MODELING FLOODING IN THE BOROUGH OF HOUNSLOW

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Abstract

This project aimed to provide the London Borough of Hounslow with an easily replicable method for estimating flood costs in order to aid in emergency planning. Information gathered from census data and case studies on past flooding was used to establish damage estimation factors that would provide a useful model of flood consequences. The team produced a modelling program to estimate the effects of a flood in terms of property damage, health concerns, school closings, utility disruption, temporary accommodation, and total monetary cost.

Acknowledgments

The Hounslow team would like to thank the members of the London Borough of Hounslow Contingency Planning Department including: Joseph McFarland, Leigh Farinia, Twm Palmer, and Matthew Innerd for their wonderful support during this project. They would also like to thank Dan Taylor of the GIS unit for his help with CadCorp GIS. Sev McGinty and Ben Pearkes were invaluable when testing the modelling program and supplying the team with useful information that helped strengthen its replicability. The members of the GLA and EA who attended the presentation of the modelling program to were also very helpful in supplying suggestions, data, and limitations. Finally the team would like to thank their advisors who helped guide them throughout the IQP experience.

Executive Summary

The city of London is continually faced with the challenge of responding to and mitigating the risk of major flooding. Recently, widespread flooding in the UK in 2007 caused an estimated 3.2 billion pounds in damage and caused significant long term disruption to everyday life. Under the Civil Contingencies Act, responsibility for responding to and planning for emergencies, including flooding, falls upon local authorities (Parliament, 2004). These obligations including producing risk registers evaluating known hazards within the borough and taking pre-emptive actions to mitigate the associated risk.

The Borough of Hounslow, located along the River Thames in southwest London, is interested in modeling the impact of flood events within the borough. Current damage estimates are generally conducted only after a flood and involve comprehensive data collection. This can be time consuming and difficult to reproduce for multiple areas or flood scenarios. An established standard model for flood consequences would improve hazard mitigation and response planning.

Methodology

The main objective was to create a model to determine the impact from various flood events. The model should involve a relatively small amount of input and computation. Widely available data was used in determining the cost estimation factors to make the model applicable in other areas outside of Hounslow. Additional methods were investigated to forecast the impact of future flooding due to population change, housing development, and climate change.

Relevant factors to include in the impact estimation were determined by reviewing case studies on major flood events in the past. The majority of the data used came from the Environment Agency report on the 2007 floods in the UK. This document attempted to estimate the total cost from the incident, and described what factors were included and how the calculations were performed. Additionally, each factor was rated with a level of uncertainty to indicate the accuracy of the impact estimate. Other case studies, such as the Pitt Review of the same flood incident, were also used to add other supplementary factors. A list of the factors can be found below, while a detailed chart for the included factors and their respective values can be seen in Appendix B.

A geographic information system (GIS) was used to assess the impact of a flood in terms of residential buildings, businesses, schools, and general practitioners affected. Maps detailing the expected area of a flood were provided by the Environment Agency and the Borough of Hounslow. Intersecting these flood maps with geographic data on building locations from the Borough of Hounslow produced details on the affected buildings. The relevant data extracted by GIS and relevant demographic statistics available from the Office of National Statistics and Greater London Authority were entered into the model in the form of an Excel spread sheet. Combining this data with the cost estimation factors established from review of case studies produced the final impact estimate.

A method was developed in the model to forecast the change in flood damage in the long term future due to population increase and new housing development. Population projections for the year 2031 on a ward level from the GLA were used to determine the percent change from the current population. Housing development was assumed to be proportional to the change in population. The adjusted values were then run through the same calculations as in the regular model to find the future cost.

Cost Estimation Factors

Included:

- *Residential property damage*
- *Business property damage*
- *Utility Disruption*
- *People reporting health concerns*
- *People requiring GP visits*
- *People requiring evacuation assistance*
- *Cost due to school disruption*
- *Waste produced*
- *Cost due to temporary accommodation*

Excluded:

- *Vehicle damage*
- *Cost to local government infrastructure*

Findings and Results

The model was used to evaluate the impacts of four types of flood events:

- Fluvial – caused by excess rainfall raising river levels
- Tidal - result of exceptionally high tides in the River Thames
- Surface water – pooling of extreme rainfall in areas with insufficient drainage
- Dam inundation – breach of nearby large water reservoirs

Two different events were evaluated for both fluvial and tidal flooding based on the probability of occurrence. In these cases, 'Zone 2' reflects a probability of occurrence of between .1% and 1% per year, while 'Zone 3' has a probability of greater than 1% per year. A significantly condensed version of the results is shown in Table 1below. Complete summary tables for flood impacts are available in the appendices.

Table 1: Condensed Final Outputs

	Number of Households Affected	Number of Businesses Affected	Number of People Affected	Number of People with Health Concerns	Number of People Requiring Evacuation Assistance	Total Cost
Fluvial Zone 3	898	58	2069	859	249	£30,599,773.29
Fluvial Zone 2	2063	165	4788	1987	576	£72,726,890.06
Tidal Zone 3	11546	860	25032	10388	3010	£401,879,710.78
Tidal Zone 2	12332	892	26843	11140	3227	£427,332,344.37
Surface Water 1-200	20614	882	50938	21139	6125	£669,793,716.13
Dam Inundation	8001	257	18604	7721	2237	£253,310,470.04

Reproducibility

After the model was completed, it was important to test its reproducibility and receive input from emergency planners from other boroughs. This information would help refine the organization of the model and provide possible factors that were not found in the initial research. Short meetings were held with emergency planners from the boroughs of Kingston and Hillingdon to explain the model and apply it to flood events in those areas. In both cases, the emergency planners provided the input data for each flood scenario though their own borough's GIS system or other resources. The team then walked through retrieving the necessary demographic data through the ONS, GLA, and other public online sources. Both of these evaluations were performed at the borough level, unlike Hounslow's which were done at the ward level. Summaries of these models can be found in Table 13: Comparison between Boroughs - Zone2 Fluvial Flooding.

During the meetings the emergency planners were asked to provide comments on the accuracy, organization, and general reproducibility of the model. Both felt that someone unfamiliar with the model would have difficulty using it based purely on the included instructions. Additionally, it was found that providing direct links to the necessary online data sources would greatly help users find and retrieve the correct information quickly. As a result, the instructions were expanded and rewritten to be more explicit and user friendly. Sources were provided as links within the spreadsheet as suggested.

Applications

Possible applications of the model were taken into consideration during its design. Factors included in the model were tailored in part to the needs of an emergency planner. Modeled floods could be used in flood response and mitigation planning through indications of the impacts in different areas. Large scale planning could take into consideration possible impacts across a wide area if the model were applied to flood events in several boroughs. Details on the possible flooding of schools has implications when considering evacuating an area or using school buildings as temporary shelters for those displaced by flooding. Impacts on general practitioners in the area could affect an area's ability to cope with the medical needs of the people directly affected. Additionally, output from evaluations of flood events could be used to create realistic training scenarios.

Climate Change

The team researched the impact climate change will have on flooding in the Borough of Hounslow. Case studies the team reviewed from around the UK, including the London area, provided significant evidence that the probability of flooding will increase in the long term future. Due to lack of data, it was not possible perform a definite assessment for the Borough of Hounslow.

Limitations

The main limitations in the model resulted from a lack of available data. A number of factors included in the reviewed case studies had to be excluded or discounted. Those that were rated with the highest level of uncertainty by the Environment Agency report were not included to maintain the accuracy of the model. A small number of other factors, including damage to roads and communication infrastructure, were dropped due to lack of supporting data. Long term economic effects, such as business disruption, were not included due to the difficulty in producing accurate estimations. Those factors not included only made up a low percentage of the total cost. Unfortunately, direct costs to local authorities and emergency services could not be calculated from available data.

Recommendations

1. **Collect additional data during flood events.** The main limitation in creating a model to project flood impacts is lack of data. The model produced in this project uses very broad strokes to produce estimation due in part to the factors that could not be adequately supported. The team was unable to use the data available in the EA 2007 flood report to accurately project the costs to the local authorities and services. This would be of immediate concern to those involved with emergency planning and impact flood mitigation efforts. Making a greater effort to collect data during and after flood events would greatly improve the accuracy of flood projections.

2. **Continue to update the model as new data becomes available.** The factors included in this model were based on the most recent and relevant data that could be located for the UK. Regularly updating the cost factors used in the model is crucial to keeping it relevant and accurate. Additional impact factors should be added to the model as supporting data becomes available.

3. **Encourage widespread use of the model.**
   Reproducing the model for flood events in all boroughs would not only provide a great deal of information to the local authorities, but would also allow for comparison of the impacts between boroughs. Reviewing relative costs could aid in planning and prioritizing flood response efforts.

4. **Be aware of the impact of future development and climate change.**
   This model attempts to provide an indication of the additional costs increased population and housing development will incur due to flooding. Attempting to shift development away from flood prone areas will limit future impacts and facilitate flood response. While the team was unable to accurately forecast the affect climate change will have on flooding in Hounslow, there was significant evidence that the probability of severe flooding will increase based on case studies done throughout the UK. Review of the Thames Estuary 2100 Project is suggested for information on the possible impacts and risk management policies.

Authorship

Michael Aschettino wrote parts of the Introduction, Background, Methodology, Results, and Conclusions and Recommendations. Frank Carnevale wrote parts of the Executive Summary, Abstract, Introduction, Background, Methodology and Results. Michael Gorgone wrote parts of the Introduction, Background, Methodology, Results and Conclusions and Recommendations. Christina Ouellette wrote parts of the Introduction, Background, Methodology, Results, and Conclusions and Recommendations. All members of the team worked to edit the entire paper. Christina Ouellette formatted the paper.

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1. Introduction

The adverse impacts of natural hazards are a fact of life with which governments and citizens must contend. Recent events illustrate that the costs and damages associated with flooding can be enormous. In 2007, floods in the United Kingdom caused a total of £3.2 billion in damage (The Enviornment Agency). These floods were the largest in UK history since 1947 and disrupted everyday life for weeks. The January 2011 floods in Australia were estimated to have caused over $2.3 billion in insured damages alone (Reinsurance Costs in Yasi Queensland Floods Trigger Australian Dollar Surge). Damages due to flooding can also cause severe disruption to daily life and serious health concerns. Through the Civil Contingencies Act, the United Kingdom places the responsibility on each individual borough to respond to emergency situations and to prepare risk maps and registers to predict potential hazards (Parliament, 2004). This is important because during a time of disaster, emergency responders must comprehend the extent of the damages quickly in order to react effectively and in a timely fashion. This requires responders to understand which areas will incur the most damage and which populations are more vulnerable than others in order to respond accordingly.

Due to past events, the Borough of Hounslow is particularly interested in estimating the impacts of urban flooding on the population. With an accurate estimation of damages, emergency responders will be able to act effectively in a time of emergency by understanding the extent of damages. Councillors and emergency planners would be able to provide better supporting evidence for future mitigation plans if they had an easy way to get an approximate figure of how much damage a flood event would cause.

Most damage estimates are conducted after a flood occurs as part of a disaster inquiry or insurance claim. The current methods for estimating damages are broad. As a result of flood insurance programs in the UK and US, some methods for estimating damages have been developed, but are still relatively limited. Current flood damage estimation methods include stage damage curves and computer based modelling. Typically these techniques have numerous inputs and require a large amount of comprehensive data to work. This makes estimating the costs of flood damages difficult for the average person. The goal of this project was to create a program to model the damages due to urban flooding in London that is based off of widely available data and is straightforward in its methodology.

The team hoped to create a method to determine the impact of a variety of flood events with minimal computation. First a basic geographic information system (GIS) map with information about the susceptible infrastructure of the borough was developed. The location of every building in the borough, both residential and commercial, was available on this map. The map also indicated the location of every school and general practitioner within the borough. The emergency planning office within Hounslow, with help from the Environment Agency, has already conducted a measurement of the risks of flooding for each area of the borough and produced flood maps for a variety of flood events. These risk maps were overlaid on the GIS map in order to determine the extent of damage done to the impacted area. These damages were then quantified using historical data from the Environment Agency 2007 UK Flooding report, and readily available borough specific statistics. Through this process, the modelling program predicted the impact of a potential flood in terms of both the direct cost and other non-monetary factors that will be useful for emergency planning purposes.

2. Background

The London Borough of Hounslow was interested in assessing and quantifying the risk associated with potential hazards, in order to properly prepare its residents for an emergency situation. The team's liaison was Joseph McFarland, the head of the emergency planning office for the London Borough of Hounslow. Mr. McFarland was particularly interested in predicting the impact of urban flooding for a number of reasons, including but not limited to being better prepared for an emergency situation and having an assessment of a potential hazard to support future mitigation plans. There have been several situations in recent history that have caused this to become an increasing concern. On August 12, 2010, a water main burst on London Road in Hounslow. The water flow from the burst flooded 170 properties, and disrupted the water supply to 27,000 properties. The emergency planning office of Hounslow spent extensive resources dealing with this emergency, evacuating over 300 people.(London Borough of Hounslow, 2010).The Council performed a detailed analysis to determine which areas of the Borough were historically affected by particular types of floods. In order to create a method most suitable to estimate flood damages, the team analyzed current methods of damage estimation and historical incidences and examined the local and national policies dealing with flooding. The team also researched the future predictions of development in the Borough as well as the predicted effects of climate change in order to forecast direct damages of floods in the future.

2.1 Recent Flooding and the Geography of Hounslow

The London Borough of Hounslow is concerned about possible flooding in part due to recent flood events in the UK, as well as its proximity to a number of rivers. There are three rivers that are in close proximity to Hounslow, the Thames River, the Brent River, and the Crane River. In the summer of 2007, the UK experienced its most significant rainfall in over two hundred years. During this time two particularly heavy periods of rain caused flash flooding throughout parts of northeast and western England. Floods caused by rapid accumulation of rainwater in addition to overflowing rivers caused the worst flooding in England in sixty years (The Enviornment Agency). Figure 1 identifies the major areas that were affected by the 2007 flood events.

Figure 1: Impact Areas of the 2007 Floods (The Enviornment Agency)

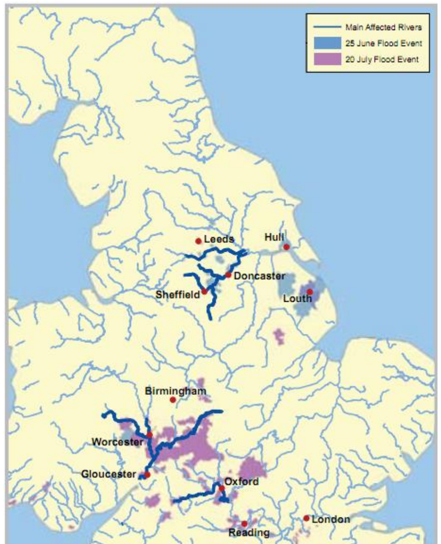


Figure 3: Flooded postcode sectors from June 25 (blue) and July 20 (purple) flood events collated by RMS Catastrophe Response, from a combination of RMS field reconnaissance, media reports, and other Web reconnaissance information. Each whole postcode sector is unlikely to have flooded everywhere, especially in rural areas, where postcode sectors cover a larger area

National infrastructure experienced heavy damage and disruption from the flooding. Major roads were badly damaged and had to be closed, disrupting travel through much of the country. Vehicles affected by the flood were often damaged to the extent that they required total replacement. Additional damage to railway lines obstructed rail traffic for almost a month after the flood events. According to Risk Management Solutions (RMS), a catastrophe management company, “at the peak of flooding, around 140,000 households were left without water and 50,000 without power” (Stuart-Menteth, 2007). Agriculture in the UK also faced considerable damage, as many crops were ruined or were discarded to due contamination.

RMS estimated the insured losses for the flooding as “1.25-1.75 billion for the June 25 floods and 1-1.5 billion for the July 20 events” (Stuart-Menteth, 2007). These values include a number of secondary effects, such as disruption to business. There were nearly 50,000 residential insurance claims, and about 25,000 commercial claims due to the flooding, averaging damages of around 30,000 and 90,000 respectively. People and businesses in some areas were displaced for significant periods of time after the flooding subsided due to significant structure damage.

In addition to the historical incident of the 2007 flood, the London Borough of Hounslow is also worried about flooding from the three major rivers located inside the borough. There are also multiple raised reservoirs on the outskirts of the borough that would cause flooding within the borough if a breech were to occur. Because of the constant risk of flooding, the City of London and the London Borough of Hounslow have put into place several policies in order to effectively react and plan for these events.

2.2 Hounslow Policies and Planning

The Civil Contingencies Act of 2004 is the primary legislation that dictates the content and implementation of emergency planning for both natural and technological hazards. The act places the principal responsibilities of civil protection on local organizations and establishes guidelines for the managing of emergencies. Local authorities are broken into two categories. Category 1 includes groups that are directly involved in emergency response, such as police and local government agencies, while Category 2 includes outside cooperating bodies, such as utility and telecommunications companies. Cooperation is encouraged between organizations in each category to keep essential services operational in the event of an emergency (Cabinet Office).

Groups falling under Category 1 are responsible for the bulk of emergency planning and preparedness activities. These organizations must periodically assess risks within the area by identifying threats to human welfare, the environment, or national security (HM Government, 2010). The likelihood and impact of possible dangers are evaluated in order to develop plans to manage the associated risk. The products of these assessments are documented in 'Risk Registers' that maintain the data for the community. These strategies aim to promote actions to prevent an emergency, reduce its impact, and confront any "secondary impacts" that might arise. Organizations must also develop business continuity strategies to keep essential services operating and facilitate their recovery in the event of an emergency. The information gathered through these methods is shared with authorities in neighbouring areas and released to the public (Cabinet Office).

The Borough of Hounslow developed its Major Emergency Plan (MEP) in response to the need for emergency planning as outlined by the Civil Contingencies Act. This plan was designed to guide local authorities, including the Hounslow Council, during a major incident where multiple agencies are responding. The Council's Contingency Planning Unit is responsible for keeping the Major Emergency Plan up to date with the 'risk registers' maintained by the borough. Subsequently it is the duty of the departments within the Council and emergency services to maintain their own risk assessments and emergency plans (Contingency Planning Unit, 2007).

Due to the critical obligations placed on local authorities to assess and respond to hazards, the Borough of Hounslow is seeking a method to estimate damages due to flood events. The effects of a flood event can be devastating and cause significant damage to a society. The severities of these impacts vary and depend on the vulnerability of the surrounding people. This makes getting an accurate estimate of the resulting damages. There are several methods for estimating the damages due to urban flooding used today, such as stage-damage curves and mathematical models. A number of government organizations have developed methods to model the impact of hazards.

2.3 Estimating Damages for Urban Flooding

There are several methodologies for estimating damages due to urban flooding. Not only can floods damage the structure and integrity of a building, but they can also cause irreversible damage to personal items and pose a number of health risks to victims. Flood damages are often difficult to estimate retrospectively because many of the effects are difficult to measure and not always reported. They become even more difficult to predict in advance because of the dynamic nature of flooding. There are a number of organizations that deal with the estimation of flood damages, two of which are the United States' Federal Emergency Management Agency and the United Kingdom's Environment Agency.

2.4 FEMA and Multi-Hazard (Hazus-MH)

The Federal Emergency Management Agency (FEMA) is the central organization for emergency response in the United States. Within FEMA the Federal Insurance and Mitigation Administration (FIMA) oversees mitigation efforts designed to reduce losses associated with a variety of natural hazards, including floods. While there are a large number of factors that are impacted by flooding, FIMA has chosen to perform their risk analysis and impact assessments in terms of direct economic losses (US Department of Homeland Security).

FIMA's Risk insurance Division is in charge of running the National Flood Insurance Program (NFIP). Through the NFIP, FEMA provides federally backed flood insurance to all community members that participate in the program. The NFIP encourages communities to adopt floodplain management ordinances for those who are in high risk flood areas. FIMA assesses the risk of floods by producing flood insurance rate maps (FIRMS). These maps are the main resource for local and state governments to manage the effects of flooding on their communities. The information included in these flood maps is floodplain boundaries, hazard area designation, base flood elevation, and zone division lines. Flood insurance policy rates are based on the flood- risk zone, age of the structure and elevation of the building in relation to the base flood elevation level. Residential one to four family unit buildings are eligible for up to $250,000 in building coverage and up to $100,000 in personal property, while non-residential buildings can receive up to

$500,000 in both building coverage and personal property. The average flood insurance claim in the United States during 2010 was $47,345, which has been steadily increasing since the NFIP was established 32 years ago (US Department of Homeland Security).

According to FEMA, "a flood certified insurance adjuster making a room-by-room item-by-item, detailed estimate of covered flood damage is the only estimating method approved by and acceptable to the National Flood Insurance Program." (US Department of Homeland Security). Figure 2is based on estimated costs for average U.S. homes of 1,000 and 2,000 square feet for a variety of flood depths. The costs were estimated using typical household items and damages that are available in Table 2.

Figure 2: FEMA's average estimate of total losses for residential homes

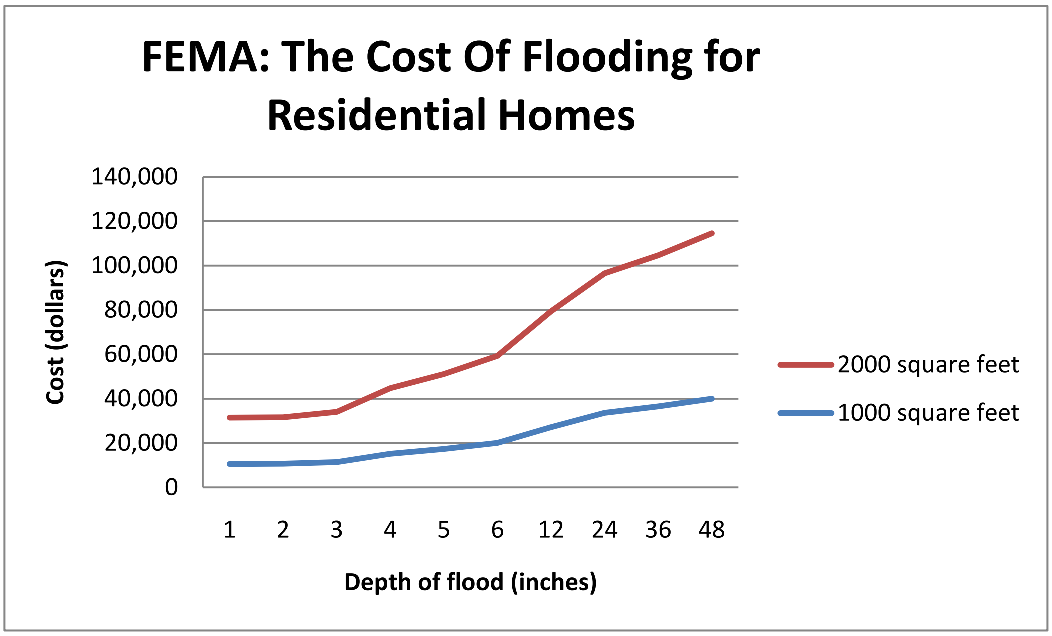


Table 2: Typical Household Items Damaged During Flood

Cleaning costs	Kitchen and bath cabinets	Living room furniture
Doors/base trim/windows	Appliances	Computer accessories
Electrical/plumbing	Repairs to furnace/AC	Television (2), DVD, Stereo
Finished floor: wood/carpet	Bedroom furniture	Washer/Dryer
Interior wall finishes	Dining room table and chairs	Accent furniture and accessories
Wall insulation, drywall, or panelling	Kitchen ware and food	Loss of personal items

FEMA recently produced a hazard modelling program called Hazus MH. The geographic information system (GIS) based program was developed to help estimate potential losses from a number of natural disasters including earthquakes, floods, and hurricane winds. This program displays hazard data and general estimates for economic loss in buildings and infrastructure. The benefit of a program like this is that it gives its user a graphical representation of the economic, physical, and social impacts of a potential hazard. Hazus MH uses a number of criteria to assess the impact of hazards; these can be seen in Table 3(US Department of Homeland Security). The variables that the computer modelling program considers also take into account indirect damages such as future economic losses. Although very helpful, a program of this complexity is fairly expensive and, at the moment, hard to obtain for public use.

Table 3: Hazus-MH Technical Manual Variables

Flood Source Agricultural Areas	Floodway Locations Business Losses
Flood Path	Building Material and Construction
Vehicles	Quality Rental Vacancy Rates
Flood Velocity	Location of Emergency Facilities
Shelter Locations	Cost of Replacement
Population Density Day and Night	Debris Generation
Building Density	Restoration Time
Economical Areas Income Levels	Location Of Schools Age
Topographical Data such as Elevation Hazardous Material Sites	Public Transportation

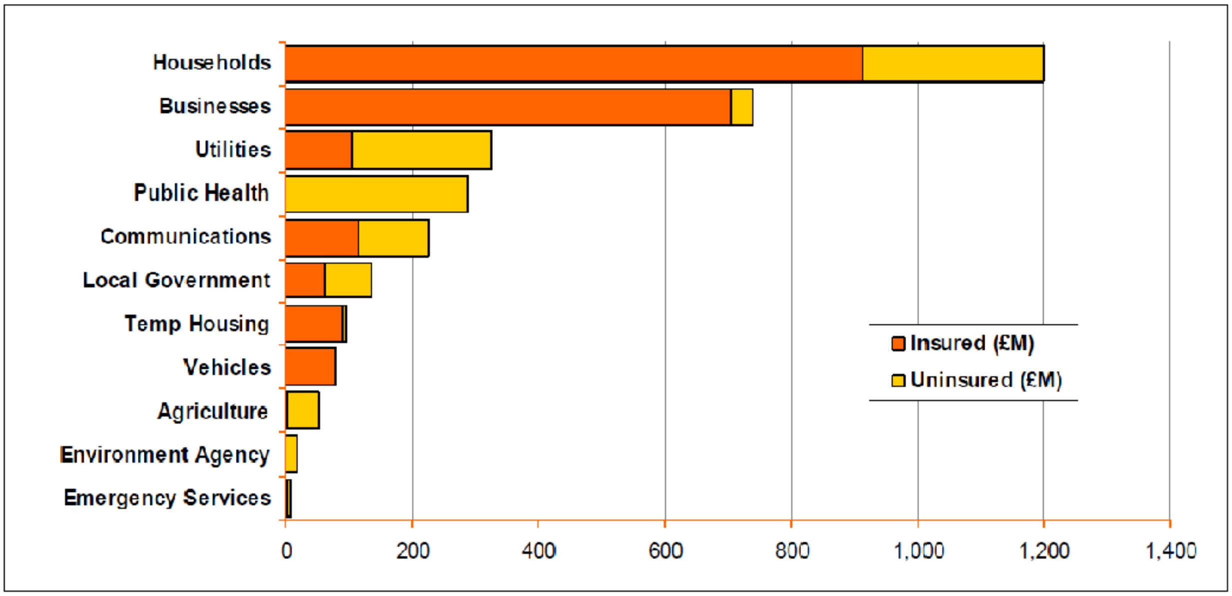
(US Department of Homeland Security)

2.5 Environment Agency

The Environment Agency is responsible for building and maintaining flood defences in England and Wales. The agency also issues flood warnings to the public, media, and other flood responding organizations in the UK. Like FEMA, the Environment Agency has developed flood risk maps that aid local insurers in determining the coverage for the area. Through the Environment Agency, local planning authorities are required to perform a Strategic Flood Risk Assessment (SFRA) when beginning to plan a development project. SFRA's provide vital information about flood risk considering the effects of climate change on river and coastal flooding.

In 2007 the Environment Agency produced a full report of the cost of the 2007 floods, estimating it to be between £2.5 billion and £3.8 billion. Figure 3provides a summary of these costs in terms of uninsured and insured victims. The data from this table was collected from records of physical damage and flood insurance claims for the area. This information was helpful when establishing typical damages caused by flooding for properties specific to the UK. From this comprehensive review it was determined that two thirds of the total damage done was incurred by households and businesses (The Enviornment Agency).

Figure 3: Cost of 2007 Floods in the United Kingdom



The financial accounts of local authorities and public services were audited so that a comprehensive list of damage expenses could be gathered. While most of this information obtained is reliable in some instances assumptions were made. Expenses like communications (including roads, railways, and telecom) have a considerable amount of uncertainty associated with them. Many times disruption costs are determined from estimations that local government authorities have made. Along with the use of in-depth damage reports and insurance claim information after a flood event, these organizations also use stage-damage curves and mathematical models to estimate damages.

The information gathered from the cost of the 2007 floods in the UK case study has proven extremely helpful in determining damage costs for flooding. This is the most up to date and relevant information regarding flood damages in the England. A summary of the specific costs can be found in Appendix A. This table helped decide the final variables that would be considered when calculating damages with this program by identifying the impacted areas that incurred the greatest costs during the 2007 floods.

2.6 Existing Flood Damage and Evacuation Estimation Methods

While preparing the methods, the team examined many of the existing methodologies for estimation of flood damage and evacuation costs. While these resources were quite useful in understanding past methods, it was decided the team could create a more accurate and more replicable estimation if the data methods were based on the most recent flooding data from the

2007 UK floods. They have been included here in order to provide a background of existing flood estimation methods.

2.6.1 Existing Estimation Methods for Evacuation Costs Due to Hazards

During a hazard it becomes extremely important to evacuate the residents that are in the most danger. Depending on the severity of the hazard this could mean thousands of residents must be evacuated to safety. There are a number of costs associated with relocating the residents within an impact area of a disaster one of which includes the cost of temporary housing. For this project the team will only be considering temporary housing costs during evacuation.

Penning-Rowsell, a leading researcher in the field of flood damage estimation, has done extensive flood research specific to the UK and has developed the table below. Table 4 shows a variety of temporary housing costs due to flood evacuation as a function of flood depth. The table also provides duration of the time that residents are expected to be away from their homes as well as the probability of evacuation for flood depths (Penning-Rowsell & Green, 2009).

Table 4: Probability of evacuation in a flood event and duration of evacuation in England and Wales

Depth	Terraced			Semi			Detached			Bungalow		
	Ave. monthly rental £436			Ave. monthly rental £473			Ave. monthly rental £640			Ave. monthly rental £449		
	Probability (%)	Duration (months)	Cost (£)	Probability (%)	Duration (months)	Cost (£)	Probability (%)	Duration (months)	Cost (£)	Probability (%)	Duration (months)	Cost (£)
3.00	100	2	872	100	2	946	100	2	1280	100	3	1347
2.70	100	2	872	100	2	946	100	2	1280	100	3	1347
2.40	100	2	872	100	2	946	100	2	1280	100	3	1347
2.10	100	2	872	100	2	946	100	2	1280	100	3	1347
1.80	100	2	872	100	2	946	100	2	1280	100	3	1347
1.50	100	2	872	100	2	946	100	2	1280	100	3	1347
1.20	100	1.5	654	100	1.5	709	100	1.5	960	100	2	898
0.90	100	1.5	654	100	1.5	709	100	1.5	960	100	2	898
0.60	100	1.5	654	100	1.5	709	100	1.5	960	100	2	898
0.30	100	1.5	654	100	1.5	709	100	1.5	960	100	1.5	673
0.20	50	1	218	50	1	236	50	1	320	100	1.5	673
0.10	50	1	218	50	1	236	50	1	320	100	1	449
0.05	25	0.5	54	25	0.5	59	25	0.5	80	50	0.5	112
0.00	25	0.5	54	25	0.5	59	25	0.5	80	25	0.5	56
–0.3	10	0.5	21	10	0.5	23	10	0.5	32	25	0.5	56

Note: Costs - duration*probability*average monthly cost for type
Duration of flooding not taken into account (<12 hours assumed)
Flats the same as bungalows
Town houses the same as terraced
Apply independently of age of house
Apply independently of social class

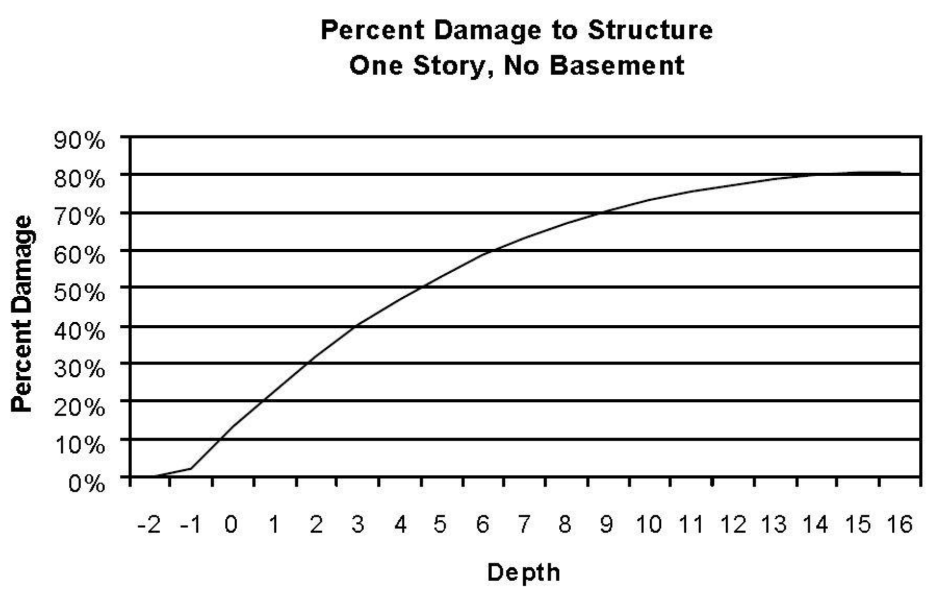
As estimations were not based off of the depth of the flood, but rather how far it extends throughout the borough, this method was not a reasonable way to calculate flood evacuation estimation data for us. This material did provide background on the average length of evacuation, and the amount of people evacuated in order to give the team a basis for their calculations.

The Environment Agency provided more up-to-date information regarding the general cost of temporarily evacuating residents and business employees in their report on the impact of the 2007 flood events. According to the case study 5800 homes were damaged to the point that their inhabitants required temporary accommodation. The average cost for the temporary accommodation of one house was £6,695 while the average cost of £5,461 was recorded for business temporary business accommodation. In total, temporary accommodation made up just over 3% of the total cost during the flood events (The Enviornment Agency).

2.6.2 Stage Damage Curves

A depth damage function is a mathematical relationship between the depth of a flood relative to the first floor of a building and the amount of damage that it causes. Depth-damage relationships are computed separately for the structure of a building and for its contents. A structure is typically defined as a permanent building and everything permanently attached to it. The contents of a building are typically defined as everything in the house that is not permanently installed. An example of a depth damage curve is shown below. The depth of the flood is on the X axis, with 0 feet being the floor level of the first floor. The percent damage on the Y axis represents the damages as a percent of the total value of the structure (Penning-Rowsell & Green, 2009).

Figure 4: Example Damage Curve



(US Army Corps of Engineers, 2000)

There are many different factors that contribute to the damages caused by a flood, including depth of flooding, time of year, velocity of floodwater, duration of flooding, sediment load, and warning time. These factors are all relevant to the damages caused, but historical assessment procedures have focused on one driving variable, depth of flooding.

The first way to create a depth-damage function is by means of a post flood analysis. The most common way to do this is to interview recent flood victims. An area that has been flooded is analyzed on the basis of types of structures and damages are estimated by the interviewer. The residents of the area are interviewed to estimate the content damage to the structures as well. This is the most precise method for gathering this information in a residential area. There are several downsides to this procedure. It requires that there be a flood in an area to analyze that particular area, and can be expensive and time consuming (US Army Corps of Engineers, 2000).

The next way to create a depth damage function is by the use of synthetic damage estimates. Synthetic flood damage functions are created from estimates of what flood damages would be at several hypothetical levels of flooding. Typical floor plans and content quantities are used to estimate the amount of damage done at different flood levels for the structure types in the area being analyzed. Unlike post flood analysis, synthetic damage estimates do not require an actual flood event, and are not as expensive or time consuming. Conducting a synthetic damage estimate requires the analyst to be experienced in damage estimation and how specific flood circumstances and structure types affect types of damages. This method also requires the analyst to go to the area and conduct interviews and structure analysis to determine the typical floor plan and content quantities. (US Army Corps of Engineers, 2000).

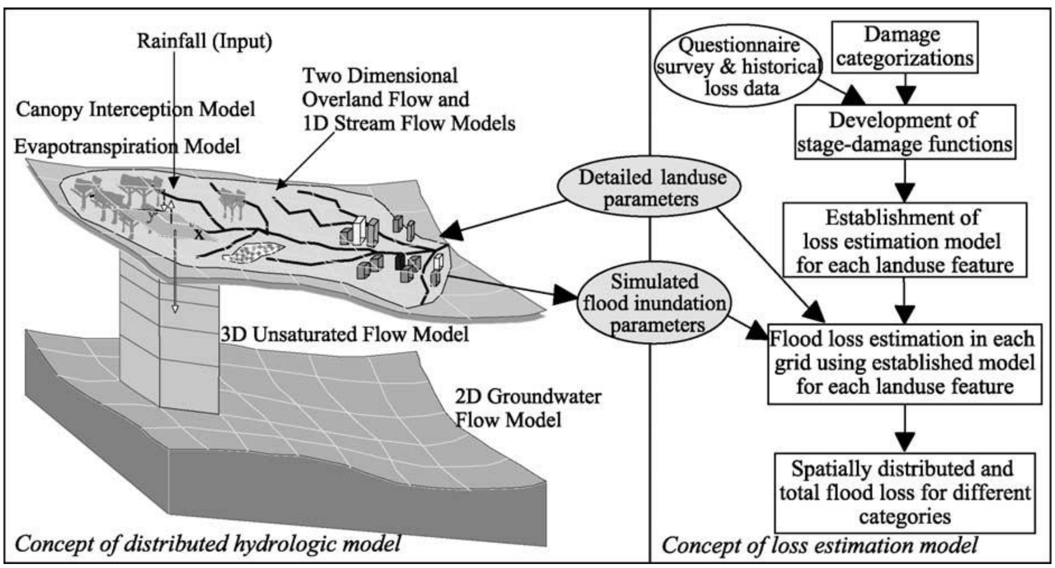
The final way to create a depth damage function is to adapt existing functions to the area. The structure types in the area must be determined, as well as the flood risk and characteristics for the area. Once these criteria are determined an existing depth damage function can be obtained for a similar region and structure type. Then the existing depth damage curve can be applied to the area. Adapting existing functions to the area is the least expensive and least time consuming method. It does not require any recent flooding or any survey of the area. This method allows using any well documented source to obtain curves, and using reasonable judgment to adapt them to the area in question(US Army Corps of Engineers, 2000).

2.6.3 Mathematical Modelling

Dutta, Herath and Musiake developed a mathematical model for estimating the losses that may be felt by flooding. There is considerable variation and low accuracy among existing estimation methodologies. Stage damage functions are often used to estimate damage, but they are not very useful for forecasting flood damage or real time damage. These stage damage functions are often based on historical damage information, rather than a mathematical model. Estimates given by stage damage functions also cannot estimate damages in many different areas, or view links between flood damage and secondary flood impacts (Dutta, Herath, & Musiake, 2003).

The approach used in this paper combined a physically based loss estimation model and a grid based loss estimation model. The grid based model breaks land loss into three different categories: urban, rural and infrastructure. It also uses a similar grid based model to the hydrologic model, which allows one to simulate flood damage in each section, which gives a more accurate picture of the damage. This can be seen in Figure 5: Schematic of the Mathematical (Dutta, Herath, & Musiake, 2003).

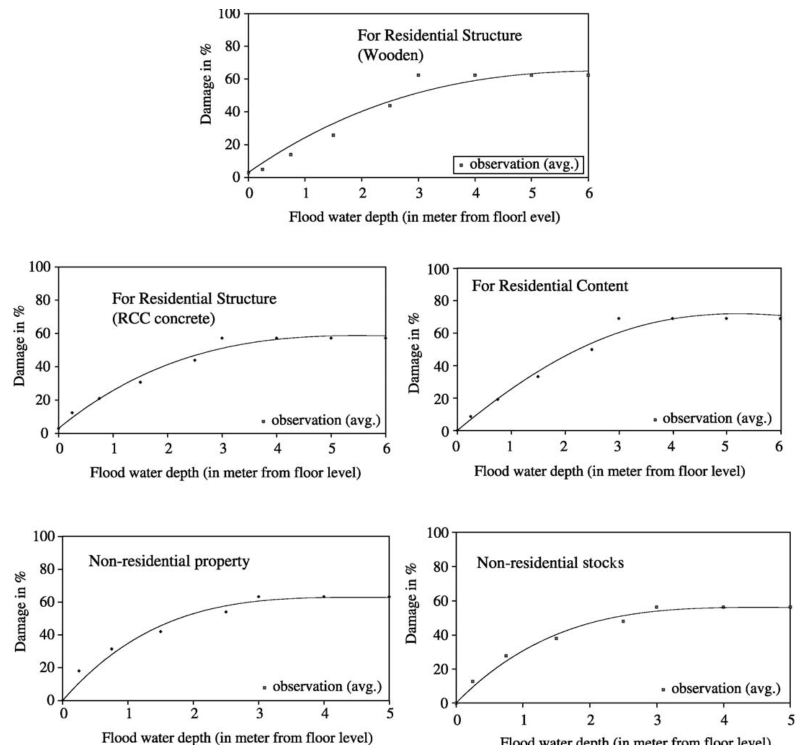
Figure 5: Schematic of the Mathematical Modelling



(Dutta, Herath, & Musiake, 2003)

The Hydrologic model addresses five major processes that occur during flooding: interception and evapotranspiration, river flow, overland flow, unsaturated zone flow, and zone flow. Each of these is calculated using specific methods developed previously to this paper. The flood loss estimation model uses two categories of loss – tangible and intangible loss – to define the types of loss necessary for this model. This method primarily looks at primary tangible damages, as other damages are difficult to predict. All damages are split into urban, rural and infrastructure. The mathematical model for determining urban damages includes damage to the building structure, damage to the contents of the building, damage to the outside of the building, and response and clean-up costs. The flood depth is the major parameter in determining the impact of the flood. The rural mathematical model creates damage curves based on the types of crops and livestock that occur in the flooded area. Infrastructure damage does not have any established methodology, due to the fact that infrastructure damage may vary greatly. This methodology is based on estimation of damages due to earthquakes, rather than flooding. After the creation of these models, stage damage curves are established for different types of possibly damaged land, seen in Figure 6(Dutta, Herath, & Musiake, 2003).

Figure 6: Stage Damage Curves for various land types



(Dutta, Herath, & Musiake, 2003)

While the stage damage curves and mathematical modelling used does give an estimation of flood depth, due to the age of the stage damage curves available, and the data received from the borough, it was decided to base the methods off of historical data, rather than these mathematical functions.

2.7 Climate Change

In order to project the effects of major issues, such as climate change, the Office of Science and Technology began the Foresight program (Foresight Committee). This program runs studies looking 20 to 80 years in the future to aid the development of government policy. In 2004 the Foresight program released a report on future flooding finding that damages due to flooding will increase between now and 2080. The number of properties and people at a high risk of river and coastal flooding was expected to considerably increase with development in flood-prone areas. Intra-urban flooding was predicted threaten at least three times as many properties by 2080, however the possible related damages spanned a wide range of values(Foresight Committee).

The Foresight Future Flooding report identified several major influences that will impact flood risk in the future. Climate change was the main factor, as a rise in sea level and rainfall would dramatically increase the area at risk, as well as the severity of the flood. Urban development would place more properties and people at risk, and possibly impact rainwater runoff. The report also found an increase in social impacts of up to twenty times the current risk (Foresight Committee).

Climate change is expected to increase the amount of winter rainfall and frequency of floods during the course of the next century. However, the government's Planning Policy Statement 25 found that "changes in the extent of inundation are negligible in well-defied floodplains" (pps25). As a result, a 1 in 2000 (.05%) flood event is thought to be equivalent to a 1 in 1000 (.01%) event in the year 2030. That is, more severe flood events will become more frequent, but the area affected will not significantly increase. If flood defences are not upgraded they will gradually degrade in protection levels relative to the effects of climate change. As flooding increases overtime due to climate change, the amount of damage will increase as well. Thus, the team has developed a method for calculating an estimation of damage from flooding due to climate change in the next 20 years. This method also takes into account the change in development and population that will occur over the next 20 years in the borough.

2.8 Overview

Research into these methods provided the team with a better understanding of the kind of solutions experts in this field produce to such a complex problem. Although these methods allowed the team to better understand current modelling techniques, the complexity and specificity of these processes would not allow the program to be used easily in many different boroughs. Thus, the team decided a new method and program needed to be created.

3. Methodology

The goal of this project was to create a program to model the damages due to urban flooding in London that is based off of widely available data and is straightforward in its methodology.

This methodology was required to be easy to understand for people with minimal experience in this field and involve as few input variables as possible. Due to the complexity of assessing damages, boundaries had to be set on the scope of the project. Intangible damages, such as psychological effects and economic repercussions, were not part of the costs estimated because of the uncertainty associated with quantifying them. The Hounslow team had to recognize that the impacts of a flood event cannot be expressed in monetary terms alone. A flood event can cause personal tragedies to those impacted that many have trouble recovering from.

The final model assessed direct damage to buildings and their contents and the direct impact to residents, businesses, and students within the flood area. Other direct damages that were taken into consideration include the cost and time associated with temporarily housing the victims of the flood event and the amount of waste produced by the flooding. The majority of the data came from the most up to date and relevant case studies available pertaining to flood damage costs.

3.1 Identifying and Calculating Relevant Variables

Throughout the literature review the team identified a number of ways that damage estimation could be performed for a flood event. Not having a computer modelling program available, the team decided that basing the method on case studies would give it accuracy while remaining easy to use. The majority of this data was supplied by the case study on the 2007 floods in the UK. This document summarizes the costs associated with the natural disaster that devastated the lives of approximately 100,000 people. While much of the data related to the costs of damages is accurate and based off of insurance claim reports, it was important to analyze where each number came from and its general accuracy. While they are explained in more detail below, Table 5 provides a summary of the variables that were considered in the flood damage modelling program.

Table 5: Cost Estimation Factors

Source	Category	Cost Estimation Factors	Value	Unit
EA 2007 Flood Report	Utility	Electricity deprivation cost Average Household Electricity Consumption Average electricity deprivation time	10 0.3767 14.6	£/household/kWh kWh/hour hours
		Water failure cost Average water failure time	10 2	£/household/day days
		Sewage failure cost Average sewage failure time	5 2	£/Household/day days
EA 2007 Flood Report	Property Damage	Average Household Insurance Claim Number of Uninsured Houses	27150 24.00%	£/Household percentage
EA 2007 Flood Report		Average Business Insurance Claim Number of Uninsured Businesses	72826 5.00%	£/Business percentage
Pitt Review Pitt Review Office for National Statistics	Health/People	People Reporting Health Concerns People Requiring GP Visit People Requiring Evacuation Assistance	41.50% 39.00%	percentage percentage of above value percentage
Department for Education	Schools	Cost of school day Average days out of school	 2.35	£/pupil day days
Disaster Reduction and Human Renovation Institution	Waste	Total Waste Produced	4.17	Tonnes/Building
EA 2007 Flood Report	Temporary Accomodations	Buildings needing temporary accomodations Ave cost of temp accom (domestic) Ave cost of temp accom (business)	30.00% 6695 5461	percentage £/Household £/Business

3.1.1 Discounted Variables

In order to provide the most accurate estimation possible, the team needed to decide on the relevance and accuracy of the data provided. Originally, the team discounted any of the variables that were not in direct correlation with the extent of flood events; these include long-term economic effects and any psychological effects, as these would be very difficult to quantify effectively. The team then examined the Environment Agency's 2007 UK Flooding report and the variables that they considered when calculating the total cost of the 2007 floods. The Environment Agency rated the uncertainty of the reliability of the data that they arrived at on a scale from 1-4, as shown in Appendix A. Many of the variables that were discounted had higher levels of uncertainty from the Environment Agency. Data that was labelled with an uncertainty value of 4 was not incorporated into the estimations. This included damage done to vehicles, communication systems, and agricultural land. Fortunately these costs made up only 7% of the total damage during this flood event. The team did not include damage done to general infrastructure and communication in the program due to the inability to accurately and reliably measure the damage done to roads and public transportation. Also, the level of variation in road and transportation structure made it unfeasible to replicate a method of evaluation in another borough. Land damage was similarly discounted as it would be difficult to define the different types of land and because damage to land is not regularly reported. Since the majority of flood damage comes from the first 9 inches of water, it assumed the average height of floods analyzed would be at that depth (SFRA, 2010). At this flood level there is not enough damage to cars to have a significant impact.

3.1.2 Loss of Utilities

During the 2007 UK flooding, disruptions to utilities incurred a cost of about £325 million, making up about ten percent of the total cost of the disaster (The Enviornment Agency). Over 100,000 households experienced power disruptions due to flooding. Most of the cost associated with electricity was caused by intermittent power outages throughout the affected areas, with physical infrastructure suffering a relatively small amount of damage. The total cost was estimated to be £130 million, calculated by estimating the willingness to pay to avoid disruption per kWh per customer at £10 and multiplying it by the estimated lost power due to disruptions (The Enviornment Agency).

Damage to water treatment plants and other infrastructure disrupted water supplies to large communities. The flooding of the Myth Water Treatment Works affected the water supply to 350,000 people at a cost burden of £23.5 million. According to the Environment Agency, "As a result of flooding, water treatment services for 2,500,000 people (just over a million homes) were affected for an average of two days."(The Enviornment Agency). Water companies were forced to respond to flooding by providing funding for flood relief organizations and incurred extra costs associated with testing of the water supply. The Environment Agency used a method similar to the one described for power above to calculate water supply disruption costs, using a cost of £10 per household per day of disrupted service established by the Water Services Regulation Authority (OFWAT). However, the Environment Agency noted that "No standard rate is available for disrupted sewage services" (Environment Agency, 2010, pg 22). These costs were estimated by assuming a cost of half of the rate of disrupted water supply, or £5. Total cost due to water supply disruption and damage was estimated around £186 million (Environment Agency, 2010, pg. 22).

The summary for the costs associated with utilities can be seen below. The cost for electricity was determined by multiplying the cost per property per kilowatt hour by the number of properties impacted and by the hours without electricity. A similar method was used to calculate the cost for water and sewage. Their rates were multiplied by the number of properties impacted.

Table 6: Utility Costs

Utility	Cost
Electricity	£10 per property/kWh
Water	£10 per property
Sewage	£5 per property

3.1.2 Damage to Properties

Damage to residential properties was the largest category of costs during the 2007 flood events. According to the Environment Agency case study done on the impact of the 2007 UK floods, the average household damage ranged from £24,300 to £30,000, with over 65,000 homes impacted. This data was based off insurance claims filed for the flooding period found through the Association of British Insurers (ABI) and a review of the aggregated claims found through Weathernet insurance validation (The Enviornment Agency). This information can be seen in Table 7. It is important to note that because owners of both residential and commercial properties filed for multiple insurance claims during the aftermath of the flood event the data has been adjusted to reflect a per property figure. These costs can be seen in the A and B residential categories in Table 7. The average single insurance claim for residential properties, shown in category C, was £13,000.

Although this is an average for the UK, the team chose to keep these costs. It was assumed that using a UK average would make the method more replicable and easy to use for other boroughs. The average damage to a residential home according to the EA's 2007 flood report was £27,150. This figure coincides with the average damage of $45,000 (£28,000) for a 2000 sq foot home in 9 inches of water as reported by FEMA. A second report by FEMA in January 2011 confirmed these approximations: the average flood insurance claim in the United States was $47,345, which is equal to £29,131(US Department of Homeland Security).The similarities between both these estimates support the argument to use the EA 2007 UK Flood Report in the team's estimates.

The Environment Agency's case study reported that the average damage done to businesses during the 2007 floods ranged from £55,652 to £90,000(The Enviornment Agency). The team decided to use the average of this damage range, as was done for residential properties. The average cost to a commercial building was £72,826. The team felt that although not every business will incur this damage, it is representative of the average damage done to a commercial property within the UK because this flood event affected over 8000 businesses. This figure will allow the method to be replicable for other boroughs.

Table 7: Estimated economic damage costs of the summer 2007 floods to residential and commercial properties

	Average insurance claim £ per property (A,B) or per individual claim (C)	Properties affected (A, B) or claims (C)	Total insurance claims £ bn	Economic adjustment factor % *	Economic losses £bn	% covered by insurance	Total economic losses £bn	Econ as % of insurance claims
Residential - A	£30,000	48,000	£1.44	53%	£0.77	76%	£1.01	70%
Residential - B	£24,303	65,000	£1.58	53%	£0.84	76%	£1.11	70%
Residential - C	£13,000	132,000	£1.72	53%	£0.91	76%	£1.20	70%
Commercial - A	£90,000	7,300	£0.66	66%	£0.43	95%	£0.46	69%
Commercial - B	£55,652	8,000	£0.45	66%	£0.29	95%	£0.31	69%
Commercial - C	£24,000	35,000	£0.84	66%	£0.55	95%	£0.58	69%
Total A			£2.10				£1.46	70%
Total B			£2.02				£1.41	70%
Total C			£2.56				£1.78	70%

DATA SOURCES	source of unit cost	source of number of claims
Residential - A	Pitt/Efra	Pitt/Efra households
Residential - B	Weathernet	ABI estimate households
Residential - C	ABI av claim	ABI claims
Commercial - A	Pitt/Efra	Pitt/Efra businesses
Commercial - B	Weathernet	ABI estimate businesses
Commercial - C	ABI av claim	ABI claims

Economic adjustment

* residential adjusted for VAT at 17.5% and assuming '75% of claims for inventory with 50% remaining value

*commercial adjusted for VAT at 17.5% and assuming '45% of claims for inventory with 50% remaining value

While the average business claim may change due to the difference in business environments between the entire UK and the Borough of Hounslow, there was no feasible way to calculate the worth of every business in the borough. Thus, the team used the average value of damage to calculate their estimation. This damage estimate and the damage estimate for residential buildings do not include the value added tax (VAT) of 17.5% because this is not a real cost but rather a transfer of money to the Government.

3.1.4 Schools

The Department for Education website provides the amount of money a borough spends per student per year for education purposes (Department for Education). Schools in the borough of Hounslow spend an average of £5,530 pounds a year on each student. As schools in the area typically run on a 190 day term schedule, one can calculate that the borough spends about £29.11 pounds per day on each pupil (Department for Education). This number was then multiplied by the number of pupils in each school that is affected by a flood event. The schools that are affected were determined through the use of the GIS map. This calculation was used to determine the amount of money that would be lost by the school system due to students not being in school.

This method is very similar to the one used by the Environment Agency to calculate the cost of a lost of a school day during the 2007 flooding. The cost of lost benefits to the school due to unplanned absences was also considered in the EA report as an estimation of the cost of a school day, but due to the unreasonably high estimate of that method it was concluded that using the loss of a school day per pupil based on the pounds per pupil spent by the school was a better estimate (The Enviornment Agency).

3.1.5 Temporary Accommodation

Temporary housing as a result of the 2007 floods was provided for about 14,500 people. The length of stay varied greatly, with nearly 5,000 people still out of their homes almost a year later. The Environment Agency calculated costs through insurance data provided by Weathernet, which found an average cost of temporary accommodation of £6,695 per household (The Enviornment Agency). The Environment Agency then multiplied this by the number of displaced households to estimate a cost of about £80 million. Some businesses also required alternative housing, costing an additional £11.2 million (Environment Agency, 2010, pg 15). The average cost for temporary accommodation to businesses was determined to be £5,461. For both residential and commercial properties the Environment Agency's case study found that 30% needed temporary accommodation.

The team used the previous information to determine the temporary accommodation impact associated with a flood event. The following table summarizes the cost of temporary accommodation:

Table 8: Temporary Accommodation Costs

Property Type	Cost per Property	% Needing Accommodation
Residential	£6,695	30
Commercial	£5,461	30

3.1.6 Health and People

One important concern is the immediate effect on people who are in buildings that are in a flood zone. The occupants of a flooded house must be evacuated, but some citizens may require evacuation assistance. These people are labelled 'Vulnerable People'. In order to estimate the number of vulnerable people, the team has considered two groups of people to belong in this category. These groups are: all residents over the age of 70, and all residents registered as disability living allowance claimants under the age of 70. In order to avoid double counting residents, the total number of residents over the age of seventy was added to disabled residents under the age of seventy. This number was then divided by the total population of the borough to find the percentage of vulnerable people. This is an estimate for the percentage of a population affected by a flood that will require special evacuation assistance.

Another problem that arises during and after flooding is related health concerns. In the Pitt Review of the 2007 floods (Pitt, 2008), it is stated that approximately 41.5% of people who were affected experienced health concerns they attributed to the flood. It also states that 39% of those with concerns visited their general practitioner (GP) as a result. The team decided to use these numbers as a basis for estimation, assuming that 41.5% of the affected population will experience health concerns, and 39% of those people with health concerns will require a GP visit. In order to get a better understanding of how this will affect the community, the team evaluated how many GPs were flooded. This data came from the GPs plotted on the GIS map, and then overlaid with the flood scenario.

3.1.7 Waste

Recovering from a flood involves removing a large amount of waste from damaged property. Research by the Disaster Reduction and Human Renovation Institution on several flood affected areas found that "the estimated amount of waste per household was 0.6 tons in the case of flooding below floor level and 4.6 tons in the case of flooding above floor level"(Disaster Reduction and Human Renovation Institution). The estimations assumed all flooding was above floor level and only used the 4.6 ton figure, which was adjusted to 4.17 metric tonnes to be appropriate to the UK. Due to lack of available data, both the residential and commercial properties were considered equivalent in terms of flood waste produced. To estimate the total waste, the number of residential and commercial buildings affected by a flood was multiplied by the average waste per structure of 4.17 metric tonnes.

3.2 Creating the Base GIS Map

To assess the impact of a flood event using this methodology, a base GIS map must be created in order determine a number of different variables within an impact area. The base GIS map used for this project was constructed on a computer program called Cadcorp SIS Map Editor (CADCorp , 2011), which is the Council of Hounslow's generic GIS mapping system. Cadcorp SIS works very similar to ArcGIS (esri, 2011) in that one can layer maps and demographic information to construct maps for a specific purpose. The different map and demographic layers specific to the borough were available to the team through a GIS network that is shared through the council office. As this is the program used by the borough and many other boroughs in the city, it was decided to use Cadcorp SIS versus using the ArcGIS provided by Worcester Polytechnic Institute.

To begin creating the base GIS map, a map of Hounslow broken into ward sections was added. This is a very common file and was readily available to the team. The next layer that was placed into the map was an ordinance survey address point layer. This information was collected by Ordinance Survey, Great Britain's national mapping agency, and contains the address and geographical location of every property (commercial and residential) within the borough of Hounslow. This data was collected in December of 2010 and was the most up-to-date information available to the team and council. Next a school location layer was added to the map so that the number of schools impacted by a flood event could be determined later in the methodology. Finally a general practitioner layer was added to the map. This provides the name and location of all GP's within a given borough. This layer is specific to each borough and is available to all boroughs.

Although they were not added to the map immediately, the council also provided the team with map layers for a number of different flood scenarios. These flood scenarios included dam inundation flooding, fluvial and tidal flood zones, and surface water flooding. Damages due to each of these flood scenarios are discussed later in the report. Once the team had a base GIS map with the important demographic information of the entire borough, damage models due to different flood scenarios were produced.

3.3 Choosing Flood Scenario

A variety of different flood scenarios were evaluated to estimate damages. Each scenario modelled different types of flooding that could occur in an urban environment. The borough of

Hounslow provided the team with six different flood scenarios that encompassed four different types of flooding: fluvial flooding, surface water flooding, tidal flooding and dam inundation. Fluvial flooding and tidal flooding were calculated for both Zone 2 and Zone 3 flood areas, which are different scenarios of varying probability and extent.

3.4 Identifying Impact Area

The first step in determining the impact of a given flood event was to overlay each flood scenario on the base GIS map. Because the extent of flooding varies for each flood scenario, the damage models are significantly different from one another. Once the specific flood scenario was overlaid on the GIS base map an application called "query" within Cadcorp SIS was run to determine the demographics of each impact area.

The query application allows the user to identify information within each ward that intersects a flood impact area. For instance, in order to identify the properties impacted by flooding within the ward of Chiswick the user highlights the flood area and the Chiswick ward and runs a query for the OSAP layer. This would produce a table of properties impacted by flooding within an excel file which can be sorted to determine their respective land use type (commercial or residential).

This process was repeated for schools and GPs, in order to get the total number of properties of each type affected. The final data set consisted of properties impacted (commercial and residential), schools impacted, GP's impacted, and number of people impacted within each ward. This process was then repeated for each flood scenario.

3.5 Projecting Flood Damages into the Future

In order to accurately reflect the number of buildings and people that a flood will affect in the future, the modelling program calculations took into consideration housing and population projections for the year 2031. The Greater London Authority (Greater London Authority, 2011) provides statistics on population increase through the year 2031 for each ward in the borough. The GLA also projected housing within the entire borough of Hounslow in 2031, but attempting to distribute this increase across Hounslow's wards would be inaccurate due to different rates of development (Greater London Authority, 2011). Two strategies were determined to estimate the future development in each ward.

The first method used GLA data on the number of households in each ward in Hounslow for the years 2001 to 2008. The team calculated the average change in households per year for each ward. The number of households was then projected forward to 2031 by applying this change to each subsequent year, as shown in the formula below. The results of this method were found to be of insufficient accuracy. The Syon ward was projected to have an 88% increase in housing but only an 18.5% increase in population, reflecting an unnatural shift in people per household. Other wards displayed similar results of housing development far outpacing population growth. The number of households in Hounslow was projected by the GLA to hit 103,100in 2031, but this method projected that number at 111,669, a difference of 8.3% (Greater London Authority, 2011).

$$ProjectedHouseholdsin\ 2031 = (AverageChangeinHouseholds \times 20\ years) + Householdsin\ 2011$$

The second method used population projections from the GLA(Greater London Authority, 2011). The change in housing was considered to be proportional to the change in population. To check that this was a reasonable assumption, the team calculated the change in people per household for each ward in each year from 2001 to 2011. While some areas had dramatic changes in a single year (near 10%), the average across all years was -.07%, with a 95% confidence interval of -.42% to .28%. This change was considered insignificant enough to be negligible for the team's purposes. The change in housing for each ward was then calculated by multiplying the percent change in population between 2011, the last year housing data was available, and 2031 by the number of houses in each ward (as shown in the formula below). The total number of households projected from this strategy was 100,937; only 2.1% off the GLA predicted 103,100(Greater London Authority, 2011).

$$Projected\ Households\ in\ 2031 = \%\ Change\ in\ Population\ 2011\ to\ 2031 \times Households\ in\ 2011$$

These calculations were used to predict the impact of flood events in 2031 based on the models for current events. Future housing developments were assumed to be evenly distributed throughout the ward. The projected number of affected households was determined by multiplying the current affected households by the percent change in population. This change to the number of households will also reflect population change in the model, since the number of affected people is determined by multiplying affected households by people per household.

In addition to modelling future damages, research was done on the effect climate change will have on current flood scenarios. The team found that the probability of a given flood event is likely to increase for the long term future. The Dumfries and Galloway Council reported that for their region in Scotland, "the indications are that the 1 in 200 year event (0.5% annual probability) will become a 1 in 100 year event (1% annual probability) by the year 2080"(Southwest Region, 2007)A report on flooding in south-west England found that “a 1 in 200 year event now … will become a 1 in 33 year event,” (Dumfries and Galloway Council, 2007)by the year 2060. The same report had assumed for its purposes that a 1 in 1000 year flood will become a 1 in 100 year event, and the 1 in 100 will eventually become a 1 in 20 event.

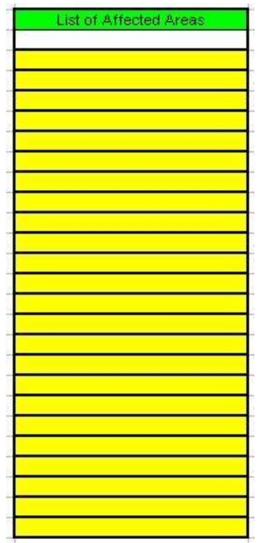
There was insufficient data to support a definite change in flood risks for the Borough of Hounslow, however it is highly probable that return periods for all types of flooding will decrease (i.e. annual probability will increase) due to climate change in the future. Based on the assumptions made in the report mentioned previously, it is likely that the costs associated with the 1 in 30 year event will gradually approach that of the 1 in 200 year event. That is to say, climate change will reduce the return period of the 1 in 200 year event, and more severe flooding would be expected at the 1 in 200 year rate.

3.6 Use of Excel Program

The final version of the modelling program was designed to be stand-alone and require minimal training to use. It is a series of excel spreadsheets that require information extracted from GIS and borough specific data. The first two sheets provide an explanation of what the program is used for and explicit instructions on how to obtain all necessary data. This increases the ease of distribution to other boroughs. An image of the instructions can be seen in Appendix B.

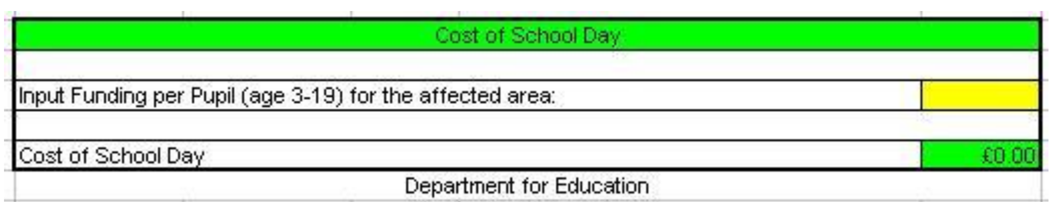
The first step in using the program is to calibrate it for the specific borough being modelled. The user is required to input the names of each area being analyzed, whether it is the entire borough, or individual wards within the borough. An image of this input section in the modelling program can be seen below in Figure 7.

Figure 7: List of Affected Areas Input



The user then inputs several variables that adjust the estimations for the specific borough. The first variable used to adjust the program to the borough being analyzed is the cost of a school day. The cost of a school day is based on the amount of money that the borough spends per pupil per year. This value is different for each borough within London and the user is provided with instructions as to how to obtain this value. An image of this input section can be seen below in Figure 8.

Figure 8: Cost of a School Day Input



The next variable that is used to adjust the program for the borough being analyzed is the percentage of people requiring evacuation assistance. This is the percentage of people in the entire borough over 70 years of age, or under 70 and claim disability living allowance. The user is provided with instructions as to how to obtain the number of people in these two groups, as well as the total population of the borough. An image of this input section can be seen below in Figure 9.

Figure 9: People Requiring Evacuation Assistance Input

People Requiring Evacuation Assistance	

Disabled Population Under 70	
-16	
16-24	
35-49	
50-59	
60-69	
Total	

Population 70 and above	
Aged 70 years	
Aged 71 years	
Aged 72 years	
Aged 73 years	
Aged 74 years	
Aged 75 to 79 years	
Aged 80 to 84 years	
Aged 85 to 89 years	
Aged 90 to 94 years	
Aged 95 to 99 years	
Aged 100 years and over	
Total	
Total Disabled and/or Elderly	
Total Population (2001)	
People Requiring Evacuation Assistance	

Office for National Statistics

The next value used to adjust the program for a specific borough is the future projections. The Greater London Authority provides the current population for each ward within every borough and projections of populations up to the year 2031. The modelling program calculates the percent change in population from the present to a future year chosen by the user. This percentage is assumed to be the same as the percent increase in the number of houses. The user is provided with instructions how to obtain the current population and the population for the future year. The projected cost takes into account this increase in the number of houses and calculates a new cost. An image of this input section can be seen below in Figure 10.

Figure 10: Future Projections Input

Future Projections			
Affected Areas	Current Total Population	Projected Future Total Population	Percent Change in Population
Greater London Authority			

The last variable required to calibrate the modelling program for a specific borough is the average number of people per house. The Office for National Statistics provides the number of addresses with the same number of inhabitants in a ward. The user is provided with instructions on how to obtain these numbers and the program calculates an average number of people per house in each area being analyzed. This value allows the program to estimate the number of people affected based on the number of houses in the flood zone. An image of this input section can be seen below in Figure 11.

Figure 11: Average Number of People in Households Input

	Average Number of People Living in Households									
	Total	1	2	3	4	5	6	7	8	Average

Office for National Statistics

The next step is entering the values extracted from GIS about the number of properties affected by the flood. There are five inputs that are required for each affected area. These are: the number of households affected, the number of businesses affected, the number of schools affected, the total number of people in those schools, and the number of GPs affected.

Figure 12: Inputs Taken from GIS Maps

	Inputs Taken from GIS Maps				
	Number of Households in Flood Zone	Number of Businesses in Flood Zone	Number of Schools in Flood Zone	Number of School Pupils in Schools in Flood Zone	Number of GPs in Flood Zone

Once these values have been entered for every affected area, the user can view a compilation of the key factors calculated in the Summary sheet, as well as a table of all outputs calculated in the Outputs sheet. In the Summary sheet, the total monetary cost of the flood, including the portion of this cost that is uninsured, and the projected future cost are provided. Also, a number of non monetary damages important to an emergency planner are provided.

Figure 13: Blank Summary Sheet

	Number of Households Affected	Number of Businesses Affected	Number of Schools Affected	Number of People Affected	Number of GPs Affected	Number of People with Health Concerns	Number of People Requiring GP Visit	Number of People Temporarily Relocated	Number of People Requiring Evacuation Assistance	Tonnes of Waste Produced	Total Uninsured Cost	Total Cost	Total Cost (20 Year Projection)
Total	0	0	0	0	0	0	0	0	0	0	£0.00	£0.00	£0.00

These factors are: the number of households affected, the number of businesses affected, the number of schools affected, the number of people affected, the number of GPs affected, number of people with health concerns, number of people requiring a GP visit, number of people requiring temporary accommodations, and tones of waste produced. The modelling program also combines all of the monetary costs that are associated with the different effects of flooding and combines them. The total monetary cost is a direct output of the modelling program, as well as the total uninsured cost and the total cost projected into the future. The total monetary cost is an important output of the modelling program as it puts the effect of the flood in terms that are easy to understand. The total uninsured cost gives a better understanding of the effects on individual people in the flooded area, while the total cost projected into the future gives a better understanding of the effects a flood will have in the future.

The user can then view a verbal explanation of all calculations done, and a list of all sources used. A blank copy of the entire modelling program can be seen in Appendix C.

4. Results

4.1 Damage Modelling Program and Hounslow Flood Scenarios

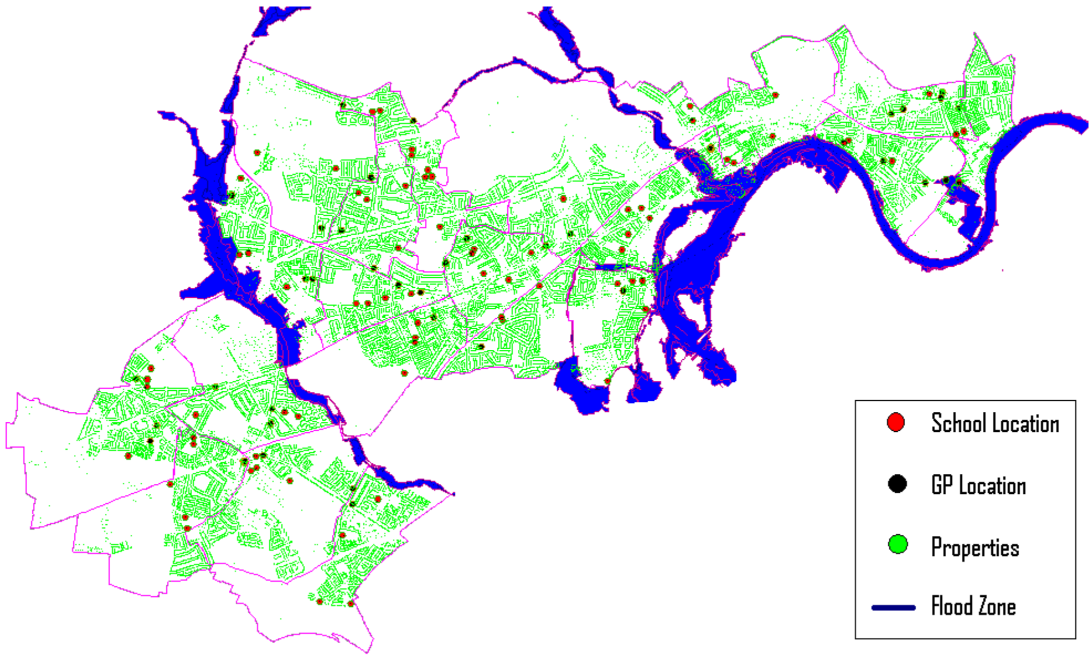
In order to test the application of the modelling program, it was used it to model the effects of six different flood scenarios in the borough of Hounslow. Maps for these six scenarios were provided by the Environment Agency. The flood scenarios included zone 2 and zone 3 fluvial events, zone 2 and zone 3 tidal events, a 1-200 year surface water event, and a dam inundation scenario. While the Hounslow team supports all of these findings, it is important to remember that the modelling program merely approximates the direct impact of a flood event and is in no way the exact or actual flood impact.

4.1.1 Fluvial Flood Model

The first scenario that the team analyzed with the modelling program was fluvial flooding. A fluvial flood is caused by river levels rising due to significant rainfall. Often a river will rise higher than the embankments or walls containing it and flood into the surrounding area. This is a very common event in many parts of London. Situated in a natural flood plain, the Thames River often floods the densely populated city causing severe damage. The presence of three rivers that run through Hounslow, the Thames, the Brent, and the Crane, make fluvial flooding the most frequent flood event experienced by the borough.

The Environment Agency has produced two maps for the London Borough of Hounslow that outline its fluvial flood risk. These two flood maps represent different flood 'zones' and differ in probability and extent. A Zone 3 fluvial flood event is defined as having an annual probability greater than 1%. A flood event like this one can be expected to happen at least once every one hundred years. The more extensive flood event, Zone 2 flooding, is defined as having an annual probability of 0.1% to 1%. This flood event can be expected to happen between every 100 to 1000 years. Both maps were provided to the team electronically in GIS format and overlaid on the base GIS map. An image of the more extensive zone 2 event can be seen in Figure 14, an image of the zone 3 event can be seen in Appendix E. A full summary of the impacts of this flood and the fluvial zone 3 event can be seen in Appendix D and Appendix F, respectively.

Figure 14: Hounslow - Fluvial Zone 2



As expected, the zone 2 scenario resulted in the most damage of the two fluvial events. A summary of the damage model outputs for both events can be seen in Table 8. While the less extensive zone 3 caused just over £30.6 million to the borough and its residents, the zone 2 event more than doubles this cost at £72.7 million. This difference in cost comes from the large change in the number of properties damaged, the models largest cost estimation factor. An additional 1165 households and 107 businesses are damaged in the zone 2 event when compared to the zone 3 event. The majority of these properties fall within the ward of Syon in Hounslow which is flooded much more extensively in a zone 2 event. Having this information could prove helpful when planning a future flood defence. If Syon is particularly susceptible to fluvial flooding than it may be cost effective to place a flood defence along the length of the Thames River here.

Another important figure to note is the difference in the number of people requiring a visit to a general practitioner between the two events. Based on the damage model, an additional 1128 people would need to visit a general practitioner putting a heavy strain on the healthcare system within Hounslow. Ideally figures like this will inform emergency planners and category 1 responders of the extent of this flood event and help them be better prepared for such a disaster.

Knowing ahead of time that a number of additional shelters and healthcare providers will be needed can ensure that no victim is left without assistance.

Table 9: Hounslow - Fluvial Flooding Results

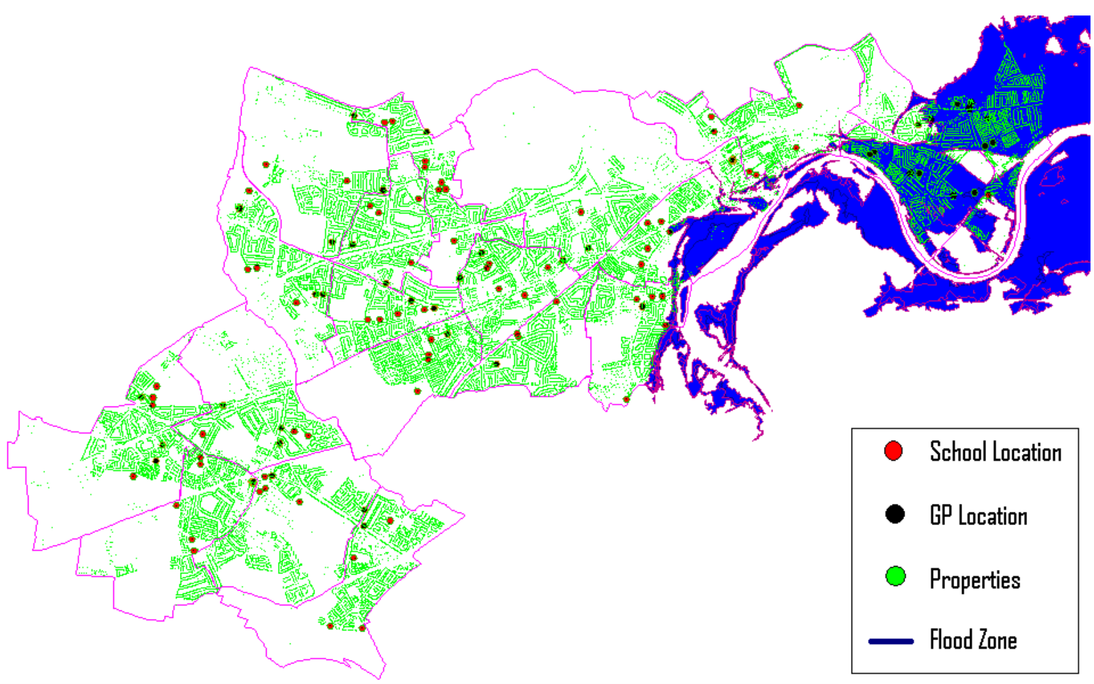
	Number of Households Affected	Number of Businesses Affected	Number of Schools Affected	Number of People Affected	Number of GPs Affected	Number of People with Health Concerns	Number of People Requiring GP Visit	Number of People Temporarily Relocated	Number of People Requiring Evacuation Assistance	Tonnes of Waste Produced	Total Uninsured Cost	Total Cost
Fluvial Zone 3	898	58	1	2069	0	859	335	621	249	3987	£6,062,563.40	£30,599,773.29
Fluvial Zone 2	2063	165	2	4788	0	1987	775	1436	576	9291	£14,043,322.50	£72,726,890.06

4.1.2 Tidal Flood Model

The next scenario analyzed was tidal flooding. A tidal flood event is a flood that occurs from extreme rise in sea levels due to sea tides. Because the Thames River is influenced by tides, the whole of London is at risk of tidal flooding. While London has built the Thames barrier to help mitigate the impact of tidal flooding, it is mainly used for large scale tidal flood risk and is often left open. This places a number of boroughs, including Hounslow, at low risk of tidal flooding during the spring season. The northeast portion of Hounslow, Chiswick Riverside and Chiswick Homefields, is at the most risk of tidal flooding.

There are two maps of tidal flooding provided by the Environment Agency. Like the fluvial flooding maps, tidal flooding has two flood 'zones' in which flooding probability and extent varies. The less extensive zone 3 tidal event has an annual probability greater than 0.5%. This flood event would be expected to occur once every 200 years. The more extensive zone 2 event has an annual probability of 0.1% to 0.5% and can be expected to occur every 200 to 1000 years. An image of the more extensive zone 2 tidal flood event can be seen in Figure 15 below, an image of the zone 3 tidal flood event can be seen in Appendix G. A full summary of the impacts of this flood event and the zone 3 tidal event can be seen in Appendix H and Appendix I, respectively.

Figure 15: Hounslow- Tidal Zone 2 Flood



The tidal flood scenarios were overlaid separately on the base GIS map and their damages were modelled. A summary of these results can be seen in Table 10. Surprisingly the difference in the two events is not nearly as significant as in the two fluvial events. The monetary cost differs only by £25 million, a mere 17% of the entire cost for zone 2. When comparing the results of the two tidal events it is interesting to note that the more extensive zone 2 event would affect only 1790 additional people. The reason for the small difference in the two results can be identified with a closer inspection of the flood maps. There is only a slight change in the impact area from zone 3 to zone 2. This small difference includes 786 households', 32 businesses, and one extra school. An analysis like this one could become helpful for a number a reasons. Not only can one understand the extent of damages done during a tidal flood event, but emergency planners in particular would understand from this result that planning for two separate tidal events is not necessary. Often emergency planners must plan for disasters with a varying degree of severity. Because the zone 2 event is only slightly more severe, an emergency planner can plan for the worse event and not worry about over estimating because the difference in effect is small. This model could save time and resources when it comes to emergency planning if used this way.

Table 10: Hounslow - Tidal Flooding Results

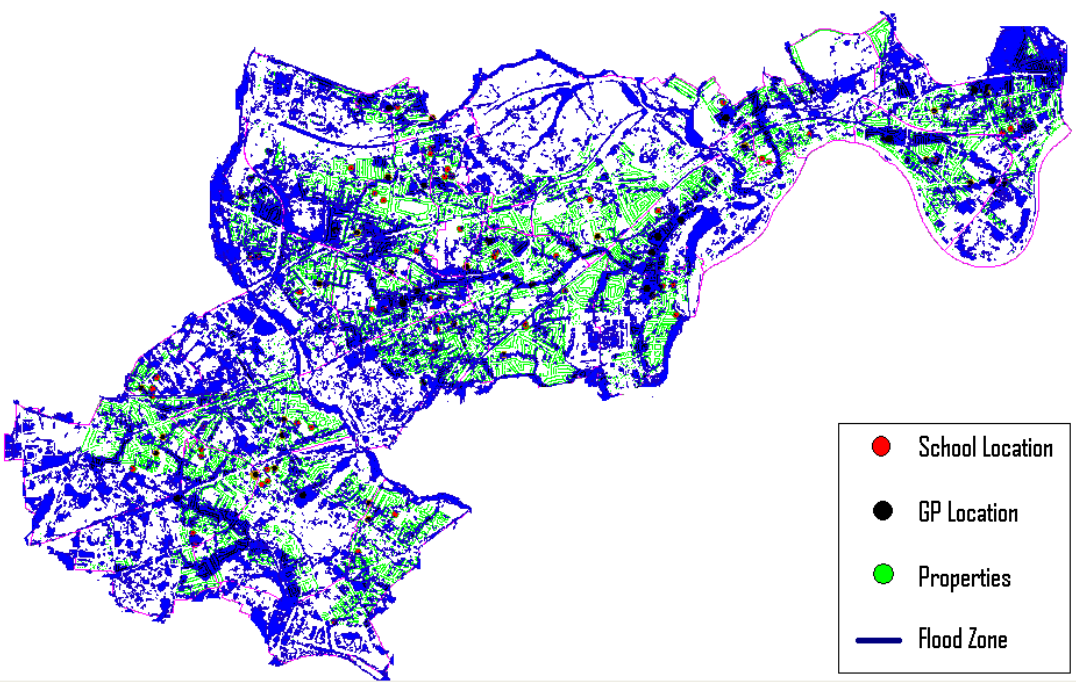
	Number of Households Affected	Number of Businesses Affected	Number of Schools Affected	Number of People Affected	Number of GPs Affected	Number of People with Health Concerns	Number of People Requiring GP Visit	Number of People Temporarily Relocated	Number of People Requiring Evacuation Assistance	Tonnes of Waste Produced	Total Uninsured Cost	Total Cost
Tidal Zone 3	11546	860	6	25032	6	10388	4051	7510	3010	51733	£78,365,254.00	£401,879,710.78
Tidal Zone 2	12332	892	7	26843	6	11140	4344	8053	3227	55144	£83,603,351.60	£427,332,344.37

4.1.3 Surface Water Flooding

The next scenario analyzed was surface water flooding. Surface water flooding is a result of excessive rainfall and standing water. Because of building development, often times rainwater cannot follow its natural drainage course and ends up pooling in urban areas. Unfortunately areas of the borough that are at lower elevation relative to the rest of the borough will typically flood first from surface water, incurring extensive flood damage.

The Environment Agency provides a map of susceptibility to surface water flooding in the borough which details which areas will flood in a 1 in 200 year surface water flooding event. This map was generated by an aircraft performing a LiDAR scan of the entire borough to measure relative topography and represents a worst case scenario. An image of the flood scenario can be seen in Figure 16. The surface water flood map was overlaid onto the base GIS map and the damages from this flood scenario were modelled. A full summary of the impacts of this flood event can be seen in Appendix J.

Figure 16: Hounslow - Surface Water 1 in 200 Years



As one can see this surface water scenario has the largest extent of any other flood scenario. There is not one ward within the borough that isn't affected by surface water flooding. According to the model, which can be seen in Table 11, over 21,000 properties would be damaged due to this flood scenario summing to a total of nearly £670 million. While this figure seems steep, it represents a worst case scenario. As stated previously, because of the lack of flood depth data, an average flood depth of nine inches was chosen. To some it may seem unrealistic to assume that nine inches of water has accumulated in all the areas on the map above. One must remember that this figure is an average value of flood depth and the team is assuming that some properties will be flooded with a few feet of flood water while others will only have a few inches. This issue of uncertainty will be discussed in more detail in the limitations section of this report. A flood event of this extent and severity would cause devastation to Hounslow. With nearly 51,000 people affected, the resources needed to deal with a disaster of this size would require careful emergency planning beforehand. Where will the 90,000 metric tonnes of waste produced go? Where will the 15,000 people requiring temporary accommodation live while they get their life back in order? While a flood event of this size is unlikely, having a model that predicts an impact this severe could help others understand the seriousness of such events and stress the importance of planning ahead.

Table 11: Hounslow - Surface Water Flooding Results

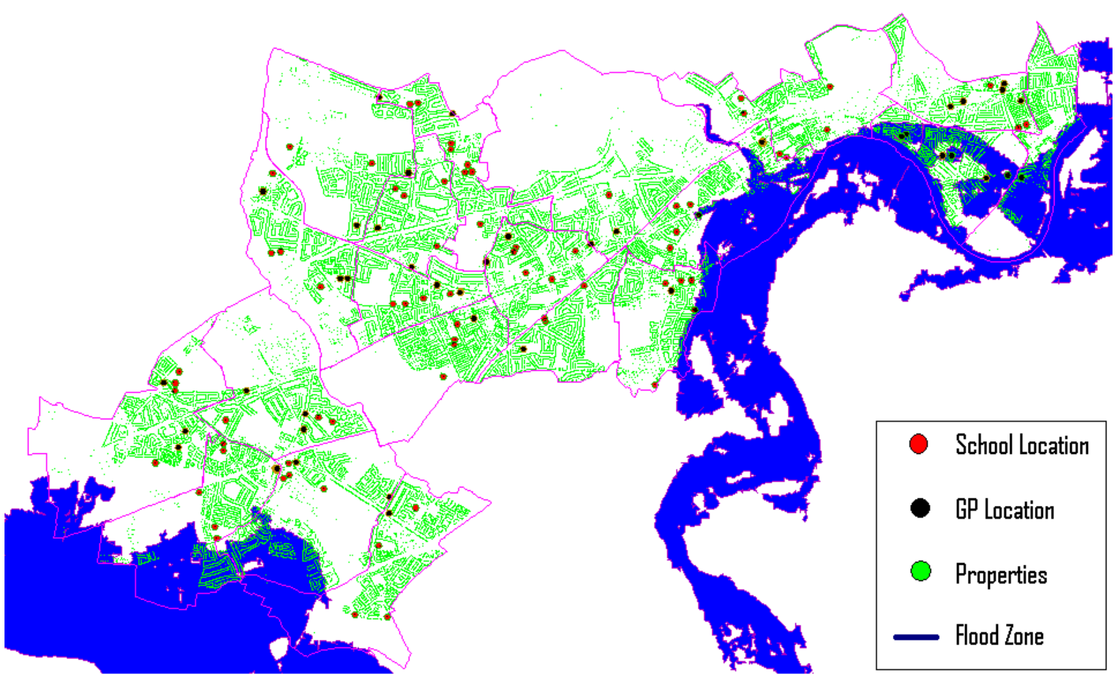
	Number of Households Affected	Number of Businesses Affected	Number of Schools Affected	Number of People Affected	Number of GPs Affected	Number of People with Health Concerns	Number of People Requiring GP Visit	Number of People Temporarily Relocated	Number of People Requiring Evacuation Assistance	Tonnes of Waste Produced	Total Uninsured Cost	Total Cost
Surface Water 1-200	20614	882	32	50938	7	21139	8244	15281	6125	89638	£137,532,450.60	£669,793,716.13

4.1.4 Dam Inundation

Within London there are a number of raised reservoirs that supply water to the surrounding areas. As part of the team's flood modelling, a dam inundation scenario was included. Figure 17 depicts the flood area that would occur if, Queen Mary, a raised reservoir containing 240 million gallons of water was breached and flooded into the surrounding areas. While the actual reservoir is located outside of Hounslow (in the bottom left hand corner of Figure 17), one can observe that a number of properties will be affected by its flood path.

The map of the dam inundation was created by the Environment Agency as a worst case scenario. It was assumed that the dam would not breach by natural causes but rather a planned terrorist attack and because of the sensitivity of this information it took some time to obtain the actual flood scenario. This flood map was overlaid onto the base GIS map and damages were modelled. A full summary of the impacts of this flood event can be seen in Appendix K.

Figure 17: Hounslow- Dam Inundation



At first glance it seems as though the flood area does not intersect as many properties as the other flood scenarios, but the opposite is true. The majority of properties impacted by this flood scenario can be found at the bottom left corner and top right corner of Figure 17. The initial flooding around the reservoir floods the bottom left portion of Hounslow while the excess water from the breech is displaced into the Thames River and floods the upper left portion of the borough. Just over 8,000 households and 250 businesses would be affected by this potential flood causing over £253 million in damage, as can be seen in Table 12. Although this hypothetical flood scenario is unlikely, being prepared for unexpected instances like this could save thousands of lives one day. Proper shelters and resources can be planned out ahead of time to ensure the safety of the citizens of Hounslow. As one can imagine, if this reservoir was breached there would be far more damage occurring than modelled here. 240 million gallons of rushing water could cause far more damage than predicted because the model does not account for extreme flood velocity.

Table 12: Hounslow- Dam Inundation Flooding Results

	Number of Households Affected	Number of Businesses Affected	Number of Schools Affected	Number of People Affected	Number of GPs Affected	Number of People with Health Concerns	Number of People Requiring GP Visit	Number of People Temporarily Relocated	Number of People Requiring Evacuation Assistance	Tonnes of Waste Produced	Total Uninsured Cost	Total Cost
Dam Inundation	8001	257	7	18604	2	7721	3011	5581	2237	34436	£53,070,330.10	£253,310,470.04

4.2 Reproducibility: Kingston and Hillingdon

To test the reproducibility and overall quality of the modelling program, it was important for it to be applied to other boroughs in London, and for the team to receive input from other emergency planners. This allowed for a comparison of the results from these boroughs to the results found in Hounslow and gave the team opinions from other emergency planners. This information helped to gage the straight forwardness of the program and how it could be further improved. The test and run through of the modelling program with the emergency planners from Kingston and Hillingdon consisted of 45 minute meetings in which the calculations behind the modelling program and the expected results were explained. The team recorded their comments and provided them with models of their flood scenarios.

After the first draft of the modelling program had been finalized, the team met with Sev McGinty, an emergency planner for the London Borough of Kingston upon Thames. While this borough experiences a number of different flooding scenarios, the emergency planning department of Kingston decided it would be useful to model the impacts of their Zone 2 fluvial event. Ms.McGinty was asked to bring the data typically extracted from GIS which included the properties within the flood zone, schools, and general practitioners impacted. She later commented that it was fairly easy to obtain the data needed for the damage estimation. The data was already available within the borough with no need to extract it from GIS. This confirmed that acquiring the inputs required for the model should not be a problem for other boroughs. After explaining the spreadsheet and having her read through the introduction and instructions, she completed the full damage estimation with no problems. The results of this model can be seen in Table 13. Due to the extent of fluvial flooding within Kingston the damage estimation was higher than that of Hounslow's. While Hounslow would incur just over £72.9 million in damage with 2228 properties impacted from a 1 in 200 year fluvial flood, Kingston would suffer over £122.2 million in damage with 3440 properties impacted from the same event. It is obvious from this assessment that Kingston is more impacted by river flooding than Hounslow.

The second emergency planner that the team met with was Ben Pearkes. Mr. Pearkes is the head of the emergency planning department for the London borough of Hillingdon and like Ms. McGinty; he brought the data necessary to complete the flood damage model for their Zone 2 Fluvial event. A summary of the Hillingdon results can be seen in Table 13. Surprisingly, Hillingdon would prove to be the most impacted of the three boroughs by a 1 in 200 year fluvial event. With a total cost of nearly £241 million, a flood event of this size within Hillingdon would severely damage the borough.

While Mr. Pearkes was impressed with the damage model, he left the team with several suggestions to improve the program. He explained that the instruction sheets accompanying the program were difficult to follow. He also suggested adding specific internet pathways to the sources to make finding specific borough calibration data easier. He finally suggested a different format for the excel sheets. This format would allow sheets to be easily printed in order to present a hard copy of the model. After rewriting the instructions page, editing the sources, and reformatting the program it was sent back to Mr. Pearkes for review. He commented saying that there was a large improvement and the changes made the damage modelling program more user-friendly. The instructions referenced here can be seen in Appendix B. Mr. Pearkes anticipated using the modelling program to model other flood scenarios in the future.

It is important to note that both the analysis of Kingston and Hillingdon were done by borough area and not by ward area as Hounslow was. This was due to the type of data available to each borough. Kingston and Hillingdon provided an excel sheet of impacted properties that was comparable to the Hounslow data extracted from the same flood scenario but their properties were not able to be sorted by ward. Although having this data sorted by ward could have allowed for a more detailed summary of impacts due to the flood scenario, it did not affect the accuracy of the model. The advantage of having impacted properties sorted into ward is that one can compare the extent of damage within each area. This may allow emergency planners to better prepared for localized flood events and have a better understanding of where vital resources should be placed while using this model.

Having the model completed by three different boroughs with two forms of data resolution reflects well on model's universality. Allowing the user to specify the resolution of the data makes the model easier to use by providing no limitations or restrictions to the input data.

Table 13: Comparison between Boroughs - Zone2 Fluvial Flooding

	Number of Households Affected	Number of Businesses Affected	Number of Schools Affected	Number of People Affected	Number of GPs Affected	Number of People with Health Concerns	Number of People Requiring GP Visit	Number of People Temporarily Relocated	Number of People Requiring Evacuation Assistance	Tonnes of Waste Produced	Total Uninsured Cost	Total Cost	Total Cost (20 Year Projection)
Hounslow	2063	165	2	4788	0	1987	775	1436	576	9291	£14,043,322.50	£72,726,890.06	£76,069,882.43
Kingston	2963	477	3	6942	1	2881	1123	2082	867	14345	£21,043,808.10	£122,241,214.88	£133,754,725.13
Hillingdon	6787	566	8	16757	0	6954	2712	5027	2228	30662	£46,285,067.80	£240,870,859.35	£254,571,386.17
Total	11813	1208	13	28486	1	11822	4611	8546	3670	54298	£81,372,198.40	£435,838,964.29	£464,395,993.73

4.3 Applications

In creating this model, it was important to consider the types of people that would be using it, as well as its general applications. The team first considered the Emergency Planning departments. In working in the Emergency Planning Office of the London Borough of Hounslow the team was given a good idea of what was useful to planners during an emergency situation. This allowed the modelling program to be tailored to the needs of an emergency planner.

These models may be used by the Emergency Planning office to create more realistic training programs for those they work with. If they are given the ability to use information and statistics backed by data such as what is given by the model, they will be able to create a more realistic and applicable exercise than just assigning arbitrary data to situations. This will allow training scenarios to have more meaning behind them and feel less hypothetical. Emergency Planning offices can also use this data to help create flood response plans. With estimations of the general impacts of a flood, and what areas would be most affected, emergency planners would be able to ensure that their flood plans meet the needs of potential emergency scenarios.

This model will be able to give emergency planners a better grasp of the effects that they can expect from a flood scenario, as well as a better understanding of which areas of the borough they can expect to be affected at different severities. The locations of schools and GPs also could provide invaluable information to emergency planners. In the event of an emergency, like flooding, schools may serve as temporary shelters for those displaced from their homes. If a school is inside the flooding zone, it would not make a very good shelter during the flood. General practitioners are necessary during and after flooding events due to the possibility of health concerns, and injuries. However, if many of these GPs are found within the flood area, there will be a severe lack of medical professionals which will greatly impact the ability of a borough to recover.

In assessing the applications, mitigation planning was also considered a purpose for the model. In areas that are expected to flood quite often, it is important to plan for ways to reduce the severity or seriousness of the flood event. With this modelling program one can see what incurs the most impact in terms of damages, and people affected. Having this data allows planners to focus their resources on areas that need the most mitigation, to prevent the greatest cost.

This modelling program may also be helpful in development planning. As more and more buildings and homes are being added to urban areas, there must be limits on the construction and development in flood areas. This flood modelling program can show the effect of flooding on this development, modelling the actual damage effects of a flood on different areas. When given this information, the council can develop plans to prevent over-development in areas that are prone to flooding. This data will also support their decisions, with numbers that provide an estimate of the damages.

If every borough is required to use the damage estimation model, the information provided can be included in the risk register for the entire city of London. This will allow the Greater London Authority to examine the effects of flooding on the entire city, not just individual boroughs. With this information, boroughs with higher flood damages can be given more support before, during and after a flood event to minimize the severity of the impact of a flood.

The hope is that this modelling program will be applied by the London Borough of Hounslow and many other boroughs, in order to help lessen the monetary and personal damage that is caused by flooding.

4.4 Limitations

The team believes that the method created provides the most accurate model of a flood event with the data available while trying to meet the objective of a reproducible method. There are some limitations to the model, however, as it is just an estimate. The following pages identify and explain these limitations in the context of this project.

A number of these limitations have resulted because of the lack of data available to the team. Some costs had to be discounted and not included in the model because of this. Obviously, the team attempted to limit the damage estimation factors in the model to ones that could be calculated reliably, and only those that had enough data supporting them. However, one cannot predict exactly what will be affected by a disaster such as flooding. As more flood data is recorded and reported, this model can be updated with the cost estimation factors that are most relevant based upon many different floods, rather than just the data located.

When researching the data provided, the team had originally wanted to base the damage estimation factors on the depth of flood water. Unfortunately, there are no maps readily available that provide the different depths of water that may occur in a flooding event. Thus, all properties that fell within the flood zone were estimated to have incurred at least 9 inches of water. The NFRA identifies this depth as the depth of flooding that 95% of all damages occur at. (NFRA, 2010)As not all properties will reach that depth, and some will surely be higher, the team assumed that the variations would average out over the entire flooding area. This compromise allows the model to be simple and easier to use but does limit the accuracy.

Another limitation encountered was the lack of data about flood durations. The team was unable to effectively estimate the duration of a given flood event. The duration figures used were based on the 2007 Environment Agency report which estimated time out of school, time without utilities and average duration of temporary accommodations. These were the only factors of the model that were dependent on duration. The team could not identify a source that could reliably estimate the amount of time an area might be flooded, and how long the effects of that flood would last. With this data the team would be able to accurately analyze costs that would result from disruption to daily life because of flooding.

The impact of climate change on future flooding suffered similarly from a lack of data. General information was available in some flood related factors, such as change in precipitation, but only case studies done for specific regions gave any conclusive data on the expected change in actual flooding. The research conducted only allowed a very broad statement on the impact climate change will have on the Borough of Hounslow. Additional inquiry into this area would aid long term planning in terms of development and flood defences.

There were also limitations due to the technology available. The GIS program provided points for every property in the OSAP layer that intersected with the flood layer. Some of these properties contained multiple addresses as they were located in a flat or apartment building. Thus the model considered some addresses as flooded even though they were located above the ground floor. While the Office of National Statistics provided information on the number of addresses located on higher floors of buildings, the team was unable to apply this percentage to the properties impacted. The information provided by the Office of National Statistics did not provide locations of the addresses above the ground floor, making mapping these points difficult. It is also possible that a flood would affect a higher floor. Properties that had damage to the ground floors of the building would most likely require some sort of repair to electricity and other utilities, which may affect the addresses on higher floors.

The population of each ward and how it was calculated was also a limit of the model. There is a very different population between the day time and night time populations of an area. People leave their homes, and drastically change the population of an area. For example, an area of a ward with many office buildings often has very few people in the population at night, and thousands during the day. Thus, basing the population affected on the amount of properties within a flood zone does not take into account this population change. Unfortunately, the team does not have a GIS map that maps the specific locations of each person in the borough during the day and night. Thus, the team had to use the population prediction method based off of the properties that were in the flood zone and the average number of people per household, rather than daytime and night time property data.

In the creation of this project the team considered many applications of the modelling program. Councillors and other government officials might be persuaded by flood estimations to invest in additional flood mitigation efforts. Unfortunately, much of the data presented in the model consists of costs to the individual, rather than to the borough. This information is less compelling to the councillors as it does not directly affect their local government and budget planning. If the model were able to consider costs such as infrastructure damage, telecommunication damage, or indirect costs such as business disruption, the estimate would become much more valuable to officials like the councillors. The Environment Agency's report on the 2007 floods was able to accurately calculate cost due to damaged infrastructure based on expenditure data from local authorities, which was likely subjective to the area in which the flood occurred. It would be difficult to forecast onto other areas due to the wide range the high variability of damage that could be expected. Other effects, such as business and transportation disruption, were not included due to their level of uncertainty and a lack of supporting data. Originally, the team was tasked with the goal of determining the affect of climate change on the effects of flooding. While it can be determined that drastic flooding events should become more common, the exact correlation between the year and the probability of a flood event is uncertain. Councils across the UK are attempting to predict what the probability of a common flood now would be in the future, but there was not sufficient information in the London Borough of Hounslow to accurately make this prediction.

Even accounting for these limitations, the estimate provided by the model is a reasonable representation of the effects of flooding on a borough. As more information is recorded, it can be modified to take into account that data. This will continue to reduce the amount of limitations and inaccuracies in the project.

5. Conclusions and Recommendations

The goal of this project was to create a program to model the damages due to urban flooding in London that is based on widely available data and is straightforward in its methodology. The models provide an approximate figure of economic damage along with information about people and properties affected by the flood. This data can be useful for emergency planning, as well as mitigation and development purposes.

The Hounslow team modelled six different types of flooding in the London Borough of Hounslow with the modelling program. To test the applicability of the program the team modelled two flood scenarios for the borough of Kingston upon Thames, and one for the borough of Hillingdon. The results produced for each flood scenario were informative; they quantify the extent and severity of a flood event in ways that are easy to understand and contextualize. Even when a small portion of the borough is affected by flooding the model shows that there are extensive costs and negative effects associated with any flood event.

Often costs and damages are not collected and recorded after a major flood event. This is due to the damages associated with a dynamic disaster such as flooding. With the results from this model, a borough can create a more complete picture of the damage. This can help with emergency planning, flood defence policies, development planning and other applications. Councillors and other law makers will be able to comprehend the outcome of a flood more easily than before. Even if one is given flood scenario maps, the total amount of damage is difficult to envision. The models give flood scenarios context outside of the square footage of the flood area, allowing the average person to realize just how devastating a flood event can be.

The main objectives of this project have been satisfied. The team's liaison, Joseph McFarland, required that the flood damage modelling program be replicable because flooding is a UK wide problem. If the modelling program is easily replicable it can be used by a number of emergency planning offices around the country. Because calculations have been placed into an easy to use excel spreadsheet, even a person with little or no experience in flood damage estimation can create a model for a flood scenario. The use of a UK specific case study to finalize the damage estimation factors allows this program to be used in any area within the UK. While a majority of the cost estimates come from the Environment Agency's case study on the summer 2007 UK floods, the excel sheet can be easily adjusted and updated when more relevant information becomes available.

The modelling program that the team produced was a single file created in Microsoft Excel. The file consisted of a series of spreadsheets that contained all the necessary instructions, input cells, and calculations to produce a model of any available flood scenario. The first two sheets were an overview of the purpose of the program and detailed instructions informing the user how to obtain every input value necessary. The first set of input values was data that was specific to the area being analyzed by the tool that served to increase its accuracy. These values were all obtained from readily available sources and links to the sources were provided. The next set of input values was data that was specific to the extent of the flood scenario being analyzed. These values came from GIS maps produced by the Environment Agency, available to the emergency planning department of every borough in London. The user was also provided with instructions explaining how to obtain these necessary values. The modelling program uses these two sets of input values, along with cost estimation factors determined by the team, to produce a model of the flood scenario. This model showed the total monetary cost of the flood event, as well as other non monetary effects of the flood that the team decided would be useful for emergency planners and first responders. The program was designed to be straightforward and applicable anywhere in the UK.

After the completion of the modelling program and speaking to a number of professionals within the field of emergency planning and flood mitigation, the Hounslow team has a number of recommendations regarding the issue of flood modelling and flood damages:

Recommendation 1: The importance of reporting data.

As already stated, the main concern with creating a damage modelling program of this sort is the reliability and accuracy of data being used within it. The Hounslow team recommends that boroughs take more responsibility in recording damage data during and after a disaster. Currently, very little documentation on the total damages of floods in urban areas exists. The EA flood report was one of the most all-inclusive articles documenting the after effects of a flood from recent years and is a step in the right direction. Having accurate and widely available data of this type will allow for a more comprehensive understanding of flood damages and could aid in the preparation for such events. In particular, data pertaining to local authorities and emergency responding costs should be recorded. The modelling program produced in this report could not take these costs into account due to their uncertainty in flood damage case studies. Having an estimate of these costs would improve the applications of the model by providing more useful information to local government and councillors. While the team stresses the importance of recording disaster damages, the difficulties of such a task must be recognized. It's not realistic to think that each borough could commit resources and man power to recording damage data during a time of disaster. Due to this limitation the team proposed an additional recommendation to aid in the recording of disaster damages. A post disaster database or website should be created in which victims can register and log in to report personal and public damages due to a number of disasters. This database would collect, store, and analyze the damage data to produce an accurate account of damages to the surrounding area. If done correctly, this data could be extremely helpful to future modelling attempts and emergency planners everywhere.

Recommendation 2: Continue to update the model.

While the modelling program is fairly easy to use and highly replicable, it is limited by the data and cost estimation factors available to it. As previously stated, modelling programs like this one could be greatly improved when more accurate data is recorded. The Hounslow team recommends that as more relevant and accurate information is found or reported that the modelling program be updated to include that data. All of the factors used within the modelling program are based on evolving data, thus it is easily amended or replaced. For example, the numbers for populations of the borough currently used are those from the 2001 census. When the 2011 census is released, it will be important to use the updated statistics to create a more accurate estimate. If after reviewing more flood data, the factors taken into account in this methodology are considered to not make up the majority of flood damages, someone may add to the program in order to make the estimation more accurate while keeping the modelling methodology straightforward and replicable. In addition, it would be ideal if someone with more advanced programming skills could make improvements to the model by creating a more user friendly interface. Although excel is a widely used program and increases this method's applicability, a more sleek user friendly interface would allow for less instruction pages and more hands on flood modelling.

Recommendation 3: Encourage widespread use of the model.

The team recommends that this modelling program be used by the other boroughs throughout the City of London in order to provide a comprehensive view of the flooding damage that the city may incur. If other boroughs were to use the same modelling program to estimate damage due to flooding, it can be used as a baseline for planning, establishing a reliable risk register, and petitioning for funding for future flood mitigations. Reproducing models for flood events in all boroughs would not only provide a great deal of information to the local authorities, but would also allow for comparison of the impacts between boroughs. Having a reliable way to quantify flood impact for all boroughs will help increase the usefulness of the community risk register which helps emergency planners prepare and compare potential crises. Understanding which boroughs are more susceptible to urban flooding than others could aid in planning and prioritizing flood response efforts for a wide scale flood event.

Recommendation 4: Be aware of the impact of future development and climate change.

This model attempts to provide an indication of the additional costs increased population and housing development will incur due to flooding. The team also attempted to contextualize the future of climate change and put it in perspective for those using the model. The team would like policy makers to become aware of the impact of future development and climate change on flood damages. Attempting to shift development away from flood prone areas will limit future impacts and facilitate flood response. Although London is a thriving and growing city, it makes little sense to continue building in flood areas with no defences that incur millions of pounds in damage each year. The modelling program produced can provide vital information about areas prone to flood damage and can persuade developers and local authorities to cease development in those areas. While the team was unable to accurately forecast the affect climate change will have on flooding in Hounslow, there was significant evidence that the probability of severe flooding will increase based on case studies done throughout the UK. Review of the Thames Estuary 2100 Project is suggested for information on the possible impacts and risk management policies. This paper outlines the projected increase in flooding events due to climate change and its findings are not optimistic. Future flooding is projected to become more frequent with the potential of causing severe damage to the societies people live in. Although climate change and future development are not entirely avoidable, being aware of the consequences of both may sway the decisions of local authorities that will benefit the citizens of today and future generations.

Throughout history flooding has been a constant presence in the lives of those who live in the United Kingdom. The Hounslow team's hope for this modelling program is that it gives people a better idea of what damages boroughs should expect when preparing for a major flood event. Once the severity of the problem has been put into perspective, people can have a better understanding of how to deal with it. These damage estimates can be used to better provide for the citizens of those areas, whether that is by protecting properties, preventing development in areas prone to flooding, or planning responses to floods. In order to effectively prepare for a flooding event, one must know the outcomes and damages that may occur. This modelling program effectively provides that damage estimate in order to save properties, livelihoods, and lives.

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Appendices

Appendix A: High level summary of estimated economic costs of 2007 floods

Impact	Best estimate £ million	% of total	Possible range £ million	% insured	Basis for estimates	Uncertainty score (see text)
Households (buildings and contents)	1,200	38%	1,010-1,430	76%	Adjusted Insurance estimates	2
Businesses (buildings, contents and disruption)	740	23%	550-800	95%	Adjusted insurance estimates	2
Temporary accommodation	94	3%	85-103	95%	Insurance claims	2
Vehicles (motors)	80	3%	72-88	95%	Adjusted insurance estimates	2
Local Government – infrastructure (excluding roads (£83 million)) and non-emergency services	134 (219 incl roads)	4% (7%)	123-151 (198-242)	45%	Audited accounts of LGAs	1
Emergency services, (LGA, police, fire and rescue)	8	<1%	7-9	45%	Audited accounts of LGAs, police and fire/rescue	1
Environment Agency (23% of costs for emergency)	19	1%	17-21	?	Audited accounts	1
Utilities (electricity, gas, water)	325	10%	253-436	32%	Company accounts, user WTP/A for services	2-3
Communications (roads (including LGA), rail, telecom)	227	7%	151-303	50% Mainly LGA road damage	Company sources, extra travel costs	2-4
Public health and fatalities (including distress, impact on education and fatalities)	287	9%	187-387	n/a	Research Literature, standard estimates, LGA accounts	3-4
Agriculture	50	2%	30-66	5%	Farm survey	2
Unquantified costs;, tourism, nature conservation, community services, Military services	n/a	n/a	n/a			
Total	3,164	100%	2,521-3795	63 %		2 overall

Appendix B: Modelling Program Spreadsheet Instructions

Modelling the Direct Impacts of Flooding in London

Overview

- **The purpose of this spreadsheet is to estimate the direct impacts of flooding in a hypothetical flood scenario in London.**
    - It is designed to be easy to use, with inputs obtained from readily available sources.
- **This spreadsheet is designed to give a rough estimate of direct impacts of flooding.**
    - The number of affected people and properties can be obtained by a simple data extraction through any GIS software.
    - Cost estimates are largely based on data from the 2007 UK Flood.
    - Since the cost estimates are based on aggregate data an exact estimate is impossible and the estimate will be rough but simple to obtain.
- **In order to use this spreadsheet you will need the following information:**
    - The names of the different regions being analyzed (either wards or boroughs).
    - A screenshot of the GIS map of the flood scenario for visual reference (if desired).
    - The number of households in the flood zone.
    - The number of businesses in the flood zone.
    - The number of schools in the flood zone.
    - The total number of students in all schools in the flood zone.
    - The number of GPs in the flood zone.
- **Read the instructions tab thoroughly before proceeding and use it a reference as to how to properly use this spreadsheet**

General Notes

- Yellow cells are input cells. Other cells contain formulas and references and cannot be edited.

- Green cells indicate a value used in calculations that is specific to the borough being analyzed.

- Inputs that are not taken from GIS maps (used to calculate values in green cells) are taken from the source referenced below them. The links to these sources can be found in the Sources tab.

- The table below describes the steps necessary to complete the spreadsheet. Follow the steps in order to obtain all of the input variables.

How To Complete This Spreadsheet

	Steps	Instructions/Explanations
1	Write the name of each area being analyzed into the yellow cells in the section titled "List of Affected Areas"	**Sheet 1 - List of Affected Areas:** If the analysis is being done on the entire borough, enter the name of the borough in the first cell in the column. If the analysis is being broken down to the ward level, enter the name of each ward in seperate cells in alphabetical order. This list will carry on to the other sheets to show which areas are being analyzed.
2	Fill in the yellow input cells in the section titled "Cost of a School Day." This data is specific to the borough containing the areas being analyzed	**Sheet 1 - Cost of a School Day:** Click the link for the source labelled Department for Education. Find the borough being analyzed. Choose results for the entire borough by clicking the word "district." Click "School Funding and Resources." Locate the value "Funding per Pupil Age 3-19" for the current year and enter it into the yellow cell. This value will be used to estimate the cost of school closings in the affected area.
3	Fill in the yelow input cells in the section titled "People Requiring Evacuation Assistance." This data is specific to the borough containing the areas being analyzed	**Sheet 1 - People Requiring Evacuation Assistance:** Click the link for the source labelled Office For National Statistics. Enter the name of the borough being analyzed. Select "Health and Care." Select "Disability Living Allowance Claimants." Enter the number of people in each age group below the age of 70 into the corresponding yellow boxes in this section. Close the link, and reopen it from the Sources tab. Enter the name of the borough being analyzed. Select "Census Area Statistics." Select "Age." Enter the number of people in each indicated age group into the corresponding yellow cells. Find the number listed for "All People" and enter it in the yellow cell labelled "Total Population" in this section. This will calculate the total number of people requiring evacuation assistance, and represent it as a precentage of the total population.
4	Fill in the yellow input cells in the section titled "20 Year Projections." This data is specific to each indivual area being analyzed.	**Sheet 1 - Future Projections:** This part of the sheet can be for any year in the future up to 20 years. Decide what year the projection will be done for. Click the source labelled Greater London Authority. Open the Excel File. Select the tab that corresponds to the borough being analyzed. First find the population for the current year. If the analysis is being done per ward, enter these values as the current population of each ward. If the analysis is being done per borough, add all the values and enter the sum as the value for the borough. Scroll down scroll down the sheet until you find the year to calculate costs for and repeat this same process. This will calculate the percent increase in population for each area being analyzed. This percent is assumed to be the same as the percent change in households and will be used as such.
5	Insert a screenshot of the GIS map	**Sheet 2** - Paste a screenshot of the GIS map for reference, if desired. This can be used as a visual reference but is not required to complete the spreadsheet.
6	Fill in the yellow cells in the section titled "Average Number of People Living in Households"	**Sheet 3 - Average Number of People Living in Households:** Click the source labelled Office for National Statistics. Enter the name of the first area being analyzed, whether it is the entire borough or the first ward in the list. Select "Census Area Statistics" then select "Number of People in Households." Enter the values shown into the corresponding yellow cells for that area. Repeat this process for each area in the list. These values will be used to estimate the number of people affected by the flood.
7	Fill in the cell under "Number of Households Affected" corresponding to each affected area	**Sheet 4 - Number of Households Affected:** This number is calculated by using GIS software. Load an Ordinance Survey Address Point layer and a flood map layer into GIS and run a query for the intersection of the two layers. Export the data as an excel file and open the file. If the analysis is being broken down to the ward level, sort the data by the column titled "Ward" and repeat the following steps for each ward. If not, do the following steps for the entire set of data. Sort this data by the column titled "Organization Name." Count the number of properties without an organization name. This is the number of households in the affected area. Enter this number in the corresponding yellow cell in the spreadsheet.
8	Fill in the cell under "Number of Businesses Affected" corresponding to each affected area	**Sheet 4 - Number of Businesses Affected:** This number is calculated by using GIS software. Load an Ordinance Survey Address Point layer and a flood map layer into GIS and run a query for the intersection of the two layers. Export the data as an excel file and open the file. If the analysis is being broken down to the ward level, sort the data by the column titled "Ward" and repeat the following steps for each ward. If not, do the following steps for the entire set of data. Sort this data by the column titled "Organization Name." Count the number of properties with an organization name. This is the number of businesses in the affected area. Enter this number in the corresponding yellow cell in the spreadsheet.
9	Fill in the cell under "Number of Schools Affected" corresponding to each affected area	**Sheet 4 - Number of Schools Affected:** This number is calculated by using GIS software. Load a layer with the location of the schools within the borough and a flood map layer into GIS and run a query for the intersection of the two layers. Export the data as an excel file and open the file. Determine the number of schools in the flood zone. Enter this number in the corresponding yellow cell in the spreadsheet.
10	Fill in the cell under "Number of Pupils in Affected Schools" corresponding to each affected area	**Sheet 4 - Number of Pupils in Affected Schools:** Once the affected schools have been extracted from GIS, open the excel file to obtain the name of each school affected. If the analysis is being broken down to the ward level, repeat the following steps for each ward. If not, do the following steps for the entire borough. Using information provided by the education department of the borough being analyzed, determine the number of pupils in each school that is affected. Sum each of these numbers to determine the total number of pupils in affected schools.
11	Fill in the cell under "Number of GPs Affected" corresponding to each affected area	**Sheet 4 - Number of GPs Affected:** This number is calculated by using GIS software. Load a layer with the location of the GPs within the borough and a flood map layer into GIS and run a query for the intersection of the two layers. Export the data as an excel file and open the file. Determine the number of GPs that are in the flood zone. Enter this number in the corresponding yellow cell in the spreadsheet.
12	Go to the Outputs sheet to view all of the values calculated	**Sheet 5** - This sheet contains all of the values that are calculated by the spreadsheet. These values are used to calculate the key statistics in the summary sheet
13	Go to the Summary sheet to view a compilation of all of the key variables, a total monetary cost, and a projected 20 year cost.	**Sheet 6** - This sheet contains a compilation of all of the key statistics that the spreadsheet calculates, and a total value for each one.
14	View the Calculations sheet for an explanation of all of the calculations done by the spreadsheet.	**Sheet 7** - This sheet is only necessary to read if clarification is desired
15	View the Sources sheet for a full list of the sources used to obtain data.	**Sheet 8** - This sheet provides all of the sources that were used to obtain all of the estimation factors.

Sources as Referenced	Location
EA 2007 Flood Report	http://publications.environment-agency.gov.uk/pdf/SCHO1109BRJA-e-e.pdf
Office for National Statistics	http://www.neighbourhood.statistics.gov.uk/dissemination/
Department for Education	http://www.education.gov.uk/inyourarea/gors/gor_H.shtml
Disaster Reduction and Human Renovation Institution	http://www.dri.ne.jp/english/research/koremadeno.html
Pitt Review	http://webarchive.nationalarchives.gov.uk/20100807034701/http://archive.cabinetoffice.gov.uk/pittreview/thepittreview/final_report.html
Greater London Authority	http://data.london.gov.uk/datafiles/demographics/popproj_ward_2010rnd_ward_shlaa.xls

Output	Explanation of Calculations
Cost of a School Day	Funding per pupil provided by the borough divided by the number of school days in one school year
Percent Vulnerable	Total number of people in the affected area over 70 plus the number of disabled people under 70, divided by the total population of the affected area
Number of People Affected	Number of households affected multiplied by the average number of people per household in the affected area
Number of People Temporarily Relocated	Percentage of households requiring temporary accomodations (30%) during the 2007 floods multiplied by the number of people per household
Number of People Requiring Evacuation Assistance	Percent Vulnerable multiplied by the number of people affected
Number of People Reporting Health Concerns	Percentage of people reporting health concerns from the 2007 flood multiplied by number of people affected
Number of People Requiring a GP Visit	Percentage of people who reported health concerns that visited a GP from the 2007 flood multiplied by the number of people reporting health concerns
Number of GPs Affected	Extracted from GIS Map
Number of Households Affected	Extracted from GIS Map
Total Cost of Damages to Households	Average household insurance claim from the 2007 flood multiplied by the number of houses affected
Total Uninsured Damage	Total cost of damages to households multiplied by the percentage of houses that are uninsured
Number of Households Requiring Temporary Accomodation	Percentage of households requiring temporary accomodations during the 2007 floods multiplied by the number of households affected
Total Cost of Temporary Accomodation for Households	Average cost of temporary accomodations for a household from the 2007 flood multiplied by the number of households requiring temporary accomodations
Number of Businesses Affected	Extracted from GIS Map
Total Cost of Damages to Businesses	Average business insurance claim from the 2007 flood multiplied by the number of businesses affected
Total Uninsured Damage	Total cost of damages to businesses multiplied by the percentage of businesses that are uninsured
Number of Businesses Requiring Temporary Accomodation	Percentage of businesses requiring temporary accomodations during the 2007 floods multiplied by the number of businesses affected
Total Cost of Temporary Accomodation for Businesses	Average cost of temporary accomodations for a business from the 2007 flood multiplied by the number of businesses requiring temporary accomodations
Number of Schools Affected	Extracted from GIS Map
Total Number of Pupil Days Lost	Average school closure duration from the 2007 flood multiplied by the number of pupils in affected schools
Total "Cost of School Day" Impacts	Total number of pupil days lost multiplied by the cost of a school day
Total Cost of Electricity Deprivation	Average electricity deprivation duration from the 2007 flood multiplied by average hourly household electricity consumption multiplied by a "willingness to pay" estimate for the cost of one kWh multiplied by the number of affected buildings (households and businesses)
Total Cost of Water Failure	Average water failure duration from the 2007 flood multiplied by a "willingness to pay" estimate for the cost of water services
Total Cost of Sewage Failure	Average sewage failure duration from the 2007 flood multiplied by a "willingness to pay" estimate for the cost of sewage
Tonnes of Waste Produced	Average amount of waste generated per building in a flood multiplied by the number of buildings
Total Cost	All previous monetary costs combined
Total Cost (20 Year Projection)	Same formula as Total Cost with household damages multiplied by the percent change in population.

Appendix C: Modeling Program Blank Spreadsheet

Source	Category	Cost Estimation Factors	Value	Unit
EA 2007 Flood Report	Utility	Electricity deprivation cost Average Household Electricity Consumption Average electricity deprivation time	10 0.3767 14.6	£/household/kWh kWh/hour hours
		Water failure cost Average water failure time	10 2	£/household/day days
		Sewage failure cost Average sewage failure time	5 2	£/Household/day days
EA 2007 Flood Report	Property Damage	Average Household Insurance Claim Number of Uninsured Houses	27150 24.00%	£/Household percentage
EA 2007 Flood Report		Average Business Insurance Claim Number of Uninsured Businesses	72826 5.00%	£/Business percentage
Pitt Review Pitt Review Office for National Statistics	Health/People	People Reporting Health Concerns People Requiring GP Visit People Requiring Evacuation Assistance	41.50% 39.00% 	percentage percentage of above value percentage
Department for Education	Schools	Cost of school day Average days out of school	 2.35	£/pupil day days
Disaster Reduction and Human Renovation Institution	Waste	Total Waste Produced	4.17	Tonnes/Building
EA 2007 Flood Report	Temporary Accomodations	Buildings needing temporary accomodations Ave cost of temp accom (domestic) Ave cost of temp accom (business)	30.00% 6695 5461	percentage £/Household £/Business

List of Affected Areas

Cost of School Day	
Input Funding per Pupil (age 3-19) for the affected area:	
Cost of School Day	£0.00

Department for Education

People Requiring Evacuation Assistance

Disabled Population Under 70	
-16	
16-24	
35-49	
50-59	
60-69	
Total	

Population 70 and above	
Aged 70 years	
Aged 71 years	
Aged 72 years	
Aged 73 years	
Aged 74 years	
Aged 75 to 79 years	
Aged 80 to 84 years	
Aged 85 to 89 years	
Aged 90 to 94 years	
Aged 95 to 99 years	
Aged 100 years and over	
Total	
Total Disabled and/or Elderly	
Total Population (2001)	
People Requiring Evacuation Assistance	

Office for National Statistics

Future Projections			
Affected Areas	Current Total Population	Projected Future Total Population	Percent Change in Population

Greater London Authority

	Inputs Taken from GIS Maps				
	Number of Households in Flood Zone	Number of Businesses in Flood Zone	Number of Schools in Flood Zone	Number of School Pupils in Schools in Flood Zone	Number of GPs in Flood Zone

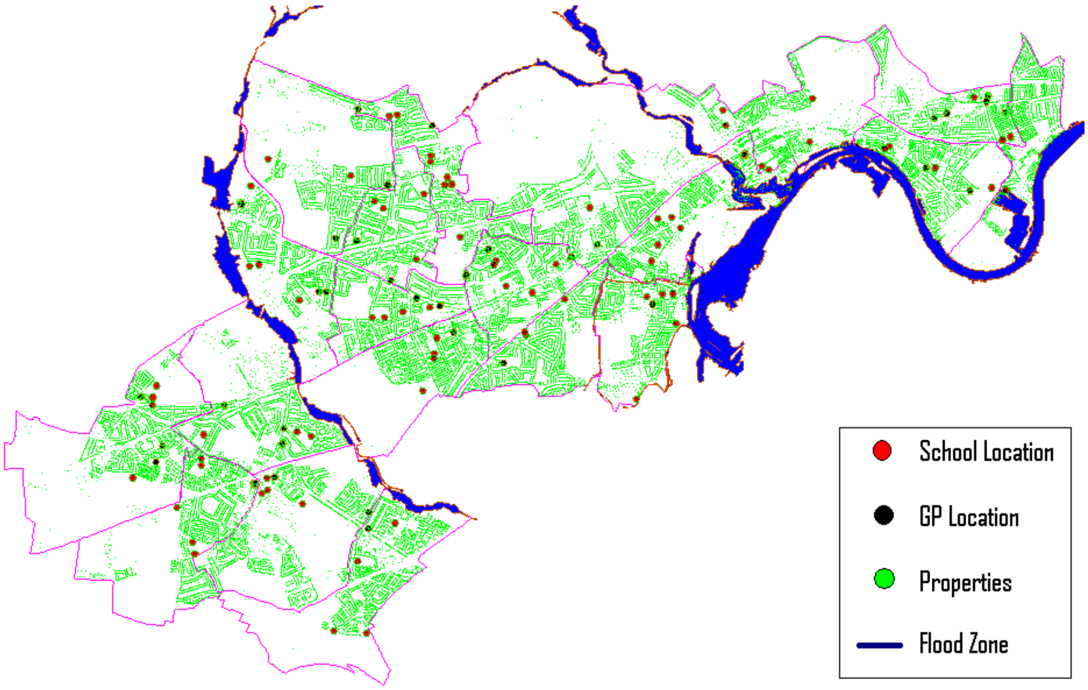
	People			Health			Domestic					Businesses					Schools			Utilities			Waste
Affected Areas	Number of People Affected	Number of People Temporarily Relocated	Number of People Requiring Evacuation Assistance	Number of People Reporting Health Concerns	Number of People Requiring a GP Visit	Number of GPs Affected	Number of Households Affected	Total Cost of Damages to Households	Total Uninsured Damage	Number of Households Requiring Temporary Accomodation	Total Cost of Temporary Accomodation for Households	Number of Businesses Affected	Total Cost of Damages to Businesses	Total Uninsured Damage	Number of Businesses Requiring Temporary Accomodation	Total Cost of Temporary Accomodation for Businesses	Number of Schools Affected	Total Number of Pupil Days Lost	Total "Cost of School Day" Impacts	Total Cost of Electricity Deprivation	Total Cost of Water Failure	Total Cost of Sewage Failure	Tonnes of Waste Produced
Total	0	0	0	0	0	0	0	£0.00	£0.00	0	£0.00	0	£0.00	£0.00	0	£0.00	0	0	£0.00	£0.00	£0.00	£0.00	0.00

	Number of Households Affected	Number of Businesses Affected	Number of Schools Affected	Number of People Affected	Number of GPs Affected	Number of People with Health Concerns	Number of People Requiring GP Visit	Number of People Temporarily Relocated	Number of People Requiring Evacuation Assistance	Tonnes of Waste Produced	Total Uninsured Cost	Total Cost	Total Cost (20 Year Projection)
Total	0	0	0	0	0	0	0	0	0	0	£0.00	**£0.00**	**£0.00**

Appendix D: Fluvial Zone 2 Summary Sheet

	Number of Households Affected	Number of Businesses Affected	Number of Schools Affected	Number of People Affected	Number of GPs Affected	Number of People with Health Concerns	Number of People Requiring GP Visit	Number of People Temporarily Relocated	Number of People Requiring Evacuation Assistance	Tonnes of Waste Produced	Total Uninsured Cost	Total Cost	Total Cost (20 Year Projection)
Bedfont													
Brentford	21	1	0	48	0	20	8	14	6	92	£140,477.30	**£688,662.76**	**£773,509.02**
Chiswick Homefields	147	7	1	327	0	136	53	98	39	642	£983,341.10	**£4,835,891.94**	**£4,835,790.61**
Chiswick Riverside	42	10	1	93	0	39	15	28	11	217	£310,085.00	**£2,055,386.36**	**£2,022,531.85**
Cranford	53	32	0	150	0	62	24	45	18	354	£461,869.60	**£3,935,482.95**	**£3,950,066.19**
Feltham North	37	1	0	92	0	38	15	28	11	158	£244,733.30	**£1,156,558.73**	**£1,159,696.50**
Feltham West													
Hanworth													
Hanworth Park													
Heston Central													
Heston East													
Heston West													
Hounslow Central													
Hounslow Heath													
Hounslow South	11	0	0	30	0	12	5	9	4	46	£71,676.00	**£321,678.48**	**£315,449.66**
Hounslow West													
Isleworth	278	25	0	645	0	267	104	193	77	1264	£1,902,480.50	**£9,993,424.95**	**£9,830,302.36**
Osterley & Spring Grove	0	4	0	0	0	0	0	0	0	17	£14,565.20	**£298,197.19**	**£298,197.19**
Syon	1474	85	0	3403	0	1412	551	1021	409	6501	£9,914,094.50	**£49,441,606.69**	**£52,884,339.05**
Turnham Green													
Total	2063	165	2	4788	0	1987	775	1436	576	9291	£14,043,322.50	**£72,726,890.06**	**£76,069,882.43**

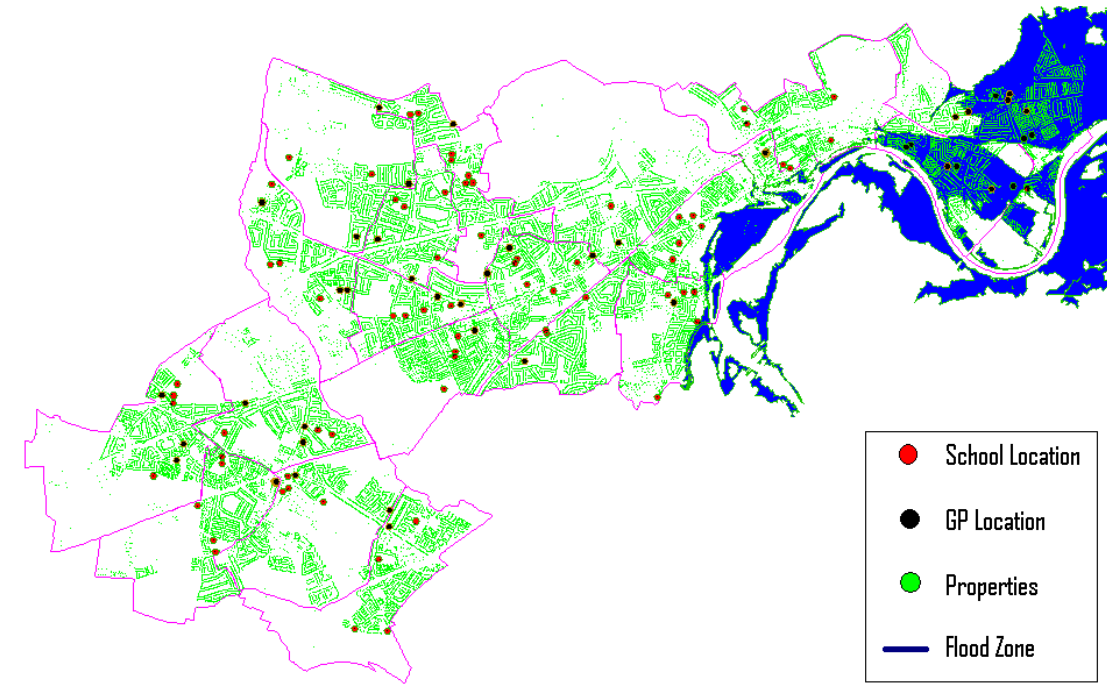
Appendix E: Fluvial Zone 3 Flooding



Appendix F: Fluvial Zone 3 Summary Sheet

	Number of Households Affected	Number of Businesses Affected	Number of Schools Affected	Number of People Affected	Number of GPs Affected	Number of People with Health Concerns	Number of People Requiring GP Visit	Number of People Temporarily Relocated	Number of People Requiring Evacuation Assistance	Tonnes of Waste Produced	Total Uninsured Cost	Total Cost	Total Cost (20 Year Projection)
Bedfont													
Brentford	21	1	0	48	0	20	8	14	6	92	£140,477.30	**£688,662.76**	**£773,509.02**
Chiswick Homefields	114	5	1	253	0	105	41	76	30	496	£761,030.50	**£3,721,757.90**	**£3,721,679.32**
Chiswick Riverside	13	3	0	29	0	12	5	9	3	67	£95,631.90	**£603,813.37**	**£593,644.12**
Cranford	0	1	0	0	0	0	0	0	0	4	£3,641.30	**£74,549.30**	**£74,549.30**
Feltham North	37	1	0	92	0	38	15	28	11	158	£244,733.30	**£1,156,558.73**	**£1,159,696.50**
Feltham West													
Hanworth													
Hanworth Park													
Heston Central													
Heston East													
Heston West													
Hounslow Central													
Hounslow Heath													
Hounslow South													
Hounslow West													
Isleworth	35	3	0	81	0	34	13	24	10	158	£238,983.90	**£1,247,170.33**	**£1,226,633.31**
Osterley & Spring Grove													
Syon	678	44	0	1565	0	650	253	470	188	3011	£4,578,065.20	**£23,107,260.90**	**£24,690,824.36**
Turnham Green													
Total	898	58	1	2069	0	859	335	621	249	3987	£6,062,563.40	**£30,599,773.29**	**£32,240,535.92**

Appendix G: Tidal Zone 3 Flooding



Appendix H: Tidal Zone 3 Summary Sheet

	Number of Households Affected	Number of Businesses Affected	Number of Schools Affected	Number of People Affected	Number of GPs Affected	Number of People with Health Concerns	Number of People Requiring GP Visit	Number of People Temporarily Relocated	Number of People Requiring Evacuation Assistance	Tonnes of Waste Produced	Total Uninsured Cost	Total Cost	Total Cost (20 Year Projection)
Bedfont													
Brentford	65	8	0	149	0	62	24	45	18	304	£452,670.40	**£2,497,221.77**	**£2,759,841.14**
Chiswick Homefields	3966	252	0	8816	0	3658	1427	2645	1060	17589	£26,760,063.60	**£134,766,137.01**	**£134,763,403.16**
Chiswick Riverside	4111	94	3	9146	2	3796	1480	2744	1100	17535	£27,129,558.20	**£127,286,613.66**	**£124,070,782.93**
Cranford													
Feltham North													
Feltham West													
Hanworth													
Hanworth Park													
Heston Central													
Heston East													
Heston West													
Hounslow Central													
Hounslow Heath													
Hounslow South													
Hounslow West													
Isleworth	129	8	0	299	0	124	48	90	36	571	£869,694.40	**£4,368,805.65**	**£4,293,112.08**
Osterley & Spring Grove													
Syon	355	22	0	820	0	340	133	246	99	1572	£2,393,288.60	**£12,021,526.42**	**£12,850,678.38**
Turnham Green	2920	476	3	5803	4	2408	939	1741	698	14161	£20,759,978.80	**£120,939,406.27**	**£121,313,952.24**
Total	11546	860	6	25032	6	10388	4051	7510	3010	51733	£78,365,254.00	**£401,879,710.78**	**£400,051,769.93**

Appendix I: Tidal Zone 2 Summary Sheet

	Households Affected	Businesses Affected	Schools Affected	People Affected	GPs Affected	Health Concerns	Requiring GP Visit	Temporarily Relocated	Requiring Evacuation Assistance	Waste Produced	Uninsured Cost	Total Cost	(20 Year Projection)
Bedfont													
Brentford	65	8	0	149	0	62	24	45	18	304	£452,670.40	**£2,497,221.77**	**£2,759,841.14**
Chiswick Homefields	3999	254	0	8889	0	3689	1439	2667	1069	17735	£26,982,374.20	**£135,880,271.04**	**£135,877,514.45**
Chiswick Riverside	4139	99	4	9209	2	3822	1490	2763	1107	17672	£27,330,212.70	**£128,559,844.56**	**£125,322,110.82**
Cranford													
Feltham North													
Feltham West													
Hanworth													
Hanworth Park													
Heston Central													
Heston East													
Heston West													
Hounslow Central													
Hounslow Heath													
Hounslow South													
Hounslow West													
Isleworth	253	20	0	587	0	243	95	176	71	1138	£1,721,374.00	**£8,889,591.01**	**£8,741,137.71**
Osterley & Spring Grove													
Syon	956	35	0	2207	0	916	357	662	265	4132	£6,356,741.50	**£30,566,009.72**	**£32,798,880.91**
Turnham Green	2920	476	3	5803	4	2408	939	1741	698	14161	£20,759,978.80	**£120,939,406.27**	**£121,313,952.24**
Total	12332	892	7	26843	6	11140	4344	8053	3227	55144	£83,603,351.60	**£427,332,344.37**	**£426,813,437.28**

Appendix J: Surface Water Flooding 1 in 200 Summary Sheet

	Number of Households Affected	Number of Businesses Affected	Number of Schools Affected	Number of People Affected	Number of GPs Affected	Number of People with Health Concerns	Number of People Requiring GP Visit	Number of People Temporarily Relocated	Number of People Requiring Evacuation Assistance	Tonnes of Waste Produced	Total Uninsured Cost	Total Cost	Total Cost (20 Year Projection)
Bedfont	1134	21	1	2742	0	1138	444	822	330	4816	£7,465,611.30	**£34,756,594.31**	**£34,169,649.12**
Brentford	1683	73	3	3845	0	1596	622	1154	462	7323	£11,232,242.90	**£54,774,839.78**	**£61,574,661.45**
Chiswick Homefields	1662	102	1	3694	0	1533	598	1108	444	7356	£11,201,004.60	**£56,221,975.04**	**£56,220,829.38**
Chiswick Riverside	1365	15	3	3037	0	1260	492	911	365	5755	£8,948,959.50	**£41,160,986.89**	**£40,093,215.32**
Cranford	952	33	2	2695	1	1118	436	808	324	4107	£6,323,394.90	**£30,321,140.31**	**£30,583,088.37**
Feltham North	548	37	0	1365	0	567	221	410	164	2439	£3,705,496.10	**£18,783,761.05**	**£18,830,233.87**
Feltham West	1251	19	1	3208	0	1331	519	963	386	5296	£8,220,700.70	**£38,023,650.01**	**£41,110,021.40**
Hanworth	523	6	1	1329	0	551	215	399	160	2206	£3,429,715.80	**£15,748,006.30**	**£15,404,971.61**
Hanworth Park	1048	45	1	2561	0	1063	415	768	308	4558	£6,992,626.50	**£34,080,971.89**	**£38,287,027.48**
Heston Central	756	40	2	2173	0	902	352	652	261	3319	£5,071,748.00	**£25,145,184.85**	**£24,906,093.12**
Heston East	626	23	3	1767	1	733	286	530	212	2706	£4,162,765.90	**£20,168,254.87**	**£20,027,365.02**
Heston West	931	42	0	2706	0	1123	438	812	325	4057	£6,219,330.60	**£30,356,767.35**	**£29,805,048.17**
Hounslow Central	1199	43	3	3058	1	1269	495	917	368	5179	£7,969,259.90	**£38,390,389.88**	**£43,924,081.10**
Hounslow Heath	922	26	2	2496	0	1036	404	749	300	3953	£6,102,425.80	**£29,070,275.77**	**£30,160,014.72**
Hounslow South	427	11	1	1152	0	478	186	346	139	1826	£2,822,386.30	**£13,311,940.62**	**£13,070,149.02**
Hounslow West	1108	25	2	3104	1	1288	502	931	373	4725	£7,310,760.50	**£34,381,735.59**	**£41,965,524.65**
Isleworth	1097	55	2	2543	1	1055	412	763	306	4804	£7,348,323.50	**£36,276,632.42**	**£35,632,943.63**
Osterley & Spring Grove	454	55	0	1131	1	469	183	339	136	2123	£3,158,535.50	**£17,376,759.58**	**£17,076,466.69**
Syon	1592	65	3	3676	0	1525	595	1103	442	6910	£10,610,156.50	**£51,458,396.92**	**£55,176,734.72**
Turnham Green	1336	146	1	2655	1	1102	430	796	319	6180	£9,237,005.80	**£49,985,452.70**	**£50,156,820.32**
Total	20614	882	32	50938	7	21139	8244	15281	6125	89638	£137,532,450.60	**£669,793,716.13**	**£698,174,939.15**

Appendix K: Dam Inundation Summary Sheet

	Number of Households Affected	Number of Businesses Affected	Number of Schools Affected	Number of People Affected	Number of GPs Affected	Number of People with Health Concerns	Number of People Requiring GP Visit	Number of People Temporarily Relocated	Number of People Requiring Evacuation Assistance	Tonnes of Waste Produced	Total Uninsured Cost	Total Cost	Total Cost (20 Year Projection)
Bedfont	2	3	0	5	0	2	1	1	1	21	£23,955.90	**£282,134.89**	**£281,099.71**
Brentford	45	6	0	103	0	43	17	31	12	213	£315,067.80	**£1,763,253.21**	**£1,945,066.62**
Chiswick Homefields	1173	17	1	2607	0	1082	422	782	313	4962	£7,705,170.10	**£35,585,214.07**	**£35,584,405.50**
Chiswick Riverside	2667	64	4	5934	2	2462	960	1780	713	11388	£17,611,215.20	**£82,904,189.77**	**£80,817,928.39**
Cranford													
Feltham North													
Feltham West	1039	32	0	2665	0	1106	431	799	320	4466	£6,886,645.60	**£32,769,572.17**	**£35,332,913.40**
Hanworth	0	2	0	0	0	0	0	0	0	8	£7,282.60	**£149,098.60**	**£149,098.60**
Hanworth Park	1391	35	0	3400	0	1411	550	1020	409	5946	£9,191,201.50	**£43,286,931.43**	**£48,869,587.27**
Heston Central													
Heston East													
Heston West													
Hounslow Central													
Hounslow Heath													
Hounslow South													
Hounslow West													
Isleworth	328	22	1	760	0	316	123	228	91	1460	£2,217,356.60	**£11,247,409.78**	**£11,054,948.59**
Osterley & Spring Grove													
Syon	1356	76	1	3131	0	1299	507	939	376	5971	£9,112,434.80	**£45,322,666.12**	**£48,489,793.04**
Turnham Green													
Total	8001	257	7	18604	2	7721	3011	5581	2237	34436	£53,070,330.10	**£253,310,470.04**	**£262,524,841.11**