create development proposal (developer action)
⊙ Evaluate development proposal (local government action)
⊙ Develop housing (developer action)
⊙ Finish house construction (developer action)
⊙ Developer flood insurance set (developer action)
⊙ Developer maintain houses (developer action)

• After the developer is processed the process local government action will be run. It is best to run this after the developer processing because in this action the local government has an income of assets (form land selling) that it now can use for flood defence building. Also the local government can react to the houses the developer has finished constructing this year when building flood defences. Within the action of processing the local government the following actions are also run:

⊙ Collect property taxes (local government action)
⊙ Collect flood protection Investment (local government action)
⊙ Decide on building flood defences (local government action)
☆ Build flood defences (local government action)

Model setup

Setup environment

• Set percentage-of-houses-for-sale-at-the-start 0.023
• Set mortgage-interest to 0.03
• Set mortgage-term to 25
• Set average-flat-value to 729400
• Set average-terraced-value 1327277
• Set average-semi-detached-value to 1750790
• Set average-detached-value to 2365034
• Set owner-warning-time to 3
• Set number-of-trade-actions to 30
• Set housing-ratio-increase to 0.05
• Set average-number-of-incomes-as-down-payment to 3.05
Appendix D Detailed model creation

- Set average-percentage-sell-price 0.25
- Set average-profit-percentage 0.10
- Set land-value-percentage 0.5
- Set flood-return-period-probabilities to a list of probabilities: 1, 0.033, 0.01 and 0.005
- Set immigration-percentage 0.047
- Set percentage-of-movers 0.027
- Set flood-risk-consider-probability to 0.57
- Set no-selling-decrease-value-percentage to 0.25
- Set inflation-percentage to 0.039
- Set percentage-of-proactive-PLPM-investors to 0.01
- Set percentage-of-reactive-PLPM-investors to 0.34
- Set PLPM-investment-flood-protection-benefit to 0.75
- Set flood-protection-budget to 220200
- Set cost-of-flood-defences to 2000
- Set flood-defence-investment-flood-protection-benefit to 0.5

**Setup persons**

- Create (percentage-of-houses-for-sale-at-the-start * the number of houses) person agents
  - Ask each created person
    - Move to one of the houses that has no person assigned to it yet
    - House-enter (*person action*)
    - Setup-general-person-states (*person action*)
    - House-market-sell (*person action*)
- Create (number of houses that has no person assigned to it yet) person agents
  - Ask each created person
    - Move to one of the houses that has no person assigned to it yet
    - House-enter (*person action*)
    - Setup-general-person-states (*person action*)

**Setup houses**

- Create 1 house agent on each location specified in GIS data
- Ask each created house
Appendix D Detailed model creation

⊙ Set house-type to 0, 1, 2 or 3 based on GIS data
  ★ If house type = 0 (detached)
    * Set house-value based on a normal distribution over the average-detached-value with a standard deviation of 0.05 * average-detached-value
    * Set building-value to house-value * (1 - land-value-percentage)
    * Set land-value of the patch under the house to house-value - building-value
  ★ If house type = 1 (semi-detached)
    * Set house-value based on a normal distribution over the average-semi-detached-value with a standard deviation of 0.05 * average-semi-detached-value
    * Set building-value to house-value * (1 - land-value-percentage)
    * Set land-value of the patch under the house to house-value - building-value
  ★ And the same is done for house type = 2 (terraced) and house type = 3 (flats)

• Set build-year based on GIS data
• Set an average house income and income standard deviation based on GIS data
• Set flood-damage-list based on GIS data
• Set flood-damage-history-list based on GIS data and build year
  ⊙ Take a random start year in the flood event data set from GIS data
  ⊙ Set the flood-damage-history-list to 95 0’s → One for every year in history since the start of data on build years (1919) to now (2014)
  ⊙ Replace a 0 with a flood damage value for every year that is later than the build year of the house and the flood event data set gives a flood event
• Set flood-insurance-excess-percentage to the initial-flood-insurance-excess, increased with the flood-increase-because-of-flooding for every value higher than 0 in the last 10 items of the flood-history-list
• Set council-tax-band
  ⊙ Appendix N specified how much houses are placed in each tax band and in which order houses are placed in it; flats in lowest tax bands, up to detached in the highest
  ⊙ Select all houses with house-type = 3 (flats)
Appendix D Detailed model creation

- Assign flats in tax band A till all flat houses are assigned a tax band, or there are as much houses as specified placed in tax band A
- If all flats are assigned a tax band, move on to terraced houses
- If tax band A is full, move on to placing flats in tax band B
- continue this algorithm till all houses are assigned a tax band → At which point the last tax band should be full

- Set property-tax-fee according to council-tax-band
  - If council-tax-band of house = A, set property-tax-fee 880.32
  - If council-tax-band of house = B, set property-tax-fee 1027.04
  - ....
  - If council-tax-band of house = H, set property-tax-fee 2640.96

Setup banks
- Create 1 bank agent
- Ask the created bank
  - Set bank assets to 0

Setup insurer
- Create 1 insurer agent
- Ask the created insurer
  - Set insurer-assets to 0
  - Set initial-flood-insurance-excess-percentage to 0.01
  - Set flood-excess-increase-because-of-flooding to 0.33
  - Set current-loss-ratio to 0
  - Set maximum-acceptable-loss-ratio to 0.6
  - Set base-flood-insurance-premium to 50

Setup local government
- Create 1 local government agent
- Ask the created local government
  - Set local-government-assets to 0
  - Set percentage-of-land-sales-used-for-flood-investments to 0.0005
  - Set percentage-of-property-taxes-used-for-flood-investments to 0.0005
  - Set maximum-fraction-of-value-at-risk 0.45
Appendix D Detailed model creation

○ Set number-of-projects-in-flood-defence-portfolio 10
○ Set minimum-houses-in-flood-defence-project 100
○ Set wanted-benefit-cost-ratio to 5
○ Set development-approval-ratio to 1

Setup developer

• Create 1 developer agent

• Ask the created developer
  ○ Set developer-assets 0
  ○ Set income-cost-ratio-for-development to 1.2
  ○ Set build-time 1
  ○ Ask all patches that are in a GIS data specified opportunity area and do not belong to a house
    ⋆ set surrounding-value to sum of house-value of 10 closest houses

Running of the model

Environment does

Flood-event

• If number of ticks = half of total run time
  ○ set flood-return-period to chosen flood-return-period in interface

Process-market

• Run the following actions for each house type, starting with detached houses
  ○ set total houses on sale of the selected house type to number of houses with status developer-owned, person-on-market or bank-owned AND with house-type = selected house type
  ○ Developer-market-run for the selected house type (environment action)
  ○ Person-market-run for the selected house type (environment action)
  ○ Bank-market-run for the selected house type (environment action)
  ○ Set total houses sold of the set selected house type to total houses on sale - number of houses with status developer-owned, person-on-market or bank-owned AND with house-type = selected house type
  ○ Building-value-update for the selected house type (environment action)
• Repeat code above for the next house type (if coming from detached, this will be semi-detached)

Developer-market-run [market-house-type]
Repeat the code below for the amount of person with homebuyer? = true
• Set developer-houses to all houses with developer-owned? = true AND house-type = market-house-type
• If number of developer-houses = 0
  ○ Stop
• Else, ask one of persons with homebuyer? = true
  ○ Set-maximum-affordable-house-price (person action)
  ○ Set best-house to nobody
  ○ Repeat the code below for the number-of-trade-actions or the number of developer-houses, whichever number is smaller
    * Set current-house to one of developer-houses
    * If flood-risk-consideration-status? = false
      * If house-value of current-house < maximum-house-price AND > house-value of best-house
        ▶ Set current-house to best-house
    * If flood-risk-consideration-status? = true
      * If flood-damage-history of the current year > 0
        ▶ The person moves on to look at a next house
      * Else, if flood-damage-history of the previous year > 0 And a random number between 0 and 1 < 0.5
        ▶ The person moves on to look at a next house
      * Else, if flood-damage-history of 2 years ago > 0 And a random number between 0 and 1 < 0.25
        ▶ The person moves on to look at a next house
      * If house-value of current-house < maximum-house-price AND > house-value of best-house
        ▶ Set current-house to best-house
  ○ After the repetition of this code is done
    * If best-house ≠ nobody
      * Ask best-house to house-dispossess (house action)
Appendix D Detailed model creation

* House-enter (*person action*)
* Set transaction-price to house-value of best-house
* Land-value-update with the just set transaction-price (*environment action*)
* Ask developer to set developer-assets to (developer-assets + transaction-price)

Person-market-run [market-house-type]
- Set home-type-sellers to persons with home-seller? = true AND house-type of persons-house = market-house-type
- Set home-buyers to persons with homebuyer? = true
- Repeat the code below for the amount of home-type-sellers
  - Set traders to home-type-sellers + home-buyers \rightarrow Creates an agent set with in it all persons selling a house of the given house type and all home buyers wanting to buy a house
  - Repeat the code below for the number-of-trade-actions
    - Select one of traders
    - If homebuyer? = true
      - Set-maximum-affordable-house-price (*person action*)
      - Form a bid-price between the maximum-house-price and 0
      - Set best-ask to highest asking-price
      - If flood-risk-consideration-status? = true
        - If bid-price > best-ask
          - Run through the flood consideration algorithm that was also done in the developer market run D.4.1. If this gives no problems;
        - Ask house of agent with best-ask
          - Set house of best-ask to best-house
          - Ask best-house house-dispossess (*house action*)
          - House-enter (*person action*)
          - Set transaction-price to house-value of best-house
          - Land-value-update with the just set transaction-price (*environment action*)
        * If flood-risk-consideration-status? = true
          * If bid-price > best-ask
Appendix D Detailed model creation

- Set house of best-ask to best-house
- Ask best-house house-dispossess (house action)
- House-enter (person action)
- Set transaction-price to house-value of best-house
- Land-value-update with the just set transaction-price (environment action)

⊙ If home seller? = true
  ♠ Form an ask-price based on house-value of persons-house and all bids of homebuyers
  ♠ Set best-bid to highest bid-price
  ♠ If ask-price > best-bid
  ♠ Run through the flood consideration algorithm that was also done in the developer market run D.4.1. If this gives no problems;
    ♠ Ask persons-house house-dispossess (house action)
    ♠ Ask person with best-bid
      ▶ Set house of ask-price to best-house
      ▶ House-enter (person action)

Bank-market-run [market-house-type]

- Same as developer-market-run but then for houses with bank-owned? = true

Building-value-update [market-house-type]

- Sales-ratio = (total-houses-sold / total-houses-on-sale) - 0.25
- Ask all houses with the selected house type AND in-construction? = false
  ⊙ Set building-value (building-value + (sales-ratio * building-value))

Land-value-update

- Set new-transaction-value-total to (transaction-price + current-transaction-value-total → The total value of previous transaction of the current house type. So this is 0 for the first house of this house type that is being sold in the current year)
- Set current-transaction-value-total to new-transaction-value-total
- Set new-transaction-number to (1 + current-transaction-number → same idea)
- Set current-transaction-number to new-transaction-number
• Set average-transaction-price to \((\text{new-transaction-value-total} / \text{new-transaction-number})\)

• Set new-land-value to \((\text{average-transaction-price} - \text{building-value of persons-house})\)

• Set land-value of patch-here to new-land-value

**Persons do**

Setup-general-person-states

• If person is home-owners or home-sellers so an initially created person

  ⊙ Set income based on a normal distribution with income assigned by GIS data as average and the calculated standard deviation based on the upper and lower bound given by the GIS data as the standard deviation

  ⊙ Set mortgage-ratio to mortgage-fee / income

  ⊙ Set housing-ratio to mortgage-ratio + housing-ratio-increase

• If new created person (homebuyers)

  ⊙ Set income to income of random person in the model

  ⊙ Set mortgage-ratio to mortgage-ratio of random person in the model

  ⊙ Set housing-ratio to mortgage-ratio + housing-ratio increase

• Set number-of-incomes-as-down-payment based on normal distribution with average-number-of-incomes-as-down-payment and a standard deviation of average-number-of-incomes-as-down-payment * 0.05

• Set percentage-sell-price based on normal distribution with average-percentage-sell-price and a standard deviation of average-percentage-sell-price * 0.05

• Set profit-percentage based on normal distribution with average-profit-percentage and a standard deviation of average-profit-percentage * 0.05

• If a random floating point between 0 and 1 <= flood-risk-consider-probability

  ⊙ Set flood-risk-consideration-status? to true

  ⊙ Else, set flood-risk-consideration-status? to false

**Process-persons**

• Ask environment

  ⊙ Create number of persons equal to (immigration-percentage * number of houses)

  ⊙ Ask each created person

    ★ Set homebuyer? to true
Setup-general-person-states \textit{(person action)}

- Ask all persons
  - If homeowner? = true
    - Set annual-fee to the sum of the annual-fees-list of persons-house
  - Decide-on-house-selling \textit{(person action)}
  - Invest-in-PLPMs \textit{(person action)}
  - If home-seller? = true
    - Selling-time = amount of years the person tried to sell his house
    - If selling-time > 0
      - Set seller-ask-price \(((1 - \text{no-selling-decrease-value-percentage}) \times \text{seller-ask-price})\)
  - Inflation-correction \textit{(person action)}

\textbf{House-enter}

- Set homebuyer? false
- Set homeowner? true
- Set best-house to persons-house → The house a person moves into is always set as the best-house. By setting this as the persons-house he 'links' to the house
- Ask persons-house
  - Set houses-agent to person-here → The house also 'links' to the person that owns him by setting it as his houses-agent. If a bank or developer owns the house the houses-agent is the bank or the developer
  - Set house-value-at-buy to house-value
  - Set not-owned-yet? false
  - Set person-on-market? false
  - Set bank-owned? false
  - Set developer-owned? false
  - Set person-owned? true
  - Set-mortgage \textit{(house action)}
- Person-flood-insurance-set \textit{(person action)}

\textbf{Decide-on-house-selling}

- If housing-ratio * income <= annual-fee
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- warning-time = amount of years after each other the annual-fee has been higher than the housing-ratio * income
- If warning-time = owner-warning-time
  - House-bank-sell (person action)
  - If the persons lived in his house for more than 3 years AND the house-value of persons-house > \(((1 + Profit\text{-}percentage) \times \text{house-value-at-buy})\) AND the person is one of the 10% of persons that would sell hi house for profit
    - House-market-sell (person action)
  - If a random floating point between 0 and 1 < Percentage-of-movers
    - House-market-sell (person action)

House-bank-sell
- Set bank-price to (house-value of persons-house)
- Ask the persons house
  - Set person-owned? false
  - Set bank-owned? true
- ask bank
  - set bank assets to (bank assets - bank-price)
- Die

House-market-sell
- Set seller-ask-price to \((1 + \text{percentage-sell-price}) \times \text{house-value}\)
- Set homeowner? false
- Set home-seller? true
- Ask the persons house
  - Set person-owned? false
  - Set person-on-market? true

Set-maximum-affordable-house-price
- Set maximum-house-price to \(((\text{income} \times \text{mortgage-ratio}) \div (\text{mortgage-interest} \div (1 - (1 + \text{mortgage-interest})^{\text{mortgage-term}}))) + (\text{number-of-incomes-as-down-payment} \times \text{income})\)

Person-flood-insurance-set
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- Ask the persons-house
  - Set flood-insured? to true

Invest-in-PLPMs
- If PLPM-invested? of persons-house = false → true if PLPMs are already installed in the house
  - If flood-risk-consideration-status? = true
    - If a random number between 0 and 1 < percentage-of-proactive-PLPM-investors
      - If flood-protection-level > 0
        - Set flood-protection-level of person-house to (flood-protection-level + ((1-flood-protection-level) * PLPM-investment-flood-protection-benefit))
        - Set flood-protection-level (flood-protection-level + PLPM-investment-flood-protection-benefit)
      - Set PLPM-invested? to true
  - If flood-status? of previous year = true
    - If a random number between 0 and 1 < percentage of reactive PLPM investors
      - If flood-protection-level > 0
        - Set flood-protection-level of person-house to (flood-protection-level + ((1-flood-protection-level) * PLPM-investment-flood-protection-benefit))
        - Set flood-protection-level (flood-protection-level + PLPM-investment-flood-protection-benefit)
      - Set PLPM-invested? to true

Inflation-correction
- If the year the person entered the model = current year we are in
  - Set income (income * (1 + (year we are in * inflation-percentage)))
  - Else, set income (income * (1 + inflation-percentage))

Houses do
Set-mortgage-fee
• Set principle to (house-value - (number-of-incomes-as-down-payment * income of houses-agent))

• If principle > 0
  ⊗ Set mortgage-fee to (Principle * mortgage-interest / (1 - (1 + mortgage-interest)^mortgage-term)))
  ⊗ Add mortgage-fee to annual-fees-list
  ⊗ If this code is run in the setup of the model
    ★ Add a random integer between 0 and mortgage term to the fee-duration-list as duration for the mortgage-fee
    ★ Else, add mortgage term to the fee-duration-list as duration for the mortgage-fee

Process-house
• Ask house with in-construction? = false
  ⊗ If the house-value is different than the initial-house-value
    ★ For every item in the flood-damage-list
      ★ set new flood-damage-value to (flood-damage-value + (flood-damage-value * ((house-value - initial-house-value) / initial-house-value) * 0.1))
  ⊗ If flood protection was installed last year for he house → PLPMs or flood defences
    ★ For every item in the flood-damage-list
      ★ set new flood-damage-value to (flood-damage-value * (1 - flood-protection-level))
  ⊗ Calculate-flood-risk (house action)

• Decrease duration of every item in the fee-duration-list by 1

• If one of the items = 0
  ⊗ Delete corresponding value in annual-fee-list → Because it is assumed all fees (except for the mortgage-fee) have a duration of a year they will all have to be set every year

• Property-tax-fee
  ⊗ Add property-tax-fee to annual-fees-list
  ⊗ Add duration of 1 to fee-duration-list

• House-ageing-repair-fee = 0.01 * building-value of house
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⊙ Add house-ageing-repair-fee to annual-fees-list
⊙ Add duration of 1 to fee-duration-list

• If flood-insured? = true
  ⊙ Set flood-insurance-premium-and-excess (insurer action)

• House-flood-repair (house action)

Calculate flood-risk

• set flood-probability-X-axis to $(((1\text{-in-30-flood-probability} - 1\text{-in-100-flood-probability}) \times 1\text{-in-30-flood-damage}) / 1\text{-in-100-flood-damage}) + 1\text{-in-30-flood-probability}$

• set flood-risk-1 to $((\text{flood-probability-X-axis} - 1\text{-in-100-flood-probability}) \times ((0 \text{(damage on x-axis)} + 1\text{-in-100-flood-damage}) / 2))$

• set flood-risk-2 to $((1\text{-in-100-flood-probability} - 1\text{-in-200-flood-probability}) \times ((1\text{-in-100-flood-damage} + 1\text{-in-200-flood-damage}) / 2))$

• set flood-risk-3 to $((1\text{-in-200-flood-probability} - 0(\text{probability on y-axis})) \times ((1\text{-in-200-flood-damage} + ((0.2 \times (1 - \text{flood-protection-level})) \times \text{house-value of house}) / 2))$

• set flood-risk to flood-risk-1 + flood-risk-2 + flood-risk-3

House-flood-repair

• Set flood-repair-fee to the item in the flood-damage-list that corresponds with the flood-return-period that occurred

• If flood-insurance status? = true
  ⊙ Set flood-repair-fee to flood-insurance-excess

• If houses-agent = person
  ⊙ If $(0.5 \times \text{housing-ratio} \times \text{income of houses-agent}) => \text{flood-repair-fee}$
     * Add flood-repair-fee to annual-fees-list
     * Add duration of 1 to fee-duration-list
     * Else, set building-value to $(\text{building-value} - \text{flood-repair-fee})$

House-dispossess

• Ask houses-agent
  ⊙ Unlink form the house
  ⊙ Set home-seller? false
  ⊙ Set home-buyer? false
• Reset all house parameters

**Bank does**

**Process bank**

• Ask bank
  - Bank-flood-insurance-set (*Bank action*)
  - Bank-maintain-houses (*Bank action*)

**Bank-flood-insurance-set**

• Ask all houses with bank-owned? = true
  - Set flood-insurance-status? to true

**Bank-maintain-houses**

• Set total-maintenance-costs to sum of annual-fee-list of all houses with bank-owned? = true
• Set bank-assets to (bank-assets – total-maintenance-costs)

**Insurer does**

**Process insurer**

• Ask insurer
  - Compensate-policy-holders (*insurer action*)
  - Calculate -current-loss-ratio (*insurer action*)
  - Adjust-insurer-assets (*insurer action*)

**Set-flood-insurance-premium-and-excess**

• Ask houses with in-construction? = false
  - If flood-status? = true
    - Set flood-insurance-excess-percentage to (flood-insurance-excess-percentage + (flood-insurance-excess-percentage * flood excess increase because of flooding))
    - If flood protection installed last year
      - Set flood-insurance-excess-percentage to (flood-insurance-excess-percentage * (1 - protection-level))
      - Set insured-value to building value or 250.000, whichever is lower
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⋆ Set flood-insurance-excess to (flood-insurance-excess-percentage * insured-value)

• Ask insurer
  ⊙ Calculate-expected-average-annual-losses (insurer action)
  ⊙ Set average-flood-risk to (sum flood-risk of houses with flood insurance and flood-risk > 0 / number of houses with flood insurance and flood-risk > 0)
  ⊙ Set average-added-insurance-premium to (((expected-average-annual-loss of insurer - (base-flood-insurance-premium * number of houses with flood insurance and flood-risk > 0)) / maximum-acceptable-loss-ratio)

• Ask houses with in-construction? = false
  ⊙ Set flood-risk-proportionality of house to (flood-risk / average-flood-risk of insurer)
  ⊙ Set flood-insurance-premium of house to (base-flood-insurance-premium of insurer + (average-added-insurance-premium of insurer * flood-risk-proportionality of house))
  ⊙ Add Flood-insurance-premium to annual-fees-list
  ⊙ Add duration of 1 to fee-duration-list

Calculate-expected-average-annual-loss

• Ask houses with flood-insurance-status? = true
  ⊙ if item 1 flood-damage-list > flood-insurance-excess; add ((item 1 flood-damage-list - flood-insurance-excess) * item 1 flood-return-period-probabilities) to the expected-average-annual-loss of the insurer
  ⊙ if item 2 flood-damage-list > flood-insurance-excess; add ((item 2 flood-damage-list - flood-insurance-excess) * item 2 flood-return-period-probabilities) to the expected-average-annual-loss of the insurer
  ⊙ if item 3 flood-damage-list > flood-insurance-excess; add ((item 3 flood-damage-list - flood-insurance-excess) * item 3 flood-return-period-probabilities) to the expected-average-annual-loss of the insurer

Compensate-policy-holders

• Ask all houses with flood-insurance-status? = true
  ⊙ Set compensation-amount to (flood-repair-fee – flood-insurance-excess) →

Seeing there is no agent that actually receives the money for repairing houses,
the transfer of money will not be modelled. Insurers simply calculate how much compensation they have to pay out and houses just lower their flood repair fees by the compensated amount (leaving the excess amount).

Calculate-current-loss-ratio

- Current-loss-ratio = total-premium-incomes / total-compensation-pay-outs
  - Total-premium-incomes = sum of flood-insurance-premium of houses
  - Total-compensation-pay-outs = sum of compensation-amount of houses

Adjust-insurer-assets

- Set insurer-assets to (insurer assets + total-premium-incomes - total-compensation-pay-outs)

Local government does

Process local government

- Ask local government
  - Collect-property-taxes (insurer action)
  - Collect-flood-protection-investment (insurer action)
  - Decide-on-building-flood-defence (insurer action)
  - Set maximum-flood-risk
    - Select all houses that will be hit by a 1 in 100 year flood
    - Maximum-flood-risk = total flood-risk of selected houses / number of selected houses

Collect-property-taxes

- Total-property-taxes = sum of property-tax-fee of all houses
- Add total-property-taxes to local-government-assets

Collect-flood-protection-investment

- Add flood-protection-budget to local-government-assets

Decide-on-building-flood-defences

- Fraction-of-value-at-risk = total-value-at-risk / total-value
  - Total-value-at-risk = sum of building-value of all houses with flood-damage of a 1 in 200 year flood > 0 and flood-defence-build? = false
Total-value = sum of building-value of all houses

- If fraction-of-value-at-risk > maximum-fraction-of-value-at-risk
  - Build-flood-defences (*local government action*)

**Build-flood-defences**

- Repeat this code for the number-of-projects-in-flood-defence-portfolio
  - set initial-house to the house with the highest flood risk that has no flood defences build for it yet
  - set housing-selection to the initial-house + (minimum-houses-in-flood-defence-project - 1) houses closest to it
  - set benefit-cost-ratio
    - Set project-cost to (cost-of-flood-defences * number of houses in housing-selection) / item
    - Set benefit-cost-ratio to (project-benefit / project-cost)
  - Repeat the code below as long as the benefit-cost-ratio => wanted-benefit-cost-ratio AND local-government-assets => project-cost
    - Select the 10 houses closest to the initial-house that are not selected yet and have no flood defences build yet
    - Add these houses to the housing-selection
    - Set benefit-cost-ratio (same as above) for the new housing selection
  - If the housing selection is found where the cost becomes too high or the benefit-cost ratio goes under the wanted-benefit-cost-ratio; add housing selection and benefit-cost-ratio to flood-defence-portfolio

- Now that there are 10 project in the flood-defence-portfolio, sort it from highest to lowest benefit-cost-ratio
- And build the first project in the list
  - Set local-government-assets to (local-government-assets - project-cost)
  - Ask housing-selection
    - If flood-protection-level > 0
      - Set flood-protection-level of person-house to (flood-protection-level + ((1-flood-protection-level) * flood-defence-investment-flood-protection-benefit))
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* Set flood-protection-level (flood-protection-level + flood-defence-investment-flood-protection-benefit)

- After this look at the second project in the list. If local-government-assets => project-cost
  - Build the project (repeat what is done above)
  - Else, go to next project in the list and do the same and keep repeating this for all projects in the list

Evaluate-development-proposals

- Ask developer to set development-approval-status? to false
- If development-proposal-status? = true
  - Set approval-chance to a random floating point between 0 and 1
  - If approval-chance < 0.75
    - Add proposed-land-value of developer to local-government-assets
    - Set development-approval-status? to true
  - Else,
    - If flood-risk of proposed development < maximum-flood-risk
      - Add proposed-land-value of developer to local-government-assets
      - Set development-approval-status? to true
    - Else,
      - If the proposed house will be hit by a 1 in 200 year flood
        - Set development-value-at-risk to proposed-building-value
        - Else, set development-value-at-risk 0
      - Set development-income to (proposed property tax fee + land-value of proposed development)
      - If (development-value-at-risk / development-income) < development-approval-ratio
        - Add proposed-land-value of developer to local-government-assets
        - Set development-approval-status? to true
      - Else,
        - Nothing happens -> development-approval-status? stays false

Developer does

Process-developer
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- Set the demand for houses to \((\text{number of persons with homebuyer?} = \text{true}) - (\text{number of houses with in-construction?} = \text{true OR developer-owned?} = \text{true OR person-on-market?} = \text{true OR bank-owned?} = \text{true})\)

- For each house demanded
  - Locate-land-for-development (developer action)
  - Decide-to-create-development-proposal (developer action)
  - Ask local government to evaluate-development-proposal (local government action)
  - Develop-housing (developer action)
  - If in the actions above at some point it is decided not to build the house (not profitable, no approval from local government) the house will not be build but it will count as a demand fulfilment this year. This means fewer houses than the demand can be build by the developer.

- Finish-house-construction
- Developer-flood-insurance-set
- Developer-maintain-houses

**Locate-land-for-development**

- Set proposed-land to patch with highest surrounding-value \(\rightarrow\) as set in the setup of the developer

**Decide-to-create-development-proposal**

- Ask local government to set development-proposal-status? to false
- Set houses-to-look-at to all houses in a radius of 20
- If houses-to-look-at \(> 10\)
  - Repeat the code below for every house-type, starting with detached \((0)\)
    - If the number of selected type houses / houses-to-look-at \(> 0.5\) \(\rightarrow\) more then 50% of the houses surrounding it are houses of the house type currently selected
      - Set proposed-house-type to selected house type \(\rightarrow\) It will go through all house types and check for each if there are more then 50% of that type in the houses o look at (houses in radius 20). If there is, the proposed house type will beset to this house type
• If houses-to-look-at \( \leq 10 \) OR the code above has not given a house type because no house type was more then 50%
  ⊙ set a random value between 0 and 1
  ⊙ If this value is \( \leq 0.1 \), set proposed-house-type to detached
  ⊙ If this value is \( > 0.1 \) AND \( \leq 0.24 \), set proposed-house-type to semi-detached
  ⊙ If this value is \( > 0.24 \) AND \( \leq 0.79 \), set proposed-house-type to terraced
  ⊙ If this value is \( > 0.79 \), set proposed-house-type to flats
• Set proposed-house-value (normal distribution of initial-house-value linked to the set proposed-house-type)
• Set proposed-land-value to \( (\text{proposed-house-value} \times \text{land value percentage}) \)
• Set proposed-building-value to \( (\text{proposed-house-value} - \text{proposed-land-value}) \)
• If house-type = flats, set council-tax-band random A or B
• If house-type = terraced, set council-tax-band random C or D
• If house-type = semi-detached, set council-tax-band random E or F
• If house-type = detached, set council-tax-band random G or H
• Set proposed-property-tax-fee \( \rightarrow \) similar code as Set-property-tax-fee (house action), but now using the proposed values
• Set flood-damage-list
  ⊙ Set 10 closest house to nearest-neighbours
  ⊙ If 5 or more of these houses are in flood risk
    ∗ Set item 1 flood-damage-list to \( ((\text{sum of items 1 of flood-damage-lists of nearest-neighbours}) / (\text{number of the 10 neighbours that are in flood risk}) \)
    ∗ Set item 2 flood-damage-list to \( ((\text{sum of items 2 of flood-damage-lists of nearest-neighbours}) / \text{number of the 10 neighbours that are in flood risk}) \)
    ∗ Set item 3 flood-damage-list to \( ((\text{sum of items 3 of flood-damage-lists of nearest-neighbours}) / \text{number of the 10 neighbours that are in flood risk}) \)
• Set proposed-flood-risk \( \rightarrow \) similar code as Calculate-flood-risk (house action), but now using the proposed values
• Expected-income-of-development = proposed-building-value + proposed-land-value
• Expected-costs-of-development = \( 0.5 \times \text{proposed-building-value} + \text{proposed-land-value} \)
• If Expected-income-of-development > \( (\text{Expected-costs-of-development} \times \text{income-cost-ratio-for-development}) \)
⊙ Ask local government to set development-proposal-status? to true

Develop-housing

• If development-approval-status? = true
  ⊙ Create 1 house at location of the proposed-land
  ⊙ Ask the just created house
    ☆ Set house-type to proposed-house-type
    ☆ Set building-value to proposed-building-value
    ☆ Ask patch under the house to set land-value to proposed-land-value of developer
    ☆ Set council-tax-band to proposed-council-tax-band
    ☆ Set property-tax-fee to proposed-property-tax-fee
    ☆ Set flood-insurance-excess-percentage to initial-flood-insurance-excess-percentage
    ☆ Set flood-damage-list to proposed-flood-damage-list
    ☆ Set flood-risk to proposed-flood-risk
    ☆ Set in-construction? to true
    ☆ Set build-year to the number of years running (ticks) + start year (2014)

Finish-house-construction

• Ask houses with in-construction? = true AND that have a build year of 1 year ago
  ⊙ set in-construction? to false
  ⊙ set developer-owned? to true
  ⊙ set flood-damage-history-list to a list of (95 + the amount of year already run) 0’s → So that when searching in flood damage list the same place is in all other lists can be searched for to get the same year
  ⊙ for 50% of houses; set flood-protection-level (flood-protection-level + flood-defence-investment-flood-protection-benefit)

Developer-flood-insurance-set

• Ask all houses with developer-owned? = true
  ⊙ Set flood-insured? to true

Developer-maintain-houses
• Set total-annual-fees to sum of annual-fees-lists of all houses with developer-owned? = true
• Set developer-assets to (developer-assets – total-annual-fees)

D.4.2 The future situation

Now that the assumption and model narrative of the current situation are created, the assumptions and model narrative of the future situation can be created.

Assumptions

• FloodRe assets will initially be set to 0 D.2.5
• The FloodRe system making or loosing money has no effect on how the system behaves D.2.5
• The FloodRe levy will not be added to a persons annual fees D.2.5
• Insurers will not provide FloodRe information to third parties, meaning other agents do not get information about houses being re-insured in FloodRe D.2.5

Model narrative

The following states and action have to be added in the model narrative to include the FloodRe system in it

Model setup

Setup environment

• Set FloodRe-assets 0
• Set FloodRe-levy 0.022

Setup houses

• Ask all houses
  ○ If the council tax band is A, set FloodRe insurer cost to £210
  ○ If the council tax band is B, set FloodRe insurer cost to £210
  ○ If the council tax band is C, set FloodRe insurer cost to £246
  ○ If the council tax band is D, set FloodRe insurer cost to £276
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⊙ If the council tax band is E, set FloodRe insurer cost to £330
⊙ If the council tax band is F, set FloodRe insurer cost to £408
⊙ If the council tax band is G, set FloodRe insurer cost to £540
⊙ If the council tax band is H, set FloodRe insurer cost to £540

Running of the model

Insurer does

Set-flood-insurance-premium-and-excess
This has to be added at the end of the already created model narrative for this action

- Set FloodRe-assets (FloodRe-assets + (Flood-insurance-premium * FloodRe-levy))
- If FloodRe policy is turned on
  ⊙ Decide-on-re-insuring-in-FloodRe (insurer action)

Decide-on-re-insuring-in-FloodRe

- Set Re-insured-to-FloodRe-status? to false → every year the insurer will check all houses again if the need to be re-insured into FloodRe
- If build-year of a house is < 2009
  ⊙ If flood-insurance-premium > FloodRe-insurer-cost
     * Set Re-insured-to-FloodRe-status? to true
  ⊙ If Re-insured-to-FloodRe-status? = true
     * Set Flood-insurance-premium to FloodRe-insurer-cost
     * Ask insurer to set insurer-assets to (insurer-assets - FloodRe-insurer-cost)
     * Ask environment to set FloodRe-assets to (FloodRe-assets + FloodRe-insurer-cost)

Compensate-policy-holders
This has to be added at the end of the already created model narrative for this action

- If Re-insured-to-FloodRe? = true
  ⊙ Ask environment to set FloodRe-assets to (FloodRe-assets - compensation-amount)

Calculate-current-loss-ratio
Calculation of total-compensation-pay-outs changes to:
• Total-compensation-pay-outs = \( ((\text{sum of compensation-amount of houses with flood-insured = true AND Re-insured-to-FloodRe? = false}) + (\text{sum of FloodRe-insurer-cost of houses with Re-insured-to-FloodRe? = true}))\)

**Developer does** Because the developer needs to set all states of the house he is proposing, he will now also have to set a proposed FloodRe insuror cost.

**Develop-housing**
This has to be added to the already created model narrative for this action after the council tax band of the house is set

• Set-proposed-FloodRe-insurer-cost the same way it was set in the setup of houses

## D.5 Step 5: Software Implementation

In this step the created model conceptualization will be implemented in an actual modelling program; Netlogo. An advantage of using Netlogo as a modelling program is the interface it provides in which modelling parameters can be changed and scenarios can be chosen. It also shows the behaviour of the model in the viewing window. Two kinds of views can selected to see the behaviour of; the houses view and the persons view.

### D.5.1 Houses view

The houses view (figure D.3) can be seen as the Jenkins model view since it clearly shows the setup of the Jenkins model with house placements and different types of houses.

### D.5.2 Persons view

The persons view (figure D.4) can be seen as the Putra model view since it shows the persons that own, buy and sell houses.

### D.5.3 Graphs

Although the model view gives a nice representation of the model behaviour, no real behaviour on which an analysis can be based can be taken from it. To analyse the behaviour of the model under different FloodRe scenarios the data the model provides
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Figure D.3: Interface of the model - houses view

Figure D.4: Interface of the model - persons view
will have to be analysed. The graphs that are also presented in the model interface (figure D.5) give an idea of the output the model will give.

Although the graphs give a good idea of the model behaviour, this is not what the behaviour of the model will be researched. To good get data that can be research for pattern the model needs to be run many times. The raw data that comes from all these runs will be analysed using data analysis tools.
D.6 Step 6: model verification

Now that a working model is created the following question should be answered: did we correctly translate the conceptualisation into the model code? This verification step will make sure the model is created right. Using the verification step as presented in the book of [van Dam, et al., 2012] as a guide, the following 4 verification tests will be executed:

- Theoretical predictions and sanity checks
- Breaking the agent
- Variability testing
- Time line sanity

*Note: Due to computer limitation the verification is performed using the Bromley Borough model area. Because the model ran too slow for the Camden an Croydon model areas on the computers that were available the choice was made to do the verification based on the Bromley borough model area. For almost all verification this will however have no consequences seeing the only difference will be that the values of input will differ a bit. The only codes that will specifically have to be checked in the Camden model are the codes that use spatial information. So the local government that builds flood defences and the developer locating land (within opportunity areas only given in the Camden model) are actions that should be verified in the Camden model*

D.6.1 Theoretical predictions and sanity checks

In this verification test explicit prediction of what we theoretically expect an agent to do when provided with well-defined inputs will be made and checked, to see if the behaviour of the model coheres with the hypothesis. The verification will be kept as simple and comprehensible as possible. If only a single agent is needed to verify the action, only a single agent will be used. If a minimal agent setting is needed, a maximum of 1 of each agent type, this will be used. Only if both single and minimal can not be used to verify the code, because of interaction between agent types for instance, multi-agent testing will be used. In this case also only the amount of agents that are needed to properly verify will be used, and not more. In this way the verification of the model is kept as clear and easy to follow as possible.

The verification of all behaviour will be done following the formalization (step 3) and model narrative (step 4). In these two steps a clear overview is given of all input
of a behaviour, what happens within the action, and the output of the behaviour. For all actions in the model buttons are made in the interface of the model. These buttons represent the actions within the model. If the button of a certain action is clicked all inputs for this actions are set, the action is run and the results are seen in an output window at the verification.

**Environment does** The verification of the environment is split up in the verification of the setup procedure and go procedure. Because the setup of the model is often quite straightforward and can literally be checked back in the code of the model, no specific buttons are made for it in the interface of the model. Only for the setup code in which actually coding could have gone wrong buttons are created to check if they are coded right. Setup procedure

- **Setup environment**: In this action all environmental states are assigned a value. The values assigned to each state are equal to values set in the model formalization (step 3), model narrative (step 4) and as specified in the table of data input L.2. No further verification is needed here.

- **Setup houses**: A single house agent should be created here and assigned all states as specified in the setup of houses in step 3, 4 and the tables of data input L.2. This hypothesis is verified since this indeed happens. However there are 2 values that are set based on a deeper thought. First the setting of the council tax band. This code needs to be tested in a multi-agent setting because more houses are needed because they are divided based on chances. The other value that is set is the assigning of flood history and excess percentage, this can be checked with a single agent.

  ⊗ Assigning of council tax: Input for this action are the house types of houses and the way they are placed in council tax bands, as specified the appendix: Assigning council tax band and tax fee N. The hypothesis here is that every house gets assigned a council tax band as specified in the appendix. The output shows the correct percentages and placing of house types in correct tax bands. Note: The percentage in tax band H is lower because it takes the remaining houses here. Because percentages round up in this code the percentage of houses in tax band A and B (7.1%) result in 8 houses in both tax bands. On a larger skill this difference is no problem.
Assigning of flood history and the excess percentage: The hypothesis for this is that for every year that house has existed in the model (in this case between 0 or 10 years) and there has been flood damage (flood damage history is higher than 0 (in this case for all years a house has existed)), the flood excess percentage (initially 0.1) will be increased by $1/3$. When running the code in the model, see ‘setup flood history and excess percentage’, it can be seen that this is indeed the case. If for instance a house has a build year of 7, the flood damage history list shows three damages (for the year 7-10 that the house existed, and the flood excess percentage I increase 3 times with $1/3$.

- **Setup persons:** A single person agent should be created here and assigned all states as specified in the setup of persons in step 3, 4 and the tables of data input L.2. This hypothesis is verified since this indeed happens. The only part of the setup of persons that could not be tested in a single agent setting is if all persons that are created properly move into houses that are created and no houses are moved into double. This can only be properly tested in a multi-agent setting.

- **Making persons move into houses:** Input for this actions are a set of houses and persons. The setup of the model is coded so that every house that will be created will be occupied by a person. Based on this the hypothesis of this code is that the number of persons in the model will be equal to the number of houses with an owner. The output shows that this is indeed the case. Note: to make sure no houses have double owners the ‘house enter’ code (which is run for every person moving into a house, both in setup and running) has an error check in it that gives an error when a person tries to move into a house that already has an owner.

- **Setup bank:** A single bank agent should be created here and assigned all states as specified in the setup of the bank in step 3, 4 and the tables of data input L.2. This hypothesis is verified since this indeed happens.

- **Setup insurer:** A single insurer agent should be created here and assigned all states as specified in the setup of the insurer in step 3, 4 and the tables of data input L.2. This hypothesis is verified since this indeed happens.

- **Setup local government:** A single local government agent should be created here and assigned all states as specified in the setup of the local government in step 3, 4 and the tables of data input L.2. This hypothesis is verified since this indeed happens.
• **Setup developer**: A single developer agent should be created here and assigned all states as specified in the setup of the developer in step 3, 4 and the tables of data input L.2. This hypothesis is verified since this indeed happens.

Go procedure

• **Flood event**: In this code a flood event happens after a set time. A flood event is equal to a value of 0, 1, 2 or 3, representing the flood return periods no flood (0), to a 1 in 200 flood (3). In other verification steps it will be verified that the model reacts appropriate to these values. However in this code a value for a flood (1, 2 or 3) is set after a set amount of ticks and the rest of the time 0 (no flood) is given. Because this code is straight forward it was checked in the model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.

• **Process market**: Can only be properly done if there are several houses and persons acting on a market. So this action will be verified in a multi-agent setting. To test the processing of the market the following input is set up. 10 houses of each house type will initially be set up for sale. Where this code asks for the developer, persons and bank to run the market, a number of houses equal to the house type (so for house type 0, 0 houses up to 3 houses for house type 3) will be sold. The hypothesis is that the house type 0 will get a sales ratio of 0 (no houses sold), house type 1 gets a sales ratio of 0.1 (1 of 10 houses sold), house type 2 gets a sales ratio of 0.2 (2 of 10 houses sold) and house type 3 gets a sales ratio of 0.3 (3 of 10 houses sold). The output shows that this is indeed the case and therefore this action is verified.

• **Developer market run**: Can only be properly done if there are several houses and persons acting on a market. So this action will be verified in a multi-agent setting. To test the processing of the market different inputs variation will have to be tested. 4 test are done to verify the developer market run code. They can be selected in the interface in the 'MarketRunSetup' chooser

  ⊗ **No flood risk consideration**: First the working of the code without flood risk consideration will be tested to see if the basic code works. For this 100 houses and persons are set up. The houses have a set house value. Person are set up in a way that 50 of them can afford this house value and 50 can not. The hypothesis here is that 50 of the developer houses will be sold if the code is
run. The output shows that this is indeed the case and therefore this part of action is verified.

- **With consideration + flood this year**: Now the code will be tested with flood consideration and a flood in the current year. To test if the flood consideration true/false works, 50 of the persons will and 50 of the persons won’t consider flood risk. Compared to the previous input, now all houses will be affordable for all persons in the model (so without flood consideration 100 of the 100 will be old). Also all 100 houses are set so that they took flood damage from the flood. The hypothesis here is that the 50 persons that consider flood risk won’t buy a house and the 50 that don’t will all buy a house. The output shows that this is indeed the case and therefore this part of action is verified.

- **With consideration + flood last year**: Now that the flood risk condensation true/false works, this verification will look at if the flood of a last year has the right effect. For this all 100 houses are set affordable and hit by a flood and all 100 persons will consider flood risk. Hypothesis here is that on average 50 houses will be sold seeing the code dictates that 50% of people that consider flood risk will not buy a house that was hit by a flood in previous year. The output shows that this is indeed the case and therefore this part of action is verified.

- **With consideration + flood 2 year ago**: This last variation looks if a flood 2 years ago also has the right effect. For this the same input as in the previous variation is used. The hypothesis is that on average 75 of the house will be sold seeing the code dictates that 25% of people that consider flood risk will not buy a house that was hit by a flood 2 years ago.

- **Person market run**: Can only be properly done if there are several houses and persons acting on a market. So this action will be verified in a multi-agent setting. For the person market run the inputs and test are used as used for the developer market run. Input that changes for this code is that now instead of a developer 100 extra persons are created that move into the initially created houses and sell them. Where in the developer market run the hypothesis were set on expected numbers, this is not entirely possible for the person market run. In the developer run it was easy to put input in a way that houses were always sold. However because in the person market run there is a bidding code this does not always have to be. Inputs can be set in a way that almost always a house it sold, but it is not a given.
Therefore the hypothesis for this code are set the same as for the developer, with
the exemption that sales can sometimes be a few houses lower because of bidding.
Just as with the developer market run, the output of the person market run show
that the hypothesis are correct and the code if verified

- **Bank market run:** Exact same code as the developer market run, so also verified
- **Building value update:** Can only be properly done if there are several houses
  and persons acting on a market. So this action will be verified in a multi-agent
  setting. Input for this action is the input and action that is used in the verification
  of the process market code. In this action the sales ratio’s is set that is used in
  the building value update code. Of every type 10 houses are created and put on
  sale. The number of houses that are sold of each type is equal to the house type
  (detached = 0, so 0 houses sold, up to flats being house type 3, so 3 sold). Building
  value of each house is initially set to 1000. Seeing the sales ratios are decreased
  by 10% the hypothesis of building value that come out of the code is for detached
  houses 10% lower, semi-detached is same, terraced is 10% higher and flats is 20%
  higher. The output shows that this is indeed the case and therefore this action is
  verified.
- **Land Value update [transaction price:** Can only be properly done if there are
  a house and person. So this action will be verified in a minimal-agent setting. Input
  for this action is 2 arrays with the current total price of transaction already
  done, set to 10,000, and the number of transactions, set to 10. Be simulating
  another transaction b putting in a transaction with value 2000, the patch should
  get new land value set. The hypothesis is that this land value is equal to 12,000
  (new total transaction price, divided by 11 (new total transaction number) = 1090.
  The output shows that this is indeed the case and therefore this action is verified.

Persons do

- **Setup general person states:** In this code states of persons are assigned values.
  Because this code is straightforward it was checked in the model and no special
  verification output was made for it. The code does what it is suppose to do and
  so this code is verified.
- **Process persons:** In this code homebuyer get created and assigned values. Home
  buyers and home seller are asked to change a few values of states and asked to
  perform a few actions. Because this code is straightforward it was checked in the
model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.

- **House enter**: In this action a person moves into a house. This code is important in the model because it is run every time a person moves into a house (initially or after buying a house). That it moves a person correctly into a house is already verified in the verification of the market run, seeing in these action houses were sold and persons were moved into houses using the house enter code within the market run code. Besides this the code assigns/changes a few values of the person and the house that re involved n the change of owner. Because this code is straight forward it was checked in the model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.

- **Decide on house selling**: Can only be properly done if there are several houses and persons acting on a market. So this action will be verified in a multi-agent setting. Input for this action are 10 houses with a changing house value at buy and a set house value. Also 10 persons are created that have random set warning time, stay times and annual fee and a set income. In this action persons decide on selling their house. The first reason for them to do this is because of a too high annual fee (income * housing ratio + annual fee), and they are warned for 3 years. The second reason is because the can make a profit (if the have stayed in the house more than 3 years and the house value is higher than the house value at buy times a set profit percentage). The last motive s moving. The hypothesis is that every person that has a warning of 3 or higher and an annual fee that is bigger than the house fee (income times housing ratio) will sell their house. After this all persons that have a stay time of 3 or higher and have a house value that is higher than the house value at buy times the profit percentage will also sell their house. A percentage, equal to the moving percentage (50% in this case), of the persons now remaining will sell their house because of moving. The output shows that this is indeed the case and therefore this part of action is verified.

- **House bank sell**: When the decision to sell to the bank is made in the 'decide on house selling' action, this action only changes the states of the house and person that are involved in the decision and changes the assets of the bank. Because this code is straight forward it was checked in the model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.
- **House market sell**: When the decision to sell on the market is made in the 'decide on house selling' action, this action only changes the states of the house and person that are involved in the decision and an ask price is set. Because this code is straightforward it was checked in the model and no special verification output was made for it. The code does what it is supposed to do (specifically the ask price is set correct) and so this code is verified.

- **Set maximum affordable house price**: Input for this action is a single person. According to the source of the formula used in this action [HSBC, 2014a] a person will have a maximum mortgage of 172,920 if the maximum mortgage fee of a person is 10,000 a year (income of 100,000 times a mortgage ratio of 0.1), if the mortgage interest is set to 4% and the mortgage term is set to 30. If we add to this that the person can pay 3 incomes as a down payment this will put the maximum house price of the person on 172,920 + 3 * 100,000 = 472,920. The hypothesis that indeed the calculated maximum house price set in this code will come to 472,920 if the incomes are set as specified.

- **Person flood insurance set**: In this code only all persons are asked to set the flood insurance for their house to true. Because this code is straightforward it was checked in the model and no special verification output was made for it. The code does what it is supposed to do (all houses get insured) and so this code is verified. The output shows that this is indeed the case and therefore this action is verified.

- **Invest in PLPMs**: Can only be properly done if there are a house and person. So this action will be verified in a minimal-agent setting. Input for this action are a house and a person. General inputs are that investing in PLPMs increases the flood protection of a house by 0.5 and that all persons are either a proactive or reactive PLPM investor, based on their flood consideration status. The house is set up in a way that it either is or is not flooded, PLPMs are not invested for it yet, and flood defences (with a protection level of 0.5) are or are not already installed for it. The person either will or will not consider flood risk. The hypothesis are that the following variations in input should lead to the following outcomes:
  ⊗ If the person is proactive, does **not** consider flood risk and the house is flooded, the flood protection level stays the same
  ⊗ If the person is proactive, does **not** consider flood risk and the house is **not** flooded, the flood protection level stays the same
If the person is proactive, does consider flood risk and the house is flooded, the flood protection level increase either from 0 to 0.5 or from 0.5 to 0.75 (increasing by 50%)

If the person is proactive, does consider flood risk and the house is not flooded, the flood protection level increase either from 0 to 0.5 or from 0.5 to 0.75 (increasing by 50%)

If the person is reactive, does not consider flood risk and the house is flooded, the flood protection level increase either from 0 to 0.5 or from 0.5 to 0.75 (increasing by 50%)

If the person is reactive, does not consider flood risk and the house is not flooded, the flood protection level stays the same.

If the person is reactive, does consider flood risk and the house is flooded, the flood protection level increase either from 0 to 0.5 or from 0.5 to 0.75 (increasing by 50%)

If the person is reactive, does consider flood risk and the house is not flooded, the flood protection level stays the same.

The output shows that this is indeed the case and therefore this action is verified.

**Inflation correction**: In this action the income of every person in the model is increased with a set percentage. Because this code is straightforward it was checked in the model and no special verification output was made for it. The code does what it is supposed to do (income is increased with the set percentage) and so this code is verified.

**Houses do**

**Set mortgage fee**: Can only be properly done if there are a house and person. So this action will be verified in a minimal-agent setting. Input for this action is a single house and person. According to the source of the formula used in this action [HSBC, 2014b] a person will have a annual mortgage fee of 7095 if the principal is equal to 100,000, the mortgage interest is 5% and the mortgage term is 25 years. The model enter year of the person is either 0 or 1. If the model enter year is 0, the mortgage fee duration should be a random number between 0 and 1, if it’s 1 it should be 25. The output shows that both the mortgage fee and the duration are set well, so this code is verified.
• **Process house**: Because the process house action asks houses and the insurer to perform several actions, the verification of this code will also be used to verify the following actions: 'Calculate flood risk', 'Set flood insurance premium and excess' (insurer action), 'Re-insure to FloodRe' (insurer action) and 'House flood repair'. In the verification interface the output at which is looked can be specified by selecting the code wanted in the 'WhichHouseVerification?' chooser. All these codes can only be properly verified if there are a house, a person and an insurer. So this action will be verified in a minimal-agent setting.

In the process house action itself the following input is used. A state stating if the house has flood protection installed the previous year (set true or false), a flood damage list, an annual fee list and a fee duration list. Hypothesis: If the house has flood protection installed the values on the flood damage list should be decreased with 50% (value of flood protection in this verification code). The values of the annual fee list should be deleted from it if the fee duration of this item decreases from 1 to 0 (except for the mortgage fee which becomes 0). And new fees should be added to the annual fee list with corresponding duration of 1 year. Item 1 and 2, property tax fee and ageing repair fee, should be set the same again and a flood insurance premium (item 3) and flood insurance execs are added, depending on what the other codes that are asked to be performed do. The output shows that this is indeed the case and therefore this action is verified.

• **Calculate flood risk**: Because this code is created based on a formula in the book of Jim Hall which who I worked together and no given value of what the formula should provide s given, no specific verification is needed. However this code is set up together with Jim Hall and the value of the flood risk that comes out of it is logical. If a simple calculation is taken that approximates what the formula does (flood probability times flood damage for all 3 flood return periods), the flood damage of a house without flood protection is 73.33. The formula calculates it on 109.5. This is correct seeing the formula calculates the flood risk better and it should be higher value. The same counts for a house with flood protection for which the flood risks in both cases are lower. So this code is verified

• **House flood repair**: Verified within the process house verification, so in a minimal agent setting. Input of this action is a possible flood, flood damage to the house, a flood insurance excess, a flood repair fee and the housing money of the person owning the house. In this action if a house is hit by a flood, the flood
repair fee is set to either the flood damage to the house or the insurance excess. If half of the house money the person owning the house can is lower than the flood repair fee, the flood repair fee is deducted from the building value of the house. Otherwise the flood repair fee is added to the annual fee list.

- **House dispossess**: In this action a person moves out of the house that run this action and the house states are reset. This code is important in the model because it is run every time a person moves out a house (when selling a house). That it moves a person correctly out of a house is already verified in the verification of the market run, seeing in these action houses were sold and persons were moved out of houses using the house dispossess code within the market run code. Because this code is straight forward it was checked in the model and no special verification output was made for it. The code does what it is suppose to do (especially the correct house states are reset) and so this code is verified.

**Bank does**

- **Process bank**: Asks the bank to perform the 2 actions below. This indeed happens, so no further verification possible

- **Bank flood insurance set**: In this action the bank insures all the houses it owns against floods. Because this code is straight forward it was checked in the model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.

- **Bank maintain houses**: In this action the annual fee lists of all bank owned houses are summed and deducted form the bank assets to indicate that the bank is maintaining them. Because this code is straight forward it was checked in the model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.

**Insurer does**

- **Process insurer**: Asks the insurer to perform actions. The correct actions are asked to be performed, so no further verification possible.

- **Set flood insurance premium and excess**: Verified within the process house verification, so in a minimal agent setting. In this action the flood insurance excess should be increased if the house is hit by a flood. The insurance excess should be set to the insurance excess times the excess percentage. And he insurance premium
should be set based on the base insurance premium and the flood risk of the house. The output shows that all this is happening and therefore the code is verified

- **Calculate expected average annual loss**: Verified within the process house verification, so in a minimal agent setting. Based on the flood damage list, the flood return periods and the flood insurance excess of a house, the insurer calculates its expected annual loss. In this case it is only done for one house. It is important here to check if the value that comes out of the calculation (the expected average annual loss) is correct. Based on the input from the process house action the flood damage list and flood insurance excess can vary for the house. In all cases the calculations are done right so the action is verified.

- **Compensate policy holders**: In this action the compensation amounts are calculated and deducted from the correct assets. Because this code is straightforward it was checked in the model and no special verification output was made for it. The code does what it is supposed to do and so this code is verified.

- **Calculate current loss ratio**: In this action the current loss ratio is set. Here it is important that the total premium incomes and compensation payouts are set correctly. With the adding of the FloodRe system this code became a bit more complex, but is still straightforward. Therefore it was checked in the model and no special verification output was made for it. The code does what it is supposed to do (values are set correct) and so this code is verified.

- **Adjust insurer assets**: In this action the insurer assets are updated with the total incomes and payouts as calculated in the calculate current loss ratio code. Because this is only basic adding and deducting a value from a value it is straightforward and was checked in the model and no special verification output was made for it. The code does what it is supposed to do and so this code is verified.

- **Decide on re-insuring in FloodRe**: Verified within the process house verification, so in a minimal agent setting. The insurance premium of a house is set to 50. The build year of the house is set to 2008 or 2009 and the FloodRe insurer cost a random value between 0 and 100. Hypothesis for this action is that if the build year of the house is 2008 and the FloodRe insurer cost is lower than the insurance premium, the insurance premium is set to the FloodRe insurer cost value and the re-insured to FloodRe status is set to true. Under all other circumstances the insurance premiums stays 50 and the re-insured to FloodRe stays false. The output shows that this is indeed the case, so the code is verified.
Local government does

- **Process local government**: Asks the local government to perform actions. The correct actions are asked to be performed, so no further verification possible.

- **Collect property taxes**: In this action the local government assets are updated by adding a percentage of property taxes to it. Because this is only basic adding a value to a value it is straight forward and was checked in the model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.

- **Collect flood protection investment**: In this action the local government assets are updated by adding the flood protection budget value to it. Because this is only basic adding a value to a value it is straight forward and was checked in the model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.

- **Decide on building flood defences**: Can only be properly done if there are several houses and a local government. So this action will be verified in a multi-agent setting. Input for this action are 10 houses that will or will not be hit by a 1 in 200 year flood, with a set building value and no flood defences build yet. The local government has a random value set for their assets. In this action the local government should choose to build flood defences if, under these inputs, 5 or more houses are hit by a 1 in 200 year flood (fraction is set to 50%) and the local government has more assets than the minimum cost of a project. The output shows that this is indeed the case; the action is verified.

- **Build flood defences**: Can only be properly done if there are several houses and a local government. So this action will be verified in a multi-agent setting. A model is set up in which there are more than enough houses to choose from. The local government gets a budget to invest in flood defences for 100 houses and the command to setup a portfolio of 3 project with minimum 10 houses in. Hypothesis is that the local government sets up 0 to 3 project and build as much projects as possible with the budget they have, building flood defences for a maximum of 100 persons. Important in this is that the local government will always sort projects on the best benefit cost ratio to build these first. The output shows that this happens; the action is verified.

- **Evaluate development proposals**: Can only be properly done if there are a local government and developer. So this action will be verified in a minimal-agent
setting. Input for this action is a send development proposal from the developer to the local government. 75% of proposal should be accepted automatically. the other 25% will be accepted if the flood risk of the proposed house to build is lower than the maximum flood risk of the local government. If this is not the case a proposal will also be accepted if the income of it is higher than then the value at risk. If this is also not the case the proposal will be denied. The output shows that this happens; the action is verified.

Developer does

- **Process developer**: Sets a housing demand and asks the developer and local government to perform actions. Because this code is straight forward it was checked in the model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.

- **Locate land for development**: Chooses the house with the highest surrounding value and sets the patches in radius 1 around it to also belong to this house. Because this code is straight forward it was checked in the model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.

- **Decide to create development proposal**: Can only be properly done if there are a several houses and a developer. So this action will be verified in a multi-agent setting. Input for this action are a set of houses that are set on a random location within a box of 50 by 50 patches. The proposed land that is set in the 'locate land for development' is in the centre of this box. If there are more than 10 houses in a range of 20 around the house, the house type of the house is set equal to that of the houses (house type 3). Otherwise it is set according to a ratio (often 2, but can also be 3). Based on this house type a house value, land value, building value, tax band, property fee and insurer cost are set. Also based on houses surrounding it the prosed flood damage is set. This should be equal to that of the surrounding houses, seeing all houses were assigned the same flood damage list. Based on this a proposed flood risk is set in the same way flood risk is set for houses (which is already verified). If the income of the development is higher than the cost times a ratio, the developer will send a proposal to the local government, if not they will not do it. The output shows that this all happens and the values are set correctly; the action is verified.
• **Develop housing**: If a development proposal was approved a house is created on the proposed location and all proposed values set in the 'decide to create development proposal' code are assigned to the house. Because this code is straightforward it was checked in the model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.

• **Finish house construction**: Sets houses that were started to be build the previous tick to developer owned and no longer in construction. Because this code is straightforward it was checked in the model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.

• **Developer flood insurance set**: In this action the developer insures all the houses it owns against floods. Because this code is straightforward it was checked in the model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.

• **Developer maintain houses**: In this action the annual fee lists of all developer owned houses are summed and deducted form the developer assets to indicate that the developer is maintaining them. Because this code is straightforward it was checked in the model and no special verification output was made for it. The code does what it is suppose to do and so this code is verified.

### D.6.2 Breaking the agent

In the previous test we have concluded that the agent behaves as expected under normal inputs. In this test the edges of of the normal behaviour are defined by trying to 'break' the agent. This action will make clear if agent will also react appropriate if presented with extreme values. If the agent reacts appropriate when providing it with extreme inputs, the agent behaviour is verified. However if the agent shows unexpected behaviour or break all together (error codes in the model), this does not have to mean the agent is coded wrong. It could be explainable behaviour or a computer imitation.

A standard computer limitation presented in a model is a division by 0. If the model attempts to divide a value by 0 an error will occur. In the many runs that have already been done in creating and testing the model through every step of creation, many of these errors have already bee eliminated by investigating what happened. Often it was the case that the code should have simply not been run if the input was 0. For these
Appendix D Detailed model creation

codes a simple 'if' function in the model code was introduced to make sure the code was not run when an input of 0 was presented to it.

Besides this another precaution was implemented in the model code. At ever end of a year (tick) in the model an 'error check' is run. In this code states that have their values changed within the model run have their values checked according to their limitation. Within the formalization step, step 3, all states that have changing values within the model run have boundaries set. Some states can for instance only have a set amount of values, other states always have to be higher or equal to zero. If a value of goes out of it’s boundary an error code is shown (telling which state has gone out of bounce) and the model stops running.

Besides these build in precautions, the verification interface in the interface of the model has a 'break agent' button whit a chooser above it in which a set of extreme input values can be selected. Not all values can be tested here, but a selection is made of the most important ones. If the 'break agent’ button is pushed he model will setup and run for 5 ticks. If in this time no errors occur it is already good. To see if the agent behaviour is not unexpected the graph shown in the interface can be looked at. These graphs show the behaviour of the model and should show weird behaviour because of extreme value inputs. Only a few values that are very influential in the model are tested.

The following values are tested:

- **Average flat value** (environment) to test the model specifically the market) under very high ($\infty$) and low ($0$) values for houses

- **Income** (persons) to test the whole model with a set very high ($\infty$) and low ($0$) income for all persons

- **Maximum acceptable loss ratio** (insurer) to test the whole model with a very high ($\infty$) and low ($-\infty$) acceptable loss ratio.

- **Local government assets** (local government) to test the whole model with a very high ($\infty$) and low ($-\infty$) value for the assets of the local government

- **Income cost ratio for development** to test the whole model with a very high ($\infty$) and low ($-\infty$) value for the income cost ratio for development

All test are run and no errors or weird behaviour is shown. So this verification test can be seen as a success.
D.6.3 Variability testing

Both tests above have shown that the behaviour of the model is verified; it is correctly translated from the model conceptualisation. In this test the variability between run will be tested. A single run of a Netlogo model can not be trusted because agent-based models are often chaotic, results can vary quite a lot between runs. Within the variability test the model will be tested under a set normal model settings (run for 10 years with all policies on and a 1 in 30 year flood after 5 years), but with a different amount of repetitions. In this way the variability between runs can be seen. With this testing the number of repetitions that should be used for experimenting on the model can be determined.

Because it will be possible to run the experiments on a cluster of computers at the TU Delft, computer limitation will be less of a problem. Still the model is very big and even running on a cluster takes up quite some time. For this reason the number of repetitions that will be used will still be tried to be kept to a minimum. The number of repetitions that will be tested are 5, 10, 25, 50 and 100. When running on the cluster of TU Delft running 5 repetitions will take an hour, while running 100 repetitions will still take up to a day.

A few standard output parameters will be monitored to see their variation over the different runs. These output parameters are selected based on the behaviour that is behind them. The chosen output have quite some behaviour behind them, which can cause for variations in the output and are therefore good output to monitor for this test. The output parameters that are chosen are:

- The average flood risk
- The amount of houses that are put on sale and are sold
- Average house values in/out flood risk
- The number of investments in flood defences by the local government
- Number of houses build

The boxplots D.6, D.7, D.8, D.9, D.10, D.11 and D.12 show the variability between run for the chosen output parameters. It can be seen that means and standard deviations of 5 repetition runs are often quite different than the rest. The mean and standard deviations of 10 repetitions runs are often quite close to those of the 25, 50 and 100. Seeing the model is already computational heavy the least amount of needed repetitions is looked for. Because of this the choice can be made to run the experiments with 10
repetitions. However it would be better to run it more often to get better results and less noise in the data. Seeing the mean of 25 repetitions is quite off to that of 50 and 100 repetitions and 50 and 100 repetitions are often close to each other, running the experiments with 50 repetitions would be the best.

**Figure D.6:** Boxplot average flood risk

**Figure D.7:** Boxplot number of houses on sale
D.6.4 Time line sanity

In this last verification test the time line of the model run is examined by performing several runs at the default parameter setting. During the creation of the model this test (to a certain extent) has been done many times already. During the creation of the model the model was run many times to see if the code worked and if the behaviour was good. Every time weird/wrong code/behaviour that was found was already changed or
Appendix D Detailed model creation

Figure D.10: Boxplot average house value of houses not in flood risk

Figure D.11: Boxplot flood defence investments

accounted for. Now that the model is done several test are again run to see if everything is still sane. Below some graphs of a typical run are shown in which the model is run 10 years with all policies are turned on and a 1 in 30 year flood happens after 5 years.

In graph D.13 the basic patterns of the investments in flood protection measures can be seen. It can be seen that proactive PLPM investments happen at a steady pace, reactive PLPM investments only happen the year after a flood happened (year 6) and flood defences are first steadily invested in till the fraction of value at risk is low enough
and then is invested in step wise when more houses in flood risk areas are developed.

In graph D.14 it can be seen that initially the average flood insurance premium is quite high; around 200 where the base value is 50. Towards the end of the model run
a slight lowering of the flood insurance premium can be seen. This most likely comes
from the effect flood protection measures have and because the flood insurance excesses
of persons have gone up after they were hit by a flood in year 5. It can also be seen
that the average flood risk initially in stable but than start to rise. At first sight this
seems weird, however there are 2 reasons for this. The main reason is that the average
flood risk is calculated over all houses in the model, also those that are not in flood risk.
Because the houses that get developed are often in flood risk, the overall flood risk in the
model increases. The flood risk these houses are in is often already covered by the base
flood insurance premium they also start paying. This causes for the average flood risk
to increase because the amount of houses in flood risk relative to the amount of houses
not in flood risk increases. The second reason is hat flood risk is partly determine based
on the house values of houses. The house values increasing during the model run, which
also causes the flood risk to go up. Th only time the flood risk goes down is in year 7.
This drop comes from the large amount of persons that invested reactively in PLPMs
in year 6 after they were hit by a flood.

![Graph D.15: Graphs of FloodRe information](image)

In graph D.15 it can be seen that the number of houses in flood risk only increases
with the number of houses in flood risk that are being developed. This is logical because
the way the model is currently coded no new houses that already existed initially in
the model can become at flood risk. Besides this it can be seen that the initial amount
of houses re-insured in FloodRe is really high. Over time the number of houses re-
insured in FloodRe lowers. This happens for the main part in the last few year of the
model. This is along the line with the slight drop in flood insurance premium that can
be seen. Although the flood insurance premium does not drop by much, it seems the
risk protection methods do their work by lowering the flood risk of the persons that
have the highest flood risk, taking them out of FloodRe. Because the average flood
insurance premium is also influenced by the new build houses it does not change that much. However the amount of houses in FloodRe does not increase, seeing new build houses are not eligible. This also causes for bigger reaction to be seen in houses re-insured in FloodRe.

In graph D.16 it can be seen that in general the average house values increase quite a lot. The interesting thing that can be seen is that till the flood happens the average house values of flood risk and non-flood risk houses is equal. but that after the flood the houses that are not in flood risk increase a bit more in value than the houses in flood risk.

In graph D.17 it can be seen that the number of houses sold follow the lines of the number of houses on sale to a certain extent. At year 5 a flood occurs and the number of houses that are in flood risk and are being sold increase quite a lot. The number of houses in flood risk follows a bit, but not like before. This is because people are less interested in buying these flood risk houses after a flood. The number of houses on sale/sold that are not n flood risk are not influenced by the flood.
In graph D.18 it can be seen that the amount of houses that are put on sale because of moving increases steadily. This is exactly coded this way and it expected (a % of total persons moves every year). Initially no-one sell their house for profit or because they can not afford it. This is because the way the initial houses are setup in a way that everyone can afford his house and because the house don’t change enough in the beginning to trigger profit sell spikes. Towards then end of the 10 year run this however starts to happen because house payments (among other things because of the flood that occurred, but also because of increasing house prices which result in increasing house costs) increase and house prices start to differ enough for people to be triggered to sell their house for profit. If longer run (of more than 10 years) are done more effects of reasoning of house selling can be explored.

It can be seen that the results are sane, so according to this last verification test the model can also be seen as verified.

D.6.5 Conclusion on verification

Based on the performed verification test it can be concluded that the conceptualisation is correctly translated into model code. The variability testing showed that 10 repetitions can in theory be used to get proper results from the model, but 50 repetitions is preferred if the computational setup allows this.
Appendix E. Model Combination

In this appendix an analyses will be made on how the 2 provided agent-based models (of Jenkins and Putra) can be combined into a single ABM model that can be used as a setup of a model on which the rest of the modelling effort can be based. To properly combine the two models, the two models will first need to be understood better separate from each other.

E.1 The Jenkins model

The model of Jenkins is a start in the right direction for the model being created in this thesis. As stated it sets up the housing area that will be investigated. This is done with the help of GIS data that is loaded into Netlogo L.1. Figure E.1 shows the visualisation of the set up housing area of the Jenkins model. Here it can be seen that houses get assigned a spot on a grid and get assigned a colour. This colour corresponds with one of the 4-house types used in the Jenkins model; detached, semi-detached, terraced and flats. Based on these house types the houses get assigned a value.

The run code of the model of Jenkins was still a work in progress when Mrs. Jenkins went on maternity leave. For this reason this code will not be used further and the focus will lie on using the setup data within this model to base all other coding effort on.

Figure E.1: Visualisation Jenkins Model
E.2 The Putra model

Specifics on the modelling and working of the Putra model can be found in the published article related to the model; Modelling Real Estate Market Responses to Coastal Flooding [Putra, 2013]. The focus here will be put on the differences between the Putra and Jenkins model to see where the main pitfalls will lie in combining the models.

Figure E.2 shows the visualisation of the Putra model at the start of the model and immediately shows big differences with the Jenkins model. The Jenkins model sets up an existing area in which heavy rain is the main cause for flooding. The Putra model takes a not existing simplified representation of a coastal area where flooding come from the sea (at the left of the picture) and spread land inward. Because of this reason the flood hydrology of the Putra model will no be used in the to be created model. In combining the models the different land setup can cause for problems and should be kept in mind.

Another thing to notice is the way houses are set up. In the Putra model a determined amount of houses get setup in fairly random location in the model. In the running of the model a house can be built on every empty spot. The Jenkins model sets up an already existing housing area and for now does not have place where new houses can be build. Where the focus in the Putra model lies on creating of new houses, the focus in the Jenkins model lies on the market of buying and selling a given set of houses. This is a second thing that needs focus when combining the models.

A third Thing to notice is the market focus of the two models. The model of Putra specifically focuses on 4 different types of land for which the market code is run separately. Besides this it not just focuses on the selling and buying of existing houses, a big part of the code also focuses on the creation of new houses. The Jenkins model however does not have a focus on land types but rather looks at 4 different types of house types with each their own values. Besides this the Jenkins model has a given set of houses on which the market should be run. No house creation market is in the model. So the focus of the Putra model on investigating how houses are build, bought and sold given different land elevations, should be changed into a focus on given set of houses that are bought and sold given different types of houses. As described before a developer will be added in a later modelling stage, but this will not be in the model now so the focus will not bye on it.
E.3 Conclusion on combining the models

After analysing the two models it is clear that the setup (data) of the Jenkins model can be used and added to this the running code of the auction market of Putra can be used. The main problems that will need solutions when combining the two models are on first sight:

- The different land setting
- The different housing setup
- The difference in emergent pattern focus
Appendix F. Justification for choosing Camden and Croydon as study areas

This document was provided to me by Katie Jenkins of the ENHANCE project. Below is a literal copy of what I received from her.

In July 2011 the Mayor published the replacement of the spatial development strategy for London – known as the London Plan. The London Plan is the overall strategic plan for London, and it sets out a fully integrated economic, environmental, transport and social framework for the development of the capital to 2031. It forms part of the development plan for Greater London. London boroughs' local plans need to be in general conformity with the London Plan, and its policies guide decisions on planning applications by councils and the Mayor.

Local Development Frameworks outline the spatial planning strategy for each Borough in London. All Local Development Frameworks must be in general conformity with the Mayor’s London Plan. The National Planning Policy Framework (NPPF) requires that the evidence base for the Local Plan includes a Strategic Flood Risk Assessment (SFRA). A Strategic Flood Risk Assessment (SFRA) is a study carried out by one or more local planning authorities to assess the risk to an area from flooding from all sources, now and in the future. This takes into account the impacts of climate change and assesses the impact that land use changes and development in the area will have on flood risk.

As a starting point for each borough the SFRA were used as a guide to the perceived level of risk from surface water flooding. For areas where the risk was high further investigation was used to highlight areas which would make interesting case studies in the context of the ABM and questions of interest, such as differences in socio-economic data (see F.1) and plans for future development. The London Boroughs of Camden and Croydon were identified for further analysis.

In Camden surface water flooding areas were reported as being in need of further investigation due to the high level of risk and historic precedent. For example, widespread
Appendix F Justification for choosing Camden and Croydon as study areas

<table>
<thead>
<tr>
<th></th>
<th>Camden</th>
<th>Croydon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (sq. km)</td>
<td>21.8</td>
<td>86.5</td>
</tr>
<tr>
<td>Population (2013)</td>
<td>228,400</td>
<td>373,100</td>
</tr>
<tr>
<td>Population density</td>
<td>10,482</td>
<td>4,313</td>
</tr>
<tr>
<td>% All Children aged 0-15 - 2013</td>
<td>15.6</td>
<td>21.6</td>
</tr>
<tr>
<td>% All Working-age (16-64) - 2013</td>
<td>73.3</td>
<td>65.6</td>
</tr>
<tr>
<td>% All Older people aged 65+ - 2013</td>
<td>11.1</td>
<td>12.7</td>
</tr>
<tr>
<td>% Employment rate (16-74) - 2011</td>
<td>62.7</td>
<td>65.8</td>
</tr>
<tr>
<td>Median house price (2013)</td>
<td>575,000</td>
<td>240,000</td>
</tr>
<tr>
<td>Number of household spaces (2011)</td>
<td>102,703</td>
<td>148,824</td>
</tr>
<tr>
<td>% detached (2011)</td>
<td>1.9</td>
<td>12.5</td>
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<tr>
<td>% semi (2011)</td>
<td>4.1</td>
<td>25.1</td>
</tr>
<tr>
<td>% terraced (2011)</td>
<td>8.8</td>
<td>26.1</td>
</tr>
<tr>
<td>% flats (2011)</td>
<td>85.2</td>
<td>36.3</td>
</tr>
</tbody>
</table>

Table F.1: Table 1: Background data for Camden and Croydon (Source: London data store)

Surface water flooding was suffered in the summer of 2002 due to a high intensity rainfall event (Drain London, 2011a). High rainfalls levels and flood events are a recurring feature in Camden due to the nature of summer thunderstorms and the topography of Hampstead. However, whilst risk is considered to be high the consequences are unlikely to restrict development providing that mitigation for surface water flooding is applied using the precautionary approach. Within Camden three opportunity areas1 and two intensification areas2 have been identified, which comprise the planned development of approximately 13,700 homes.

In Croydon high risk was also identified. Croydon has historically suffered significant surface water flooding, and is ranked the 4th settlement in England most susceptible to surface water flooding, with as many as 21,100 properties estimated to be at risk (Drain London, 2011b). Croydon is also identified as an opportunity area within the London Plan, including the development of approximately 7,300 new homes.

**Background data for Camden and Croydon**

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1Opportunity Areas are London’s major reservoirs of brownfield land with significant capacity to accommodate new housing, commercial and other developments linked to existing or potential improvements to public transport accessibility

2Intensification Areas are typically built up areas with good existing or potential public transport accessibility which can support redevelopment at higher densities. Source: The London Plan (July 2011)
Appendix G. Walking through Camden

While I was in Oxford to work on my thesis I also took a day in a weekend to go to London to walk around Camden, the area of which I am making an agent-based model. Although the things I saw will have no influence in how I have modelled Camden, the walk did help me understand why Camden has problems with surface water flooding.

Figure G.1 shows the route I walked though Camden. I entered Camden (my model) in the north-west and after walking through it for 9 kilometres I left it again in the south-west.

While walking through Camden there were several things I noticed.

Figure G.1: My walking map of Camden
1. The whole area of Camden is quite hilly. Throughout my whole walk I was almost always walking either up or down hill, as shown in the graph my Runkeeper app made of my elevation while I was walking G.2.

2. Many of the houses in Camden had living spaces below street level. As photo G.3 and photo G.3 show, people often had their kitchen or living room below street level. This will make it that surface water flooding faster does more damage because it doesn’t stay on the street but seeks lower areas where it easily goes into people’s living areas where it does way more damage it can ever do on the street.

3. The third I noticed that even though it had not rained for a while, on some places there was still a constant stream of water going down hill, as photo G.5 shows. This
shows to my that at some places the draining system in Camden is not optimal and because of the hills this causes for constant streams of water down hill. This is another indicator of why surface water flooding can be such a problem for the Camden area.

4. The fourth and last thing I noticed, of which I took no pictures, is that when I was walking though the top left opportunity area in which the developer in the model can build, I saw a lot of flats being build. I won’t do anything with this information, but its still an interesting thing to mention I think. I also walked a bit
through the opportunity areas in the south of the model, but I did not see much building going on here. This fits with how the model run, seeing the developer often prefers to build in the top left opportunity area because he prices are highest their.
Appendix H. Flood modeling analysis

This appendix will elaborate on the way flooding will be modelled in the agent-based model. For this the data that is available will first be looked at. After this the different aspects and choices that are made in choosing a way to model flooding will be elaborated on, to end with a final conclusion on how flood events will be modelled in the agent-based model for this research. An important note to make here is that the type of flooding that will be modelled is surface water flooding. The area of Camden is not influence by river flooding coming from the river Thames.

H.1 Available flood data

The following flood data is available to model flooding with in the FloodRe-model:

- GIS data on flood damages to both building and content of each initial house in the model. Where this data comes from is outlined in the GIS data explanation (see 'Flood damage values' in appendix section L.1). Appendix I summarizes the way this data is gathered. The data provides damage data on three flood return periods; 1 in 30, 1 in 100 and 1 in 200 year.

- The data above presents data from the entirety greater London area split up in Grid cells. The modelled area, Camden, only encompasses 5 of these grid cells. For each of these grid cells there is also flood event data available that represent 3000 years of flooding within these grid cells. Where this data comes from is outlined in the GIS data explanation (see 'Flood event data' in appendix section L.1).

Important to note is that in the way the flood damage is calculated the duration of floods are included. In normal flood events the duration of a flood is quite important. The longer a flood stays within an area, the water does not go away, the more severe the structural damage to houses is and the higher the total damaged done by the flood. Because floods will now be executed on yearly basis it does not mean this duration aspect is gone. The data the model needs is the total damage to houses, and this is what is put into it. Also on yearly basis policy options that reduce durations of a flood can be implemented by lowering the total damage the flood does.
Appendix H Flood modeling analysis

H.2 Flooding aspects

When modelling floods there are three important aspects to look at; the type of flood (flood return period), the probability of the flood happening and the location where the flood happens.

Figure H.1 shows a simple representation of what an exceedance curve of surface water flooding looks like. When modelling flood events every point on this curve can in theory be used to represent a flood event. Based on the three data points available this graph could also be drawn for the FloodRe model. Together with the probabilities that link to the flood return periods (a flood return period of 1 in 100 years has a 1% chance of happening every year) a large range of possible floods can be modelled.

This way of modelling flood events will be chosen when the flood events itself are an important part of what is researched. In the research done in this thesis this is not the case though. The flood events that will be modelled are there to give input data to the model to which the agents in the model can react. The input data and the reaction of agents is the most important aspect that will be researched here and not how the timing and sequences of flood events influence the model. For this reason a quite arbitrary way of modelling flood events will be chosen for this model.

Given that specific data is available on three flood events, these flood events will be used and no others. Besides this, chances of a flood happening will not play any role. Because the input data and the reaction of agent on this is the most important, the choice is made to make a flood event happen at a set time within the model. Given that the behaviours of agents both before and after a flood event wants to be investigated the flood will happen in the middle of the model run (time span of the model run not
yet chosen). This automatically also means that the whole model will be hit by the same type of flood at the same time and no split will be made in different types of flood events at different times in different areas.

H.2.1 Conclusion on the way flood events will be modelled

The choice is made to model single flood events at a set time in the model run for the whole model at the same time. It must be stated thought that this is specifically chosen for goal of the research done in this thesis. If more advanced studies want to be done different kind of flooding can be modelled. For this reason these flood event model options are also included in the model. The options to make models happen in probability and to make them happen at different times for the different grid cells based on flood event data are included. These flood events also have data n them to simulate future climate change scenario’s. This is something that can be done in further research to investigate the consequences of climate changes.
Appendix I. Impacts of surface water flooding in Greater London

The text below is a rewritten copy of the document Katie Jenkins provided on the method that is used to calculate impacts of surface water flooding in Greater London.

The data on the damages floods do to houses in the studied area are provided by DrainLondon. They provide spatial maps of the depth of surface water flooding for Greater London for 1/30, 1/100, and 1/200 year return periods. Data is at a 5x5m gridded scale, as shown in figure I.1.

The following is a summary of the method used to gathered this data:

1. The basic method aims to establish a link between precipitation data from the spatial WG and the flood depth data from DrainLondon. Damages are then calculated based on the depth data.

2. As the flood depth maps are presented for given return periods these return periods are used to determine a link between precipitation data from the WG and flood depth data.

3. The return level of extreme precipitation events of 1/30, 1/100, and 1/200yr return periods are estimated based on the baseline data from the spatial WG. The daily annual maximum (one day duration at the moment but when I have the new WG version this will be hourly data) series (AMS) is derived from the precipitation times-series data, for each grid cell under the baseline scenario. Extreme Value Analysis (EVA) is used to calculate the return levels for each return period. The Generalised Extreme Value (GEV) distribution function is fitted to the AMS. For

Figure I.1: Flood maps DrainLondon
each return period the GEV distribution allows the equivalent return level to be determined for each grid cell. The GEV has been fitted based on all the 100 x 30yr runs and then the return levels determined. Results for all the grid cells are presented in the figure I.2.

4. **Present day damages based on DrainLondon maps:** It was decided to start using the simple method proposed to use the current flood depth maps provided and for each return period calculate the present day damages to residential and commercial buildings. The results below provides a simple snapshot of the total costs to Greater London based directly on the DrainLondon maps and assuming that the 1/30yr, 1/100yr, and 1/200yr flood event affected the whole of Greater London on a single day only. Using GIS the flood depth maps were overlaid onto a map of residential buildings (categorised by building type) for Greater London (using the LandMap Building Blocks dataset)\(^1\), and affected residential buildings identified, as show in figure I.3

Economic damages to building fabric and contents were estimated based on the MCM depth-damage functions for short duration (<12hrs) flood events for each building type identified in the LandMap data (semi-detached, detached, terraced, and flats). A second more detailed option when repeating the analysis would be to use the MCM damage functions calculated based on building age and building type as building age data is also available from LandMap.

The preliminary results indicate that based on the DrainLondon maps 127,970 to 156,402 properties are at risk from surface water flooding in Greater London for 1/30 and 1/200 year flood events respectively. This is lower than the estimated

\(^1\)This data does not appear to be complete for the whole of Greater London but is freely available and the only source I have been able to identify so far which does provide characterisation of buildings by property type. In some cases the polygons which represent buildings cover whole rows of terraced houses, semi-detached housing etc. I am discussing disaggregating this data based on postcode data with Simon Abele. In this example I have just used the dataset as it is and so the number of properties affected by surface water flooding is underestimated
800,000 properties cited as being at risk from surface water flooding by the GLA (2011). Part of this may be due to the incomplete data on residential building locations in the LandMap Building Block dataset, and that the blocks need to be disaggregated to individual properties in many cases.

Total economic damage to residential buildings in Greater London was estimated to cost £1.7bn, 2.0bn, and 2.2bn for 1/30yr, 1/100yr, and 1/200yr flood events respectively (based on 2010 prices). In comparison, flood claims for the UK following the 2007 floods were estimated to be £3.2bn (Environment Agency – although not only from surface water flooding). As such, the implications of such an event effecting the Greater London area would be very severe.

The GLA (ibid.) also report that most drainage systems are designed to cope with a 1/30 year storm event but as maintenance is often poor some parts of the network may perform below this standard, also increasing the risk of surface water flooding.

5. Adaptation at a household level: In addition to the standard MCM depth-damage functions information can be incorporated to consider potential adaptation options and the additional issue of water contamination. This is important as contamination has the potential to increase damages significantly (Messner et al., 2007). Based on the study by Thieken et al., (2008), which collated large datasets of flood losses and influencing factors in Germany, property level measures (PLM)
and contamination of flood water can be factored into the damage estimates to provide an illustrative example of additional costs/benefits. Additionally, in the MCM it is reported that flood incidents are accompanied by significant emergency costs such as additional expenditure due to increased demand for police, fire and ambulance services. It has been estimated that these are equivalent to 10.7% of property damages (Penning-Rowsell et al., 2010). Figure I.6 illustrates the additional increase in cost if emergency costs are included.
Figure I.6: The additional increases in cost

and the effects of medium and high levels of water contamination. Thieken et al., (2008) estimated that water contamination could increase costs by 20-58%, depending on the level of contamination, resulting in residential damages of up to 3.5bn for high level contamination during a 1/200yr event. On the other hand medium or high levels of household preparedness could reduce costs by £620 million and £1bn for 1/30yr flood events. Links could be established between specific property level responses and the estimated benefits.

6. **Linking the DrainLondon maps to output from the Spatial WG**: Estimated economic costs (in this example for residential buildings) can be aggregated for each of the spatial WG gridcells for each return period. For example, the aggregate cost per grid cell in terms of economic damage to residential building fabric and contents of 1/30yr surface water flooding in Greater London is shown in figure I.7 as total costs to building fabric and contents, and as the average cost per building in each grid cell.

This data is linked with the precipitation levels previously defined for each grid cell and return period (table 1), and used to look up the damage per grid cell associated with precipitation events in the baseline time period and for the 2030s and 2050s of a given return level. Damages can then be compared across the different scenarios (for the future scenarios it is assumed that there is no change in the spatial pattern of residential buildings or the number of buildings).

Diagram I.8 shows the total damage to residential buildings (both building fabric and contents) against the number of grid cells affected per daily event. Results
are for the 1/30 year return period, calculated using baseline, 2030 High and 2050 High scenarios. Some summary results are shown in the table below.

Once the above processes has been repeated for 1/100 and 1/200 year return periods damage per time-period and grid cell will also be aggregated across all events and return periods to get the EAD. Spatial maps can then be created in ARCGIS showing the change in EAD from the baseline period with and without various adaptation options in terms of household property level measures, and with and without water contamination.

Benefits can be postulated based on the assumed assumption that e.g. drainage systems will be upgraded to cope with 1/100yr return periods rather than 1/30 years.

A sensitivity ‘what-if’ analysis can be carried out making assumptions about the potential influence of SUDS on changes in flood depth.
Figure I.8: Total damage to residential buildings against the number of grid cells affected per daily event

The above will also be repeated for commercial properties and also include a sensitivity analysis assuming that floor space remains unchanged and assuming the future floor-space calculated in the CASA model extends the current building footprints.

Sources used:

- THIEKEN, A. H., ACKERMANN, V., ELMER, F., KREIBICH, H., KUHLMANN,
Appendix J. Flood protection measures

When looking at flood protection measures against water surface flooding, a distinction can be made between protection at the household level (PLPMs) and protection at a larger scale, outside the household level (flood defences).

J.1 PLPMs

In the model the investing in protection at the household level will be done in a general sense. There are quite some possibilities to protect ones own house against surface water flooding. In this model all these investments are taken together into a single investment, following the summary report of JBA consulting [JBA Consulting, 2012] on the PLPM scheme of DEFRA, that provides a good look into PLPM investing and policies on it in the UK. These PLPM investments include both flood resistant (preventing or reducing the amount of water that gets inside the house) and flood resilient (reducing the damage water causes when water gets inside a house) PLPMs.

The assumption of it being a single investment is in line with what happens in the real world. Persons often decide at a given point that they want to invest in PLPMs. This will often be after a flood, but does not have to be. Furthermore many PLPM investments are small adaptation to a house, but are quite a nuisance for the person living in the house. This means that when person decides to invest in PLPMs he will often choose for several adaptations at once so that the effect is larger and the overall nuisance is smaller. On top of this investing in this way is often also more cost effective.

According to figures in Harries [2012] as taken from figures of DEFRA outlined in the summary report on the DEFRA PLPM scheme [JBA Consulting, 2012], the cost of such investments in PLPMs are between 3,000 and 10,000 pounds.

Data coming from a study by Thurston [2008] gives a benefit of 65% damage reduction for an investment of £3000 and 85% benefit for an investment of £10,000. A study by Thieken [2008] which provides scaling factors for high and medium levels of PLPMs and water contamination, shows similar values.

Given the above the following values and assumption are made for modelling PLPMs

- Investing in PLPMs costs between the 3,000 and 10,000 pounds
- PLPMs reduce damages done by flooding by 75%
J.2 Flood defences

When it comes to flood defences the choice lies different than with PLPMs. Many of the common flood defences (like dikes) are effective against river/coastal flooding. The case of water surface flooding is different however. Dikes can not be used to protect houses against surface water flooding seeing the flood comes from above (rain) and not from the sides. This limits the options for flood defences to choose from.

Research into flood defences have provided 3 kinds of possible flood defence methods; green roofing, sustainable urban drainage systems (SUDS) and expanding sewers. The problem however is that for all these 3 options almost no information could be found. Katie Jenkins, who provided a lot of data for this research, helped to find information on this subject by talking to other researchers she knew, but she also came up almost empty handed. The only method that showed some positive results and for which some information could be found were SUDS.

The data on SUDS however was also often case specific and focused on new builds and not on urban retrofitting. However, both retrofitted and new SUDS have been demonstrated to be cost effective [Department for Environment, Food and Rural Affairs, 2011] & [Environment Agency, 2007]. The Environment Agency (2007) have highlighted benefits of retrofit in certain localities, particularly for use of permeable paving and water butts. A reduction in run-off to connected areas is assumed to have a linear impact on flood events, up to a reduction of up to 10% which results in a reduction in flood events of 90%. For new developments DEFRA (2011) consider a range of options for the implementation and coverage of SUDS. The option covering all major and minor developments (1 or more dwellings) resulted in the best benefit to cost ratio (3.2:1), and provides most coverage as minor developments make up over 90% of planning applications. When considering new developments DEFRA (2011) assumed that SUDS could reduce flood damage by up to 35%.

Evidence suggests that SUDS are cheaper to build (up to 30%), than traditional drainage systems, addressing the concern of some developers that SUDS give rise to significant costs. This will be case specific, but even in complex cases costs are only assumed to be up to 5% higher than traditional drainage system costs. As such, it is assumed that SUDS will be no more expensive than conventional drainage in the DEFRA CBA. For urban retrofitting however there is very little data on the cost. Taking an
average of some data that was available, the assumption is made now that the cost of retrofitting a house is 2000 pounds.

Results so far suggest that on average 38% of minor developments and 58% of major developments are now being built 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 new build houses are not yet build with SUDS.

Given the above the following values and assumption are made for modelling flood defences:

- SUDS will be the chosen flood defence method to model
- 50% of new build houses will be build with SUDS in place to no extra cost
- Retrofitting houses with SUDS costs 2000 pounds per house
- SUDS reduce damages done by flooding by 35%
Appendix K. The way protection measures influence flood consequences

Appendix H shows the choices made and the way flooding will be modelled in the FloodRe model. Based on this a choice will have to be made on how flood protection methods lower the damages a modelled flood do to houses. The choice is made to model 4 floods (including no flood) for which data is available on the damages done to the houses by this flood. There are different ways flood protection can lower the damage done by a flood. Looking back at the surface water exceedence curve, figure H.1, flood protection can lower the damage shown within this curve in two simplified ways, as shown in figure K.1.

The green, damage with protection 1, line shows how flood protection can lower the damages done by a flood if the method would reduce damage over all flood-return periods. If a flood protection measure lowers flood damage by 50%, this would mean that over the whole line the damage goes down by 50%. A 1 in 30 flood would do 100 instead of 200 damage and a 1 in 200 flood would do 500 instead of 1000 damage. The purple, damage with protection 2, line shows how flood protection can lower the damage done by a flood if the method would focus on low flood return period floods. These kinds of method focus on eliminating the damages down by smaller floods, but do not have much effect against larger floods.

Both lines do not fully present the real world, it however does give a good insight into how different methods can work in different ways. In reality ever method will have

![Surface water flooding exceedance curve with protection measures](237)
Appendix K The way protection measures influence flood consequences

a different way it reduces damage which will often lie somewhere in between the two graphs. The damage done by lower level flood return periods are lowered more than that of higher level flood return periods. This is especially true for surface water flooding protection, seeing it has to deal with chaining flood patterns on chaining positions. A flood protection measure like a dike will stop all lower level flood protection measure, but if it is over-topped the damage will often almost be just as high as if the dike wouldn’t have been there.

For the FloodRe model a simplified way of modelling flood protection is chosen however. The choice is made to make flood protection lower the damage equal over all flood return periods because this will give the simplest insights into the effect of flood protection. For future research it will definitely be recommended to look at different ways flood protection lowers damages to see what the effect of this assumption we made now are.
Appendix L. Tables of data input

As input to the model a lot of data has been used. The data that is used can be split up in 3 types: GIS data, Values and distributions.

L.1 GIS data input

The area that will be investigated is set up using GIS data. All GIS data that is used in the model was provided by Katie Jenkins. By importing GIS data in the model the following data and values for the model are set:

- **Model area**: Provides the outlines of the modelled area. The outer lines of the Camden area and the general outlay of the housing grid. This data is coming from the London Datastore [London datastore, 2013].
- **House information**: Gives data on locations, type and build year category of the initial houses in the model. This data is coming from the GeoInformation group [The GeoInformation Group, 2014] An important note to make with this GIS data is that it is data that is based on spatial foot prints of the houses. This means that a flat will count as a single house in which a single person will live. Given the goal of the model, looking at the consequences of flooding, this is not a problem seeing higher levels of a flat will most likely not be flooded anyway. This is still an important thing to keep in mind though when looking at the model. Because of the use of footprint the model of Camden also only has 23,545 houses in it, and not 102,703 houses as the data suggests. This comes of course from flats (and terraced and semi-detached) being seen as a single house in the model. For the rest of the model the use of footprints instead of all houses only has effect on the property taxes that the local government will receive to build flood defences. Seeing we have no insight in how much of the property taxes they spent on flood defences and assumption are made for that now, there is no problem that this won't be right.
- **Average incomes in areas**: Provides income data for all initial houses in the model. This data can be transferred to the person moving into the house. This data is coming from ONS small area model based income estimates [Office for National Statistics, 2014d]
- **Flood event data**: Provides 3000 years of flood event data for 5 separate areas within Camden. The data is modelled externally using urban version of the
UKCP09 spatial weather generator: "Hourly precipitation time-series data for 30 year stationary sequences are taken from the WG for each grid cell in the study area. These series are generated 100 times each based on a different randomly sampled vector of change factors, to allow probabilistic analysis. Data is generated for the baseline period (1961–1990) and for the 2030s and 2050s under high and low emission scenarios (equivalent to the IPCC SRES B1 and A1FI scenarios). In order to assess surface water flood risk the first step is to calculate the return level of extreme precipitation events for 1/30, 1/100, and 1/200 year return periods from the baseline data. To calculate the recurrence interval the daily annual maximum (one day duration) series (AMS) is derived from the 100x30 year precipitation times-series data for each grid cell. Extreme Value Analysis (EVA) is used to calculate the return levels for each return period. The Generalised Extreme Value (GEV) distribution function is fitted to the AMS. EVA allows the probability and return levels of extreme events to be determined, for return periods exceeding that of the original data series, and even if events are more extreme than exists in the data series (Sanderson, 2010). For each return period the GEV distribution allows the equivalent return level to be determined for each grid cell. This gridded data provides the precipitation thresholds above which surface water flooding of a given return period would be assumed to occur in each grid cell.” (Quote from Katie Jenkins). Description of the spatial weather generator and further references available in Jenkins et al. [2014]

• **Flood damage values**: Provides flood damage values for all initial houses for each modelled flood event (1 in 30, 1 in 100 and a 1 in 200 year flood). The values are calculated externally based on.
  - MCM Depth Damage Functions: Multi-Coloured Manual (MCM), for short (<12hr) duration floods [Penning-rowsell, 2010]
  - DrainLondon flood risk maps - surface water flood depth maps for Greater London based on precipitation data, topographic data and information on the surface water drainage system [Greater London Authority, 2011a]
  - UKBuildings residential building class dataset [The GeoInformation Group, 2014]

• **Opportunity areas**: Provides outlines of opportunity areas within Camden where developers can build new housing projects. This data is coming from the Greater London Authority [Greater London Authority, 2011b]. This data provides
details on specific areas available from Camden Council Core Strategy 2010-2025 [District of Camden, 2010]. Note: the data itself is not GIS data, but it is used to drawn outlines in GIS to be used in the model.

The nice thing about using GIS data in this way is that different areas can also be investigated using the same model. If an area with similar behaviour (or different behaviour and the model needs to be adjusted a bit) wants to be investigated. GIS data simply has to be provided and loaded in the model, and this area can be investigated.

L.2 Value data input

Besides GIS input, a lot of data sources have also been used to get values for states in the model. These could be set values to stay the same throughout the model run, but could also be initial values that change during the model run.
<table>
<thead>
<tr>
<th>#</th>
<th>Data</th>
<th>Camden parameter value</th>
<th>Source</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Percentage of houses for sale at the start</td>
<td>2.3%</td>
<td>Of the total 102,703 houses in Camden [London Datastore, 2014b]</td>
<td>Assumption based on data on sold houses, not on total houses on market. However, current properties in market = 2,130 so seems a reasonable assumption</td>
</tr>
<tr>
<td>2</td>
<td>Mortgage interest</td>
<td>3%</td>
<td>London Datastore [2014a]</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mortgage term</td>
<td>25 years</td>
<td>BBC [2014]</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Owner warning time</td>
<td>3 year</td>
<td>Because no real data can be found on this, the value of Putra (3 years) is taken. It is unclear where Putra found this value and is therefore likely also an assumption he made</td>
<td>Putra assumption</td>
</tr>
<tr>
<td>6</td>
<td>Number of trade actions</td>
<td>30</td>
<td>Because no real data can be found on this, the value of Putra (30) is taken. It is unclear where Putra found this value and is therefore likely also an assumption he made</td>
<td>Putra assumption</td>
</tr>
<tr>
<td>7</td>
<td>Housing ratio increase</td>
<td>5%</td>
<td>Based on data the mortgage ratio of a person can be sort of calculated. The housing ratio we have no data at all on. The housing ratio needs to be a bit higher than the mortgage ratio because it is the mortgage fee ± a few small fees more. For now I assumed it is 5% higher</td>
<td>Own assumption. Elaboration on sensitivity needed</td>
</tr>
<tr>
<td>8</td>
<td>Average number of incomes as down payment</td>
<td>3.05</td>
<td>[Office for National Statistics, 2014a]</td>
<td>No data available specific for Camden, so this will be OK for now</td>
</tr>
<tr>
<td>9</td>
<td>Average percentage sell price</td>
<td>25%</td>
<td>Because no real data can be found on this, the value of Putra (25%) is taken. It is unclear where Putra found this value and is therefore likely also an assumption he made</td>
<td>Putra assumption</td>
</tr>
<tr>
<td>10</td>
<td>Average profit percentage</td>
<td>10%</td>
<td>Because no real data can be found on this, the value of Putra (10%) is taken. It is unclear where Putra found this value and is therefore likely also an assumption he made</td>
<td>Putra assumption</td>
</tr>
<tr>
<td>11</td>
<td>Land value percentage</td>
<td>50%</td>
<td>Because no real data can be found on this, the value of Putra (50%) is taken. It is unclear where Putra found this value and is therefore likely also an assumption he made</td>
<td>Putra assumption</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>229,700 population of Camden [District of Camden, 2014]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10.6% of Camden population immigrates</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Office for National Statistics, 2014b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Calculated that is 4.7% of houses</td>
</tr>
<tr>
<td>13</td>
<td>Percentage of movers</td>
<td>2.7% of all houses</td>
<td>[Office for National Statistics, 2014c]</td>
<td>102,703 houses in Camden [London Datastore, 2014b]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>229,700 population of Camden [District of Camden, 2014]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.1% of Camden population moves</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Office for National Statistics, 2014c)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Calculated that is 2.7% of houses</td>
</tr>
<tr>
<td>14</td>
<td>Flood risk consider probability</td>
<td>57%</td>
<td>[Home Check, 2012]</td>
<td>Know Your Flood Risk - A recent survey conducted by the Know Your Flood Risk campaign revealed that just over half of people (57%) would investigate the flood risk of a property they considered buying in the future</td>
</tr>
<tr>
<td>15</td>
<td>No selling decrease value percentage</td>
<td>25%</td>
<td>Because no real data can be found on this, the value of Putra (25%) is taken. It is unclear where Putra found this value and is therefore likely also an assumption he made</td>
<td>Putra assumption</td>
</tr>
</tbody>
</table>

Table L.1: Table of data input (1)
<table>
<thead>
<tr>
<th>#</th>
<th>Data</th>
<th>Camden parameter value</th>
<th>Source</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Inflation percentage</td>
<td>3.9%</td>
<td>[Office for National Statistics, 2014c]</td>
<td>Results for Inner London used to present Camden. Based on changes in real household disposable income from 2011-2012.</td>
</tr>
<tr>
<td>17</td>
<td>Percentage of proactive PLPM investors</td>
<td>1%</td>
<td>Assumption based on personal communication with Jim Hall</td>
<td>Tim Harries Harries [2012] stated a value of 9% in 2014. This is too high though seeing that up till not not much houses have installed PLPMs in the UK. For now a value of 1% is assumed (Personal communication Jim Hall). Changing it will increase the number of PLPMs every year, but will most likely change the behaviour of the model.</td>
</tr>
<tr>
<td>18</td>
<td>Percentage of reactive PLPM investors</td>
<td>34%</td>
<td>Harries [2012]</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Cost of PLPMs</td>
<td>£13,000 – 10,000</td>
<td>JBA Consulting [2012]</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>PLPM investment flood protection benefit</td>
<td>25-34%</td>
<td>Thurston [2012]</td>
<td>百合</td>
</tr>
<tr>
<td>22</td>
<td>Cost of flood defences</td>
<td>£2000</td>
<td>No good data can be found on this. An assumption of £2000 is made now.</td>
<td>Own assumption. Expert communication. Sensitivity analysis can be interesting.</td>
</tr>
<tr>
<td>24</td>
<td>Initial flood insurance excess percentage</td>
<td>1%</td>
<td>Personal communication in meetings on the 17th of December in London.</td>
<td>Expert communication. Sensitivity analysis can be interesting.</td>
</tr>
<tr>
<td>25</td>
<td>Flood excess increase because of flooding</td>
<td>1/3</td>
<td>Personal communication from DEFRA in a meeting on the 17th of December in London.</td>
<td>Expert communication. Sensitivity analysis can be interesting.</td>
</tr>
<tr>
<td>26</td>
<td>Maximum acceptable loss ratio</td>
<td>0.6</td>
<td>No real data can be found on this, the value of Putra (0.01) is taken. It is unclear where Putra found this value and is therefore likely also an assumption he made.</td>
<td>Putra assumption</td>
</tr>
<tr>
<td>27</td>
<td>Base flood insurance premium</td>
<td>50%</td>
<td>Own assumption.</td>
<td>Own assumption. Elaboration on sensitivity needed</td>
</tr>
<tr>
<td>28</td>
<td>Percentage of land sales used for flood investments</td>
<td>0.05%</td>
<td>Own assumption (backed up by Jim Hall).</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Percentage of property taxes used for flood investments</td>
<td>0.05%</td>
<td>See above</td>
<td>See note above</td>
</tr>
<tr>
<td>30</td>
<td>Maximum fraction of value at risk</td>
<td>0.45</td>
<td>Based on identification of flooded houses (see data sources on ‘flood damage values’ above)</td>
<td>Own assumption. Expert communication. Sensitivity elaboration not needed now because its not an important factor for the model behaviour.</td>
</tr>
<tr>
<td>31</td>
<td>Minimum houses in flood defence portfolio</td>
<td>100</td>
<td>Assumption: no data available</td>
<td>Own assumption. Expert communication. Sensitivity elaboration not needed now because its not an important factor for the model behaviour.</td>
</tr>
<tr>
<td>32</td>
<td>Number of project in flood defence portfolio</td>
<td>100</td>
<td>Assumption: no data available</td>
<td>Own assumption. Expert communication. Sensitivity elaboration not needed now because its not an important factor for the model behaviour.</td>
</tr>
</tbody>
</table>

Table L.2: Table of data input (2)
<table>
<thead>
<tr>
<th>#</th>
<th>Data</th>
<th>Camden parameter value</th>
<th>Source</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>Wanted benefit-cost ratio</td>
<td>5:1</td>
<td>JBA Consulting, 2012</td>
<td>Projects funded by the Flood Defence Grant must achieve a cost benefit ratio of 5 to 1.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Environment Agency, 2009</td>
<td>raid ES 5:1 average ratio across programme is the economic requirement for flood risk investment</td>
</tr>
<tr>
<td>34</td>
<td>Development approval ratio</td>
<td>1</td>
<td>Own assumption.</td>
<td>Own assumption. Blaketon on sensitivity needed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Assumed to be 1 for now, no data. A ratio of 1 indicates that a development is OK when value at risk is same as income of the project.</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Income-cost ratio for development</td>
<td>20%</td>
<td>Wainwright, 2014</td>
<td>Not the best source. But for now time can be spent better than searching for a better source for this. Income and cost have no influence on developer behaviour in current model.</td>
</tr>
<tr>
<td>36</td>
<td>Build time</td>
<td>8 months</td>
<td>Homebuilding &amp; Renovating, 2013</td>
<td>Not the best source. But for now time can be spent better than searching for a better source for this. Income and cost have no influence on developer behaviour in current model.</td>
</tr>
<tr>
<td>37</td>
<td>FloodRe levy</td>
<td>2.2%</td>
<td>Association of British Insurers, 2014</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>FloodRe insurer cost</td>
<td>A = £220</td>
<td>Tax band A – G: Department for Environment, Food and Rural Affairs</td>
<td>Tax band H: Christie [2014]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B = £210</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C = £246</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>D = £276</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>E = £330</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>F = £408</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>G = £540</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>H = £540</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table L.3: Table of data input (3)
L.3 Distributions used for data input

Within the model also some distributions are used. The distributions that are used are presented in table L.4. The main goal of these distributions was to deviate from averages for some values. Values that are set to all persons or houses in the model and that only have a single set value are not representable for the real world. Not every person has the same income, or use the same values on their reasoning. For this reason some values are assigned to persons by sing a distribution over the average, better representing the real world situation.

<table>
<thead>
<tr>
<th>Data</th>
<th>Note</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income</td>
<td>Normal distribution with a standard deviation based on the provided upper and lower bound in the GIS data</td>
<td>GIS data, see paragraph L.1</td>
</tr>
<tr>
<td>Number of incomes as down payment</td>
<td>Normal distribution with a standard deviation of 5% of the average</td>
<td>No source, 5% assumed as a simple way to deviate on the set average value</td>
</tr>
<tr>
<td>Percentage sell price</td>
<td>Normal distribution with a standard deviation of 5% of the average</td>
<td>See source above</td>
</tr>
<tr>
<td>Profit percentage</td>
<td>Normal distribution with a standard deviation of 5% of the average</td>
<td>See source above</td>
</tr>
<tr>
<td>House value</td>
<td>Normal distribution with a standard deviation of 5% of the average</td>
<td>See source above</td>
</tr>
</tbody>
</table>

Table L.4: Distributions used in the model
Appendix M. Flood risk calculation

This appendix will elaborate on how flood risk is calculated within the model. Because the model is created to look into how homeowners react to a changing insurance market, and flood risk are an important part of insurances, it is important flood risk will be calculated in a correct manor in the model to make the model provide useful output. The flood risk will be calculated based on the way it is explained in the book ’Applied Uncertainty Analysis for Flood Risk Management’ [Beven & Hall, 2014]

For calculating flood risk the following formula is given:
• In any given year (t), the risk, \( R_i,t \) is given by: 
  \[
  R_i,t = \int_0^{\infty} D(x_t) f(x_t) dx_t
  \]
  ⊗ \( t \) = the year in which it happens
  ⊗ \( D(x_t) \) = a damage function in which it is expected \( x \) changes over the years
  ⊗ \( f(x_t) \) = the probability distribution for the source of flooding

This function will be filled in based on the information that is available within the model. Based on GIS data every house in the model was assigned a flood damage value for three separate flood return periods: 1 in 30 year, 1 in 100 year, 1 in 200 year. So this gives us 3 data points with a probability and a damage for every house in the model. By filling in these point in a probability-damage graph and by making a few assumption, the following probability-damage graph can be made for each house M.1.

The following assumptions are made to make this probability-damage graph. These assumption are made in collaboration with Jim hall, the author of the book these risk calculation are based on.

• The damage-probability function is assumed to be linear between the known damage points

![Figure M.1: Full damage-probability graph](image)
• Because the damage probability function is an exponential function that will never have probability of zero (even a 1 in 10000 year flood has a probability of 1/10000) an assumption needs to be made where the damage-probability function touches the 0 probability line. The damage at probability ‘0’ is assumed to be at the maximum damage a flood can do to a house. Because there are many factors involved in what this maximum damage is (type of house, emotional damage, etc.) no clear data can be found on this value. Jim Hall, whose formula is used here and who is an expert in this area, suggested to assume a value of 20% of the building value of the house for now (personal communication, Jim Hall, 12-12-2014).

• For the horizontal tale an assumption also needs to be made. Initially the assumption will be made that the slope of the line between the 2 damage points of 1 in 100 an 1 in 30 year will be continued to the zero damage line (see solid line in the graph right of the 1 in 30 damage-probability point). However since damage between the 1 in 30 and 1 in 100 points can be almost equal (which will mean an endless horizontal tale) a max needs to be put on it. Sine it is unlikely that persons will be hit with a flood more than once every 2 years (1 in 2 year flood, 50% probability), the line will always at a maximum slop to the 50% probability (the theoretical dotted line in the graph if the damage difference between the 1 in 100 and 1 in 30 flood would be less).

What can be seen clearly in the full damage-portability graph is the large tails of the graph, both vertical and horizontal. Following the formula, as specified above, the flood risk that we want to calculate is equal to the space under the graph. Because Netlogo is a discrete modelling tool the space under the graph will have to be calculated n a discrete way. This can be done in the form of a summation. To illustrate how it is done, M.2 shows the damage-probability graph with both it tails cut off to just show the important part where the calculations are made. It shows where the damage and probabilities are of the three flood return periods of which we have data. The red line shows the damage-probability curve as we assumed it (with linear lines between points). The flood risk will be calculated by adding up the spaces gray spaces (for the tails these gray spaces can continue further than shown here). Each box that is connected to a line is equal to the space underneath it because... The size of the boxes is equal to the width of the box (distance between two two probabilities) times the hight of the box (the halfway point on the line for which the box is calculated).
So for instance if we want to calculate the space under the line that goes from a 1 in 100 year flood to a 1 in 200 flood, we simply multiply the width of the box (the probability of a 1 in 100 year flood - the probability of a 1 in 200 year flood) with the height of the box ((the damage of a 1 in 100 year flood + the damage of a 1 in 200 year flood) / 2).

To calculate the full flood risk, all the sizes of the boxes need to be added up. If we take the probabilities of the flood return periods and give the flood return periods the following dummy data for damage; a 1/30 flood = 1000 damage, a 1/100 flood = 3000 damage, a 1/200 flood is 8000 damage and we give a dummy value of 100.000 pounds as a house value for the house we calculate if for, the following calculations will be made for the flood risk:

- First we have to calculate the probability where the damage will be 0, this is at the point where the line between the 1 in 100 flood and 1 in 30 flood crosses the line if continued linear. In this case the line went from damage 3000 to damage 1000 in a probability difference of 0.233 and it needs to cover another 1000 damage (from damage of a 1 in 30 year flood to 0 damage). To cover this extra 100 the following probability gets added 
  \[(0.0233 \times 1000) / 2000 = 0.01165\].
  This needs to be added to the probability from which it was calculated, the 1 in 30 probability, which gives a probability of 
  \[0.01165 + 0.033 = 0.04465\].
• The damage under this line (from a 1 in 100 damage to the 0 line) is then equal to $(0.04465 - 0.01) \times \left(\frac{0 + 3000}{2}\right) = 52$
• $(0.01 - 0.005) \times \left(\frac{3000 + 8000}{2}\right) = 27.5$
• $(0.005 - 0) \times \left(\frac{8000 + (0.2 \times 100000)}{2}\right) = 70$
• Adding these numbers up gives a flood risk of 149.5
Appendix N. Assigning Council tax band and tax fee

This document was provided to me by Katie Jenkins of the ENHANCE project. Below is a literal copy of what I received from her.

Every home has to be placed within a band for council tax purposes. Which band a property falls in is based on a property valuation. The basis of valuation for a dwelling (which is not used for any business purpose) is the amount which, subject to certain assumptions, it would have sold for, on the 'open market' by a 'willing vendor' on 1 April 1991 in England. Council Tax came into affect on 1 April 1993. However, the process of valuing every domestic property in England and Wales for banding purposes started some time before this. Therefore, a valuation date prior to 1 April 1993 was adopted so that all properties would be valued on a common footing. Even if a property was built after 1 April 1993, the property is banded according to what the value would have been on 1 April 1991 N.1

<table>
<thead>
<tr>
<th>Valuation Band</th>
<th>Value (1991)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&gt; 40,000</td>
</tr>
<tr>
<td>B</td>
<td>&gt; 40,001 - 52,000</td>
</tr>
<tr>
<td>C</td>
<td>&gt; 52,001 - 68,000</td>
</tr>
<tr>
<td>D</td>
<td>&gt; 68,001 - 88,000</td>
</tr>
<tr>
<td>E</td>
<td>&gt; 88,001 - 120,000</td>
</tr>
<tr>
<td>F</td>
<td>&gt; 120,001 - 160,000</td>
</tr>
<tr>
<td>G</td>
<td>&gt; 160,001 - 320,000</td>
</tr>
<tr>
<td>H</td>
<td>320,001 &gt;</td>
</tr>
</tbody>
</table>

Table N.1: Valuation Bands England, 1991

However, this means that recent sale prices are not necessarily a good guide to the correct band for a property. It has not been possible to find detailed data on the property values and tax bands of properties in Camden and Croydon. We do have data on average property values per build type (comprising detached, semi-detached, terraced properties, and flats) for the areas N.2. Data is also available on the percentage of properties in each band N.3.

As such, a simple assignment of council tax bands can be made to properties based on the average values of property types. So, 14.2% of properties in Camden will be randomly...
Appendix N Assigning Council tax band and tax fee

<table>
<thead>
<tr>
<th>Average value per build type</th>
<th>Camden)</th>
<th>Croydon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detached</td>
<td>£3,756,152</td>
<td>£633,151</td>
</tr>
<tr>
<td>Semi-detached</td>
<td>£2,362,440</td>
<td>£364,760</td>
</tr>
<tr>
<td>Terraced</td>
<td>£1,667,644</td>
<td>£301,002</td>
</tr>
<tr>
<td>Flat</td>
<td>£756,163</td>
<td>£222,883</td>
</tr>
</tbody>
</table>

Table N.2: Average property values per build type

<table>
<thead>
<tr>
<th>Council Tax Bands</th>
<th>Camden</th>
<th>Croydon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band A or B</td>
<td>14.2</td>
<td>15.8</td>
</tr>
<tr>
<td>Band C/D/E</td>
<td>59.7</td>
<td>71.0</td>
</tr>
<tr>
<td>Band F/G/H</td>
<td>26.1</td>
<td>13.3</td>
</tr>
</tbody>
</table>

Table N.3: Percentage of properties in each band. Source: DCLG Website

assigned equally across Bands A and B, weighted first by properties of type flat. 59.7% of properties will be assigned equally across bands C, D and E, and weighted first by flats, and then terraced and semi-detached properties, and then 26.1% of properties assigned equally across bands F, G, and H, and including detached properties. This should provide some spatial pattern of bands across the study area. This will also reflect the different make-up of the study areas N.4. For example, in Camden flats will make up the majority of property types in Bands A-E, whereas for Croydon there will be a broader spread across property types.

<table>
<thead>
<tr>
<th></th>
<th>Camden)</th>
<th>Croydon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Detached</td>
<td>1.9</td>
<td>12.5</td>
</tr>
<tr>
<td>% Semi-detached</td>
<td>4.1</td>
<td>25.1</td>
</tr>
<tr>
<td>% Terraced</td>
<td>8.8</td>
<td>26.1</td>
</tr>
<tr>
<td>% Flat</td>
<td>85.2</td>
<td>36.3</td>
</tr>
</tbody>
</table>

Table N.4: Percentage of properties in Camden and Croydon (Source: London data store)

Based on the council tax bands the following values for the council tax (property tax) can be assigned:
<table>
<thead>
<tr>
<th>Council Tax Band</th>
<th>Camden</th>
<th>Croydon</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>880.32</td>
<td>980.26</td>
</tr>
<tr>
<td>B</td>
<td>1,027.04</td>
<td>1,143.64</td>
</tr>
<tr>
<td>C</td>
<td>1,173.76</td>
<td>1,307.02</td>
</tr>
<tr>
<td>D</td>
<td>1,320.48</td>
<td>1,470.39</td>
</tr>
<tr>
<td>E</td>
<td>1,613.92</td>
<td>1,797.14</td>
</tr>
<tr>
<td>F</td>
<td>1,907.36</td>
<td>2,123.90</td>
</tr>
<tr>
<td>G</td>
<td>2,200.80</td>
<td>2,450.65</td>
</tr>
<tr>
<td>H</td>
<td>2,640.96</td>
<td>2,940.78</td>
</tr>
</tbody>
</table>

Table N.5: Annual Council Tax 2014/15 (£)
Appendix O. Repair and Renewal Grants

This document was provided to me by Katie Jenkins of the ENHANCE project. Below is a literal copy of what I received from her.

Homeowners that have been flooded may consider whether they might be eligible for a flood resilience grant.

Grants are intended only to fund measures which improve the properties resilience or resistance to flooding, over and above repairs that would normally be covered by insurance. Where resilient repairs can be provided at the same cost as standard like-for-like repairs, insurers should act to encourage take-up as part of the standard reinstatement process.

However properties will not be eligible if they are due to benefit from a planned flood risk scheme (the Environment Agency must have announced plans for the scheme and be due to complete it within the next five years i.e. before December 2018). The details of the process are still being worked on. Only works identified through surveys carried out by professionals will be covered by the grant. The grants made available will be up to £5,000 (to include the cost of the survey), depending on whether the survey identifies sufficient appropriate resilience measures.

Croydon Council will be adopting a local scheme and decide case by case whether grant can be awarded and at what level. Repair and renewal grants will also be adopted by Camden. The council also offer advice to residents on managing flood risk.

Sources:
Appendix P. Full schematic model layout

Figure P.1 shows the full schematic model layout with all states, actions and interaction within the model.

**Figure P.1:** Schematic model layout - Full
Appendix Q. Full schematic model layout with FloodRe Added

Figure Q.1 show the full schematic model layout with all states, actions and interaction within the model with FloodRe added. The states, actions and interactions that were added with the adding of the FloodRe system are shown in green. The states, actions and interactions that were changed are shown in orange.
Appendix R. Data analysis

In this appendix the data analysis that is done is presented. The data that is gathered from the experiments that are ran is analysed using the data processing program R. With this the large sets of data are made understandable by plotting regression lines through the data. In this way the general patterns that the data show can be seen and insights based on this can be gathered on the behaviour of the model.

R.1 Choice in presentation of data

Because of the large data sets and many measurements the choice is made not to show the data itself, the data points, but just the regression lines. The regression lines that are made are based on the "Loess" method in the ggplot2 package of R. 'Loess' is not an initialism itself but is coming from the initialism of a very similar technique, Lowess, which stands for LOcally WEighted Scatterplot Smoothing [Iowa State University]. With the Loess method a regression line is approximated using locally weighted regression. The process is local because "each smoothed value is determined by neighbouring data points defined within the span. The process is weighted because a regression weight function is defined for the data points contained within the span" [Iowa State University]. The only difference between Lowess and Loess is that Loess uses a quadratic polynomial instead of a linear.

The choice was made for this type of regression line approximation because the data that is analysed can vary quite a bit from step to step. It can for instance be 0 for a few years and then jump to a high value all of a sudden. In these kinds of cases many regression approximations, like a normal quadratic polynomial regression line, will not show the right pattern seeing they try to find a fitting pattern over all values. By using a locally approximated regression line the data in which sudden changes occur is shown better.

That the data points are not shown does not mean they are not analysed. Just looking at regression lines alone is dangerous seeing very locally changes will never properly be shown, also not with the Loess method. However no data was found that was not properly approximated by the Loess method regression lines.

The last thing that has to be mentioned here is that all averages that are calculated and shown in the data analysis below are calculated over all houses/persons in the model. So this often also includes the houses not in flood risk. This is done because the
complete housing market wants to be analysed, not just the flood risk part. If averages are calculated over any other seduction of houses/persons, for instance only houses in flood risk, it will be clearly mentioned.

**R.2 Confidence and significance of the results**

In plotting regression lines R also provides the possibility to automatically plot a confidence interval for a regression line. Because of the complexity of the model, the variability the model can show and the underlying goal of this data analysis, gaining confidence in the way this model presents the situation that is modelled, a choice is made to plot a confidence interval with a 99% confidence level. In this way it can be said with quite certainty that, given the model choices and assumptions, the true value of the parameter is within the given confidence interval.

Based on the regression lines together with the confidence intervals the represented data can often already be judged on the significance of it. Regression lines lying far apart with no overlap in confidence interval already give a clear indication of a significant difference in values, showing a significant effect of a parameter change. However because the Loess method and its confidence interval are just a local approximation of the data and the differences can not always be clearly seen (data is different but close together) more significant test are performed for data sets in which the confidence is not clear.

Appendix S provides an elaboration on how the significance tests are performed. In the cases in which extra significance test are needed in the data analysis below only the results will be shown.

**R.3 Specific graphs**

First the parameter specific graphs will be looked at because they give information that can be used in understanding the graphs showing the effects the parameters have on the housing market
R.3.1 Houses re-insured in FloodRe

Figure R.1 shows that both protection measures lower the number of houses that have to be re-insured in FloodRe. PLPMs have a larger effect than flood defences because they lower the flood risk houses are in more than flood defences, as can be seen in R.18. When looking at the combined effect of the flood protection measures nothing special can be seen.

Important to note for these graphs is that the average is taken over all houses in the model. Seeing a starting value of around 51% can be seen and around 52% of houses in the model are in flood risk and build before 2009. This means that almost all houses that are eligible for FloodRe are re-insured in FloodRe.

![Diagram of Figure R.1: effects on the percentage of houses re-insured in FloodRe]
Appendix S elaborates on the significance of the results shown below. Significance test shows that the investing in PLPMs and the building of flood defences have a significant effect on the percentage of houses re-insured in FloodRe.

![Figure R.2: effects on the percentage of houses re-insured in FloodRe - 30 year run](image)

**Figure R.2:** effects on the percentage of houses re-insured in FloodRe - 30 year run

Graph R.2 shows the effect of flood protection measures on the percentage of houses re-insured in FloodRe for the '30 year multiple flood events' experiments that are run. Comparing this to the '10 year single flood event' runs, graph R.1c a similar effect can be seen. Because of protection measures the number of persons re-insured in FloodRe decreases. The increase in FloodRe insured persons in the end can not be explained but is sin line what can be seen in graph R.18d, an increase in premiums which is equal to an increase in FloodRe insured persons.

Because the reasons of doing these longer runs was to see if the same patterns show as in the shorter runs these unexplainable patterns in the end o runs is not something that will be looked into further in this research. Given the large increases that can be seen this is something that definitely comes from a mistake made in the model. This can be a small mistake that causes for a large chain reaction because all the interactions within the model. However to find this mistake another look needs to be taken into the specific of the model. Before further research will be done for longer time frame experiments this mistake needs to be taken out first. *Thesis writer note: Because I will also be the first person to do further research with this model this is something that does
not have to be fixed now. It is something I will definitely keep in mind and look into when I continue my research with this model.
R.3.2 FloodRe assets

Figure R.3 shows that in the runs in which flood events happen the FloodRe system has a large deficits. In the case of Camden (as presented in the model) the FloodRe system has an income of 4 million each year. However when a flood events happens the cost are around 30 times the income of a year.

<table>
<thead>
<tr>
<th>Flood return period</th>
<th>No flood</th>
<th>1 in 30 years</th>
<th>1 in 100 years</th>
<th>1 in 200 years</th>
</tr>
</thead>
</table>

![Graph showing FloodRe assets](image)

(A) PLPMs  (B) Flood defences  (C) All combined

**Figure R.3: effects on Floodre assets**

It is important to mention here that this is a very simple representation of the FloodRe assets, seeing the choice is made to have a single flood event happen at a given time in the model run. Also seeing almost 50% of all houses, almost 100% of houses in flood risk, are re-inured in FloodRe and the expectation is that for the real system only
1-2% of houses will be put in FloodRe, the proportions are off. So this does not tell us exactly how much money the FloodRe system will make or will need extra. It does however give an idea on the difference between the money going into FloodRe every year and the cost of a flood event for FloodRe.

It can be seen that the flood protection measures seem to have a positive effect on the FloodRe assets. This is logical seeing is houses are better protected less compensation have to be paid out from the FloodRe system. The difference are however not significant as can be seen from the overlapping confidence intervals and the t-test that is performed over all three flood event runs on the data comparing a run with only FloodRe to one with both protection measures active. Figure R.4 shows a one tailed p value that is higher than 0.01 which means the difference is not significant.

Graph R.5 shows the effect of flood protection measures on the FloodRe assets for the '30 year multiple flood events' experiments that are run. Comparing this to the '10 year single flood event' runs, graph R.3c a similar effect can be seen. All the years no flood event occurs the FloodRe assets increase, but the years there is a flood event the FloodRe assets decrease by a lot. Logically a larger effect of flood protection measures can be seen in the 30 year run than in the 10 year run seeing more flood protection is installed.
Figure R.5: effects on the FloodRe assets - 30 year run

**R.3.3 PLPM investments**

Figure R.6 shows the expected pattern for PLPM investing. In the first few years there is a steady stream of investments in PLPMs by proactive PLPM investors. However the real effect can be seen in year 6, the year after the flood event, when all reactive persons invest in PLPMs.

When looking at the effect the other parameters have on PLPM investing it can be seen that FloodRe has no effect on the percentage of persons that are investing in PLPMs. This is logical seeing PLPM investing is triggered by being in flood risk and a flood event effecting houses. FloodRe does not effect this, just insurance premiums. Also all parameters combined, so also adding flood defences compared to the FloodRe graph, shows no effect on the investments in PLPMs. This is also logical seeing flood defences lower the flood risk houses are in, but does not take the complete flood risk away. Being in flood risk and being hit by a flood is what triggers investments, no the height of the risk or the flood damage.

What has to be mentioned here is that the assumption that flood defences, and also PLPMs, only lower the flood risk a house is in is important. If a house is in little risk it can of course be possible that an investment in PLPMs or flood defences will decrease the risk to 0. This is however not modelled this way because the line at which this
Appendix R Data analysis

Figure R.6: effects on the PLPM investments

happens is not very clear and can be different for each house. But seeing the way it is modelled now is also not optimal this is something that can be looked at for further research.

Graph R.7 shows the effect of all parameters on the percentage of houses protected by PLPMs for the ’30 year multiple flood events’ experiments that are run. Comparing this to the ’10 year single flood event’ runs, graph R.6b a similar effect can be seen. Every year after a flood event the PLPM investments shoot up because reactive insurers invest in PLPMs. Besides this it can also be seen here that the parameters have no effect on PLPM investing.
R.3.4 Building of flood defences

Figure R.8 shows that the number of houses for which flood defences are build decreases over the years. This is logical seeing that in the start of the model there is the most opportunity for building flood defence projects in areas where there is a high flood risk. Because the best project with the highest benefit, so in the areas with the highest flood risk, are build first, projects will get a lower and lower benefit while the cost per house stays the same. Because of this less and less project will reach the wanted benefit-cost ratio and less projects will be build.

When looking at the effect the other parameters have on flood defence building it can be seen that FloodRe has a very small effect on the percentage of houses for which flood defences are build. This effect comes from FloodRe effecting house values, which influences the decision of the local government to build flood defences. Only if enough house value is at risk compared to the total value of houses, the local government decides to build flood defences. The effect mostly lies in the last few years so a significance test is done for the data on the last 5 years. Figure R.9 shows the results of this test in which unfortunately can been that the effect is not significant, seeing that the one-tailed p value is higher than 0.01. Because there is no significant effect this will not be further researched in this thesis. However the effect that can be seen is the only effect
that FloodRe has on flood risk management that could be found in the execute data analysis. So it can be an interesting aspect to look further into in further research.

![Figure R.8: effects on the building of flood defences](image)

When looking at combination of all parameters, so also adding PLPM investing compared to the FloodRe graph, it is interesting to see that a significant negative effect can be seen on the percentage of houses for which flood defences are build in the last few years. This is because investments in PLPMs lower the benefit reached with flood defence project. If houses are already protected by PLPMs less benefit can be gained from also building flood defences for them. This makes some projects that otherwise would have been build are now not build because their benefit-cost ratio is too low.

![Figure R.9: Results t-test building of flood defences](image)
Graph R.10 shows the effect of all parameters on the percentage of houses protected by flood defences for the '30 year multiple flood events' experiments that are run. Comparing this to the '10 year single flood event' runs, graph R.8b a similar effect can be seen in the first 10 years. However after the first 10 years it can be seen the the trend flattens out and the local government can not find any more projects to invest in. With all parameters turned on the same effect as before can be seen that the PLPM investing has a negative influence on the building of flood defences.
R.4 Housing market graphs

Now that the specific data on the parameters is analysed and it is understood how the parameters behave, this information can be used to understand how the parameters influence the housing market.

R.4.1 House values

The graphs shown in figure R.11 show that the house values in the model increase quite a lot. A part from the first 3 years, in which the housing market is still setting up and the adjusting of house values is turned off on purpose, the house values increase by around 7-8% each year. This is a bit lower than the current house prices increases seen in the London area, around 10%, but the expectation however are lower, around 5-6% on yearly basis [Office for National Statistics, 2015]. So the 7-8% yearly increase in house values in the model is not unrealistic.

The graphs also show that the effects the parameters have on house values, separately and combined. It can be seen that the only parameter that has a minor influence on the house values is FloodRe. This effect comes from FloodRe lowering the amount of houses that have to be put up for sale because the owner can’t pay for the house any more, as can be seen in R.14. Less houses that are but on sale because the owner is forced to do so is good for the housing market and has a positive effect on the average house values. Because the difference is only very minor a t-test is done over the data on the last 5 years. The results of the t-test, as seen in R.12 show that FloodRe indeed has a significant, even if it is only barely, effect on house values.

That besides the minor effect of FloodRe the flood protection measures do not effect the average house values is not unexpected. This because house values are mainly determined by the buying and selling of houses and the protection measures do not influence this. The difference that can be seen between in and out of flood risk houses is also not influenced because here the fact of a house being in or out of flood risk is the key factor, not how much a house is in flood risk. Seeing the protection measures only influence the height of the flood risk house is in they do not influence house prices in this way. If a house is affected by a flood, no matter how much, it will be less wanted by buyers.

In the combined effect only the effect of FloodRe can be seen. The combination of parameters does not cause for unexpected emergent behaviour.
Graph R.13 shows the effect of all parameters on the average house values for the '30 year multiple flood events' experiments that are run. Comparing this to the '10 year single flood event' runs, graph R.11d a similar effect can be seen that the parameters do not have much influence on the average house values. The graph however does show and interesting pattern, flattening out around year 12 after which it start to increase again. This is an effect coming from the developer running out of space to build on in year 12. This has an effect for a year because the number of new homebuyers coming into the market is not yet updated at that point. After which it updates the increase in housing value returns to normal.
R.4.2 Number of houses put on sale

For tracking the number of houses put on sale the specific choice is made to only look at the number of houses that are put on sale because of too high annual fees, seeing this is the only interesting reason when looking at the connection with flooding. Selling a house because of moving or because profit can be made are not connected to flooding.

The graphs in R.14 show that in general at the start of the model run no houses are sold but that towards the end of the 10 year more and more houses are being sold because of too high annual fees. This is logical seeing that initially the model was set up in a way that everybody could afford their house. But with house prices that increase by
quite a lot, as could be seen in R.11, more and more people can not afford their house any more because their income does not increase as much as the value of their house and the fees they have to pay on it.

A difference can be seen between houses in flood risk ad houses not in flood risk. Because houses that are in flood risk often also have higher flood insurance premium, which means a higher flood insurance fee for the house, the logical effect can be seen that houses in flood risk are sold more often because of too high annual fee than houses not in flood risk. Note: It should be noted that we are talking about numbers here and not percentages. The in and out of flood risk lines are still very comparable though.
seeing around 51% of the houses in Camden are in flood risk and 49% are out of flood risk.

When looking at the effects the parameters have it can be seen that the expected happens. FloodRe significantly lowers the number of houses in flood risk that are sold because of too high annul fee. It lowers it to the line of houses that are not in flood risk. Where without FloodRe more houses in flood risk are sold because of high insurance premiums, FloodRe cuts these insurance premiums to affordable prices which makes persons not having to sell their house.

Both protection measures do not have a significant effect on the number of houses that have to be sold because of too high annual fees. Although both protection measures lower the flood insurance premiums of persons, as can be seen in R.18, they do not lower it to an affordable level and person still have to sell their house. In the combined effect of the parameters only the effect of FloodRe can be seen back. The combination of parameters does not cause for unexpected emergent behaviour.

Graph R.15 shows the effect of all parameters on the number of sales because of too high annual fee for the '30 year multiple flood events' experiments that are run. Comparing this to the '10 year single flood event' runs, graph R.14d a similar effect can be seen. The parameters, mainly FloodRe, is successful in making flood insurance premiums affordable and bring the number of forced sales for houses in and out of flood risk to the same level. Interesting to see is that the number of sales because of too high annual fee for houses that are not in flood risk increases because of the parameters. No reason for this deviation can be given now. If this effect shows itself again in further research it can be interesting to look into
R.4.3 Flood risk

The graphs in figure R.16 show the pattern of the average flood risk in the model. In general, not taking the parameters into account, the flood risk is only affected by new houses being build and house values. The lowering of flood risk in the start is because in the start the houses that are build are not in flood risk areas yet, lowering the average flood risk over all houses. The increase after that comes from house values that increase, increasing the value of flood risk, and from houses being build in higher flood risk areas.

Besides this the graphs show the FloodRe has no significant effect on the average flood risk. This is logical seeing FloodRe effects flood insurance premiums and not flood risk. However it can be seen that both protection measures have a significant effect on the flood risk, of which PLPMs by far the most. This is because simply more houses are affected by PLPMs and PLPMs lower the flood risk of a house by more than flood defences. Flood defences target areas with high flood risk more precise and effective than PLPMs, but because they effect an area they can also effect houses that are not in flood risk, having no effect.

Last it can be seen that the combination of parameters show nothing else than a combined effect of the protection measures. The combination of parameters does not cause for unexpected emergent behaviour.
Graph R.17 shows the effect of all parameters on the average flood risk for the ’30 year multiple flood events’ experiments that are run. Comparing this to the ’10 year single flood event’ runs, graph R.16d a similar effect can be seen. The flood risk is significantly decreased because of flood protection measures investments. The fats increase in average flood isk is just s the increase in re-insured FloodRe persons and average flood insurance premiums no explainable and is something that has to be looked into before using the model for further research in longer time frame experiments.


**R.4.4 Flood insurance premiums**

The graphs in R.18 show the pattern of average flood insurance premiums a somewhat similar pattern as with the average flood risk can be seen R.16. This is logical seeing flood insurance premiums are set based on flood risk. The patterns are not completely alike because the flood risk of a house is not directly set to a flood insurance premium but flood insurance premiums are set based on the total portfolio of flood risk of the insurer. Besides this, the belated rise in premium is because of two factors. One because a change in flood risk is only converted to a new flood insurance premium the next year. And two because in year 6 when the flood risk increases the consequences of the flood in year 5 shows. As a consequence of the flood event the flood insurance excesses of persons with a flood-affected house increase, which means that premiums on average can decrease because more of the risk in the model is captured by the excesses of persons.

The graphs also show that FloodRe has a huge and significant effect on the average flood insurance premium persons have to pay. This is logical seeing this is the main thing the FloodRe system does; it lowers the flood insurance premium of persons that have a too high premium. Besides this it can also be seen that both PLPMs and flood defences have significant effects. Because the flood insurance premiums persons have to pay is connected to the flood risk their houses are in, the effects of both protection
measures are the same as could be seen in the graphs in R.16.

In the combined effect it can be seen that FloodRe is the main effective parameter. Here the effect of flood protection measures is less because it does not lower the flood insurance premiums of persons already in FloodRe. Flood protection measures lower the flood risk of houses. If a house is put in FloodRe it gets a set flood insurance premium, not affected by flood risk any more. The only effect of flood protection measures that can be seen is from them also effecting the flood insurance premiums of houses that are not eligible for FloodRe, the houses build after 2009.

Figure R.18: effects on the flood insurance premiums

Graph R.19 shows the effect of all parameters on the average flood insurance premium for the '30 year multiple flood events' experiments that are run. Comparing this to the
'10 year single flood event' runs, graph R.18d a similar effect can be seen. The average flood insurance premium is lowered by quite a lot and stable because of mainly FloodRe. Here the same strange effect can be seen as in graph R.17, a strong increase after year 20, for which no explanation can be given now but is something that has to be looked into before using the model for further research in longer time frame experiments.

Figure R.19: effects on the average flood insurance premium - 30 year run
R.4.5 Flood insurance excesses

The graphs in R.20 show that the average flood insurance excess has a similar pattern as the average flood risk and the average flood insurance premiums. The exact pattern is different however. The similar pattern comes from the average flood insurance excess also being influenced by new houses being build (that start with a low initial excess) and house values that increase in the second part of the model run. Besides this a very sharp increase can be seen in year 5-6 when the flood events occurs an the flood insurance excesses of houses that are affected by the flood increase.

When looking at the effect of the parameters it can be seen that unlike with the flood insurance premiums, FloodRe does not effect flood insurance excesses. This is logical seeing FloodRe focuses on lowering flood insurance premiums and does nothing with too high flood insurance excesses. The effect of PLPMs and flood defences are the same as could be seen in the flood insurance premium graphs, they significantly lower the average flood insurance excess. This is also logical seeing the flood protection measures effect the insurance excesses in the same way they effect premiums. Better protection means lower excesses.

Because the effect of the building of flood defences is quite small a significance test is performed to see if the effect is really significant. Figure R.21 show the result of the test and show that over the whole range, all years, the building of flood defences has a significant effect on the flood insurance excesses.

The combined effect shows a combination of the PLPM and flood defences effects. The combination of parameters does not cause for unexpected emergent behaviour.

Graph R.22 shows the effect of all parameters on the average flood insurance premium for the '30 year multiple flood events’ experiments that are run. Comparing this to the '10 year single flood event’ runs, graph R.20d a sort of similar effect can be seen. The average flood insurance excess is lowered by quite a lot because of flood protection measures. Here the opposite as what happens in graph R.19 can be seen, a drop after year 20. Also for this pattern no explanation can be given but is something that ha to be looked into before using the model for further research in longer time frame experiments.
R.4.6 Flood repair fees persons have to pay

Instead of regression lines the choice is made to show the repair fees person have to pay in box-plots. This is done because the flood repair fees are a singular data set, gathered when a flood event occurs, and do not have to be plotted over the years. Box-plots are chosen because they represent such singular data very well.

Because everybody in the model is flood insured the flood repair fees that persons have to pay will often be equal to the value of the flood insurance excesses of their flood insurance. So a good idea on the flood repair fees can already be gained from the graphs in R.20. However sometimes excesses can be so high that the damage doe in a flood is
lower than the flood insurance excess of the person. Also because this just looks at the case of the flood event it is in an interesting value to track.

The box-plots in R.23 show that logical pattern that the larger the flood, the more damage that is done. The average flood repair fee, calculated over all houses in flood risk, is for a 1 in 200 year flood event around the 3000 pounds. For a 1 in 30 this average lies around the 2450 pounds, which is also still high. Although the general, non parameter influence, values are directly coming from GIS data that is provided and not from modelling behaviour, it is interesting to see that 1 in 30 year floods already do so much damage compared to 1 in 200 year floods. This means that for the area of
Camden the flood damage of already a quite same flood event is already big and that with increasing severity of the flood the damages do no increase that much.

When looking at the effects of the parameters it can be seen that FloodRe has no effect. The small difference that can be seen are due to variation in data assigning in the model. Besides this it can be seen that both flood protection measures have a small effect. This is logical seeing they effect the flood insurance excesses, as seen in R.20, and the flood repair fees persons have to pay are equal to their excesses. The effects are only small because the flood happens in year 5 and as can be seen in the flood insurance excess graphs the effect of the protection measures on the flood insurance excesses in year 5 was not large yet.

The effect of the combination of parameters shows nothing else than the combined effect of both flood protection measures. The combination of parameters does not cause for unexpected emergent behaviour.
R.4.7 Uninsurable houses

The reasons a system like FloodRe is set up is because houses are becoming uninsurable. However in this model the assumption is made that all houses will have insurance. Because of this the model can not provide insights into the number of houses that would go from being uninsurable to being insurable because they can be re-insured in FloodRe. Houses can be uninsurable if either their flood insurance premium or flood insurance excess have become too high. Because this is data that can no be tracked in the model assumption can be made at which moments a house would be uninsurable and these houses can then be flagged uninsurable in the model. Because extra assumption will be
needed to gather this data it is not set a value on which conclusion will be drawn up. It can however be an interesting factor to see.

Sources indicate that a flood insurance excess higher than £2,500 pounds is a level at which a house can be seen as uninsurable [Financial Times, 2014]. For a level of flood insurance premium no real sources could be found. The cost insurer have for placing a policy in FloodRe can however give us an idea about this number, seeing this is equal to the flood insurance premium at which a house (policy holder) will be placed in FloodRe. However being eligible for FloodRe does not mean that you would have not have had insurance before being placed in FloodRe. For this reason the assumption is made that if a persons flood insurance premium is twice the cost an insurer would have to place this person in FloodRe, the house of the person can be seen as uninsurable. Monitoring both the amount houses that would be uninsurable because of too high flood insurance premiums and/or excesses will also give a good idea on the effect FloodRe will have.

The graphs in R.24 show that for the number of houses that are uninsurable because of too high flood insurance premiums the pattern is similar to the one seen in R.18. For flood insurance excesses it can be seen that before the flood event no houses had a too high flood insurance excess yet. After the flood event in year 5 the excesses of houses affected by a flood increases which makes many persons now live in a house with a too high excesses to be insurable.

When looking at the effects the parameters have it can be seen that FloodRe significantly decreases the amount of houses that are uninsurable because of insurance premiums, but has no effect on the excesses. This is conform with the pattern that could seen in R.18 & R.20. It is good to see that FloodRe does what it being created for, making flood insurance payable. The only houses that keep a too high insurance premium to be insurable are the houses not eligible for FloodRe. Because more houses are build that are not eligible for FloodRe every year the number of houses that are uninsurable because of flood insurance premiums still increases over the years with FloodRe on.

When looking at the effect the flood protection measures have on the percentage of houses that are insurable it can be seen that both protection measures have effect on both reasons for uninsurable. As already could be seen in R.18 & R.20 PLPMs have a larger effect than flood defences and therefore also lower the percentage of houses that are uninsurable by more.
In the combined effect off all parameters it can be seen that when looking at flood insurance premiums it is mainly FloodRe that causes for the effect. The flood protection measures do not decrease the amount of houses that are uninsurable by much. In the end it is for both the case of only FloodRe and for the combined case around 5% of the houses that are uninsurable because of too high premiums, houses not eligible for FloodRe. When looking at excesses as the reason for uninsurability the combined effect of the flood protection measures can be seen.

**Figure R.24:** Effects on the flood repair fees
Appendix S. Significance testing of data

In this appendix the way data is analysed for its significance is further elaborated on. The significance test shown here are based on the graphs on the percentage of houses re-insured in FloodRe (R.3.1). The significance tests are performed using Microsoft Excel 2010 with the ‘Analysis ToolPak’ add-in. Just as with the confidence intervals a significance level of 99% want to be reached.

Figure S.1: effects on the percentage of houses re-insured in FloodRe

S.1 Significance of the investing in PLPMs

When looking at the graph on how the investing in PLPMs effect the number of houses re-insured in FloodRe, S.1a, a quite strong effect can be seen. Based on the difference in percentage with and without PLPM investing and the confidence intervals that are really small, almost no deviation compared to the line, it can already quite certain be stated that the investing in PLPMs has a significant effect on the percentage of houses re-insured in FloodRe. To test this significance a student t-test will be performed over the whole range of data, all 10 year.

To determine if the variance between the two data sets is equal or unequal, determining if a t-test for equal or unequal variance needs to be performed, an F-test will be performed first. Figure S.2 shows that the p-value (2.60E-36) is smaller than the chosen alpha of 0.01 (1 - 0.99 (the 99% significance that wants to be reached). This means that the null hypothesis, that states that the two selected data sets are of an equal variance,
Appendix S  Significance testing of data

**Figure S.2:** F-test FloodRe re-insurance comparing FloodRe-PLPMs

<table>
<thead>
<tr>
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<th>Variable 1</th>
<th>Variable 2</th>
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<td>Variance</td>
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<td>0.001001318</td>
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<td>Observations</td>
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<tr>
<td>F Critical one-tail</td>
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</tr>
</tbody>
</table>

**Figure S.3:** T-test FloodRe re-insurance comparing FloodRe-PLPMs

<table>
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<tr>
<td>Mean</td>
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<tr>
<td>Variance</td>
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<td>t Critical two-tail</td>
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</table>

is rejected and we can conclude that the two data sets have an unequal variance an a t-test assuming unequal variance has to be performed.

Figure S.2 shows the results of the performed t-test. Given that there is specific direction within the significance that is tested, the percentage of houses re-insured in FloodRe decreases with the adding of the investing in PLPMs, the one-tailed p value will be looked at. The results show a p value (5.384E-13) that is smaller than the chosen alpha (0.01). This means that the null hypothesis, that states that there is no significant difference between the two selected data sets, is rejected and we can conclude that the investing in PLPMs has a significant effect on the percentage of houses re-insured in FloodRe.

**S.2  Significance of the building flood defences**

When looking at the graph on how the building of flood defences effect the number of houses re-insured in FloodRe, S.1b, only a small effect can be seen, a lot less than could be seen with PLPM investing. Although here in the last few years a clear difference can be seen without overlapping confidence intervals, the significance of the effect can be question more than with PLPM investing.
To test the significance tests will first be done over the whole range of data. The F-test that is first performed, figure S.4 shows that the p-value (0.30) is smaller than chosen alpha (0.01). This means that the null hypothesis, that states that the two selected data sets are of an equal variance, can not be rejected and we can conclude that the two data sets have an equal variance an a t-test assuming equal variance has to be performed.

Figure S.5 shows the results of the performed t-test. The results show a one tailed p value (0.28) that is larger than the chosen alpha (0.01). This means that the null hypothesis, that states that there is no significant difference between the two selected data sets, can not be rejected and we can conclude that the building of flood defences does not have a significant effect on the percentage of houses re-insured in FloodRe.

However this is measured over the whole range of data, all 10 years. In graph S.1b it can be clearly seen that the real difference caused by the building of flood defences lies in the last 5 years. To see if over these last 5 years the difference is significant the same test can be performed but now with a data set that only contains the last 5 years. The
Appendix S Significance testing of data

Figure S.6: T-test FloodRe re-insurance comparing FloodRe-floodDefenceBuilding data - last 5 years

<table>
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<th>t-Test: Two-Sample Assuming Unequal Variances</th>
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<td>Variance</td>
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<td>Observations</td>
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<td>Hypothesized Mean Difference</td>
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<td>P(T&lt;=t) one-tail</td>
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<td>t Critical one-tail</td>
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<tr>
<td>P(T&lt;=t) two-tail</td>
</tr>
<tr>
<td>t Critical two-tail</td>
</tr>
</tbody>
</table>

Variance of this data set is also equal and the preformed t-test can be seen in figure S.6. These results show a one tailed p value (0.004) that is smaller than the chosen alpha (0.01). This means that in the case of the last 5 years the building of flood defences does have a significant effect on the percentage of houses re-insured in FloodRe.
Appendix T. Further research on improving current aspects of FloodRe

In the analysis on the current system it can be seen that houses built after 2009 and commercial buildings will not be included and that until recently tax band H was not included. Although no real official motivation was given why tax band H was included again, it begs the question what the effects really are of these demarcations. It is of special interest seeing recent events push for the inclusion of all houses in the FloodRe system, also the ones built after 2009. The current housing shortage in the UK is pushing developers to built in flood plain areas [Wilson, 2010]. Besides this research indicates that an additional 250,000 households with will experience increased flood risk by 2035 due to climate change [Adaptation Sub-Committee Secretariat, 2014]. This begs the question that although the FloodRe system works under current circumstances, what would happen when circumstances change? To also make the FloodRe system work properly than the following demarcations can be looked at and possibly changed:

- **Demarcation on build years:** In the current FloodRe houses built in 2009 or later are excluded. This is done to not give the wrong incentives to new housing developments. Although this idea is maybe quite logic, the specifics of it are a bit unclear. It would be first interesting to hear from the creators of FloodRe why the year 2009 is chosen as cut off point. If the goal is to not give incentives to new housing development, why is the current year not chosen? And how sure are we that it would give the wrong incentives to developers? Research shows that developer do not really account for flooding in housing development anyway. The demarcation on build years can easily be tested in the model by changing the year from which houses are excluded from the FloodRe decision of the insurer, or by throwing this exclusion out completely. To get a better idea on how developers would react to the information of their houses also being able to be re-insured in FloodRe, more research will be needed on the topic seeing this behaviour is not in the model yet.

- **Demarcation on tax bands:** In original FloodRe plans tax band H would be excluded from FloodRe because the idea behind FloodRe was that it would cater to the people that need it and not the riches. However in December 2014 it was decided tax band H would be included in FloodRe. No proper explanation was
Appendix T Further research on improving current aspects of FloodRe

given for this decision, begging the question if it was the right decision. *This can simply be added in the model by excluding houses in tax band H from going into the FloodRe decision process (just as is done with houses after 2009).* When looking at the incentivizing person to invest in protection measures by showing them how the will benefit financially from it in the long run, it can be interesting to see how maybe persons in different tax bands react different to different incentivizes. Maybe financial incentivizes will not work on person in tax band H and they need other incentives.

- **Demarcation on type of building:** Currently commercial buildings are not included in FloodRe. Something to possibly look at is also including commercial buildings. The reasoning of FloodRe not to include them is as follows: "The individual nature and assessment of business and commercial property risks means that available and affordable flood insurance is less of an issue than for homes. While some individual firms may experience problems in accessing flood insurance, these can usually be resolved by using (as most do) an insurance broker. FloodRe will establish clear rules for 'borderline' cases such as 'Bed and Breakfast' properties" [Department for Environment, Food and Rural Affairs, 2013]. *Within the current model there is not GIS data on commercial buildings. If this GIS data is available, research will also have to be done on who different the behaviour of commercial building owners is compared to house owners. so given the effort that will be needed to research this topic it will probably be best to assume for now that their reasoning to no include commercial buildings is correct.*
Appendix U. Further research on improving the working of the model

In this appendix the further research that can be done on improving the model is elaborated on. The research that is done with the model in this thesis has already provided confidence that the model can be used to do further research with. However the research that is done and the insights that are gained have also shed a light on some aspects that can be improved. Besides this there are also some aspects that are not included in the model yet that can be included to improve the model. These are all aspects that are not directly connected to FloodRe, but are important for the working of the model and if improved will most likely provide results that lie closer to reality which means FloodRe adaptation and the incentivizing of flood risk management can be researched better.

Because in such a large model there will always be things that can be improved a selection is made of the most promising improvements that can be made to the model, starting with the most promising/most necessary.

1. Flood insurance premium and excess: The way flood insurance premiums and excesses are set in the model need to be improved. Flood insurance premiums are set based on the flood risk a house is in. Insurers calculated the expected amount they have to pay out in compensations to houses every year and on this base the flood insurance premiums persons have to pay to insure their house. Results show that both the flood insurance premium and excess amount are set really high in the model and on top of this they also change quite a bit during the model run. There are several reason for these high and changing values:

(a) The initial flood insurance excess is set too high. This is either because a too high initial insurance excess percentage is assumed, or because the house values in Camden are too high. Given the house values are based on GIS data they are quite trustworthy. Given that the initial insurance excess percentage is coming from personal communications with expert, this value may need to be changed, also seeing the expert did not have the exact knowledge on the model (such high house values for instance), but seeing that an average flood insurance premium for houses in flood risk lies around 250-500, while the average in Camden lies around the 3000, the value is definitely too high.
(b) Another issue is in the comparison with the flood damages done to a house. The flood damages that are done by a flood are set based on GIS data and only change very limited during the model run. The flood insurance excess is set every year based on the flood insurance excess percentage and the insured value (value of the building of the house). Because the building value of houses increase during the model run, house prices increase, the flood insurance excess also increases, while damages only adjust slightly. Because the cap of the insured value is set to 250,000 this effect is limited seeing many houses in Camden already have a building value that is higher than this value from the start. However during the model run more and more houses reach this cap of insured value.

(c) A third aspect, that can be a cause for the rapidly changing values, is that the portfolio over which the insurer calculates its coverage is only the size of Camden, around 24000 houses (30000 with development towards the end). Although this sounds like a lot, for an insurance portfolio it is not that much I think. Such insurances are often covered in portfolios that are much larger, dampening the effect of occurrences in a single district. Because this larger portfolio is not modelled changes rapidly are processed into premiums and excesses. What enforces this rapid changing is that also only the technical flood risk is modelled and not the commercial flood risk. The technical flood risk is only a small part of what determines the final premium and excess amount.

To really improve the behaviour in the model and to better the way FloodRe has effect on behaviours it might be good to do further research on these aspect and improve them.

2. Flood modelling: The choice modelling flooding in the experiments that are run for this thesis is far from optimal. The model already has the ability to model flooding in a better way. By modelling random flood event pattern in which different part of Camden can experience different flood events, a better representation of the houses in the model being hit by a flood can be modelled. To get better results in further research it will be necessary to do some initial research on the way it is modelled at the moment. This is simply looking at the time series of flood event data that are used to make sure these can be properly used to run experiments on.
3. **Different risk scenarios:** In the current model a quite straight forward way of modelling the risk scenario is chosen. A standard given flood occurs after a set amount of time in the model. However the model is already build with much more possibilities in it. Within the Camden model there are 5 different areas that can flood independently and for each these areas there is data loaded into the model of 3000 years of baseline flood events, but also 2050H climate scenarios (see 'Flood event data' in L.1). Based on this data many different risk scenario can be tested that can show the resilience of FloodRe under changing circumstances. Climate change was a main reason why this research was started, so FloodRe definitely has to be checked under such circumstances.

4. **Knowledge of being placed in FloodRe:** At the moment it is still unclear if person will be clearly informed if they are placed in FloodRe. Insurers are not legally obliged to tell persons they place them in FloodRe. A person can notice it himself if he is placed in FloodRe seeing his flood insurance premium becomes lower. However because this fee is combined in it its total home owners insurance fee only big changes will most likely be noticed. Smaller changes will not be noticed. In the current model persons don’t react in any way to being placed in FloodRe, other that making decision based on a lower flood insurance premium. Because it is very unclear at the moment how a person would act different if given the knowledge he is placed in FloodRe, this will first need to be researched before putting it in the model. Connected to this future research is the research that than can be done with the model on deciding if it will be beneficial to always inform people that they are placed in FloodRe.

5. **Knowledge on exclusion of FloodRe:** Connected to the above, there is no knowledge on how people would react to being excluded from FloodRe when it is scaled down. The flood insurance premium of these persons would go up again, but will this be enough to incentives to take action? Just as there is no knowledge on what being placed into FloodRe will do to a person, there is also no knowledge on what being excluded form FloodRe will do to a person. On this topic more research should be done first before different transition mechanisms can properly be tested.

6. **Flood insuring houses:** In the current model the assumption is made that all houses are flood insured, this does however not need to be the case. The assumption is made because it is almost mandatory to have it when requesting a mortgage. However it is technically only needed at the time a mortgage is taken, it does not
have to be extended after it. Also the persons that don’t take a mortgage when buying house don’t have to have flood insurance. On top of this there are also houses that are uninsurable because they are in too much flood risk and the insurer does not want to insure these houses or the person living in the house thinks its too expensive. The goal of FloodRe is to help these houses, which in theory it will as the results show (flood insurance prices of houses drop down). However FloodRe is for insured houses and not for uninsured houses. However with the FloodRe system being in works in the future the interesting situation can occur that previously uninsured houses are being sought out by insurers to insure. On the flood insurance the insurer won’t be able to make any money (money that they get from premium goes straight to FloodRe), however they will be able to make money on the other services they can provide to these persons, making these houses interesting new insurance opportunities. How these dynamics will work and how much this will influence the system can be an interesting topic for future research on the basis of which the working of the FloodRe model can be tested even better to show its also resilient in these situations. This improvement also opens up the way for insurers to react different to flooding, Now the only thing they can do is increase excesses of house. When the options for insurance is modelled an insurer can also choose for no longer insuring this house.

7. Influences of flood protection: As explained in appendix J clear choices are made into how flood protection measures are modelled in the FloodRe model. However there are more possibilities into modelling these protection measures. Future research can be done into more methods. However, the most interesting thing to look at regarding this is the assumption made in appendix K. Here it is assumed the flood protection measures reduce damage done by flooding in an equal way over all flood return periods. This does however not need to be the case. Although both cases shown in this appendix both do not show the real world situation, they show the outer lines of it. Now a fully equal way is chosen in the model. However it will also be interesting to see how methods that would go more towards stopping small floods completely and not having effect against larger floods influence the model behaviour. Although the overall flood risk will probably be not much different, actions sometimes specifically focus on types of floods (so do local government specifically look at 1 in 100 flooding). It can be interesting to do further research
on the effect the assumption of equal damage reduction has made on the model behaviour.

8. **Loss ratio of insurer**: Within the current model the insurance premiums of persons are set in a way that the insurer should stay below its maximum loss ratio that it want. However this is based on the probabilities of floods as they currently are. In a situation in more floods happen than expected (for instance because of climate change), this maximum loss ratio is maybe not kept. Within the current model a current loss ratio is calculated, however nothing happens yet when the current loss ratio goes over the maximum loss ratio. The reason this is not included yet is because in conversation with experts from Willis on this topic the way insurers use the loss ratio became clear. Insurers do not really look at loss ratio’s over their total portfolio, but rather look a specific cases. On top of this their focus is mostly put on unexpected floods. If a house is hit with expected flood probabilities, nothing happens, even if this is a more than normal. However if a house that should not be flooded will be flooded, the insurer will react. these unexpected damages are important for the insurer to react to. The research topic above already addressed these unexpected flood damages, for which more research is needed. To code how these insurers reacts to these unexpected flood damages is also something in which more further research is needed. Maybe the experts from Willis can be helpful in this.

9. **Influencing neighbours and friends**: When going through the code of the Putra model it was clear that he intended to add in code in which persons would influence their neighbours in selling their houses. Although this code did not work at all, it is still an interesting thing to possibly add to the FloodRe model. Persons are very much influenced by the people around them (neighbours and friends). If all your neighbours move away or all your friend move to a different place, you yourself are also more included to move. But this influence can also be extended to investing in PLPMs for instance. If everybody around you does it, it is more likely you also do it yourself. This dynamic can be interesting to add to the model. How exactly this dynamic will work will need further research first and will most likely be based on some assumptions. **Personal note: In a previous assignment I did for my study in the course 'Advanced ABM' I made an agent-based model that research the way persons invest in renovating their house energy efficiently. An important aspect in this model was the way persons influenced and got influenced by their neighbour**
and friends. Although this model was based on quite some assumptions, I think it is still to quite some extent transferable to the FloodRe model.

10. Risk awareness: Within the current model persons are either labelled as risk aware or not risk aware. Risk aware people are separated in being proactive, reactive or neither. This is a very black and white way of modelling risk awareness. If proper research wants to be done on the effect policies in which persons are tried to be made more aware (by giving information for instance) an improvement step should maybe be made in the way risk awareness is modelled. A scale from 1-10 can for instance be used in how risk aware persons are. Different policies will have different effect on this scale and at different levels persons will act in different ways. However the problem with this will probably be that it has to be based on a lot of assumptions on persons behaviours. So clear further research needs to be done on this topic first to make sure if it will be something that is capable of being modelled and it will be something that will actually present viable data to use, before it being coded into the model.

11. Interest in flooding: For experimenting the choice was made to only look at different kinds of flood scenario’s as input to the model. However more input scenario’s are possible. With the current flooding in the UK the interest in flooding is quite high and people want to undertake action. However if say the upcoming 20 years there would be no flooding at all, it is likely that the interest in flooding will die down. What would this mean for FloodRe? And what if in the upcoming years another big flood happens and interest only increases more, what would this mean for FloodRe? Just as above with the different risk scenario’s this can give a good insight into the resilience of FloodRe

12. Finance of flooding: Connected to the interest above, the finances are also important an important part of FloodRe which no different scenario’s are tested for. If interest would die down, the financial flow will most likely also die down. And what if the UK/the world will be hit with another financial crisis. Will there then still be the same amount of money available to invest in flood protection an FloodRe?

13. Grants for PLPMs: In the current model the assumption is made that all persons that are reactive; would take action after being hit by a flood (this can range from requesting information to fully installing flood protection for the house), will invest in PLPMs because it is subsided by repair and renewal grants. These grants
are currently framed as a temporary thing. However FloodRe will maybe provide options to include such grants for persons. This is connected to the 'promoting resilience effort' plan of DEFRA. Future research can be done on how such grants would effect decision of persons. For this the assumption made now in the model will have to be changed. Future research will be needed on how important the money aspect is to persons when deciding on investing in PLPMs. This also links to the importance of information. The money question will never play a role if persons don’t even know they can make such investments. How this all plays together will need further research and with this information it can be implemented in the model to investigate the effect of it.

14. Research and development: In the current model the cost and effectiveness of PLPMs and flood defences is kept the same over the years. However with more research and development the cost and effectiveness of both PLPMs and flood defences are bound to go down. This can be another input scenario to look at for the model. This topic is very much connected to the topics of interest and finance in flooding. If there is more interest in flooding there is most likely more financing for it, there is more money to be made by companies that deal in flood protection and there is more research and development in this field.

15. Unpredictability of water surge flooding: Within the current model the houses that are flooding at given flood return periods are always the same. Data provides information no which houses will be flooded and damage by how much. However flooding, and especially water surge flooding, is not so predictable. Heavy rain fall can come in many patterns. To make the model better represent the reality a unpredictability to the floods can be implemented. Houses that would normally be flooded suddenly don’t flood and houses that should not flood suddenly are flooded. Further research will be needed on how exactly this can be added to the model.

16. Proactive versus reactive: Further research can be done on the difference proactive versus reactive action undertaking has. in the plans of DEFRA a clear sense of reactive undertaking was given. However both proactive and reactive have their pro’s and con’s. Acting reactive is in fact too late, the damage has already been done. However if damage is already done the house will need to be repaired anyway and the burden of also installing protection is lower. Acting proactive will have the advantage that if a flood happens protection is already installed and the damage
will be lower. However the burden of installing the PLPMs will be bigger seeing construction will need to be done on the house while the owners are living in it. The specifics of these pro’s and con’s can be further research and the model can be used to figure out what is better by looking at both proactive and reactive action undertaking separately and seeing which has more effect. In this research the difference in cost for proactive versus reactive PLPM investing can also be taken a step further. This is cost both in the implementing (if house is already worked on after a flood it can be cheaper to install) but also potentially quantifying the burden in a cost element.

17. **Insurance market:** In the current model only a single insurer is modelled. The insurance market is not modelled. If the research on FloodRe will be expended it can however be interesting to look at how it will act within an insurance market. How will insurers work with FloodRe with they have to compete with other insurers for the insurance policy. How these insurers will compete needs further research before it an be coded into the model. Besides this a change in how the model is coded will need to be made. In the current model the information of policies of the insurance holders is gathered on the policy holders them self. Because there is only a single insurer in the model this is no problem, seeing it is clear all policies belong to this insurer. However if an insurance market want to be modelled with more than a single insurer in the market, it will be better to have this information gathered at the insurer. This will give the insurer an policy portfolio on basis of which he can act.
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