Mapping Vulnerability to Climate Change in the Royal Borough of Kingston upon Thames

An Interactive Qualifying Project Report submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfilment of the requirements for the Degree of Bachelor of Science

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29 April 2010

Abstract

Due to increasing concern about the potential impacts of climate change, the Royal Borough of Kingston decided to perform a vulnerability, hazard, and risk analysis to assist emergency planning and preparedness as well as help shape climate change adaptation strategies. Our team incorporated aspects from several methods of performing a vulnerability analysis to produce the preferred method for Kingston. A social vulnerability index was calculated using variables identified by three of more sources as being indicative of increased vulnerability to identify the most socially and economically vulnerable areas in Kingston.

Executive Summary

As a result of the increased amount of greenhouse gases (GHG) in the atmosphere, the surface temperature of the Earth has been slowly rising over the past century. This rise in surface temperature will have an unprecedented impact on the Earth's climate, with effects ranging from an increased number of heat waves to increased precipitation in the winter. As a result, local and national governments have begun to set forth agendas to create preventative measures and help mitigate the negative effects of the coming climate changes.

The London Borough of Kingston (RBK) upon Thames has begun to create policy to better adapt to effects of climate change for emergency planning purposes. To assist the RBK in implementing these policies, our team performed an assessment of vulnerability to climate change throughout Kingston. The overall goal of the project was to develop and evaluate various vulnerability mapping methods to identify an approach that best suits the needs of the RBK. The goal of this project was achieved by the completion of four objectives.

- Objective 1: Compare and contrast the state-of-the-art in vulnerability mapping and emergency planning and preparedness for climate change in the United States, Canada, and United Kingdom
- Objective 2: Derive a composite method for Kingston by comparing the advantages and disadvantages of alternate methods
- Objective 3: Generate and compare GIS based vulnerability maps using the methods in preceding objective
- Objective 4: Explore hazard mapping for the Royal Borough of Kingston as well as overlays between hazard and vulnerability mapping

Through our research, we identified three key methodologies from Susan Cutter, Bryan Boruff, and W. Lynn Shirley (2003), Rob Bell, Joseph McFarland, and Matt Innerd (2008), and Jayajit Chakraborty, Graham Tobin, and Burrell (2005). Each methodology presented their own set of variables and method for calculating a vulnerability score. Cutter et al. (2003) focused on social variables and implemented a factor analysis in order to reduce a large set of variables into a small list of factors. However, Chakraborty, Tobin, and Montz (2005) offered an alternative for calculating a vulnerability score by using averaging to create a social vulnerability index (SVI). When assessing vulnerability in the London Borough of Hounslow, Bell, McFarland, and Innerd

(2008) used a wide range of variables and used a percent population method for calculating a vulnerability score.

To develop the best methodology to implement in Kingston's vulnerability analysis, our team used an iterative process to produce, compare, and contrast different sets of vulnerability maps. Each set of maps contained their own unique combination variables and scoring method. These methodologies and the maps they produced were assessed to determine how well each method reflected the actual vulnerability in Kingston. We evaluated the strengths and weaknesses of each methodological approach based on the following criteria: ease of data acquisition, ease of data compilation (vulnerability score calculation and formatting of data to export to GIS), the reproducibility of the method (ability to be amended to future changes and ability to be modified in other areas), and the quality of the output produced.

Data for each variable was acquired from the Office of National Statistics (ONS) Neighbourhood Statistics website[1]. The ONS is the British government body responsible for the collection and publication of various statistics, including census data and statistics relating to the population. Data gathered by the ONS is divided into output areas, which were created to allow for a fine-grain analysis of the census data in order to reflect the character of local areas. There are three categories of output areas: lower, middle, and upper. When available, our data was gathered in terms of lower super output areas (LSOAs), which provide the highest resolution by dividing Kingston into 96 different LSOAs. When LSOA data was unavailable, middle super output area data (MSOA) was used in its place.

Our team went through a series of five iterations before final economic and social vulnerability maps were produced. These maps were made using the scoring method developed by Chakraborty, Tobin, and Montz (2005) and variables that were identified by three or more sources as being indicative of vulnerability. Each LSOA was given a SVI score based on the data provided by the ONS for each variable and the SVI equation developed by Chakraborty, Tobin, and Montz (2005). Equal intervals and a quintile method (quantile with five divisions) were looked into as methods for classifying each LSOA into one of five levels of vulnerability. The quintile method was chosen to categorize the data because it ensures that 20% of the LSOAs are placed in each level. As a result, 20% of the LSOAs will always be categorized in the highest level of vulnerability. Using equal intervals, it is possible to have very few LSOAs in the top two

[1] http://www.neighbourhood.statistics.gov.uk/dissemination/Download1.do?$ph=60_61

categories, a flaw our team had to address while performing our analysis. The final social and economic vulnerability maps (Figures 1 and 2) are displayed below.

Figure 1: Social Vulnerability Map

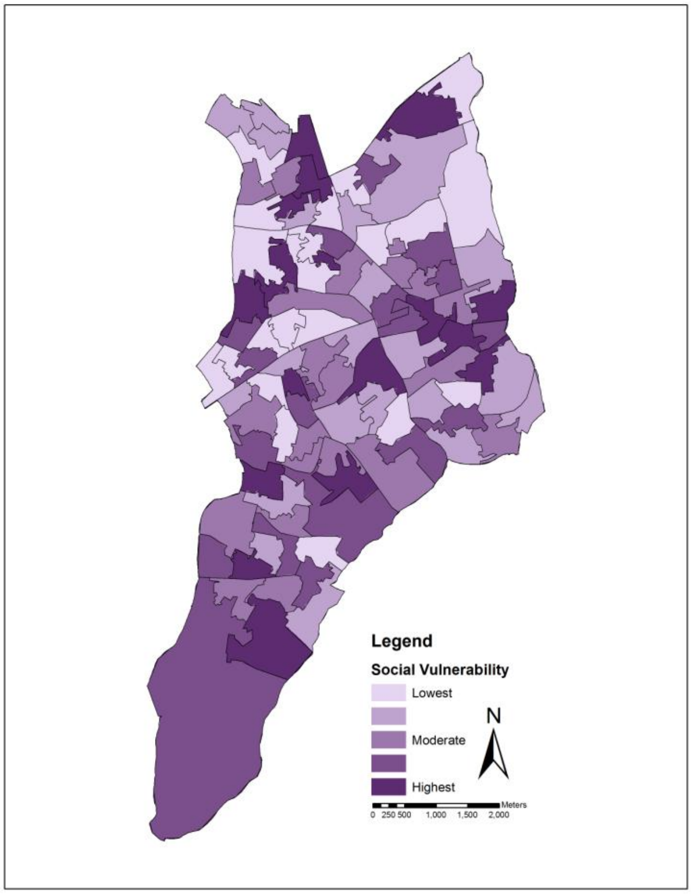
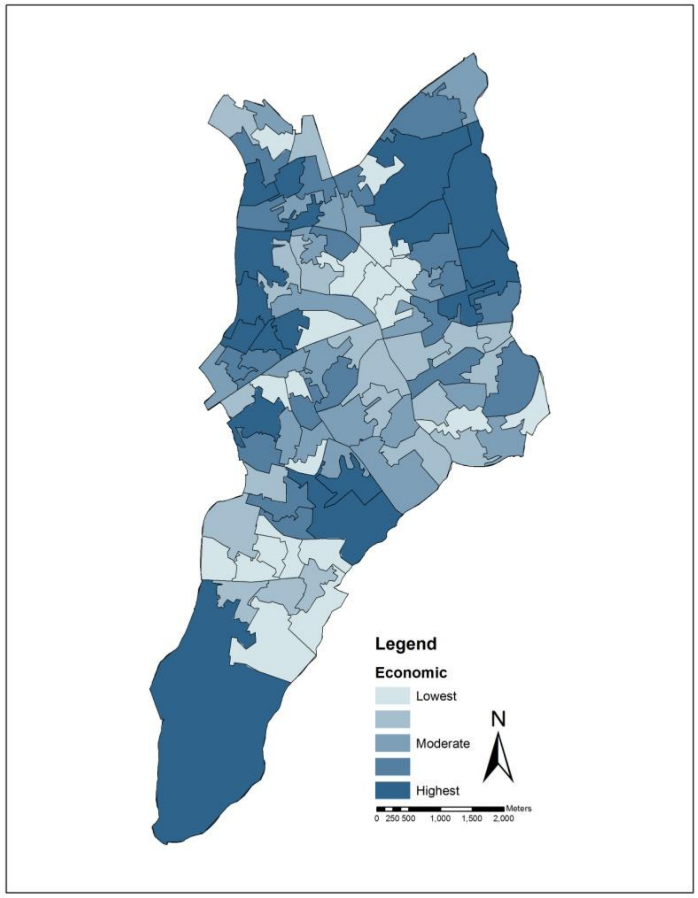


Figure 2: Economic Vulnerability Map



Our team also briefly investigated hazard and risk mapping for the Borough of Kingston. We performed this analysis for the hazards of surface water flooding and fluvial flooding. Hazard scores for each event were assigned based on the rate of occurrence. Although the surface water flooding did not have a rate of occurrence, the hazard scores for those layers were given the same values as those used for fluvial flooding. These hazard scores were then multiplied with the vulnerability scores from our finalized social and economic vulnerability maps based on the equation risk = hazard * vulnerability from *At Risk* (Blakie, Cannon, Davis, & Wisner, 2001).We also investigated how the frequency of hazards is likely to change as a result of climate change. This was done through the use of the UK Climate Projections 2009 (UKCP09) Weather Generator and Threshold Detector. These tools allowed our team to input weather thresholds to determine how flooding and heat waves will increase in the coming years. Our final social and economic risk maps (Figures 3 and 4) are displayed respectively below.

Figure 3: Social Flood Risk Map

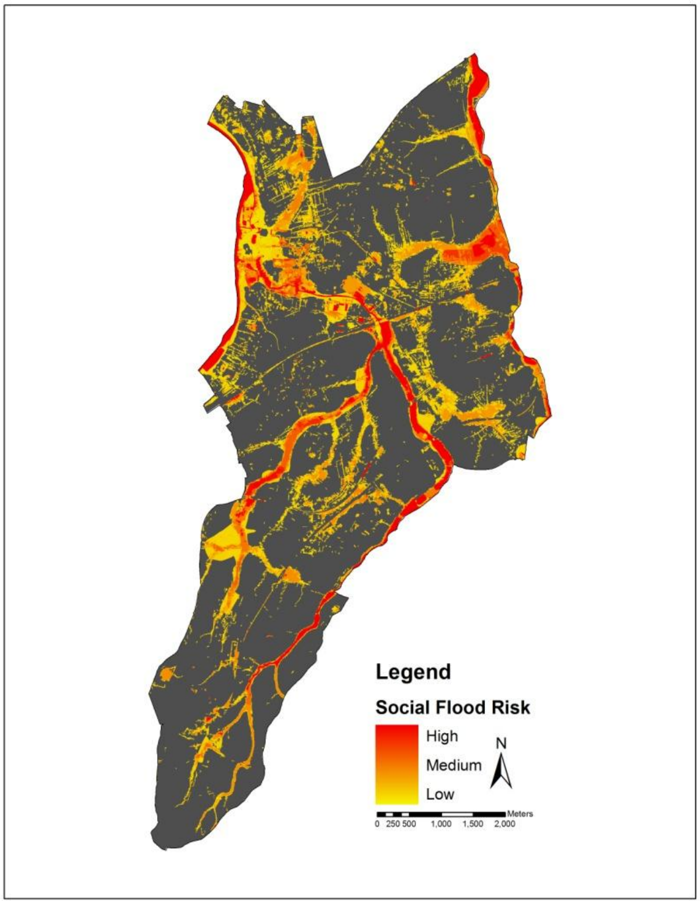
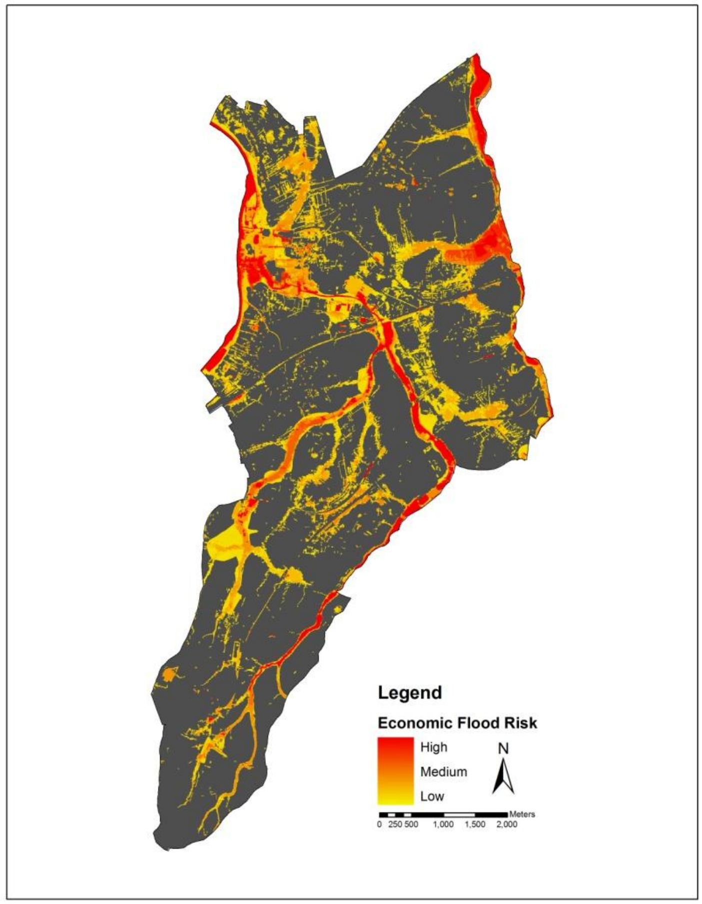


Figure 4: Economic Flood Risk Map



Through the completion of our project, we reached the following conclusions:

- It is best to separate vulnerability mapping into two categories: economic and social
- The Chakraborty, Tobin, and Montz (2005) method for calculating a SVI is the best way to calculate a vulnerability score
- The quintile method of dividing LSOAs into different levels of vulnerability is the most comprehensive way to classify the vulnerability of the LSOAs across an area
- The variables used in our analysis give the best representation of vulnerability throughout Kingston (for our project's purposes)
- The most socially vulnerable LSOAs in Kingston contain the Alpha Road Estates and the Cambridge Road Estates

- The most economically vulnerable LSOA in Kingston contains the shopping districts east of the Thames River

Our team has numerous recommendations for how to expand on our project in the future. The first is to incorporate new and updated data as it becomes available to the RBK. This will allow for a more recent snapshot of Kingston when analyzing vulnerability because a lot of the data we incorporated in our analysis was from the 2001 census. New economic data and data on the day/night population shift would also expand on our analysis. Data that is currently in MSOA format should be gathered in LSOA format to allow for a higher resolution in our vulnerability maps. Another recommendation our team has is to make our analysis available to different groups throughout the RBK through the ISIS Program used in the Borough. This would allow each group to use our analysis for their own specific applications. Our team also recommends performing our analysis across the Greater London area. This will allow our methods to be tested throughout London. Finally, more research needs to be done in the areas of risk and hazard mapping and a more complete hazard analysis should be performed throughout Kingston. This includes looking into more refined methods of calculating a hazard score. Our analysis only looked at flood hazards throughout Kingston and is flawed as a result of the data we were provided. This data needs to be more complete before it can be used in a final hazard analysis. Furthermore, our analysis did not take into account other hazards the RBK faces, such as from oil and gas pipelines and severe heat waves. These need to be accounted for in a complete hazard analysis.

Climate change has become a rapidly growing concern over the last decade. According to simulations run through the UK Climate Projections Weather Generator, the Royal Borough of Kingston could be facing up to 6 heat waves a year and increased flooding. The RBK needs to take into account and plan for the impact of these events. The production of our vulnerability, hazard, and risk maps will assist the Royal Borough of Kingston with emergency planning and preparedness purposes. This will allow Kingston to better prepare for the likely impacts of climate change through identifying the areas of the Borough that are the most vulnerable and at the highest risk to hazardous events.

Acknowledgements

We would like to thank the following, without whom this project would not have been possible:

Professor Dominic Golding

Professor Ruth Smith

Sponsor Liaison Nia Prys-Williams

Rob Bell

Tony Klein

Joseph McFarland

Darren Tuckett

The Royal Borough of Kingston Planning Group

The Royal Borough of Kingston Neighbourhood Team

The Royal Borough of Kingston Climate Change and Sustainable Travel Group

Authorship

This project was completed equally by all four members of the team.

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1. Introduction

Governments throughout the world have become extremely concerned about the potential effects of climate change over the past few decades. Since As a result of human actions over the past century, the amount of greenhouse gases (GHG) emitted into the atmosphere has substantially increased. As a result, current climate models predict that the surface temperature of the Earth could rise by 7.2°F by the end of the century (Environmental Protection Agency, 2009). The changing climate is expected to create a variety of adverse environmental and health impacts around the world. In the United Kingdom, environmental hazards such as flooding, heat waves, and outbreaks of infectious diseases are expected to become more frequent and more severe (The Office of the Mayor of London, 2010).

The Civil Contingencies Act of 2004 placed increased responsibility on local governments, including the boroughs of London, to plan and prepare for these kinds of hazardous events. In response to this increased responsibility, the Borough of Hounslow has constructed hazard and vulnerability maps that identify which groups, institutions, and geographic areas may be at higher risk so they can target their emergency planning and response activities more effectively. The goal of this project was to assist the Royal Borough of Kingston Council in developing a similar methodology that maps social vulnerability to various hazard events that are likely to become more frequent and more severe due to future climate changes.

This project began by comparing and contrasting the state-of-the-art in vulnerability mapping and emergency planning and preparedness for climate change in Canada, the United States and United Kingdom. This included critically assessing each methodology for their strengths and weaknesses. Building on the work conducted in Hounslow and our research, our group determined the best set of variables to use in Kingston, as well as the best method to use for computing a composite vulnerability score. We began by replicating the methods used in Hounslow by Bell, McFarland, and Innerd (2008), three individuals responsible for emergency planning and preparedness, before incorporating different variables and a different method of computing a vulnerability score for Kingston. Our Worcester Polytechnic Institute (WPI) student team developed multiple sets of maps that show vulnerability throughout Kingston using different combinations of variables and vulnerability scores. After five iterations of mapping and numerous discussions with the Kingston staff, including the Neighborhood Team, we determined which of these maps give the most useful and representative picture of vulnerability throughout the Borough. We determined that a modified version of the method used by Chakraborty, Tobin, and Montz (2005) to calculate a social vulnerability index (SVI) was the most appropriate to meet the needs of the Borough. We also concluded that rather than develop one composite map, two vulnerability maps give a clearer picture of vulnerability. One map shows economic vulnerability and the other shows social vulnerability. Our team also explored hazard mapping for the RBK, and was able to produce a preliminary risk map for flooding.

Through research, we were able to achieve our project goals. We accomplished these goals by developing economic and social vulnerability maps which give a good representation of the vulnerability in Kingston. Also, we were able to create a flood hazard map to show the probability and locations of flooding within Kingston. To link vulnerability to hazards, a risk map was created to show which vulnerable populations are susceptible to hazards in order to determine which populations are at risk. The production of these maps can to help numerous groups in Kingston including emergency planners and groups focused on adapting to climate change.

2. Background on Climate Change

The coming impacts of climate change are becoming an increasing concern for London and the Royal Borough of Kingston upon Thames. In response, Kingston is in the process of developing an adaptation strategy and action plan to help mitigate the coming impacts of climate change. In order to understand why Kingston has put this plan high on their list of priorities, it is first necessary to understand what climate change is, why it is happening, and how it will affect the United Kingdom (UK) and the Royal Borough of Kingston (RBK).

The greenhouse effect is a naturally occurring phenomenon that keeps the Earth's surface temperature more consistent and higher than it would be otherwise. Greenhouse gases include carbon dioxide (CO_2), water vapor, methane (CH_4), chlorofluorocarbons (CFCs), and ozone (O_3). These gases absorb infrared radiation given off by the Earth and re-radiate it back to the surface. Without the greenhouse effect the Earth would be unable to sustain life (Environmental Protection Agency, 2009). Recent human activities have led to an increased build up in greenhouse gases within the Earth's atmosphere. Since the start of the Industrial Revolution, carbon dioxide concentrations in the atmosphere have risen from 280 parts per million (ppm) to 380 ppm today, an increase of just over 35%. This rise in CO_2 concentrations has been accompanied by a rise in the concentrations of other greenhouse gases as well (Stern, 2006). As a result of the increased concentration of greenhouse gases in the atmosphere, the surface temperature of the Earth has been rising. Current climate models predict that this rise in surface temperature could reach as high as 7.2°F by the end of the century (Environmental Protection Agency, 2009). This dramatic increase in surface temperature has serious repercussions for Earth's climate and will have a drastic impact felt throughout the world.

2.1 Climate Change as it Effects the UK

The City of London is likely to be greatly affected by the adverse effects of climate change. In 2007, the City of London Corporation issued a document entitled *Rising to the Challenge – The City of London Corporation's Climate Adaptation Strategy*. This report identified a range of climate change risks that threaten the City of London and its boroughs, including: drier summers, wetter winters, more frequent extreme high temperatures, more frequent heavy downpours of rain, possible higher wind speeds, significant reduction in soil moisture content in the summer, sea level rise, and increased storm surges (City of London

Corporation, 2007). These changes are expected to lead to increased flooding throughout the city, more severe heat waves, and an increase in the outbreaks of infectious diseases. If London does not prepare for these changes, it could experience severe property damages and increased rates of mortality and morbidity as a result of these events. The Office of the Mayor of London identified a similar range of effects associated with climate change (Table 1) in *The Draft Climate Change Adaptation Strategy for London*. The Mayor's Office believes that rising temperature and an increased likelihood of flooding are the two biggest threats London is facing. It points to the fact that this increase in flooding can come from "the sea (tidal flooding), from the Thames and tributaries to the Thames (fluvial flooding), from heavy rainfall overcoming the drainage system (surface water flooding), from the sewers (sewer flooding), and from rising groundwater (groundwater flooding)" (The Office of the Mayor of London, 2010).The table below outlines some of the climate projections for London in the 2050s.

Table 1: UK Climate Projections 2009 for London (2050s medium emissions scenario)

Rising temperatures	Summers will be warmer, with the average summer day[12] being 2.7°C warmer and very hot days 6.5°C warmer than the baseline average. By the end of the century the hottest day of the year could be 10°C hotter than the hottest day today. Winters will be warmer, with the average winter day being 2.2°C warmer and a very warm winter day 3.5°C above the baseline.
More seasonal rainfall	Summers will be drier, with the average summer 19 per cent drier and the driest summer 39 per cent drier than the baseline average. Winters will be wetter, with the average winter 14 per cent wetter and the wettest winter 33 per cent wetter than the baseline average.
Tidal surges	Tidal surges (see Chapter 3 for description) are not projected to increase in frequency, though the height of a one-in-fifty-year tidal surge is projected to increase by up to 70cms by the end of the century.
Sea level rise	Sea levels are projected to rise by up to 90cms by the end of the century. An extreme projection of a 2-metre increase has been generated using the latest ice-sheet modelling published after the IPCC (Intergovernmental Panel on Climate Change) Fourth Assessment report.

(The Office of the Mayor of London, 2010)

Climate change also poses substantial economic risks for the UK and the rest of the world. *The Stern Review on the Economics of Climate Change* concluded that if action is not taken now it will be equivalent to losing five percent of the global gross domestic product (GDP) every year forever (Stern, 2006). Using a wider range of impacts and events, that figure could rise as high as twenty percent. The Stern Review estimates the cost of adapting to climate change is likely to be about one percent of the global GDP every year. Combating and adapting to climate change now significantly reduces the economic damages that could occur later. Furthermore, the review estimated that low-carbon energy products are likely to be a $500 billion market by the year 2050 (Stern, 2006), so there are economic gains as well as possible costs associated with climate change adaptation. By adapting to and planning for climate change now, countries and companies are putting themselves in a situation to take advantage of these opportunities in the future. The economic changes brought on by climate change could be as disastrous as any depression or world war. However, adapting to these changes now can put the UK in a stronger economic position for the future. One aspect of adaptation involves examining vulnerability to hazards whose frequency and severity will increase as a result of climate change. By decreasing the vulnerability of an area, its economy will be more resilient to the changes that are likely to occur as a result of climate change.

2.2 Emission Reducing Policies in the UK

The 2008 UK Climate Change Act set a goal for the UK to reduce carbon dioxide emissions by 26 percent relative to 1990 levels by 2020 and by 60 percent or more by 2050. This act required the government to create the Committee on Climate Change (CCC) in order to advise the UK government on carbon reduction budgets and whether or not to increase the 2050 target. In addition, the CCC is responsible for reporting to Parliament on the progress of greenhouse gas reduction. The act also requires the government to publish yearly carbon budgets, assess risk in the UK due to the impacts of climate change, establish trading schemes to reduce greenhouse gas emissions, create waste reduction pilot schemes, and amends the provisions of the Energy Act of 2004 regarding renewable transport fuel obligations (Parliament, 2008). In order to assess climate change risk in the UK, the act requires the British government to implement a UK-wide Climate Change Risk Assessment (CCRA) every five years starting in 2012. The CCRA will study UK climate projections to provide ongoing estimates of risk, so decision-makers can identify and implement appropriate adaptive actions (Department for Environment, Food and Rural Affairs, 2009a).

The UK Climate Impacts Programme (UKCIP) advises other organizations within the UK to help them make decisions on climate change adaptation. Its responsibilities include providing tools to explain how climate change can impact the Earth, including UK national and regional climate projections, offering advice on adaptation strategies, and participating in climate change research. The British government has also set up an Adapting to Climate Change Programme (ACC) which is led by the Department for the Environment, Food, and Rural Affairs (Defra). The ACC is responsible for building on previous climate change data in order to aid in individual and organizational decisions. In addition, the ACC is responsible for raising awareness, measuring progress, and embedding climate change policies within the British government at a national, regional, and local level. The Natural Adaption Programme is another program that will be launched by the government in 2012 to promote adaptation to the changing environment via the creation of future strategies for using power. Information from authorities, based on climate change projections and the CCRA, is directed to the Natural Adaption Programme (Department for Environment, Food and Rural Affairs, 2009a).

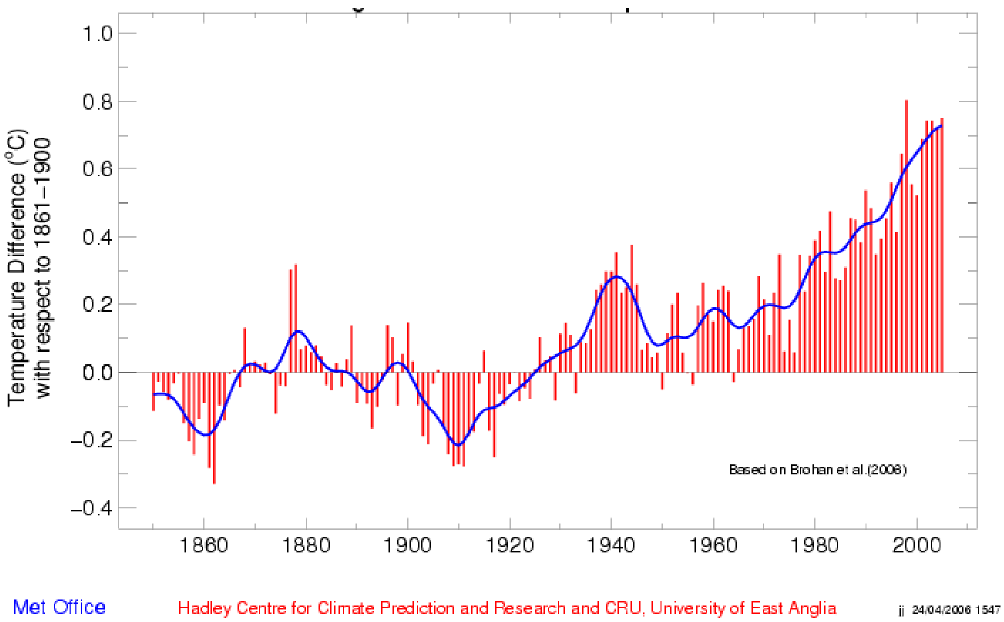
2.3 Facing the Inevitable

New research raises questions about not only how to halt further climate change but how to adapt to the world as it inevitably changes. The emission of GHGs has already caused enough damage to have serious repercussions in the future. Even if carbon and other GHG emissions were to halt today, there would still be many decades of climate change due to the length of time that greenhouse gases stay within the atmosphere (City of London Corporation, 2007). Furthermore, many scientists are now believe that stabilizing CO_2 levels below 450 ppm, which is necessary in order to prevent catastrophic climate change, is impossible, and research suggests that stabilization below 550 ppm may be unattainable (The Office of the Mayor of London, 2010). This places an increased emphasis on the need to adapt to climate change to a greater degree than previously believed.

As shown in (Figure 5) below, the global average near-surface temperature has steadily increased over the last 60 years. This increase in temperature has already begun to change the environment in many parts of the world. These changes vary from the melting of the polar ice caps to longer and more intense droughts. This warming trend will continue into the future regardless of what we do to curb greenhouse gas emissions today. To make matters worse, scientists now believe that the warming effect to be caused by the past emissions has not fully been felt yet.

“Observations show that the oceans have taken up around 84% of the total heating of the Earth’s system over the last 40 years. If global emissions were stopped today, some of this heat would be exchanged with the atmosphere as the system came back into equilibrium, causing an additional warming. Climate models project that the world is committed to a further warming of 0.5° - 1°C over several decades due to past emissions.” (Stern, 2006)

Figure 5: Global Average Near-Surface Temperatures 1850-2005



(Stern, 2006)

This new research showing that climate change is inevitable is beginning to force governments to think in new ways. While halting climate change might still be the overarching goal, there is a greater need to adapt to the inevitable changes that are going to occur. Preventing climate change can no longer be the only approach. Thus, the central government is adopting a two-pronged approach that includes climate change mitigation as well as adaptation strategies. Mitigation includes efforts to reduce greenhouse gas emissions. Mitigation can mean multiple things, such as reducing the likelihood of a hazard event or limiting the adverse effects of a hazard in a given area. Adaptation incorporates adjusting to the inevitable changes in the climate, weather, and the environment. Some local governments are taking steps to not only increase mitigation but also implement climate change adaptation policies. The Royal Borough of Kingston (RBK) is one of the local governments in the UK that is taking action in the field of climate change adaptation. One of the major focuses of the Kingston plan is "A coordinated approach to tackling climate change mitigation and adaptation" (Royal Borough of Kingston Council, 2008). This new shift in paradigm exposes a key idea in how climate change is perceived. In spite of the policies that have been implemented in the past, climate change is now considered inevitable regardless of what steps are taken to reduce GHG emissions in the future. National and local governments must continue efforts to prevent or limit future changes, but they must also implement policies to adapt to the inevitable challenges that loom ahead.

2.4 Introduction to the Climate Change Adaptation Agenda

The UK Climate Change Act of 2008 made the UK the first country to adopt a legally-binding framework to cut carbon emissions in the coming years and it created a framework for the UK to adapt to climate change. This framework was further strengthened when the Department for Environment, Food and Rural Affairs (Defra) created the National Indicator 188 (NI 188) to "embed the management of climate risks and opportunities across the all levels of services, plans and estates" (Department for Environment, Food and Rural Affairs, 2009b). Essentially, the indicator gauges how well an area has adapted to climate change and assesses its risks and vulnerabilities. Part of this is due to the level of development of an adaptation strategy and action plan that identifies risk and priority areas. The RBK is currently in the process of designing an adaptation strategy and action plan that coincides with NI 88 and the UK Climate Change Act.

In November of 2008 the Royal Borough of Kingston passed the Kingston Plan, which became effective of March 2009. The Plan outlines the priorities of those who deliver public services in the Kingston area. One of the themes identified in this plan was that of a sustainable Kingston, which encompassed protecting the environment and tackling climate change. This led to the creation of the Climate Change and Sustainable Travel Group (CCST), which was tasked with establishing a coordinated approach to tackling climate change adaptation and mitigation. The primary objectives of the CCST are to assess the risks and opportunities comprehensively across the RBK, take action in any identified priority areas, develop an adaptation strategy and action plan developing risk assessment, and determining how risks will be continually assessed and monitored in the future. These objectives echo the themes found in NI 188. In order to meet these objectives, the RBK is looking at various ways to adapt to climate change and its inevitable impacts to develop appropriate emergency response plans. This is a difficult task due to the unpredictable nature of climate change.

2.5 Introduction to the Emergency Planning Agenda

Emergency planning is a general term that encompasses work that the government, emergency services, and health services do in preparing plans and procedures for dealing with any emergency that might impact a large numbers of people. It is essential that all necessary organizations work together in order to ensure that any response to an emergency is well coordinated and that practice exercises are carried out to test any procedure that is put in place. In the UK, emergency preparedness responses are based on risk assessment. Legislation appoints emergency responders to identify localized risks by compiling risk registers. Mitigation activities in a particular area can be implemented once the impacts and likelihood of potential hazards are identified. UK response agencies are able to develop planning necessities by forming a risk assessment at national and local levels. Unfortunately, this process of risk assessment only satisfies current hazards and does not consider long-term risks (Bell, McFarland, & Innerd, 2008a). Thus, the risk assessment process in the UK is considered "Incomplete in its aim to determine preparedness requirements for the area" (Bell et al., 2008a).

With the passing of the Civil Contingencies Act of 2004, local governments and other "category one responders", which include emergency services and National Health Service (NHS) bodies, have increased responsibilities when dealing with an emergency. Local councils and other bodies must now provide greater support during the response to an emergency and take the lead in the recovery phase. Some of these new responsibilities include assessing the risk of occurring emergencies, information sharing with local responders, making information publically available, and emergency planning. In response to these new responsibilities, the Royal Borough of Kingston Council is assessing areas of high risk and high vulnerability within their borough in order to develop more focused emergency response procedures.

3. Risk and Vulnerability

Emergency planners and other council staff in Kingston need to know which areas in the Borough are at the greatest risk to the coming changes before they can begin to plan how they will adapt to climate change. This requires extensive research in the field of risk analysis in order to cultivate a deep understanding of what makes an area vulnerable. Thus, it is necessary to study how groups in the US and UK define and operationalize risk and vulnerability. These groups can be differentiated by the computational method each one uses to calculate a vulnerability score as well as by the variables they incorporate in their analysis. Some groups and individuals, such as Susan Cutter and her colleagues in the US and the Mayor of London's Office in the UK, place an emphasis on social vulnerability when defining risk, while other groups focus more on economic vulnerability. Social vulnerability encompasses the indicators that deal with aspects of the community in question, such as age, health, and race. On the other hand, economic vulnerability deals with the potential financial losses of a community, such as the asset value of a building, and the replacement cost of damaged areas. Some indicators, such as income levels, are a hybrid of social and economic vulnerabilities (socioeconomic) and can fit in either category.

3.1 Methods Developed by Susan Cutter et al. (2003)

Susan Cutter is one of the leading individuals in the field of risk analysis. She and others created a highly developed approach to analyze and assess risk and vulnerability that has been tested throughout the United States. In their article *Social Vulnerability to Environmental Hazards,* Cutter et al. (2003) use county-level socioeconomic and demographic data of the United States from 1990 to construct an index of social vulnerability to environmental hazards called the Social Vulnerability Index (SoVI) (Cutter, Boruff, & Shirley, 2003). Using a factor analytic approach, Cutter et al. (2003) were able to reduce 42 social vulnerability variables to 11 factors, which accounted for about 76.4 percent of the variance among all US counties (Cutter et al., 2003). In order to conduct their analysis of social vulnerability, they adhered to the.

> "…three main tenets in vulnerability research: the identification of conditions that make people or places vulnerable to extreme natural events, an exposure model; the assumption that vulnerability is a social condition, a measure of societal resistance or resilience to hazards; and the integration of potential exposures and societal resilience with a specific focus on particular places or regions." (Cutter et al., 2003)

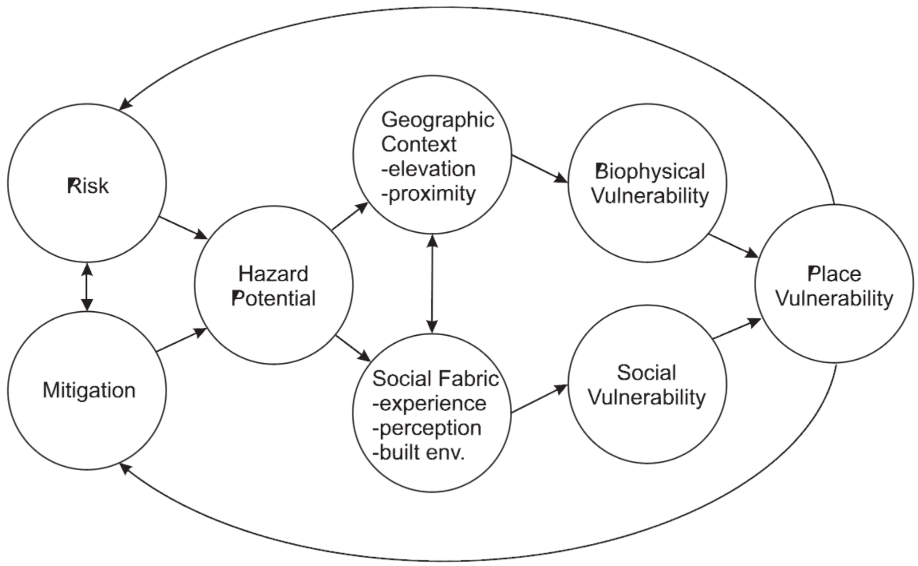
However, Cutter et al. (2003) met a vulnerability paradox due to the fact that even though considerable research attention has been paid to biophysical vulnerability and vulnerability of the built environment, socially created vulnerabilities are largely ignored due to the difficulty in quantifying them (Cutter et al., 2003). Thus, social vulnerability is most often described using individual characteristics of people such as age, race, health, income, type of dwelling unit, employment, etc. These variables are partially the product of social inequalities, which Cutter et al. (2003) define as "…those social variables that influence or shape the susceptibility of various groups to harm and that also govern their ability to respond" (Cutter et al., 2003). Also, Cutter et al. (2003) include place inequalities, which are characteristics of communities and built environments such as the level of urbanization, growth rates, and economic vitality which contribute to the social vulnerability of places (Cutter et al., 2003). Nevertheless, there is no concrete research comparing the social vulnerability of one place to another, which leads to a set of inconsistent indicators regarding the social vulnerability and ultimately the place vulnerability of a certain location. Therefore, Cutter et al. (2003) created a comparative analysis of social vulnerability to natural hazards among US counties in order to develop a consistent and comparable set of indicators or variables that would illustrate the social vulnerabilities of different locations (Cutter et al., 2003).

To construct their comparative analysis, Cutter et al. (2003) implement the hazards-of-place model of vulnerability in order to examine the components of social vulnerability, which can be seen in (Figure 6). According to Cutter et al. (2003)

> "… in this conceptualization (Figure 14), risk (an objective measure of the likelihood of a hazard event) interacts with mitigation (measures to lessen risks or reduce their impact) to produce the hazard potential. The hazard potential is either moderated or enhanced by a geographic filter (site and situation of the place, proximity) as well as the social fabric of the place. The social fabric includes community experience with hazards, and community ability to respond to, cope with, recover from, and adapt to hazards, which in turn are influenced by economic, demographic, and housing characteristics. The social and biophysical vulnerabilities interact to produce the overall place vulnerability." (Cutter et al., 2003)

The hazards-of-place model provides an optimal visualization of risk and vulnerability through both biophysical and social scopes, which helps to create a total place vulnerability of a specific locale.

Figure 6: The Hazards-of-Place Model of Vulnerability



(Cutter et al., 2003)

According to Cutter et al. (2003), there does not exist a consensus within the social science community regarding the variables that influence social vulnerability. Many broad concepts that individuals agree reflect vulnerability include the lack of access to resources, limited access to political power and representation, social capital, beliefs and customs, building stock and age, frail and physically limited individuals, and type and density of infrastructure and lifelines (Cutter et al., 2003). Most of the conflict arises in the selection of specific variables to represent these broader concepts. The table below shows those characteristics that Cutter et al. (2003) consider most often influence social vulnerability (Table 2) (Cutter et al., 2003).

Table 2: Social Vulnerability Concepts and Metrics

Concept	Description	Increases (+) or Decreases (-) Social Vulnerability
Socioeconomic status (Income, Political Power, Prestige)	The ability to absorb losses and enhance resilience to hazard impacts. Wealth enables communities to absorb and recover from losses more quickly due to insurance, social safety nets, and entitlement programs.	High Status (+/-) Low Income or Status (+)
Gender	Women can have a more difficult time during recover	Gender (+)

	than men, often due to sector-specific employment, lower wages, and family care responsibilities.	
Race and Ethnicity	Imposes language and cultural barriers that affect access to post-disaster funding and residential locations in high hazard areas.	Non-white (+) Non-Anglo (+)
Age	Extremes of the age spectrum affect the movement out of harm's way. Parents lose time and money caring for children when daycare facilities are affected; elderly may have mobility constraints or mobility concerns increasing the burden of care and lack of resilience.	Elderly (+) Children (+)
Commercial and Industrial Development	The value, quality, and density of commercial and industrial buildings provide an indicator of the state of economic health of a community, and potential losses in the business community, and longer-term issues with recovery after an event.	High Density (+) High Value (+/-)
Employment Loss	The potential loss of employment following a disaster exacerbates the number of unemployed workers in a community, contributing to a slower recovery from the disaster.	Employment Loss (+)
Rural / Urban	Rural residents may be more vulnerable due to lower incomes and more dependent on locally based resource extraction economies (e.g., farming, fishing). High-density areas (urban) complicate evacuation out of harm's way.	Rural (+) Urban (+)
Residential Property	The value, quality, and density of residential construction affect potential losses and recovery. Expensive homes on the coast are costly to replace; mobile homes are easily destroyed and less resilient to hazards.	Mobile Homes (+)
Infrastructure and Lifelines	Loss of sewers, bridges, water, communications, and transportation infrastructure compounds potential disaster losses. The loss of infrastructure may place an insurmountable financial burden on smaller communities that lack the financial resources to rebuild.	Extensive Infrastructure (+)
Renters	People that rent do so because they are either transient or do not have the financial resources for home ownership. They often lack access to information about financial aid during recovery. In the most extreme cases, renters lack sufficient shelter options when lodging becomes uninhabitable or too costly to afford.	Renters (+)
Occupation	Some occupations, especially those involving resource extractions, may be severely impacted by a hazard event. Self-employed fishermen suffer when their means of production is lost and may not have the requisite capital to resume work in a timely fashion and	Professional or Managerial (-) Clerical or Laborer (+)

	thus will seek alternative employment. Those migrant workers engaged in agriculture and low skilled service jobs (housekeeping, childcare, and gardening) may similarly suffer, as disposable income fades and the need for services declines. Immigration status also affects occupational recovery.	Service Sector (+)
Family Structure	Families with large numbers of dependents or single-parent households often have limited finances to outsource care for dependents, and thus must juggle work responsibilities and care for family members. All affect the resilience to and recovery from hazards.	High Birth Rates (+) Large Families (+) Single-Parent Households (+)
Education	Education is linked to socioeconomic status, with higher educational attainment resulting in greater lifetime earnings. Lower education constrains the ability to understand warning information and access to recovery information.	Little Education (+) Highly Educated (-)
Population Growth	Counties experiencing rapid growth lack available quality housing, and the social services network may not have had time to adjust to increased populations. New migrants may not speak the language and not be familiar with bureaucracies for obtaining relief or recovery information, all of which increase vulnerability.	Rapid Growth (+)
Medical Services	Health care providers, including physicians, nursing homes, and hospitals, are important post-event sources of relief. The lack of proximate medical services will lengthen immediate relief and longer-term recovery from disasters.	Higher Density of Medical (-)
Social Dependence	Those people who are totally dependent on social services for survival are already economically and socially marginalized and require additional support in the post-disaster period.	High Dependence (+) Low Dependence (-)
Special Needs Populations	Special needs populations (infirm, institutionalized, transient, homeless), while difficult to identify and measure, are disproportionately affected during disasters and, because of their invisibility in communities, mostly ignored during recovery.	Large Special Needs Population (+)

(Cutter et al., 2003)

In order to examine social vulnerability, Cutter et al. (2003) collected socioeconomic data from 1990 for all 3,141 US counties, using the county as a unit of analysis (Cutter et al., 2003). Starting out with more than 250 variables, Cutter et al. (2003) selected 42 independent variables

(Table 3) after comprehensive computation and normalization of the data originally collected (Cutter et al., 2003). In order to reduce the data, the primary statistical procedure Cutter et al. (2003) implemented was factor analysis or more specifically, principal components analysis (Cutter et al., 2003). The main reason Cutter et al. (2003) implemented factor analysis was to allow for, "a robust and consistent set of variables that can be monitored over time to assess any changes in overall vulnerability. The technique also facilitates replication of the variables at other spatial scales, thus making data compilation more efficient" (Cutter et al., 2003). Overall, Cutter et al. (2003) utilized a total of 11 composite factors, which explained 76.4 percent of the variance among all the counties. These 11 composite factors include personal wealth, age, density of the built environment, single-sector economic dependence, housing stock and tenancy, race – African American, ethnicity – Hispanic, ethnicity – Native American, race – Asian, occupation, and lastly infrastructure dependence. These final eleven factors of social vulnerability (Table 4) also show each factor's percent variation, its dominant variable, as well as the correlation of the dominant variable (Cutter et al., 2003).

Table 3: Variable Names and Descriptions

Name	Description
MED_AGE90	Median age, 1990
PERCAP89	Per capita income (in dollars), 1989
MVALOO90	Median dollar value of owner-occupied housing, 1990
MEDRENT90	Median rent (in dollars) for renter-occupied housing units, 1990
PHYSICN90	Number of physicians per 100,000 population, 1990
PCTVOTE92	Vote cast for president, 1992—percent voting for leading party (Democratic)
BRATE90	Birth rate (number of births per 1,000 population), 1990
MIGRA_97	Net international migration, 1990–1997
PCTFARMS92	Land in farms as a percent of total land, 1992
PCTBLACK90	Percent African American, 1990
PCTINDIAN90	Percent Native American, 1990
PCTASIAN 90	Percent Asian, 1990
PCTHISPANIC90	Percent Hispanic, 1990
PCTKIDS90	Percent of population under five years old, 1990
PCTOLD90	Percent of population over 65 years, 1990
PCTVLUN91	Percent of civilian labor force unemployed, 1991
AVGPERHH	Average number of people per household, 1990
PCTHH7589	Percent of households earning more than $75,000, 1989
PCTPOV90	Percent living in poverty, 1990
PCTRENTER90	Percent renter-occupied housing units, 1990
PCTRFRM90	Percent rural farm population, 1990
DEBREV92	General local government debt to revenue ratio, 1992
PCTMOBL90	Percent of housing units that are mobile homes, 1990
PCTNOHS90	Percent of population 25 years or older with no high school diploma, 1990
HODENUT90	Number of housing units per square mile, 1990
HUPTDEN90	Number of housing permits per new residential construction per square mile, 1990
MAESDEN92	Number of manufacturing establishments per square mile, 1992
EARNDEN90	Earnings (in $1,000) in all industries per square mile, 1990
COMDEVDN92	Number of commercial establishments per square mile, 1990
RPROPDEN92	Value of all property and farm products sold per square mile, 1990
CVBRPC91	Percent of the population participating in the labor force, 1990
FEMLBR90	Percent females participating in civilian labor force, 1990
AGRIPC90	Percent employed in primary extractive industries (farming, fishing, mining, and forestry), 1990
TRANPC90	Percent employed in transportation, communications, and other public utilities, 1990
SERVPC90	Percent employed in service occupations, 1990
NRRESPC91	Per capita residents in nursing homes, 1991
HOSPTPC91	Per capita number of community hospitals, 1991
PCCHGPOP90	Percent population change, 1980/1990
PCTURB90	Percent urban population, 1990
PCTFEM90	Percent females, 1990
PCTF_HH90	Percent female-headed households, no spouse present, 1990
SSBENPC90	Per capita Social Security recipients, 1990

(Cutter et al., 2003)

Table 4: Dimensions of Social Vulnerability

Factor	Name	Percent Variation Explained	Dominant Variable	Correlation
1	Personal wealth	12.4	Per capita income	+0.87
2	Age	11.9	Median age	–0.90
3	Density of the built environment	11.2	No. commercial establishments/mi^2	+0.98
4	Single-sector economic dependence	8.6	% employed in extractive industries	+0.80
5	Housing stock and tenancy	7.0	% housing units that are mobile homes	–0.75
6	Race—African American	6.9	% African American	+0.80
7	Ethnicity—Hispanic	4.2	% Hispanic	+0.89
8	Ethnicity—Native American	4.1	% Native American	+0.75
9	Race—Asian	3.9	% Asian	+0.71
10	Occupation	3.2	% employed in service occupations	+0.76
11	Infrastructure dependence	2.9	% employed in transportation, communication, and public utilities	+0.77

(Cutter et al., 2003)

> "In order to create the Social Vulnerability Index (SoVI), the factor scores were added to the original county file as 11 additional variables and then placed in an additive model to produce the composite social vulnerability index score (SoVI) for each county. The SoVI is a relative measure of the overall social vulnerability for each county. We selected an additive model, thereby making no *a priori* assumption about the importance of each variable in the overall sum. In this way, each factor was viewed as having an equal contribution to the county's overall vulnerability." (Cutter et al., 2003)

Cutter et al. (2003) explain that there is no consensus within the social science community about social vulnerability or its correlates. However, they explain that using the hazards-of-place model of vulnerability allows for social vulnerability to be a multidimensional concept that ultimately helps to identify characteristics of communities as well as individuals, which enable them to respond to and recover from environmental hazards (Cutter et al., 2003).

Cutter et al.'s (2003) approach and methodology provide an in-depth analysis of risk and vulnerability in an area. The approach can be applied to both large and small areas. The social variables that influence vulnerability can be difficult to map, yet the variables they use to define social vulnerability provide a valid reflection of those people who are the most socially vulnerable. However, there are some limitations with Cutter et al.'s (2003) approach. Their method of calculating a vulnerability index is mathematically complex, making it difficult to replicate and time consuming. Also, this method requires the reduction of a large number of variables to a more concise list of factors. This reduction of variables may cause some data to be lost or masked. Therefore, Cutter et al.'s (2003) approach may not be not be best suited for a framework dealing with policy planners. Chakraborty, Tobin, and Montz (2005) also note that the methods developed by Susan Cutter and various others "need considerable refining before they can be successfully employed within a policy-making framework" (Chakraborty, Tobin, & Montz, 2005). Furthermore, while Cutter et al. (2003) do an excellent job identifying social vulnerability, their method lacks the variables necessary to perform an analysis of the vulnerability of an areas' economy.

3.2 Alternative Methods for Calculating a Vulnerability Score

After critiquing the method employed by Susan Cutter et al. (2003), Chakraborty, Tobin, and Montz (2005) develop a method of their own to assess vulnerability within an area. Their overall approach to a Geographic Information System (GIS)-based vulnerability analysis is the same as that used by Cutter et al. (2003), in that they assess both the social and geo-physical components, overlay them, and develop a cumulative vulnerability map. The major difference is in the way they calculate a vulnerability score. Straying from the complex factor analytic methods employed by Cutter et al. (2003), Chakraborty, Tobin, and Montz (2005) use a far more simple mathematical formula for the calculation of a social vulnerability index (SVI) score. After identifying the relevant variables that influence social vulnerability, Chakraborty, Tobin, and Montz (2005) determine the ratio of a variable in the block group to the total number of that variable in the county, which he gives the denomination R_i. A standardized social vulnerability index (SVI_i) is then calculated using the formula $SVI_i = \frac{R_i}{R_{max}}$, where R_{max} is the maximum ratio for a given variable across the county. Finally, the total social vulnerability index is calculated by averaging the SVI_i scores across all variables. This produces a SVI score between 0 (least vulnerable) and 1 (most vulnerable) (Chakraborty et al., 2005). This method was also implemented by Andrea Hebb and Linda Mortsch (2007) when they performed their analysis of vulnerability in the Upper Thames Watershed in London, Ontario (Hebb & Mortsch, 2007). Though they researched a number of different sources (including Susan Cutter et al. (2003)), they felt that this method was the most applicable way to calculate their vulnerability scores, because "averaging the values makes is easy to compare vulnerability across space and time" (Hebb & Mortsch, 2007).

Rob Bell, Joseph McFarland, and Matt Innerd, three individuals who dealt with emergency planning and preparedness in the London Borough of Hounslow, conducted a vulnerability assessment for the London Borough of Hounslow and present a third alternative to calculating a vulnerability score. Bell, McFarland, and Innerd (2008) calculated vulnerability based on percent population. For each variable chosen, they divided the value of the variable in the block group by the total population in the borough. For example, if block group A has 100 people above the age of 75 and the total population of area X is 1,000 people, then the vulnerability score would be calculated as 100/1,000 or 0.1. This alternative model is a simpler model compared to those used by Cutter et al. (2003) and Chakraborty, Tobin, and Montz (2005). Cutter et al.'s (2003) factor analytic approach can be considered a fine grain analysis for calculating a vulnerability score index as opposed to Bell, McFarland, and Innerd's (2008) approach, which is a more coarse grain analysis. The approach used by Chakraborty, Tobin, and Montz (2005) to calculate a vulnerability score falls somewhere between these two extremes.

3.3 Variables

Regardless of which method is used to calculate a vulnerability score, it is the variables incorporated in the approach that determine who counts as vulnerable within the area studied. It is important to sort out the variables which positively and negatively load into a method's vulnerability map. Each variable positively correlated with vulnerability will increase the vulnerability score of an area while each negatively loading variable will decrease the score. Most variables identified fit into one of three categories: economic, social, and health vulnerability. Some sources tend to focus on one particular aspect of vulnerability, whereas others try to incorporate all aspects. While there are some variables which clearly fall within one of these categories, there are others which are disputed amongst groups and individuals as to which category they belong to. Thus, disputed variables can be classified in multiple categories.

A list of variables discovered through researching different methodologies can be found in Appendix C.

3.4 An Economic Focus on Vulnerability

A prime example of an organization which focuses on the economic aspects of vulnerability is the Federal Emergency Management Agency (FEMA). FEMA is a United States government agency that is tasked with disaster mitigation, preparedness, response, and recovery planning. FEMA's primary focus is to plan for and mitigate disaster throughout the US. However, they have a very narrow definition of vulnerability due to the nature of their disaster management and planning. In the past, FEMA has focused heavily on the insurance and economic aspects of protecting against climate change. This heavy economic basis is the main reason why FEMA's definition of vulnerability is narrow. Although FEMA has a narrow view of climate change, they are still a leader in emergency preparedness and climate change mitigation, so their definition of vulnerability is still important when identifying different points of view.

When examining risk and vulnerability over a given area, FEMA uses HAZUS-MH which is "a powerful risk assessment methodology for analyzing potential losses from floods, hurricane winds and earthquakes" (FEMA, 2009). This methodology is combined with GIS in order to develop maps that can estimate the damages due to a hazard, whether they are physical, economic, or social damages. In the table below (Table 5), FEMA describes risk as the "estimated impact that a hazard event would have on people, services, facilities, and structures in a community, or the likelihood of a hazard event resulting in an adverse condition that causes injury or damage" (FEMA, 2009). Risk can be expressed in two ways: in terms of relatively (such as high, moderate, or low risk), or terms of monetary losses due to a disaster. The differences in the way they choose to describe risk reflect FEMA's focus on economics. This difference is important for Kingston because it allows contradictory ideas to be viewed comparatively so that the best option for each area can be determined.

Table 5: FEMA's Definitions of Risk and Vulnerability

	Definition
Risk	The estimated impact that a hazard event would have on people, services, facilities, and structures in a community, or the likelihood of a hazard event resulting in an adverse condition that causes injury or damage. Risk is often expressed in relative terms such as a high, moderate, or low likelihood of damage being sustained above a particular threshold as a result of a specific type of hazard event. Risk also can be expressed in terms of potential monetary losses associated with the intensity of the hazard event.
Vulnerability	How exposed or susceptible to damage an asset is. Vulnerability depends on an asset's construction, its contents, and the economic value of its functions. Like indirect damages, the vulnerability of one element of a community is often related to the vulnerability of another. For example, many businesses depend on uninterrupted electrical power; if an electrical substation is flooded, not only will the substation itself be affected, but a number of businesses as well. Indirect effects can often be much more widespread and damaging than direct ones.

(FEMA, 2009)

FEMA's definition of vulnerability further shows FEMA's focus on economics. The definition discusses of economic value and assets and seems to overlook the social impact of a hazard. An important part to their definition is the idea that "one element of a community is often related to the vulnerability of another" (FEMA, 2009). This idea is extremely important. When one is looking at vulnerability it is important to know the ties each community has to sources outside the community. This translates to the idea that looking at an individual area as its own entity might not be the best practice when looking at vulnerability.

Looking at the variables HAZUS uses to create its maps is another way to determine what aspects FEMA focuses on in its analysis of risk. While these variables do not comprise a formal definition it is important to know, on a detailed level, exactly what FEMA uses to identify areas of risk, vulnerability, and resilience. The HAZUS-MH Flood Technical Manual includes these variables. These variables have been grouped into common themes for organizational purposes. The variables in the technical manual are located in Table 6 below. Some of these variables are flood specific while others, such as age, reflect variables that can be applied to many different climate change hazards, such as heat stress and disease. These variables can be compared and contrasted with variables from other sources in order to select a set of variables that is specific to an area.

Table 6: HAZUS-MH Flood Technical Manual Variables

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

(FEMA, 2009)

3.5 Variables Specific to London

The Office of the Mayor of London recently released *The Draft Climate Change Adaptation Strategy for London*. This strategy outlines the primary threats facing London as a result of the coming climate change and how the city plans to adapt to it. While the definitions and concepts implicit in this strategy are not as developed as those used by Susan Cutter et al. (2003), they are specific to London and share many commonalities. In the strategy, the Mayor's Office identifies what they believe are the two key aspects of risk: probability and consequence. They define probability as the likelihood of an event or change that exceeds London's ability to cope with it. The consequence of the event or change encompasses "who and what is affected and how severely affected they are" (The Office of the Mayor of London, 2010). Consequence is in turn determined by an individual's exposure and the vulnerability of an area. The Mayor's Office gives an example of exposure as being located on the ground floor of a building in a flood zone. They define vulnerability as "how sensitive those affected are to an impact, what ability they have to respond, and how much time they have to react" (The Office of the Mayor of London, 2010).

The Mayor's Office goes into great detail about exposure and vulnerability for each hazard that may affect London. The Mayor's Office focused primarily on social variables that parallel those that are central to Susan Cutter et al.'s (2003) work. In the case of flooding, exposure can consist of living on the ground or lower-ground floor or having limited advance warning of a flood. Vulnerability variables can include age (the very young and old), health, disability, proficiency in English, living alone or not having a support network, low income and inadequate insurance cover (The Office of the Mayor of London, 2010). “The variables, either independently or in combination, mean that an individual may be:

- Physically more at risk from a flood if flooding occurs
- Less likely to be aware of the flood risk they live at
- Less likely to know what to do and be able to do it
- Less likely to receive and use information on what to do through regular communications channels
- Less likely to be able to recover independently, or access services to aid recovery”

(The Office of the Mayor of London, 2010)

The Mayor of London’s Office also looked closely at vulnerability to drought and overheating. During a drought period “the main groups of people vulnerable are those who would be financially affected by non-essential uses bans enforced in a “Non-Essential Use Drought Order” (The Office of the Mayor of London, 2010). This shows a focus on income because those with a low income will not be able to afford the higher cost of water. According to the Mayor’s Office, in an overheating situation, the level of exposure will be determined by a variety of variables, including housing types, place of work, and level of physical activity. For individuals confined to their homes, exposure will vary according to variables such as: building type, condition, aspect, ventilation, and insulation; floor of occupancy; and the availability of air conditioning (The Office of the Mayor of London, 2010). Out of the individuals exposed to overheating, vulnerability can be determined using variables including age, gender, pre-existing medical conditions, those who use certain medications or substances, impaired cognition, and social variables such as homelessness or no support network. With regard to age individuals who are vulnerable include those under the age of four and over the age of 65, with elderly individuals over the age of 85 being exceptionally vulnerable (The Office of the Mayor of London, 2010).

The Office of the Mayor of London also identifies buildings that house vulnerable populations, such as nurseries and elderly care centers as vulnerable locations. This leads to the idea that elements of a location’s infrastructure must remain intact during a hazard.

The Mayor of London's Office divides infrastructure vulnerability into three categories (Table 7). When designing a risk or vulnerability assessment tool it is important to note where these buildings are located so that important infrastructure can be protected in times of need. Susan Cutter et al. (2003) also include a focus on infrastructure in their analysis.

Table 7: Degree of Infrastructure Vulnerability

Degree of Vulnerability	Vulnerable Infrastructure
Highly Vulnerable	Police, ambulance and fire stations, emergency command centers and basement dwellings
More Vulnerable	Hospitals, dwellings, residential care homes, GP surgeries, prisons, schools and nurseries
Less Vulnerable	Shops, offices, restaurants, waste and water treatment sites

(The Office of the Mayor of London, 2010)

By analyzing patterns of risk and vulnerability, the Mayor's Office is able to develop strategies for adaptation that target critical problems and geographic areas. The Mayor of London's Office is also focused on the development of adaptation strategies that are sustainable both economically and environmentally. "For example, air conditioning is not generally considered to be a sustainable adaptation action (because of the large energy demands), whereas developing flood resilient buildings on a floodplain may be sustainable" (The Office of the Mayor of London, 2010).

The Mayor of London's Climate Change Adaptation Strategy has many health and social aspects similar to those developed in the vulnerability research conducted by both Bell, McFarland, and Innerd (2008) as well as Susan Cutter et al. (2003), but lacks the focus on economic variables emphasized by groups like FEMA. The Mayor of London's Office also extends Bell, McFarland, and Innerd's (2008) risk and vulnerability analysis by including a complete four part strategy for climate change adaptation. This 'Prevent, Prepare, Respond, Recover' strategy could be used in Kingston in conjunction with the risk and vulnerability analysis to help create policies and increase emergency preparedness.

3.6 London Borough of Hounslow

Before the Mayor of London's Office issued *The Draft Climate Change Adaptation Strategy for London*, Bell, McFarland, and Innerd (2008) performed a vulnerability and risk analysis in the Borough of Hounslow. The London Borough of Hounslow is about 12 miles west of central London and about six miles north-west of the Royal Borough of Kingston. Bell, McFarland, and Innerd (2008) have been very active in generating risk maps that show areas of hazard, vulnerability, and resilience in Hounslow. They plan to use the maps to coordinate public awareness efforts and help direct the distribution of crucial resources for emergency planning and preparedness (Bell, McFarland, & Innerd, 2008b).

In the article *A Changing Climate: Developing Community Resilience in the UK*, Bell, McFarland, and Innerd (2008) define a hazard as "A natural, technological or social phenomenon that threatens human lives, livelihoods, land use, properties, or activities" (Bell et al., 2008a). This definition encompasses many hazards, including heat waves, floods, diseases, and fires. Bell, McFarland, and Innerd (2008) define vulnerability as the "susceptibility to loss, damage, destruction, disruption or casualty if exposed to the impacts of a major emergency" and distinguish between health, social, and economic vulnerability (Bell et al., 2008a). There are many variables and subcategories which feed into the operationalized definitions of hazard, vulnerability, and resilience that allow these concepts to be mapped. Thus, Bell, McFarland, and Innerd (2008) have listed and described the variables which they consider to be the most important and contribute the most towards mapping the three components of risk.

3.7 Hazard and Risk Mapping in Hounslow

Bell, McFarland, and Innerd (2008) considered geographic hazards and inherent hazards to be the primary variables which are used to develop a hazard score in the impacted area (Table 8). Geographic hazards are physical properties of an environment which facilitate or exacerbate disasters or emergencies which threaten communities within close proximity. For example, a low elevation flood plain along a river may permit torrential rain to flood the area more easily and extensively as opposed to an area not compromised by low elevation and proximity to a water source. An inherent hazard is identified as a threat to a community caused by atmospheric and/or social event. For example, a heat wave that compromises the health of a community is an inherent hazard caused by an atmospheric event. An inherent hazard caused by a social event would be the occurrence of a flu outbreak in a local area which threatens the lives of people in the immediate area. Using data from the Community Risk Register, the Borough mapped the hazard impact extent areas together with their likelihood and impact scores (Bell et al., 2008a). Table 9 presents an example of an entry from the Community Risk Registry. The entry identifies the type of hazard, as well as the likelihood of it occurring and the impact it will have. Likelihood measures the probability of an event occurring over the next five years, ranging from a 1 in 20,000 chance to a 1 in 2 chance, as well as risk ratings. Bell, McFarland, and Innerd (2008) then created a hazard map to display the types of dangers that are in their vicinity to aid policy planning purposes and inform the public. This will increase awareness in hazardous areas, which will then increase the resilience of these areas. In Bell, McFarland, and Innerd's (2008) hazard map (Figure 7), the darker areas represent areas which are the most hazardous according to the combined community risk register score. Each hazard shown on the left side of the figure is overlaid in the cumulative hazard map to the right. Although not all layers are shown, there are additional hazards which are present in the cumulative hazard map such a fuel storage sites. Fuel and oil sites are typically mapped with circles that show the extent of the hazard that each site presents. Pandemic disease is shown evenly-distributed across Hounslow, because the authors believe that everyone in Hounslow is vulnerable to disease. By adding pandemic disease to all of Hounslow, this would show that all citizens to believe that they are at risk.

Table 8: Hazard Mapping Dataset

Data Source	Dataset
Community Risk Register (public version):	Geographic hazards 1 non-geographic/inherent hazard (such as storms & gales or human pandemic) Impact areas sizes for each hazard Hazard scores

(Bell, McFarland et al., 2008b)

Table 9: Excerpt from Community Risk Register

Risk ref.	Hazard category	Hazard sub-category	Outcome Description/ Variation and Further Information	Likelihood	Impact	Risk rating	Lead responsibility
			impossible.				
SEVERE WEATHER							
H17	Severe Weather	Storms & Gales	**Outcome Description** Storm force winds affecting most of the country for at least 6 hours. Most inland, lowland areas experience mean speeds in excess of 55 mph with gusts in excess of 85 mph. Consequent damage to infrastructure (e.g. telecommunications, power, transport). **Variation and Further Information** England and Wales are at the lower end of the likelihood range.	Medium (3)	Moderate (3)	High	Local Authority
H18	Severe Weather	Low temperatures and heavy snow	**Outcome Description** Snow lying over most of the country for at least one month. Most inland areas experience some snow falls in excess of 30cm, some drifts in excess of 1m, and a period of at least 7 consecutive days with daily mean temperatures below -3 degrees centigrade **Variation and Further Information** London, South West and Northern Ireland are at the lower end of the likelihood range.	Medium (3)	Moderate (3)	High	Local Authority
H48	Severe Weather	Heat Wave	**Outcome Description** Daily maximum temperatures above 32 degrees centigrade and minimum temperatures above 15 degrees centigrade over most of the area for at least 5 consecutive days **Variation and Further Information** Scotland is at the lower end of the likelihood range.	Medium High (4)	Minor (2)	Medium	Health

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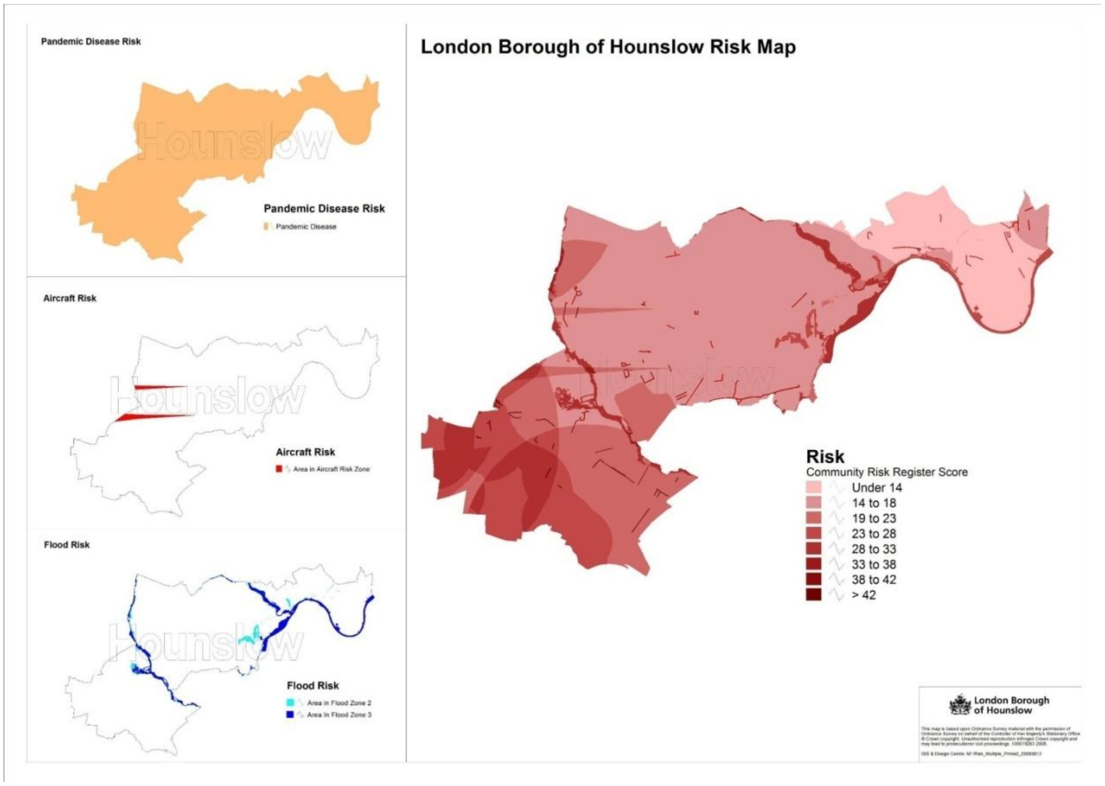
Figure 7: Hounslow Combined Hazard Map



(Bell, McFarland et al., 2008b)

3.8 Vulnerability Mapping in Hounslow

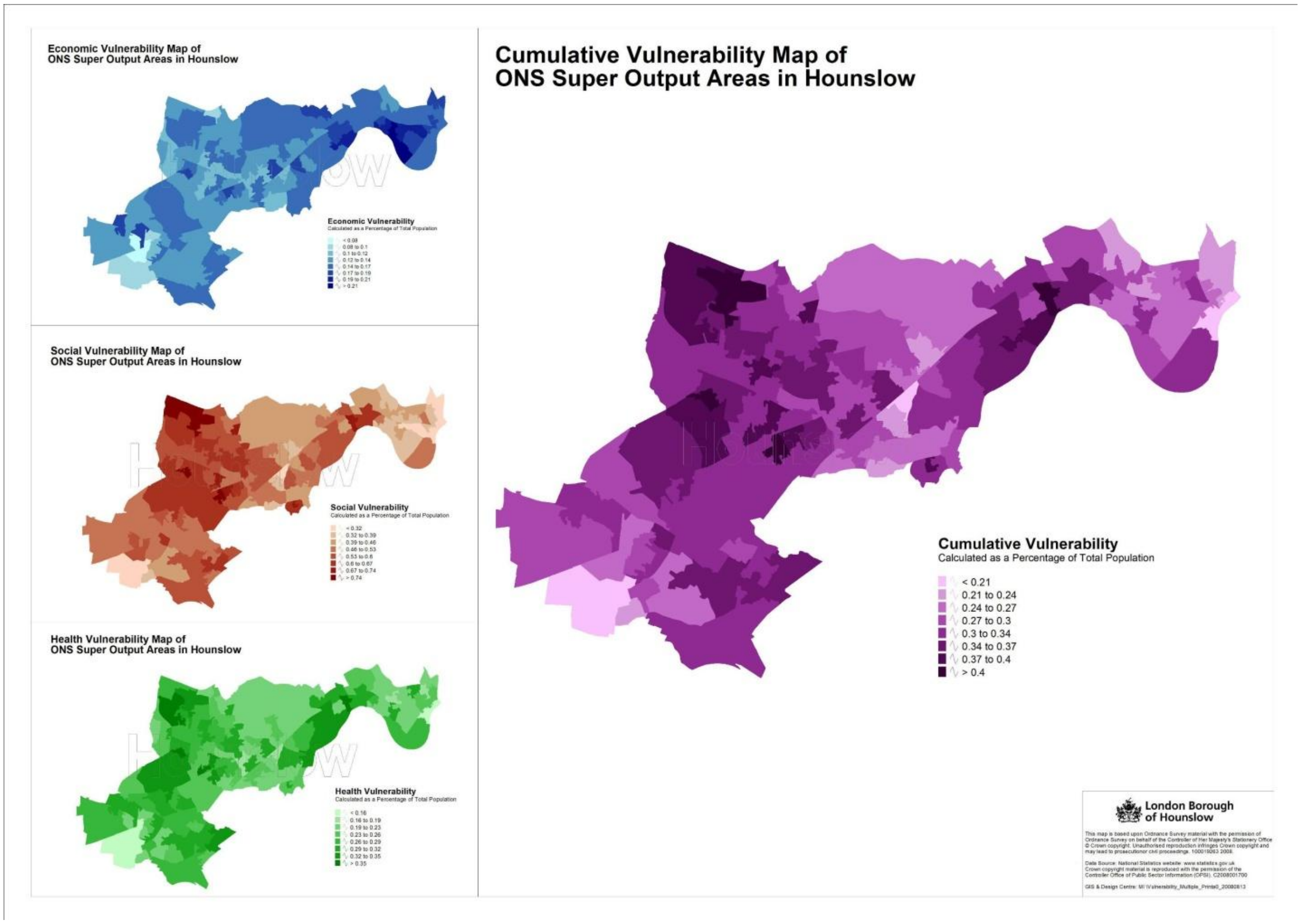
Before a risk analysis can be completed, it is necessary to perform an analysis of vulnerability throughout an area. Bell, McFarland, and Innerd (2008) distinguish between three categories of vulnerability: economic, social, and health. They used various data as surrogate measures of these three categories. For example, someone might be considered economically vulnerable if they work at home because "In the event of an incident damaging property or requiring evacuation the person is more likely to suffer residential and business disruption" (Table 10). Someone may be considered socially vulnerable if they lack qualifications because they may be "...less likely to be able to find alternative employment" (Table 10). Someone may be considered vulnerable based on their health if they are "... dependent on medication or have a reduced ability to physically recover from illness or injury" (Table 10). Using data from the Office of National Statistics (ONS), Bell, McFarland, and Innerd (2008) mapped the number of people by super output area in each of these categories. They condensed mapping their vulnerability map (Figure 8) into five primary indicators: "those with a limiting long-term illness, those seeking employment, indices of multiple deprivation, population density, and age" (children under five and adults over 70) (Bell et al., 2008a). The darker areas represent areas which are most vulnerable. A super output area may be more vulnerable if it has a large number of people working at home or on state benefits because those individuals are considered economically vulnerable. These areas highlight where emergency planning and training groups should focus most extensively on before and after the event of an emergency or hazard. Thus, vulnerability can be mapped to a specific hazard and effectively operationalized to develop an effective emergency plan. However, Hounslow plans to increase emergency preparedness to all hazards in general. Such emergency plans would focus their attention on how to develop different methods of disaster awareness in addition to emergency training and planning programs. The overall purpose of the vulnerability map is to assist a borough in the areas of emergency planning and preparedness and raise awareness in vulnerable populations (Bell et al., 2008a).

Table 10: Vulnerability Mapping Variables

ECONOMIC VULNERABILITY		
ONS (Office of National Statistics) UV39 Method of travel to work – resident population	Works mainly at or from home (persons)	In the event of an incident damaging property or requiring evacuation the person is more likely to suffer residential and business disruption.
ONS UV50 Approximated Social Grade	E: On state benefit, unemployed, lowest grade workers (persons)	Those less likely to have suitable insurance, savings or the ability to support themselves following an incident.
SOCIAL VULNERABILITY		
ONS UV21 Provision of unpaid care	Provides 50 or more hours per week unpaid care (persons)	Less likely to be able to sustain the current level of care or support others (family and friends) in the event of an incident.
Qualifications		Those less likely to be able to find alternative employment.
Born in Less Economically Developed Countries		Those born in countries classified as Less Economically Developed by the World Health Organization.
Single Person Households		Absence of localized support mechanism
HEALTH VULNERABILITY		
ONS UV04 Age	Aged under 5 years (persons)	Sphere Minimum Standards of disaster response outlines those under the age of 5 as high vulnerability due to underdeveloped immune system.
	Aged over 70 years (persons)	Sphere minimum Standards in disaster response recognize those over the age of 65 due to reduced resilience to disease.
ONS UV22 Limiting Long-term Illness	With a limiting long-term illness (persons) Limiting long term illness covers any long-term illness, health problem, or disability that limits daily activity or work.	Those more vulnerable to the effects of extremes of temperature, diseases or epidemics etc. Those less likely to be able to support themselves following an incident.
Not in good health		Those who may be dependent on medication or have a reduced ability to physically recover from illness or injury.

(Bell, McFarland et al., 2008b)

Figure 8: Hounslow Combined Vulnerability Map

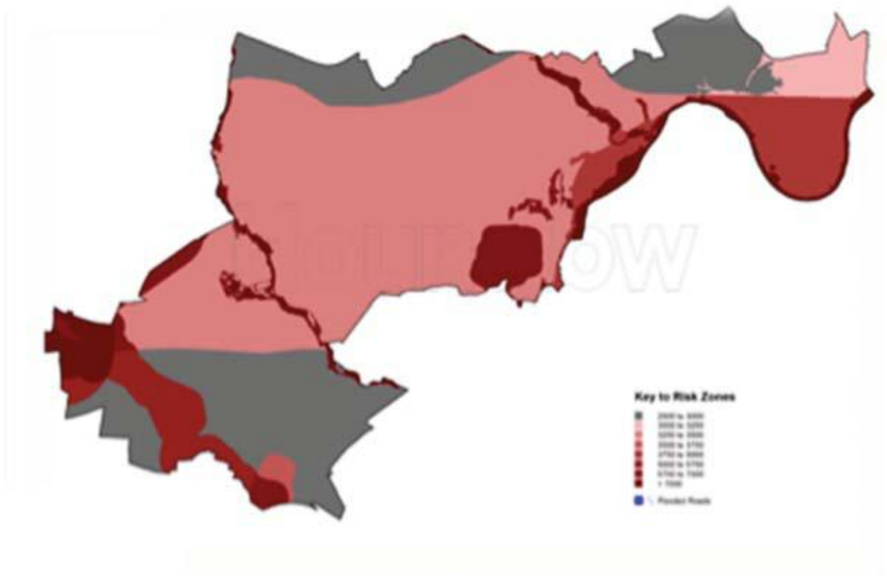


(Bell, McFarland et al., 2008b)

3.9 Risk Mapping and Resilience in Hounslow

Finally, Bell, McFarland, and Innerd (2008) combined their hazard and vulnerability maps to produce a risk map (Figure 9) which shows the groups that are most vulnerable in the areas of greatest risk during a disaster or emergency. This allows for more targeted emergency response planning for such groups (Bell et al., 2008a).

Figure 9: Hounslow Combined Hazard and Vulnerability Map



(Bell, McFarland et al., 2008b)

Bell, McFarland, and Innerd's (2008) resilience mapping methodology focuses primarily on which services are available to which citizens and how involved they are in their neighborhood's safety (Table 11). They used various data sources to map how resilient an area is. For example, a community might be considered resilient if the number of people in each postcode area that signed up to the Flood Warning Direct Service is high. Similarly, a community might also be considered resilient if the number of people signed up for local area messaging system/emergency email subscriptions is high. Using data from various organizations, Bell, McFarland, and Innerd (2008) mapped resilience in the Borough. Hounslow's ability to reach and maintain a desirable level of resilience is made possible by identifying levels of vulnerability within the Borough before a disaster and/or emergency occurs. The UK's Place Survey collects information on how individuals view resilience and response from all over the country. However, Hounslow has identified other variables which contribute to bolstering resilience in an area. Such variables include the number of people registered for volunteer activities, the number of individuals attending community meetings, and the number of citizens signed up to receive emergency alert notifications. Also, Hounslow has identified different approaches to improve emergency response in order to increase a community's resilience. This can be done by incorporating emergency response networks into every voluntary and community group rather than relying on a few organizations to focus entirely on emergency response. For information to remain up to date, each organization must have a familiar basis on emergency response procedures and discuss changing environmental conditions which pertain to these procedures. In addition, community involvement incentives would promote community involvement and knowledge. The preceding variables and approaches deal primarily with the social aspects of resilience rather than the environmental conditions, because humans have the capacity to change social aspects rather than environmental conditions. Ultimately, Hounslow aims to reduce vulnerability and increase resilience in communities when dealing mostly with emergency situations that can result from climate changes and abnormalities (Bell et al., 2008a). Table 11 below comprise of variables which Hounslow believes to be important when mapping vulnerability whether it be economic, social, or health vulnerability (Bell, McFarland et al., 2008b).

Table 11: Resilience Mapping Dataset

Data Source	Dataset
Police Neighbourhood Watch Co-coordinator or equivalent	The number of households in each Neighbourhood Watch scheme
	The postcode of each Neighbourhood Watch scheme in the area
Environment Agency Flood Warnings Direct service	The number of people in each postcode area signed up to the Flood Warning Direct Service
Local area messaging system/Emergency email subscriptions	The number of people subscribed in each area
National Indicator sets	(Available from April 09)
Awareness of responses	
Belong to neighbourhood	
Community orgs in area	
Participation in volunteering	

(Bell, McFarland et al., 2008b)

4. Methodology

The goal of this project was to assist the Royal Borough of Kingston (RBK) Council in developing and evaluating various vulnerability mapping methods to identify an approach that best meets the needs of the RBK. Accordingly, the Borough wanted a method that would clearly distinguish more vulnerable areas from less vulnerable areas, use readily available local data, be easy to implement, and be easy to update in the future. These criteria would also ensure that the methodology can be easily replicated in other boroughs. The goal of this project was achieved by the completion of four objectives.

Objective 1: Compare and contrast the state-of-the-art in vulnerability mapping and emergency planning and preparedness for climate change in the United States, Canada, and United Kingdom

Building on the literature review, our project team reviewed definitions and concepts of risk and vulnerability used in the US and UK which may be applicable to Kingston. We compared and contrasted the approaches used by different research groups and organizations to determine the key similarities and differences. Our team focused on the methods each group used to measure vulnerability as well as the variables they incorporated into their analysis.

Objective 2: Derive a composite method for Kingston by comparing the advantages and disadvantages of alternate methods

Based on the literature review, our team identified key methodological approaches that have been developed and evaluated in the US and UK. These methodological approaches were then critically assessed for their strengths and weaknesses. We evaluated the strengths and weaknesses of each source based on the following criterion: ease of data acquisition, ease of data compilation (vulnerability score calculation and formatting of data to export to GIS), the reproducibility of the method (ability to be amended to future changes and ability to be modified in other areas), and the quality of the output produced. With regard to our project goal, a strong methodology fulfilled all of the above criteria.

Objective 3: Generate and compare GIS based vulnerability maps using the methods in preceding objective

Through an iterative process, our team produced multiple sets of vulnerability maps to determine which vulnerability scoring method and which choice of socio-demographic variables gave the clearest picture of vulnerability throughout the Borough. These maps and their corresponding methods were then evaluated using the criteria in Objective 2 to assess the validity and the accuracy of the vulnerability map produced. The validity and accuracy of the maps was assessed through consultation with the 2009 Borough Profile and the Kingston Neighbourhood Team along with other members from the RBK staff, who were able to tell us how well the vulnerable areas in the Borough are represented by the maps produced. Also, our team further tested the validity of our maps through a ground-truthing process which included visiting sites of highest vulnerability.

Objective 4: Explore and create preliminary hazard and risk maps for the Royal Borough of Kingston

Our team explored hazard mapping as well as methods to produce hazard scores and how to integrate those scores into our vulnerability maps. By doing this, we were able to produce preliminary risk maps for the Royal Borough of Kingston. These risk maps show areas of overlay between hazard maps and the vulnerability maps our team produced during Objectives 2 and 3.

4.1 Objective 1

After identifying key sources from the US and UK during our research, we first compared and contrasted them by studying the way each source calculated a vulnerability score. We identified three different means of calculating a vulnerability score. Cutter et al. (2003) used a principal components analysis after normalizing all variables, Chakraborty, Tobin, and Montz (2005) and Hebb and Morstch (2007) used an averaging and normalizing approach, and Bell, McFarland, and Innerd (2008) used percent population as a method to calculate a vulnerability score. Our team compared and contrasted the relative complexity and reproducibility of each method to determine which method(s) for calculating a vulnerability score should be tested for Kingston's vulnerability analysis.

Our team also compared and contrasted the variables used in each source's analysis of vulnerability. Each source was grouped into one of three categories: economic focus, social focus, and no distinguishable focus. The variables used by Cutter et al. (2003), Chakraborty, Tobin, and Montz (2005), and Bell, McFarland, and Innerd (2008) focused more on the social aspects of vulnerability whereas the variables used by FEMA had a very strong focus on economics. Other sources contained a number of variables with no particular focus. Our team developed a series of tables to visually compare and contrast the variables each source used in their vulnerability analysis. These tables are located in Appendix C.

4.2 Objectives 2 & 3

4.2.1 Recreating Bell, McFarland, and Innerd (2008)

After we held discussions with our sponsors to ensure we had a good understanding of the RBK's goals, we reached the conclusion that it would be beneficial to begin our analysis of vulnerability in Kingston by replicating the methodology employed by Bell, McFarland, and Innerd (2008) in Hounslow. We began this process by gathering all necessary data from the Office of National Statistics (ONS) Neighbourhood Statistics website.[2] This website includes all the census data from 2001 as well as other data that are as recent as 2009. We entered the data into the Excel spreadsheets developed by Joseph McFarland and Matt Innerd for the vulnerability analysis of Hounslow. We exported the Excel data to ArcGIS. The variables used in this analysis are listed in Table 12.

Table 12: Variables Used to Produce First Iteration of Vulnerability Maps

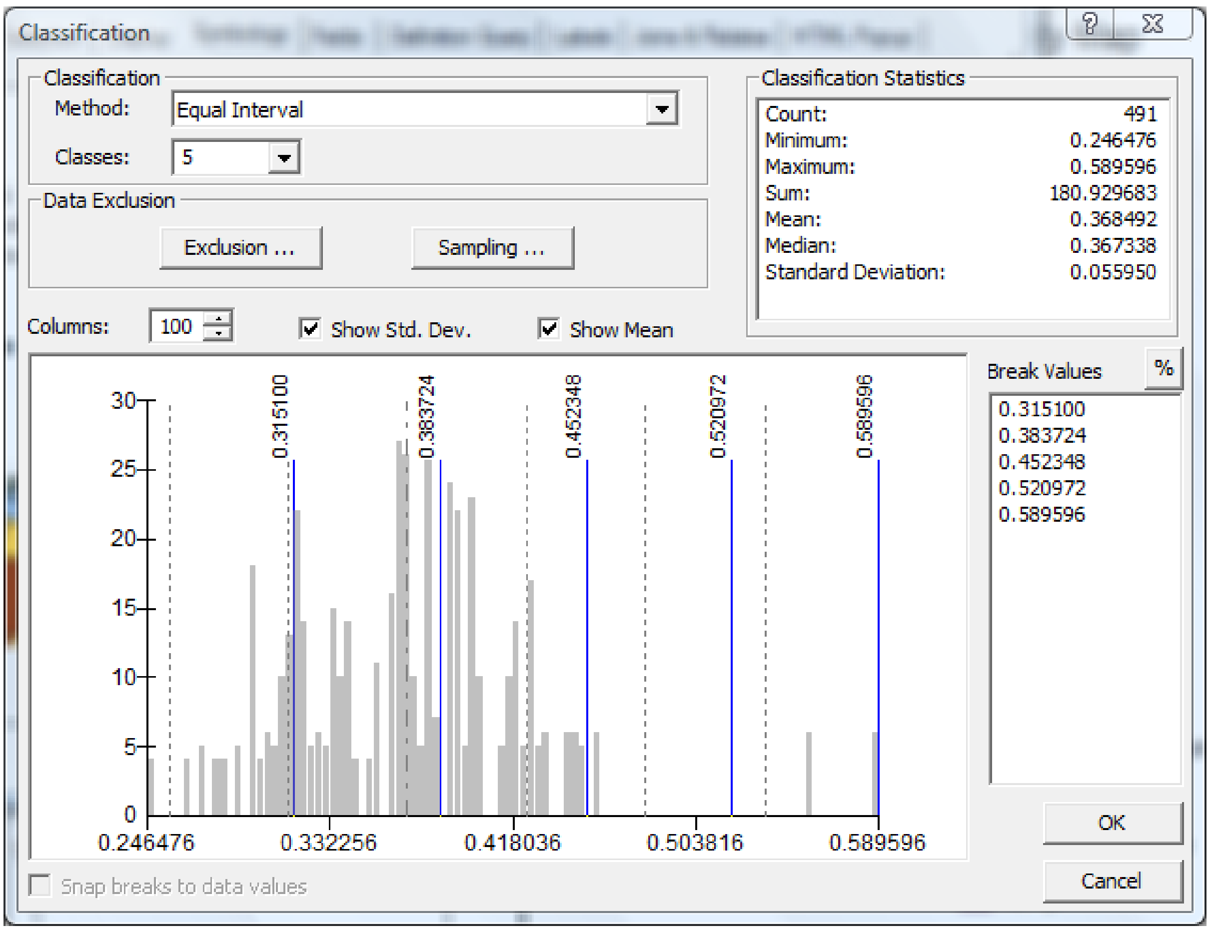
Iteration	Variables Used		Score Calculation Method	Data Display Method
First Iteration	Works from Home	Identified Health status as "Not Good"	Bell, McFarland, and Innerd (2008)	Equal Interval
	Age (0-7, 75+)	Long Term Limiting Illness		
	Single Parent Households	Born in Less Economically Developed Countries		
	Low Qualifications (None - 1)	Provide 50+ Hours of Unpaid Care		
	Self Employed			

The spreadsheets grouped the variables into three categories: economic, social, and health. Vulnerability scores for each of the categories (economic, social, and health) in each lower super output area (LSOA)[3] were calculated by summing the value of each variable within each LSOA in order to calculate the total number of vulnerable people. This number was then divided by the total population of the Borough to produce a vulnerability score for each LSOA. The scores for

[2] http://www.neighbourhood.statistics.gov.uk/dissemination/Download1.do?$ph=60_61
[3] LSOA is a unit of area created by the ONS. A single LSOA contains a minimum of 1,000 people.

each category (economic, social, and health) were averaged to calculate the cumulative vulnerability of each LSOA. The spreadsheets were then imported into ArcGIS and joined with the 2004 census output area layer to produce a series of vulnerability maps. We used five equal interval breaks to divide the categories of vulnerability on the maps produced. Equal interval breaks divide the difference between the highest and lowest vulnerability score into five equal intervals. An example of how the LSOAs were divided using equal interval breaks is provided in Figure 10 below. Four individual maps were created: social, economic, health, and cumulative.

Figure 10: Equal Interval Classification of Vulnerability Scores



4.2.2 Introducing a New Method of Calculating a Vulnerability Score

Upon reviewing the first set of maps created with our sponsor, we decided to invest our time into testing alternative methods to calculating a vulnerability score. We then tested the Chakraborty, Tobin, and Montz's (2005) (2005) method for calculating a vulnerability score using the same set of variables used by Bell, McFarland, and Innerd (2008) in Hounslow (Table

12). This allowed our team to make a direct comparison between the two methods of calculating a vulnerability score. We began this process by creating new Excel spreadsheets based on those already completed by Bell, McFarland, and Innerd (2008). The ratio of a variable in the block group to the total number of that variable in the county was calculated and given the denomination R_i. A standardized social vulnerability index (SVI_i) was then calculated using the formula $SVI_i = \frac{R_i}{R_{max}}$, where R_{max} was the maximum ratio for a given variable across the county. Finally, the total social vulnerability index was calculated by averaging the SVI_i scores across all LSOAs. This produced a SVI score between 0 (least vulnerable) and 1 (most vulnerable). The following tables show how we calculated a social vulnerability index (SVI) using this method in Excel. Table 13 provides an example of how the calculation was entered into Excel, while Table 14 shows how the spreadsheet looked when completed (note: the columns containing the data and factor ratio were hidden in the final spreadsheets to make the SVI easier to locate).

Table 13: Excel Spreadsheet Example of How to Compute and SVI using Chakraborty, Tobin, and Montz's (2005) Equation

	A	B	C	D	E
1					
2		**Data**	**Factor Ratio = Data/Sum of Variable Data**	**SVI = Factor Ratio/Max all Factor Ratio**	
3		People aged 0-4	Use $ sign to set unchanging variables	Use $ sign to set unchanging variables	
4		Count	How the formula looks below	How the formula looks below	
5		Persons	"=B7/SUM($B$7:$B$103)"	"=C7/MAX($C$7:$C$103)"	
6		**DATA_VALUE**	Fill this formula down length of the data	Fill this formula down length of the factor ratios	
7		56	0.006077048	0.311111111	
8		80	0.008681498	0.444444444	
9		74	0.008030385	0.411111111	
10		160	0.017362995	0.888888889	
11		105	0.011394466	0.583333333	
12		119	0.012913728	0.661111111	
13		41	0.004449267	0.227777778	
14		67	0.007270754	0.372222222	
15		90	0.009766685	0.5	
16		100	0.010851872	0.555555556	

Table 14: Excerpt from Excel Spreadsheet Used to Generate SVI Scores

	A	B	C	F	I	L	O	R
1								
2			All People	People who work mainly at or from home	People aged 16-74: Economically active: Self-employed	E: On state benefit, unemployed, lowest grade workers	People aged 16-74 with: No qualifications	People aged 16-74 with: Highest qualification attained level 1
3			Count	SVI	SVI	SVI	SVI	SVI
4			Persons					
5	LSOA_CODE	LSOA_NAME	DATA_VALUE					
6	E01002915	Kingston upon Thames 014A	1345	0.548387097	0.740963855	0.30964467	0.558962264	0.579545455
7	E01002916	Kingston upon Thames 014B	1471	0.669354839	0.644578313	0.304568528	0.41745283	0.583333333
8	E01002917	Kingston upon Thames 014C	1434	0.596774194	0.638554217	0.296954315	0.492924528	0.579545455
9	E01002918	Kingston upon Thames 017A	1638	0.508064516	0.542168675	0.269035533	0.627358491	1
10	E01002919	Kingston upon Thames 017B	1580	0.540322581	0.626506024	0.449238579	0.608490566	0.723484848
11	E01002920	Kingston upon Thames 014D	1577	0.491935484	0.668674699	0.340101523	0.422169811	0.602272727

Once the data was finalized and in the proper format, it was imported into ArcGIS and joined with 2004 census output area layer to produce a second set of economic, social, health, and cumulative vulnerability maps. The variables and scoring method used in this iteration are listed in Table 15 below. Again, equal interval breaks were used to divide the vulnerability categories. These maps were then compared with the maps we previously produced.

Table 15: Variables Used to Produce the Second Iteration of Vulnerability Maps

Iteration	Variables Used		Score Calculation Method	Data Display Method
Second Iteration	Works from Home	Identified Health status as "Not Good"	Chakraborty, Tobin, and Montz (2005)	Equal Interval
	Age (0-7, 75+)	Long Term Limiting Illness		
	Single Parent Households	Born in Less Economically Developed Countries		
	Low Qualifications (None - 1)	Provide 50+ Hours of Unpaid Care		
	Self-Employed			

4.2.3 Recreating Chakraborty, Tobin, and Montz (2005)

After analyzing and comparing the two sets of maps we produced and discussing them with our sponsors, we discovered a flaw in the second set of maps we produced. Upon looking at the data behind the maps, we realized that certain variables were over-emphasized in the vulnerability maps and led to a misrepresentation of vulnerability throughout the Kingston. For example, in one LSOA there were four individuals born in the USSR. Since this was the highest number of people born in the USSR, the LSOA was given a SVI score of 1, and the LSOA was placed in the category of high vulnerability. Since four individuals were able to have such a high impact on the vulnerability map, we felt this was a flaw in the methodology. This led us to take the vulnerability analysis in a new direction. Rather than using the variables used by Bell, McFarland, and Innerd (2008) in Hounslow (Table 12), we used the variables Chakraborty, Tobin, and Montz (2005) used when they performed their analysis of social vulnerability in Hillsborough County, Florida. The variables used in this analysis are listed in Table 16. Unfortunately, not all of the variables could be incorporated into our analysis since the data for some were unavailable and others did not apply to Kingston, as indicated in Table 16. The Excel sheets were made in the same way as the previous map and imported into ArcGIS. Since we had eliminated many of the variables originally used we could not produce maps of social and economic vulnerability but generated only a cumulative vulnerability map instead. Equal interval breaks were again used to divide the vulnerability categories. This map was then analyzed and compared to the previous two cumulative vulnerability maps.

Table 16: Variables Used to Produce the Third Iteration of Vulnerability Maps

Iteration	Variables Used		Score Calculation Method	Data Display Method	Notes
Third Iteration	Income*	Disability**	Chakraborty, Tobin, and Montz (2005)	Equal Interval	*Income data not available and was supplemented by: on state benefit, unemployed, and lowest grade workers **Disability data not available supplemented by: long-term limiting illness and health identified as not good ***Data inapplicable
	Age (0-7, 75+)	Households per LSOA			
	Population per LSOA	No Vehicle			
	No Telephone***	Mobile Homes per LSOA***			
	Institutionalized population in group quarters***				

4.2.4 Using Common Variables

After analysis and discussion with RBK staff, we concluded that the map generated using the edited list of variables described in 2.2.3 did not accurately reflect vulnerability throughout Kingston, in part because some variables (e.g. old age and long-term limiting illness) were positively correlated with vulnerability while others (e.g. self-employment) could be negatively correlated with vulnerability. To address this issue, we created a new vulnerability map using a different set of variables. We selected only variables that three or more sources had identified as being indicative of vulnerability. However, since some variables, such as age, may be positively or negatively correlated with vulnerability, we defined our variables so that they all correlated positively with vulnerability. This avoids the problems caused by trying to create an index based on variables that both positively and negatively correlate with vulnerability. The variables used in this iteration are listed in Table 17. We felt that area of buildings per LSOA would be a good indicator of vulnerability because it was identified by three or more sources as positively reflecting vulnerability as well as the fact that an area with a high number of buildings in it would sustain more damage in the event of a hazard. Since the UK census collects and reports different data than the US, some variables were not available and we were forced to substitute the British equivalent. For example, three or more sources indicated health facility density was correlated with vulnerability; however the UK data was not in a suitable format for our team to incorporate this data into our analysis. Our team used the Chakraborty, Tobin, and Montz (2005) method for calculating a vulnerability score and used equal intervals to display the information. This cumulative vulnerability map produced allowed us to directly compare how well these variables reflect vulnerability in the Borough relative to the previous map created, because the rest of the methodology between the two maps remained constant. We did not create the social, economic, and health vulnerability maps due to the limited number of variables involved in each.

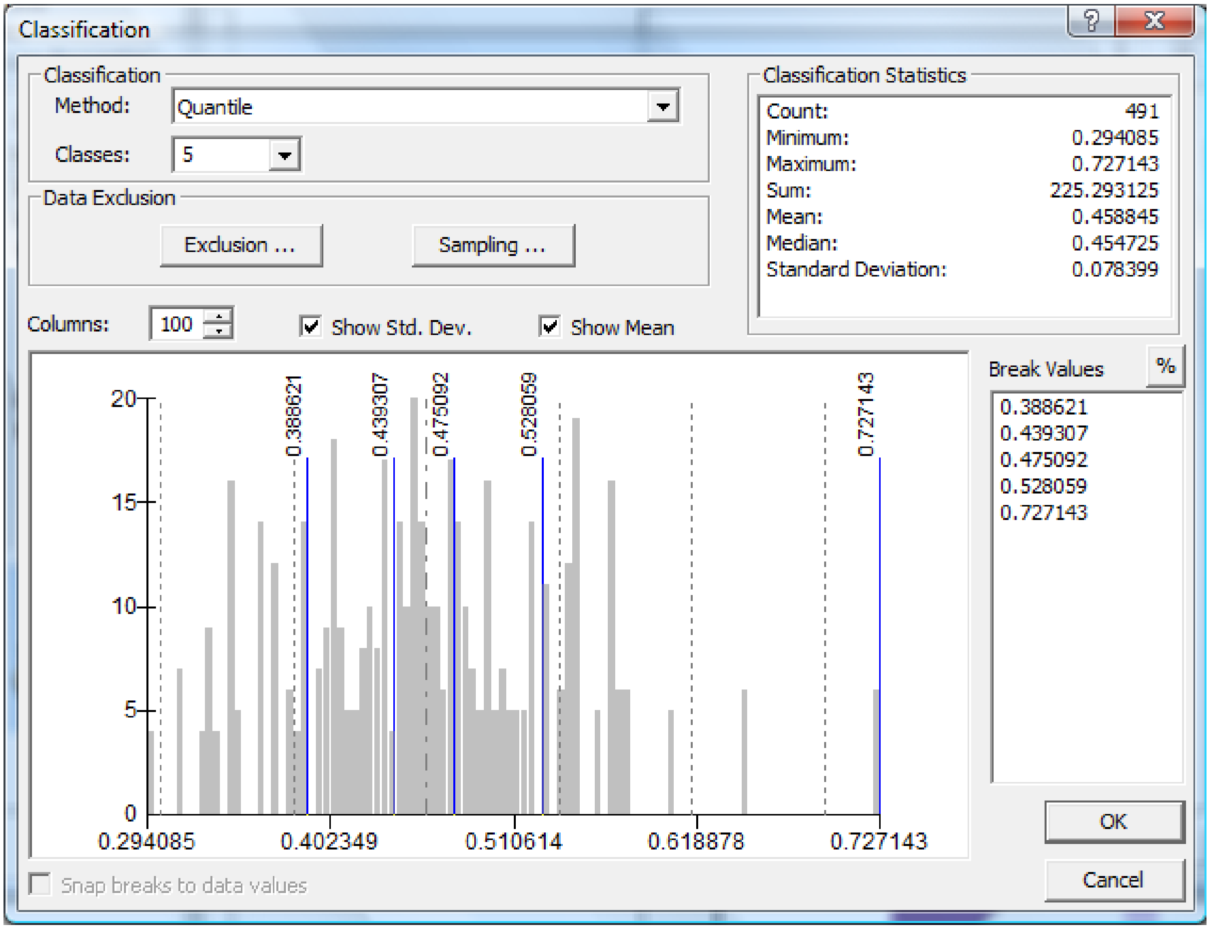
Table 17: Variables Used to Produce the Fourth Iteration of Vulnerability Maps

Iteration	Variables Used		Score Calculation Method	Data Display Method	Notes
Fourth Iteration	Income*	Disability**	Chakraborty, Tobin, and Montz (2005)	Equal Interval	*Income data not available and was supplemented by: on state benefit, unemployed, and lowest grade workers **Disability data not available, supplemented by long-term limiting illness and health identified as not good ***Data not available (non-compatible format)
	Age (0-7, 75+)	Buildings Per Area			
	Single Parent Households	Provide 50+ Hours of Unpaid Care			
	Health Facility Density***				

4.2.5 Using a Quintile and Replacing One Variable

A common problem amongst all the maps we produced was observed. Two LSOAs in the Borough had such a high vulnerability score that, regardless of the scoring method used, they distorted the mapping process. As statistical outliers, they necessarily formed the 'most vulnerable' category, which then compressed the remaining data into the remaining categories. As such, they masked the "true" variation in vulnerability in Kingston. We concluded that this was due to the way the data was being displayed on the map using equal interval breaks. ArcGIS has multiple ways to divide statistical data in order to create categories for mapping, including equal interval, quantile, and standard deviation. After looking into the strengths and weaknesses of each method, our team concluded that a quintile (quantile with five divisions) would be the best way to divide the vulnerability categories on the maps. Figure 11 shows how this process works. Values for each of the LSOAs are plotted on a histogram. If there are 491 LSOAs, the first quintile contains the 98 LSOAs with the lowest values, the next quintile contains the 98 LSOAs with the next highest values and so on. Thus, rather than grouping the two outlying LSOAs in one extreme category, they are grouped with 96 other LSOAs with the highest values. This creates a better differentiation among areas when they are mapped.

Figure 11: Quintile Classification of SVI Scores



After presenting the new map with a quintile to our sponsors, we decided to remove area of buildings per LSOA as a variable in our analysis because it was not a direct indicator of vulnerability. The variable was replaced with population per LSOA, since a large number of individuals living in the same LSOA will be more vulnerable to hazards and diseases. A new map was created incorporating this variable in the place of area of buildings per LSOA, the Chakraborty, Tobin, and Montz (2005) scoring method, and a quintile. The variables used in our final vulnerability map are listed in Table 18.

Table 18: Variables Used in the Final Social Vulnerability Map

Iteration	Variables Used		Score Calculation Method	Data Display Method	Notes
Final Social Map	Income*	Disability**	Chakraborty, Tobin, and Montz (2005)	Quintile	*Income data not available and was supplemented by: on state benefit, unemployed, and lowest grade workers **Disability data not available, supplemented by long-term limiting illness and health identified as not good
	Age (0-7, 75+)	Population per LSOA			
	Single Parent Households	Provide 50+ Hours of Unpaid Care			

4.2.6 Economic Vulnerability Map

Due to the need to display economic vulnerability throughout the Borough, we created an economic vulnerability map. This map was designed to show the vulnerability of Kingston's economy and not the economic vulnerability of a person. The variables incorporated in this analysis were: self-employment, works from home, employment location, and area of non-domestic buildings per LSOA. We continued to use the Chakraborty, Tobin, and Montz (2005) method for calculating a SVI and a quintile method to separate the data. The variables used in the final economic vulnerability map are listed in Table 19 below.

Table 19: Variables Used in the Final Economic Vulnerability Map

Iteration	Variables Used		Score Calculation Method	Data Display Method	Notes
Final Economic Map	Area of Non-Domestic Buildings	Work From Home	Chakraborty, Tobin, and Montz (2005)	Quintile	*Data only available in MSOA format, converted to LSOA formatted but resulted in heavy groupings
	Self-Employed	Employment Location*			

4.2.7 Finalization of the Vulnerability Maps

Our team went through a series of processes to finalize the vulnerability maps. Our team visited the areas of highest vulnerability to ground-truth that data and then discussed our maps with the Kingston Neighbourhood Team. Using the most recently created social and economic vulnerability maps, our team visited the areas of highest vulnerability within the Borough and took photographs of the areas to document our ground-truthing process. Next, our team conducted a meeting with the Neighbourhood Team managers in order to utilize their local knowledge to further validate the accuracy of our maps. The Neighbourhood Team is a group of employees who work for the Borough that are responsible for neighborhood affairs within the Borough. Since each manger of the team is responsible for a specific neighborhood within the Borough, collectively their knowledge of Kingston is extensive. During the meeting, our team displayed the economic and social vulnerability maps in conjunction with a street map to view where each LSOA is located. After explaining to the Neighbourhood Team the legend of our maps, our team then asked managers to use their extensive local knowledge to analyze our maps and confirm whether or not they provide a good representation of vulnerability throughout Kingston. The data behind the maps was also made available to answer any questions the managers had about our maps.

After having our maps validated by ground-truthing, the Neighbourhood Team, and the 2009 Borough Profile, we finalized the formatting of the vulnerability maps. The final social vulnerability map was the map produced in section 4.2.5 and the final economic map was the map produced in section 4.2.6. To finalize the formatting of the vulnerability maps we highlighted the LSOAs of extreme vulnerability. Extremely vulnerable LSOAs are defined as the outliers in the highest vulnerability class.

4.3 Objective 4

4.3.1 Hazard and Risk Mapping

After the creation of the finalized economic and social vulnerability maps, our team explored the feasibility of conducting a hazard and risk assessment for the Royal Borough of Kingston (RBK). Our team began by compiling a list of hazards that will increase as a result of climate change. These include fluvial flooding, surface water flooding, and the heat island effect. Using this compiled list of potential hazards, our team searched through the RBK GIS database in order to find specific GIS hazard layers that the Borough had records of or data on. Through coordination with Tony Klein and Darren Tuckett, who are part of the RBK GIS Team, we retrieved the GIS hazard layers relating to fluvial flooding and surface water flooding. Fluvial flooding layers were retrieved via two studies: a study performed by the Environmental Agency as well as a study done solely for Kingston by Jacobs Corporation. Surface water flooding layers were also retrieved from an Environmental Agency study.

Since the available hazard layers dealt with flooding, our team decided to focus on creating a flood hazard map in order to conduct a flood hazard and risk assessment. Our team chose to use the fluvial flooding hazard layers developed by Jacobs Corporation since they were created solely for Kingston and the detail of the data collected was higher than in the general study performed by the Environmental Agency. Furthermore, the study conducted by Jacobs Corporation took into account the flood zone delineations developed by the Environmental Agency. The fluvial flooding (river flooding) layers prepared by Jacobs Corporation were separated into flood zones as shown in Table 20 and separated by probability of occurrence in accordance with the planning policy guidance document Planning Policy Statement 25: Development and Flood Risk (PPS25).

Table 20: PPS25 Fluvial Flood Zones

Flood Zone	Probability of Occurrence (P)	Description
Zone 3b	Functional Floodplain $P \geq 5\%$ AEP*	Land assessed as having a 1 in 20 or greater annual probability of flooding in any year; and/or areas susceptible to flooding within which "water has to flow or be stored in times of flood" (PPS25)
Zone 3a	High Probability $P \geq 1\%$ AEP*	Land assessed as having a 1 in 100 or greater annual probability of flooding in any year
Zone 2	Medium Probability 1% AEP* $\geq P \geq$ 0.1% AEP*	Land assessed as having between a 1 in 100 and 1 in 1000 annual probability of river flooding in any year
Zone 1	Low Probability $P \leq 0.1\%$ AEP*	Land assessed as having a less than 1 in 1000 annual probability of river flooding in any year

*AEP – Annual Exceedance Probability e.g. 1% AEP is equivalent to 1% probability of occurring in any one year (or, on average, once in every 100 years)
(Jacobs Corporation, 2009)

The surface water flood hazard layers used were from an Environmental Agency study called "Areas Susceptible to Surface Water Flooding". Surface water flooding in this study is defined as an,

> "…event that results from rainfall generated overland flow before the runoff enters any watercourse or sewer. Usually associated with high intensity rainfall (typically >30mm/hr) resulting in overland flow and ponding in depressions in the topography, but can also occur with lower intensity rainfall or melting snow where the ground is saturated, frozen, developed or otherwise has low permeability. Urban underground sewerage/drainage systems and surface watercourses may be completely overwhelmed, preventing drainage. Surface water flooding does not include sewer surcharge in isolation." (Environment Agency, 2009)

The surface water flooding hazard layers retrieved show all areas that are susceptible to surface water flooding into three bandings: less, intermediate, and more. The 'more' band corresponds to areas that have a natural vulnerability to: flood first, flood deepest, and/or flood for relatively frequent, less extreme events.

The fluvial flood zone layers retrieved were the Zone 3b, Zone 3a, and Zone 2 layers. The surface water flood layers retrieved were the more, intermediate, and less zones. In order to create a hazard map, each layer was assigned a hazard value in order to create a score index for the hazard map. Using Cutter et al.'s (2003) technique regarding hazard mapping, the probability of occurrence (rate of occurrence) was used as the hazard score for each hazard layer. Therefore, fluvial flood zone 3b was assigned a hazard score of 0.05 since it had a 5% AEP chance or greater of occurring. Fluvial flood zone 3a was assigned a hazard score of 0.01 since it has a 1% AEP chance or greater of occurring. Lastly, fluvial flood zone 2 was assigned a hazard score of 0.001 since it had a 0.1% AEP chance or greater of occurring. Since the surface water flood bandings have no set definition of a rate of occurrence, the same scaling that was used for the fluvial flood layers was used for the surface water flooding layers. Using this scoring, the more, intermediate, and less bands were assigned hazard scores of 0.05, 0.01, and 0.001, respectively. This scoring method was chosen because our team believed that while surface water flooding may not have as severe an impact as fluvial flooding, the fact that surface water flooding is a more frequent event would allow the layers to have the same score. We were aware of the flaws and limitations with the use of this scoring system, however due to time constraints we were unable to devise one that would more accurately reflect hazards. In order to create the hazard and risk maps, each vector-based layer was converted into a raster-based layer, so that each layer could be correlated with a corresponding hazard or vulnerability score. Each layer was summed into one cumulative hazard layer using an ArcGIS Spatial Analyst tool. Using this tool we created the flood hazard map of the RBK, which displays areas in the Borough that have a high, medium, and low chance of being affected by a flood hazard.

In order to create the risk maps, the mathematical framework used to compute a risk index score was derived from the work done by Ben Wisner and others in *At Risk*, where they defined risk as equaling the product of vulnerability and hazard $R = V\ x\ M$(Blakie et al., 2001). Using this equation and the Spatial Analyst tools, each vulnerability map was multiplied by the hazard map to obtain a social and economic flood risk map. These risk maps showcased areas of high to low risk due to flood hazards within the RBK.

4.3.2 UK Climate Projections

In order to better understand how climate change will affect the United Kingdom in the coming years, the Department for Environment, Food, and Rural Affairs (Defra) produced the UK Climate Projections User Interface (UKCP UI). This tool allows a user to select a climate variable and an emissions scenario and model how the climate will change for a specific UK location for a specific time period. By utilizing the UK Climate Projections User Interface, our team was able to model how the climate of Kingston will change in the future as well as assess how the frequency of hazards will increase as a result of climate change.

Our team began by running a series of climate variables through the program for a high and medium emissions scenario. The emissions scenarios relate to the amount of emissions of greenhouse gases over the coming years. Under a high emissions scenario, the dominance of fossil fuels is maintained through the 21st century and the portion of energy generated by coal is increased to 30% by 2050. A medium emissions scenario assumes there is a balance between fossil fuels and alternative energy sources, such as nuclear and solar energy, being used for power (Department for Environment, Food and Rural Affairs, 2010). According to our sponsor, the Earth's current emission scenario remains between the medium and high emissions scenarios defined by the UKCP.

To generate climate prediction data, a new request was generated by selecting a climate variable (mean air temperature, precipitation, specific humidity, etc.) and a data source (either

UK Probabilistic Projections of climate change over land or marine area). A climate change type was chosen by selecting future climate change only or future absolute climate change values. The desired emissions scenario was then selected, either high, medium, or low. Once this was completed the UKCP requested a time period and temporal average type. Time periods begin at 2010 and end at 2099 with seven time period options spanning 29 years each. The desired temporal average type was chosen by selecting an annual, seasonal, or monthly averaging type. The desired UK location was then chosen. This was either done manually by entering the latitude and longitude of the location or by triple-clicking the cursor over the desired 25 km X 25 km grid region. Either Cumulative Distribution Function (CDF) data or sampled data was selected to run the desired projections. Finally, an output type such as a map, graph, or raw data was selected to display the data in the desired graphical format.

The climate variables our team used in the generation of our UKCP data were the temperature of the warmest day and warmest night, temperature of the coolest day and coolest night, and precipitation on the wettest day. These variables were run for the 25km X 25km grid which contains Kingston using a CDF data source. These variables were run for the summer and winter seasons, under both a medium and high emissions scenario for the 2030s (2020-2049), 2050s (2040-2069), and 2080s (2070-2099). The projections generated took in to account all future climate change, rather than absolute climate change. The raw data outputs were analyzed to determine the climate changes that are likely to occur in Kingston.

The Weather Generator and Threshold Detector are other powerful tools that the UKCP UI has built into it. The Weather Generator is able to generate weather predictions based on climate models, and the Threshold Detector is used in conjunction with the Weather Generator data to detect user-specified thresholds as well as thresholds specified by the UKCP. It can be accessed by selecting a data source when beginning a job request. After selecting the Weather Generator, the user must select an emission scenario, time period, UK region, and a sampling method. It is necessary to use a random sampling of 100 model variants in order for the Threshold Detector to work. Finally, the time frequency of the weather generator output and the duration of each Weather Generator run need to be specified. These need to be set to a daily frequency and a 30 year duration for the Threshold Detector to be used in conjunction with the Weather Generator.

Our team utilized the Weather Generator and Threshold Detector to predict the frequency of certain events that may take place in Kingston as a result of climate change. The events we modeled were heat waves and severe rainfall. After generating models of the weather for the 2030s and 2050s under both a medium and high emissions scenario, thresholds were input into the Threshold Detector to determine the monthly and annual rates of certain events. The threshold for a heat wave was set using the definition of a heat wave for London provided by the Met Office. A heat wave for London is defined as two or more consecutive days where the maximum temperature was above 32 °C and the minimum temperature was below 18 °C (Met Office, 2010). The threshold for severe rainfall was based on the July 2007 flooding that took place throughout the United Kingdom. The threshold was set as at least one day where the total precipitation exceeded 75 mm in one day. The frequency for these events was calculated for both the 2030s and 2050s under both a medium and high emission scenario.

5. Findings and Conclusions

5.1 The First Maps

After applying the methodology used by Bell, McFarland, and Innerd (2008) in Hounslow to the data in Kingston, we discovered that the method used for calculating a vulnerability score in each lower super output areas (LSOA) had a few weaknesses. The primary weakness of the method is that the variables need to be in units of population. To create a vulnerability score in percent population, each variable is summed up within each LSOA and then divided by the total population of the Borough. Therefore, each variable needs to be in units of population in order to be properly summed together and to achieve a percent population score. The second weakness of the method was that the Excel sheets used to produce the maps are difficult to read. When looking at the Excel sheets, it is extremely difficult to compare the scores of two different LSOAs to determine which is more vulnerable. The Excel sheets also make it difficult to understand what variable is making a LSOA more vulnerable. This issue is avoided using the Chakraborty, Tobin, and Montz (2005) method because the SVI scores calculated always range from 0 (lowest) to 1 (highest). Conversely, in the method created by Bell, McFarland, and Innerd (2008), it is necessary to look at the data as a whole to determine whether an LSOA has a high or low vulnerability since each variable has its own range of values.

Closer examination of the data led us to discover a flaw in the way that our data was displayed. When equal intervals were used to divide the levels of vulnerability, the method suppressed the spatial variation by highlighting two particular extreme LSOAs. These two LSOAs had a considerably higher cumulative vulnerability score relative to the remaining LSOAs (Figure 12). As a result, only the two highest LSOA's were present in the highest category of vulnerability, as displayed in Figure 13. The dark blue lines indicate the category breaks and where in the range they occur, while the grey lines indicate the vulnerability score of a LSOA. The taller the grey line, the more LSOAs there are that have that vulnerability score. Therefore, we concluded that the category cut offs masked the vulnerability of the LSOAs with lower vulnerability scores.

To correct the issues raised from using Bell, McFarland, and Innerd's (2008) method, we decided to use a different method of calculating a vulnerability score. Although we considered Cutter et al.'s (2003) method of calculating a vulnerability score initially, we chose not to pursue it because it was too mathematically complicated to be easily replicated in future applications by borough staff with limited time and resources. Instead, we decided to use the formula developed by Chakraborty, Tobin, and Montz (2005).

Figure 12: Vulnerability Maps Created by Recreating the Methodology Developed by Bell, McFarland, and Innerd (2008)

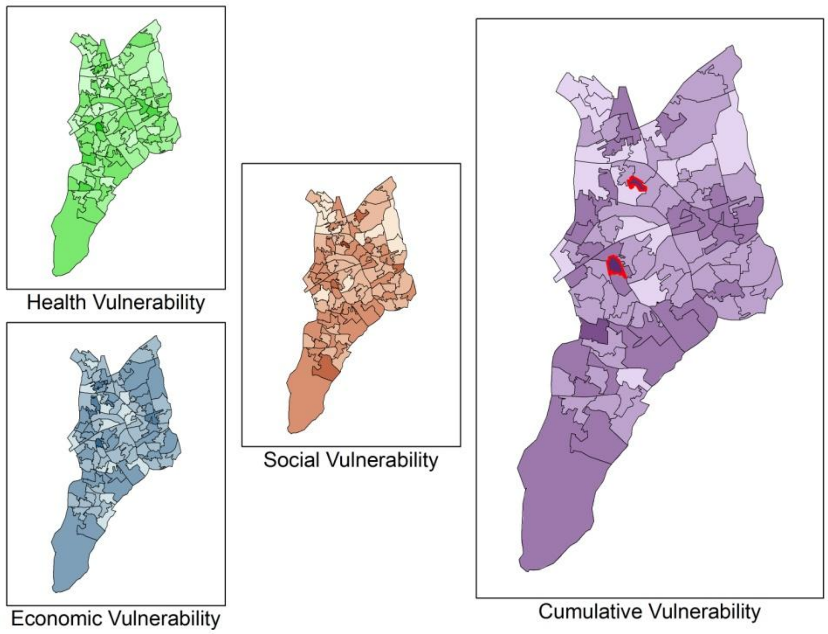
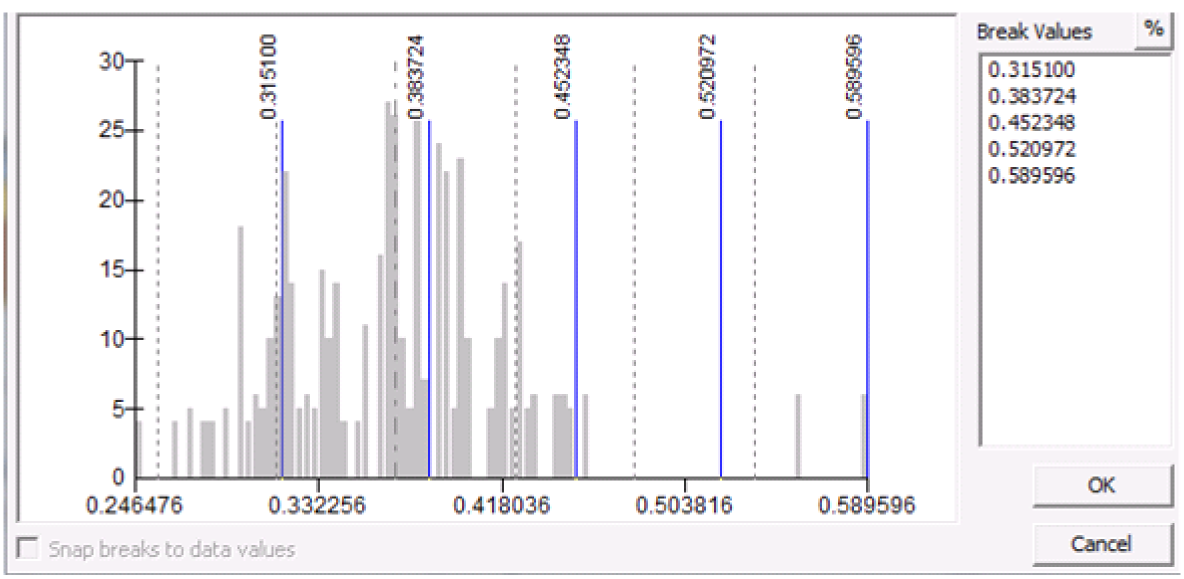


Figure 13: Vulnerability Score Classification for the Cumulative Vulnerability Map in Figure 12

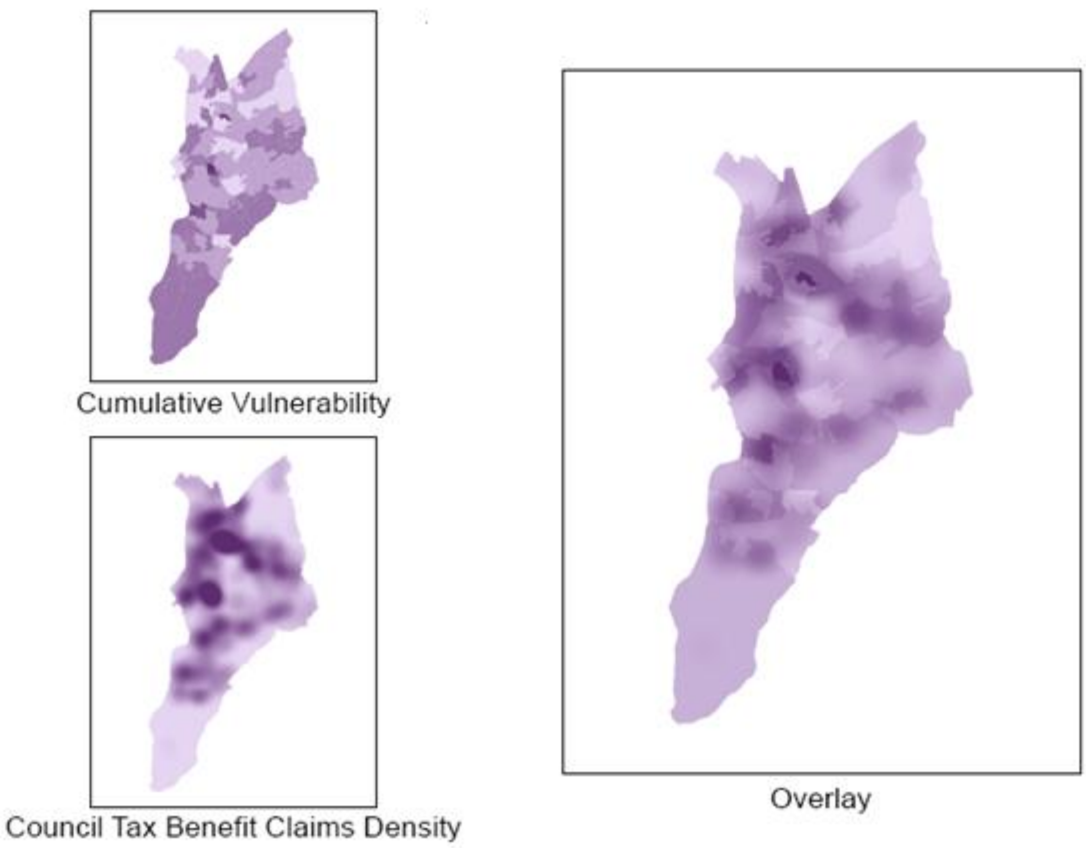


5.2 Council Benefits Tax Data

One of the problems with vulnerability mapping is overlap among variables or 'confounding.' For example, within an LSOA, it is likely that many of those who are old also have a long-term limiting illness and identify themselves as 'not in good health.' Under Bell, McFarland, and Innerd's (2008) (date) method, such occurrences would tend to enhance the overall vulnerability score for affected LSOAs, though they felt this was acceptable since such individuals might indeed be considered excessively vulnerable. Cutter et al. (2003) dealt with this problem by using factor analysis. In an attempt to address this issue more simply, we found that the variables used by Bell, McFarland, and Innerd (2008) can be adequately represented by just one variable, namely individuals who claim Council Tax Benefits. We compared a map showing the density of individuals who claim Council Tax benefits (Figure 14) to the cumulative vulnerability map produced using Bell, McFarland, and Innerd's (2008) methodology. An overlay of the two maps revealed that many of the areas highlighted by the cumulative vulnerability map were also highlighted by the Council tax benefits density map. Although this approach is imperfect and an inadequate measure of vulnerability, the map of the density of Council Tax benefits claims can be used as a rough indicator for areas of vulnerability.

While the Council Tax benefits density map may be used as a rough indicator of vulnerability, there are several problems. The Council Tax benefits data is not displayed in a format which can be used to implement policy, because it is difficult to identify precise areas which have the highest vulnerability. There are no set boundaries which separate areas of high vulnerability and low vulnerability because the Council Tax benefits density map does not contain borders that divide Kingston into small divisions of land. Such divisions make it easier to locate vulnerable populations. Also, Council Tax benefits data does not include all variables which are believed to contribute towards vulnerability such as females, employment location, area of non-domestic buildings, etc. For these reasons, a more comprehensive analysis is necessary to truly assess vulnerability and implement policy based on the results.

Figure 14: Cumulative Vulnerability Map from Figure 12 vs. a Density Map of Individuals Who Claim Council Tax Benefits

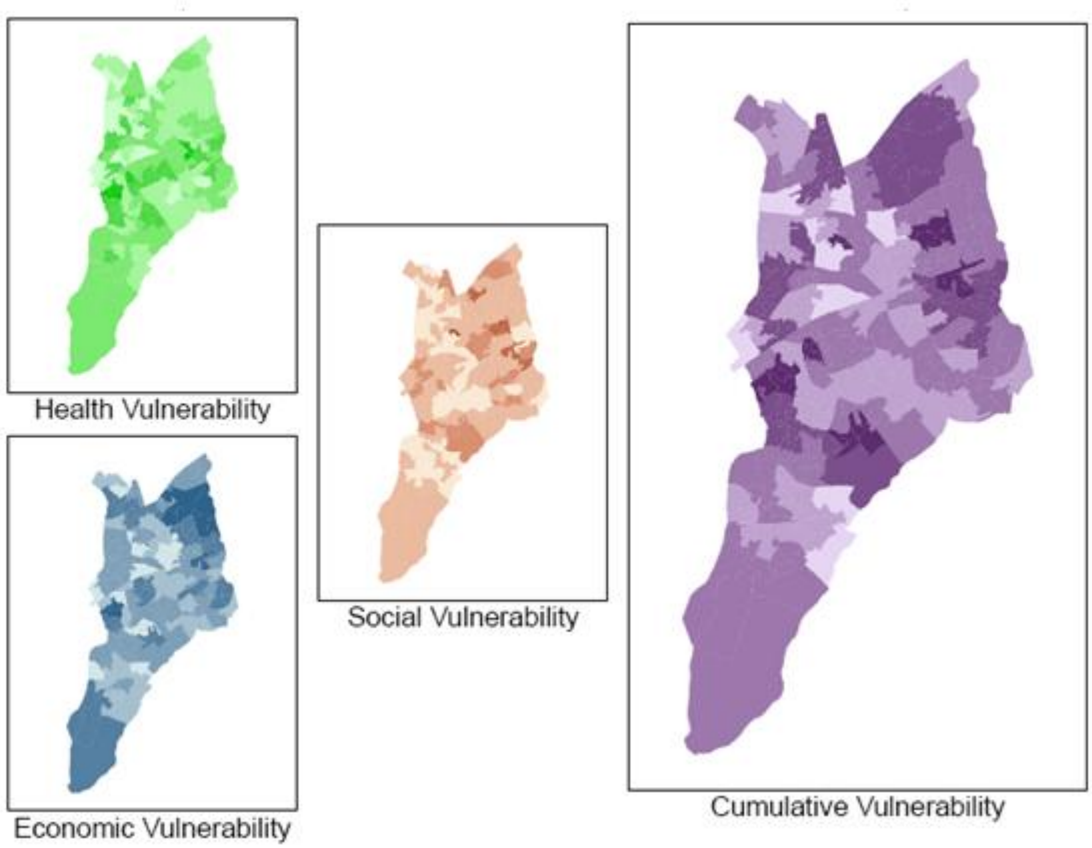


5.3 The Second Set of Maps

The following economic, social, health, and cumulative vulnerability maps (Figure 15) were created by combining the variables used by Bell, McFarland, and Innerd (2008) with the method for calculating a vulnerability score developed by Chakraborty, Tobin, and Montz (2005). Economic vulnerability shows the vulnerability of a person to financial loss, health vulnerability relates to an individuals' susceptibility to a hazard based on their physical condition, and social vulnerability shows all other social aspects of vulnerability not shows in the other two maps. Cumulative vulnerability is produced by averaging the three scores of the social, health, and economic maps. We initially felt that these maps highlighted some of the areas that were masked in the previous maps because there was a better spread of LSOAs amongst all vulnerability categories. However, when the raw data was double checked an issue with the variables was uncovered. One variable selected by Bell, McFarland, and Innerd (2008) to gauge

English speaking skills was individuals born in the Union of Soviet Socialists Republics (USSR). When this variable was used in our analysis using Chakraborty, Tobin, and Montz's (2005) method of calculating a vulnerability score, one LSOA had a disproportionately high SVI because it had the highest number of individuals born in the USSR relative to the other LSOAs. As a result, it was placed in the category of "high" vulnerability even though there were only four people born in the USSR. This variable did not considerably impact the vulnerability scores when we recreated the methodology used by Bell, McFarland, and Innerd (2008) because the variable count in each LSOA is divided by the total population of the Borough. Thus, the addition of four people pertaining to one variable will not change significantly the LSOAs vulnerability score when dividing by the relatively large total population of the Borough. Conversely, the scoring method used by Chakraborty, Tobin, and Montz (2005) computes a score based on each variable individually. Therefore, a variable with a maximum value of four people in an LSOA would increase the score of the LSOA containing the maximum significantly more than it would using the method used by Bell, McFarland, and Innerd (2008).

Figure 15: Vulnerability Maps Produced Using Bell, McFarland, and Innerd's (2008) Variables and Chakraborty, Tobin, and Montz's (2005) SVI Calculation (Equal Interval)

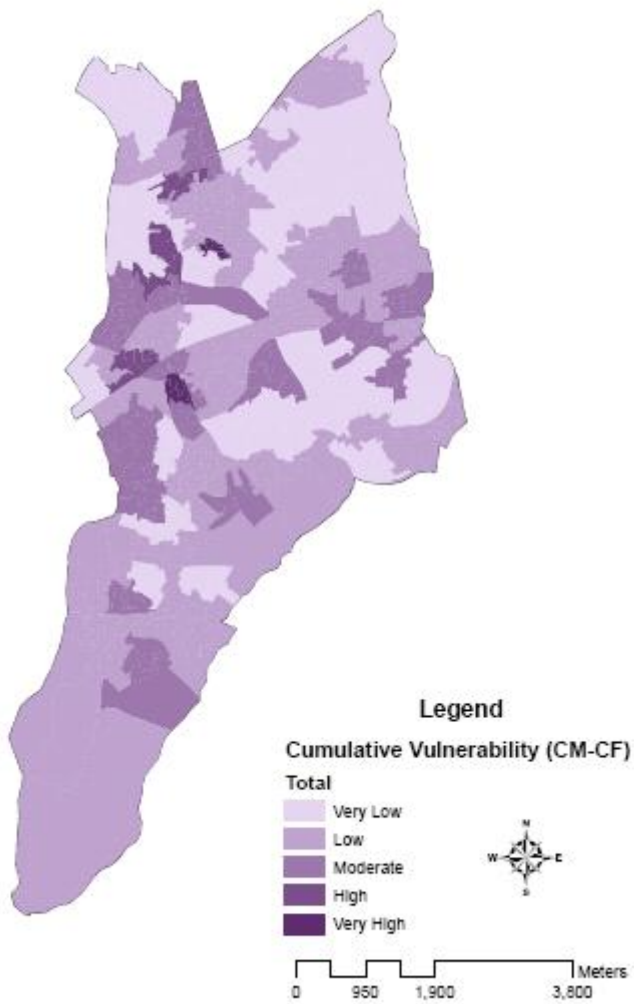


The increased emphasis on individual variables led us to two conclusions. First, in order to use the scoring method used by Chakraborty, Tobin, and Montz (2005) it is necessary to use only variables that positively influence vulnerability. For example, self-employment may indeed increase ones vulnerability to hazards but given the data available it is impossible to distinguish those who are self-employed and poor and those who are self-employed and wealthy. As a result, by simply looking at the data it is impossible to tell who among those who are self-employed is more vulnerable. Age is another variable that can represent either high or low vulnerability, with the young and old having increased vulnerability relative to middle-aged people. However, since the data is broken into age brackets, it is possible to distinguish those individuals who are actually more vulnerable as a result of their age (0 – 7 and over 75). Second, the variables used must be available regardless of location, so a unique variable that is unavailable in other locations cannot be used.

5.4 The Third Set of Maps

Understanding the limitations in the variables that can be used with the scoring method developed by Chakraborty, Tobin, and Montz (2005), we decided it would be beneficial to see how well the variables they used in their analysis of social vulnerability worked when applied to Kingston (Figure 16). Much like the map produced when we recreated the methodology used by Bell, McFarland, and Innerd (2008), there were two areas of extreme vulnerability that the map highlighted. Like before, we suspected that these outliers were masking the vulnerability of the other LSOAs throughout the Borough. Furthermore, while the variables used by Chakraborty, Tobin, and Montz (2005) were good at representing vulnerability throughout Kingston, through our research we discovered some variables that we believed would be more applicable for use in Kingston. The Chakraborty, Tobin, and Montz (2005) method for calculating a vulnerability score was found to be the most applicable because it allowed multiple types of variables to be used together. For example, this method allows for square meters of buildings and the number of females to be used in the analysis despite the two variables having completely different units. Bell, McFarland, and Innerd’s (2008) method would not allow variables with units other than population to be used. Our overall conclusions were that the Chakraborty, Tobin, and Montz (2005) method for calculating a vulnerability score was the method that we should be using in our analysis, and that the set of variables used by Chakraborty, Tobin, and Montz (2005) should be replaced in favor of a more comprehensive set of variables.

Figure 16: Cumulative Vulnerability Map Produced by Recreating Chakraborty, Tobin, and Montz's (2005) Methodology (Equal Interval)



5.5 The Fourth Set of Maps

To derive a different set of variables to use in the vulnerability analysis, only variables which were identified by three or more of sources as relating to vulnerability were included in the production of the new cumulative vulnerability map (Figure 17). These variables, listed in Table 17, should be applicable to measuring vulnerability everywhere, since more than one source identified the variable as an indicator of increased vulnerability. Our team as well as our sponsors determined that the common variables chosen would give a valid representation of vulnerability in Kingston. However, we noticed that once again two LSOAs had significantly higher SVIs than the other LSOAs in the Borough. These outliers with a high SVI score were skewing the data in a way that masked the full representation of vulnerability within the Borough.

To address the problem of LSOAs with high SVI scores masking the full representation of vulnerability throughout Kingston, equal interval breaks were removed in favor of a quintile approach of dividing the data. A quintile method ensures that the same number of LSOAs appear in each category, so that 20% of all LSOAs appear in each category of vulnerability. For example, if there are 90 LSOAs throughout a borough, using a quintile method 18 will appear in the category of highest vulnerability, 18 in the category of lowest vulnerability, and 18 in each of the three categories in between. The graph below (Figure 18) shows how a quintile method distributes the vulnerability categories in ArcGIS. The two bands of outlying LSOAs in Figure 18 are now grouped with several other LSOAs in the lower end of the highest vulnerability category, while the remaining LSOAs are divided into four categories of vulnerability. Thus, a quintile method ensures that the areas of highest vulnerability will always be highlighted on the map and areas with extremely high vulnerability scores will not misrepresent the areas in categorized in the lower vulnerability categories. Through feedback from our sponsor, we ultimately concluded that the quintile method was the better way to divide the data due to the fact that it will always highlight the most and least vulnerable areas of the Borough, regardless of a small number of extreme outliers in the data. As a result, we reproduced the cumulative vulnerability map in Figure 17 using a quintile method to divide the SVI scores. This map is displayed in Figure 19.

Figure 17: Cumulative Vulnerability Map Produced Using Common Variables (with building area per LSOA) and Chakraborty, Tobin, and Montz (2005) SVI Calculation (Equal Interval)

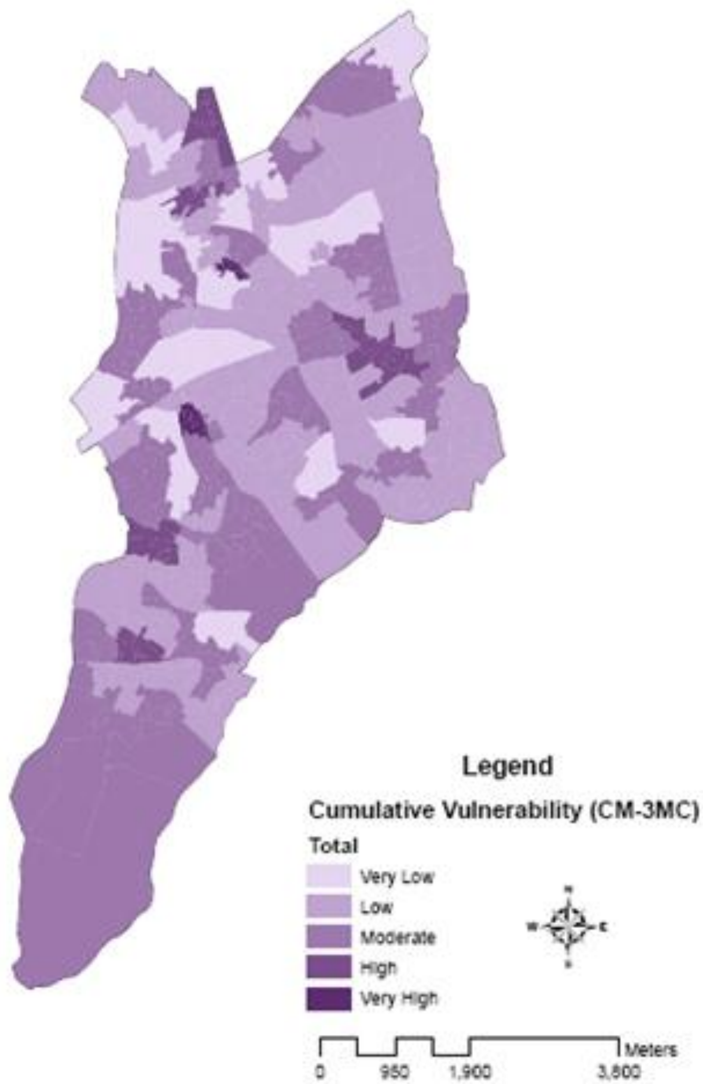


Figure 18: Example of Quintile Classification of SVI Scores

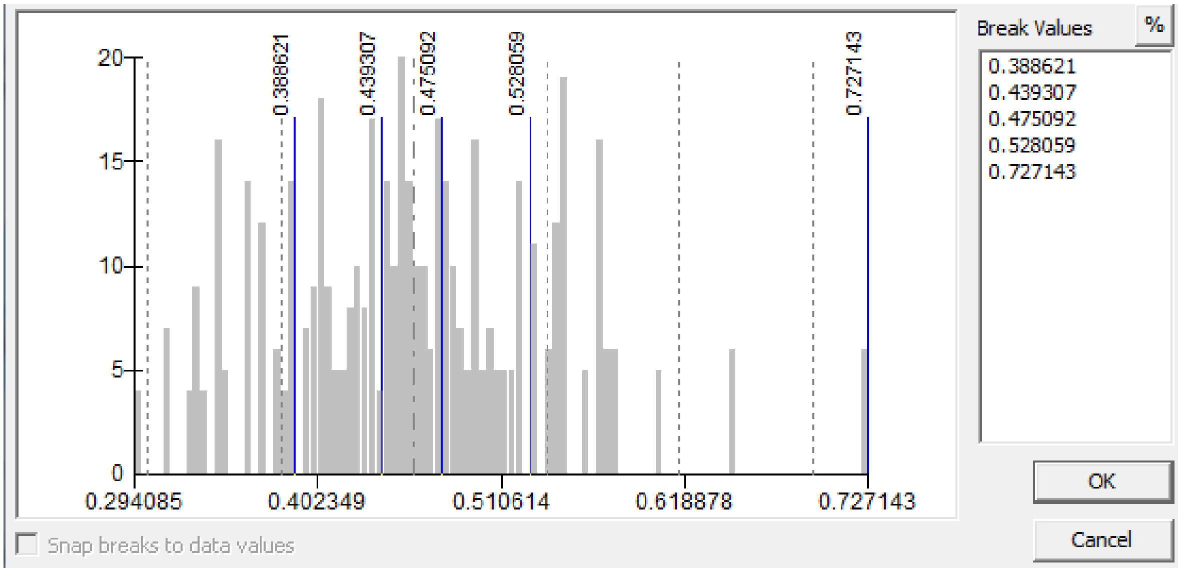
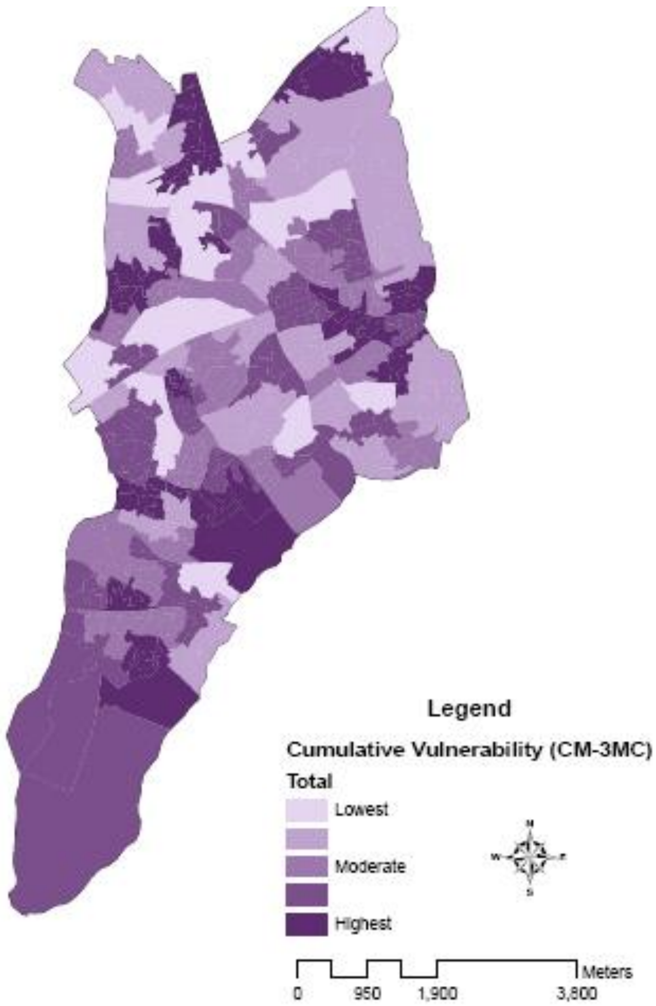


Figure 19: Cumulative Vulnerability Map Produced Using Common Variables (with building area per LSOA) and Chakraborty, Tobin, and Montz (2005) SVI Calculation (Quintile)

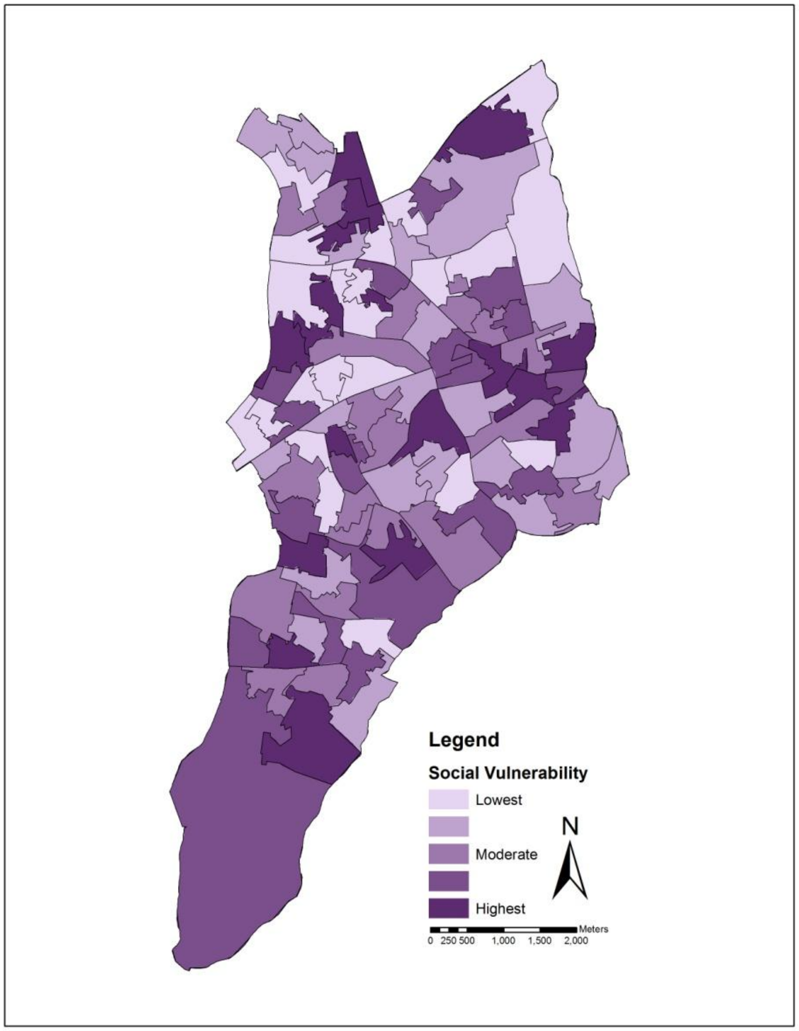


Our team decided that using a cumulative vulnerability map (social, economic, and heath combined into a single map) would misrepresent each category of vulnerability. Thus, it was decided that it is better to separate our vulnerability maps into two components: one showing the vulnerability of a person (social vulnerability map) and another showing the vulnerability of a place's economy (economic vulnerability map). This separation of vulnerability maps allows for a more specific analysis of vulnerability, since the person doing the analysis is able to look at each category separately.

5.6 The Final Social Vulnerability Map

Before producing our final social vulnerability map, it was decided that the area of buildings per LSOA was not a good indicator of social vulnerability. We believed locations with a high building area per LSOA would be indicative of areas with a high concentration of people. However, through discussions with our sponsor, we realized it was not a good indicator of social vulnerability. This was caused by the fact that large, luxurious ‘flats’ (apartment blocks) with few people living in them would appear as areas of increased vulnerability, despite the fact they are areas of reduced vulnerability. This violated our previous conclusion that only variables that are indicative of increased vulnerability can be used in our analysis. Building area per LSOA was replaced with population per LSOA, which was a variable identified by three of more sources but was not included in the previous maps due to an error in the way our variables were identified in the table of variables located in Appendix C (Note: this error was fixed before the tables were placed in the appendix). Our final social vulnerability map is shown in Figure 20.

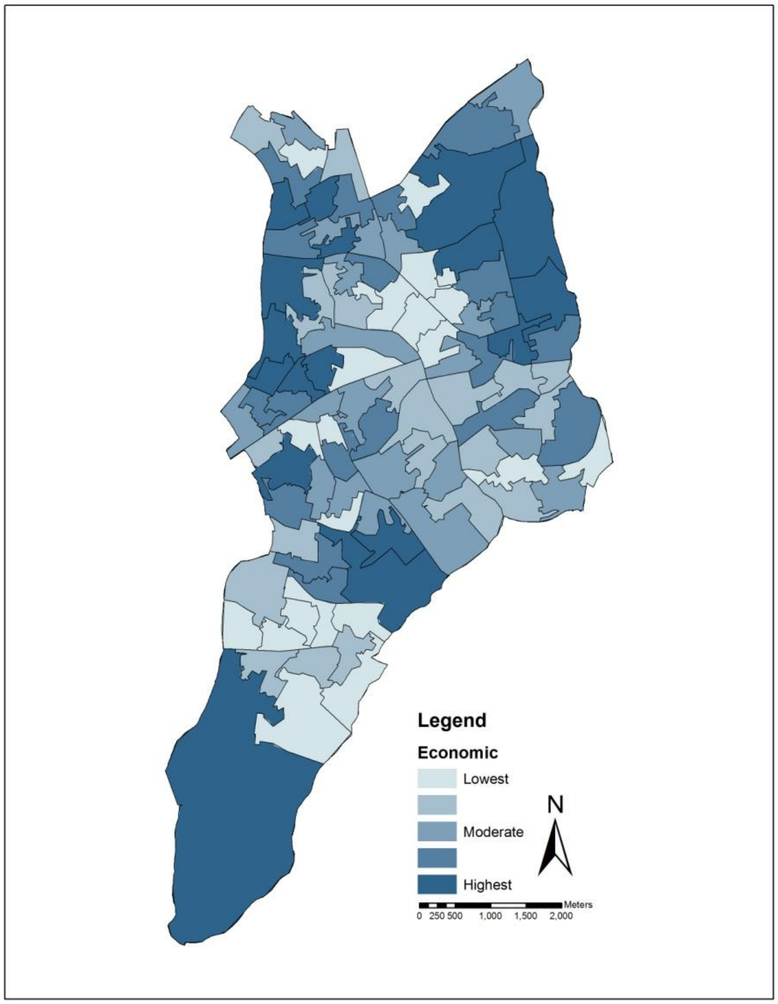
Figure 20: Final Social Vulnerability Map



5.7 The Final Economic Vulnerability Map

Since the map produced using variables identified by three or more sources did not reflect the economic vulnerability of the Borough due to the fact that the variables involved reflected the vulnerability of an individual, a separate map was created using variables that would show economic vulnerability within the RBK (Figure 21). This map was designed to show areas that contain the highest economic assets for the Borough. While the Neighbourhood Team expressed their belief that that this map was a reasonable representation of economic vulnerability, the general consensus was that the employment data, which was formatted in middle super output area (MSOA) instead of lower super output area (LSOA), data decreased the resolution which could have been obtained had it been in LSOA format. We concluded that this map gave a valid depiction of the vulnerability of the Borough's vulnerable economic assets.

Figure 21: Economic Vulnerability Map Produced Using Economic Variables and Chakraborty, Tobin, and Montz (2005) SVI Equation (Quintile)



5.8 Proving the Accuracy of Our Vulnerability Maps

The finalized social and economic vulnerability maps were tested to determine how well they represent the vulnerability throughout Kingston. After identifying the most vulnerable LSOAs, we preformed a ground-truthing exercise in these areas. This was performed to see the vulnerable areas on the ground. This allowed us to prove that our vulnerability maps accurately reflected what is present on ground. Figures which show photographs of vulnerable areas from each location on both the social and economic vulnerability maps are located in Appendix A.

To further assess the validity of the two final vulnerability maps we produced, our team held a meeting with the Neighbourhood Team and compared the maps we produced with the Kingston Borough Profile 2009. Then, by looking into each LSOA and the data associated with it, we were able to explain to the Neighbourhood Team why each LSOA was showing up in the vulnerability category assigned to it. The Neighbourhood team was then able to decide whether or not each LSOA's SVI score was comparable to the LSOA's composition. During the process the Neighbourhood team identified a few areas that needed further clarification. Some areas misrepresented the current vulnerability of the LSOA because of the age of the data. For example, one LSOA showed a large number of elderly people in the Borough composition. The Neighbourhood Team could not understand why there were a large number of elderly people in the area until one of the members remembered that there used to be an elderly home in that LSOA. After taking a closer look at a few of the LSOAs, the Neighbourhood team decided that the maps effectively matched vulnerability scores to the composition of the Borough as it existed in 2001 but still reflected vulnerable areas in Kingston well. However, once the new census data was used it would be a truer reflection of the vulnerability of Kingston.

The last method we used to test the validity of our maps was the use of the Borough Profile 2009. This profile mapped indexes of deprivation throughout the Borough. To see if our map was a good representation of the vulnerability in Kingston we compared different areas of deprivation to the vulnerable areas of our maps. The three areas of highest vulnerability that were present in our vulnerability analyses were described in the Borough profile as being "In the top 10% of elderly deprivation in all of England" (Royal Borough of Kingston upon Thames, 2009). This fact, plus the other areas of deprivation, provided a rough validity of our maps as the higher areas of vulnerability matched main areas of deprivation. There existed a difference in our maps and the areas of deprivation since Borough Profile and our vulnerability analysis analyzed different variables. We were able to evaluate the areas of difference on our map using the previously discussed methods.

5.9 Hazard and Risk Mapping

A hazard map depicts the likelihood of a hazard occurring over the desired area. We created a hazard map for flooding hazards by adding the hazard scores between fluvial flooding and surface water flooding. Our team assigned hazard scores to each hazard layer based on the rate of occurrence for each flooding event. Through this process, we created our flooding hazard map (Figure 22). Additional hazards would have been beneficial to add out our flooding hazard map, but additional time and resources were needed to accomplish this. However, it is important to identify where hazardous sites (facilities of concern) are located to increase hazard awareness throughout Kingston. These sites include facilities such as power plants, dams, and oil pipelines. A benefit to adding these hazardous sites on a map is to show how a hazard may influence a nearby hazardous site. Also, it is beneficial to identify the location of other potential hazards to make a future hazard assessment easier to conduct. We decided to identify the location of oil and gas pipelines, petroleum stations, and gas holders in Kingston. This hazard map with facilities of concern identified is shown in Figure 23.

Figure 22: Royal Borough of Kingston Flood Hazard Map

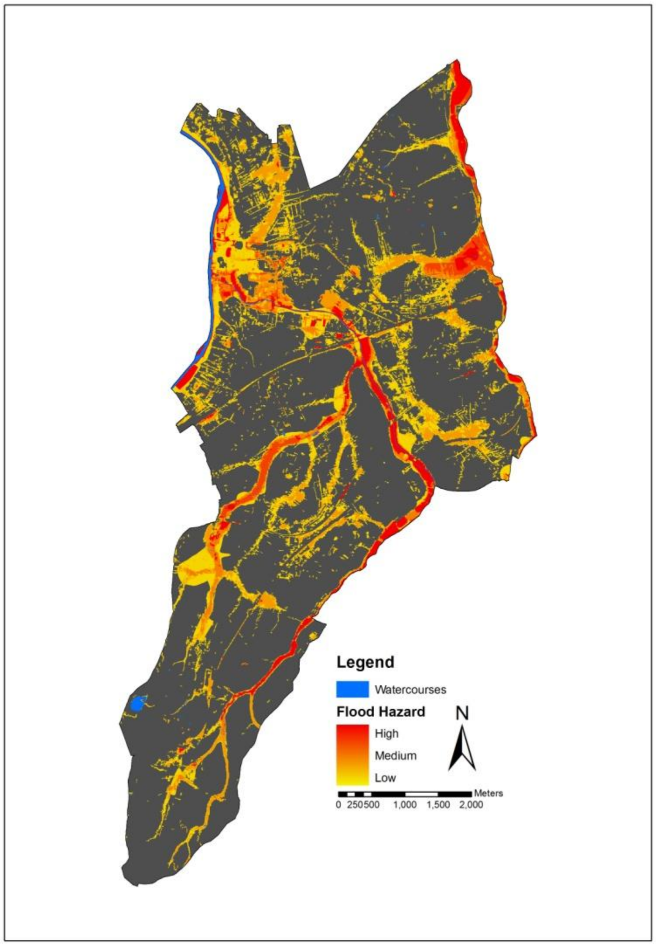
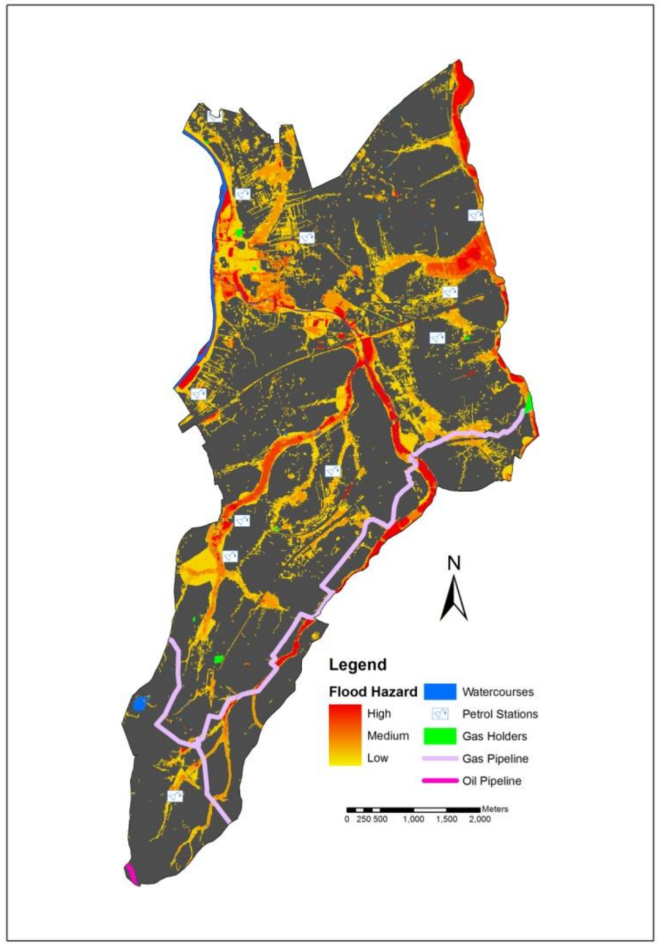


Figure 23: Royal Borough of Kingston Flood Hazard Map with Facilities of Concern



Although we were able to successfully create a hazard map for the RBK, there are several problems with our analysis and out final maps should be taken as more of a 'proof of concept' than a final product. This is largely due to the surface water flooding data we incorporated in our hazard analysis. The surface water flooding data we were able to obtain from an Environmental Agency (EA) study only shows areas that are susceptible to surface water flooding, not where surface water flooding actually occurs. As a result, the study performed by the EA does not take into consideration factors such as flood depth and flood speed, which are both needed for a full analysis of surface water flooding. Furthermore, the EA listed a number of ways their data should not be used. Among them were "Don't rely on the maps alone to show expected areas of surface water flooding" and "Don't incorporate the maps into fluvial or tidal flooding maps…" (Environment Agency, 2009). Both of these warnings were ignored in our analysis of flood hazards in Kingston. Finally, the bands of surface water flooding were not given any 'rate of occurrence', so the hazard scores used for the fluvial flood layers were also used for the corresponding surface water flood layers (fluvial flood zone 2 corresponded to the 'low' band of surface water flooding and fluvial flood zone 3b corresponded to the 'high' band of surface water flooding). This scoring method is highly inaccurate and is not a valid way to assign a hazard score to surface water flooding. Given the limitations of the data we had access to, our analysis should not be considered a final product and should be treated as a 'prototype' for a more in-depth study of hazards throughout Kingston.

Once the hazard map was finalized, it was possible to create a risk map. This was done by multiplying by the hazard scores with vulnerability map scores within each LSOA using the equation risk = hazard x vulnerability (Blakie et al., 2001). If there is area of extreme vulnerability, but no hazard present, then the risk in that area should equal to zero. Likewise, if there is an area that is very susceptible to hazards but no vulnerable people living in that area there is no risk. This formula was applied to both our economic and social vulnerability maps. Figures 24 and 25 show the economic and social risk maps, respectively, we produced from this analysis. The nuances in shading between the two maps reflect the change in risk as a result of the differences between economic and social vulnerability. These are more easily seen in the maps with blown-up sections located in Appendix A. Since the hazard map these were derived from has some flaws, these should not be treated as a final product and all warnings that apply to the hazard map apply to these as well.

Figure 24: Economic Flood Risk Map

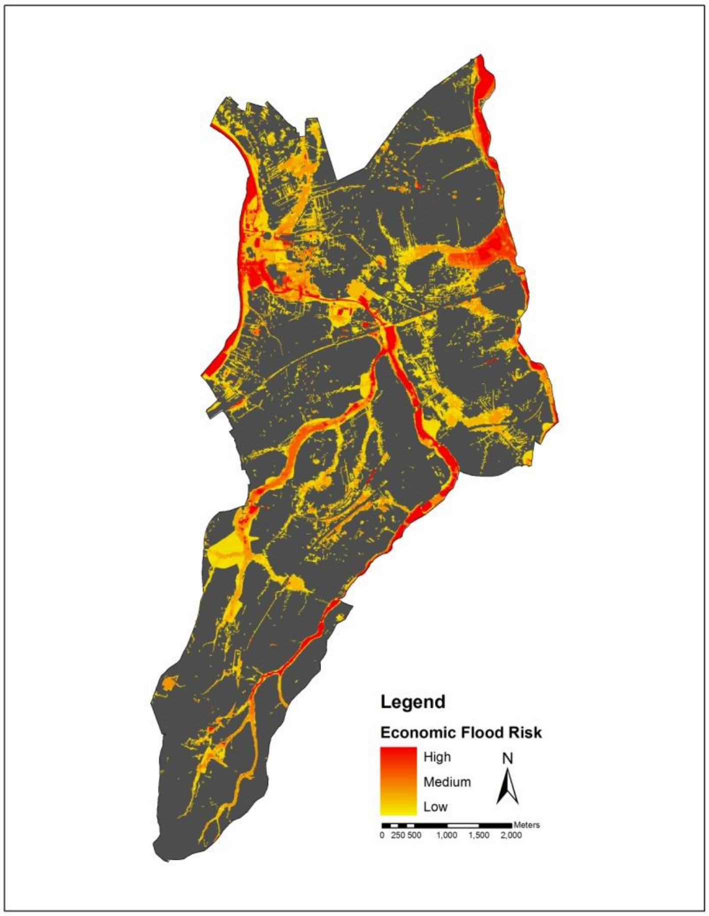
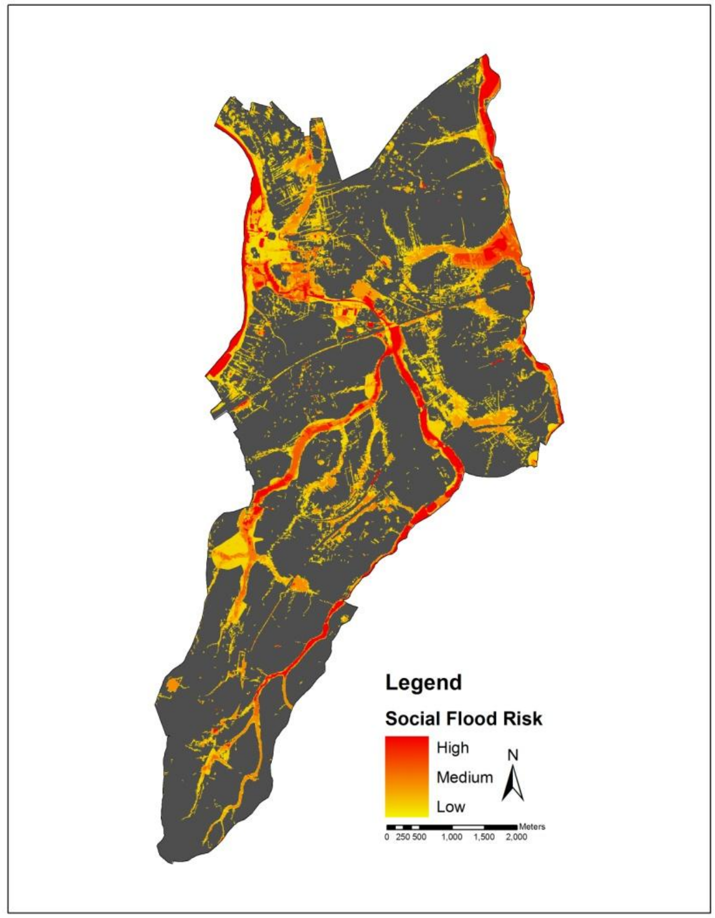


Figure 25: Social Flood Risk Map



5.10 UK Climate Projections

In order to understand the pattern of risk throughout the Royal Borough of Kingston it is necessary to use a combination of hazard and vulnerability data due to the fact we are defining risk using the equation risk = hazard * vulnerability (Blakie et al., 2001). In order for a risk map to reflect possible future changes, it is necessary to determine how hazards are going to change in the future. This is especially true for hazards that are likely to become more frequent or severe as a result of climate change. In order to better understand how climate change will impact hazards that affect Kingston, a series of projections were generated using the UK Climate Projections 2009 (UKCP09) program. This program generates predictions about the UK climate based on various different inputs, including different greenhouse gas (GHG) emissions scenarios. The first series of requests dealt with how the climate of the UK will change in the 2030s, 2050s, and 2080s under both a high and medium emissions scenario. Variables looked at included

‘Change in temperature of the hottest day’, ‘change in precipitation on the wettest day’, and ‘change in temperature of the coolest night’. These predictions were made for both summer and winter months. These changes were calculated as a difference from the baseline, which is the 30 year average of each variable from 1961 to 1960 (UK Climate Impacts Programme, 2009). Some findings from these requests are given below:

Change in Temperature on the Warmest Day
High Emissions Scenario

Under a high emissions scenario, the central estimate of the change in temperature of the warmest day during the summer in Kingston is 2.1 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than -1.8 °C and a 90% probability that it will be less than 6.2 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the warmest day during the summer in Kingston is 2.9 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than -2.1 °C and a 90% probability that it will be less than 8.7 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the warmest day during the summer in Kingston is 4.2 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than -2.4 °C and a 90% probability that it will be less than 12.5 °C.

Change in Temperature of the Warmest Night
Medium Emissions Scenario

Under a medium emissions scenario, the central estimate of the change in temperature of the warmest night during the summer in Kingston is 1.8 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than -0.2 °C and a 90% probability that it will be less than 3.8 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the warmest night during the summer in Kingston is 2.5 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than 0.3 °C and a 90% probability that it will be less than 4.9 °C.

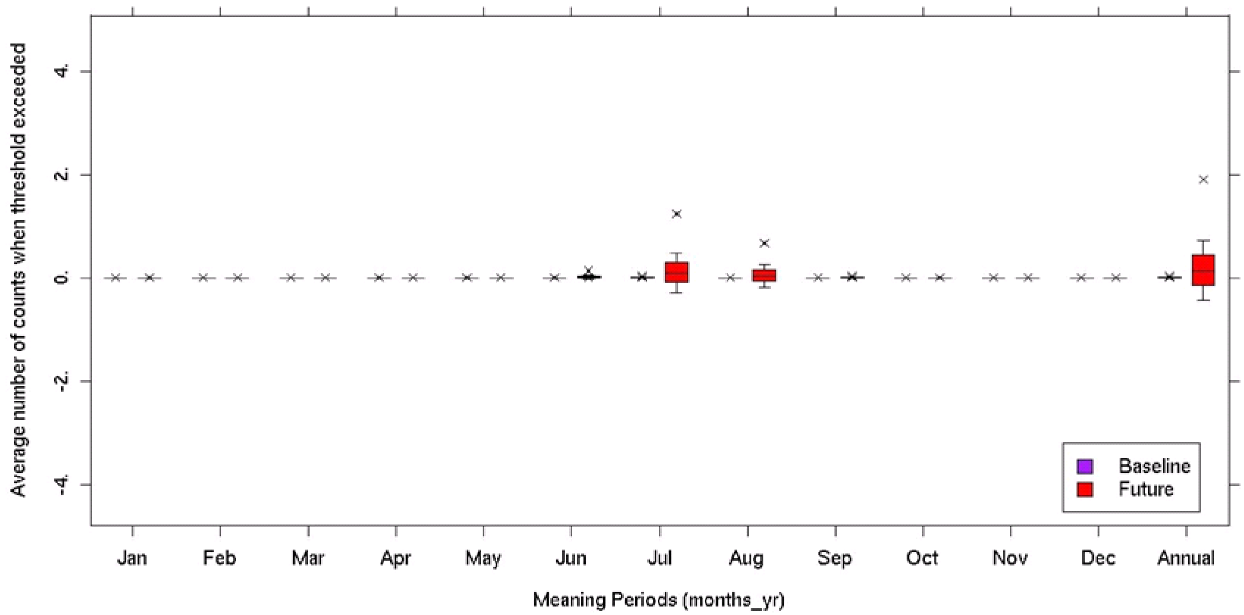
Under a medium emissions scenario, the central estimate of the change in temperature of the warmest night during the summer in Kingston is 3.3 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than 0.6 °C and a 90% probability that it will be less than 6.5 °C.

A complete list of findings from these requests can be found in Appendix D.

After assessing how the climate is likely to change in Kingston, we took a more in-depth look at how climate change will impact hazards. This was done through the use of the Weather Generator and Threshold Detector, two powerful tools made available through UKCP09. Through the use of these tools, we were able to generate predictions on how severe events and hazards, such as heat waves and flooding, will change as the result of a changing climate. Thresholds for heat waves and flooding were selected based on the definition of a heat wave and historic flood data. A heat wave is defined as two or more consecutive days where the daily maximum is above or equal to 32^0C and the daily minimum is above 18^0C as defined by the Met Office for the greater-London region (Met Office, 2010). The threshold for severe rainfall was based on the July 2007 flooding that took place throughout the United Kingdom. The threshold was set as at least one day where the total precipitation exceeded 75 mm in one day. Using these thresholds, we found the predicted number of heat waves and floods that are likely to occur each year during the 2030s and 2050s under a medium and high emissions scenario. Some of the findings from these requests are shown below. A full list of the generated predictions can be found in Appendix E.

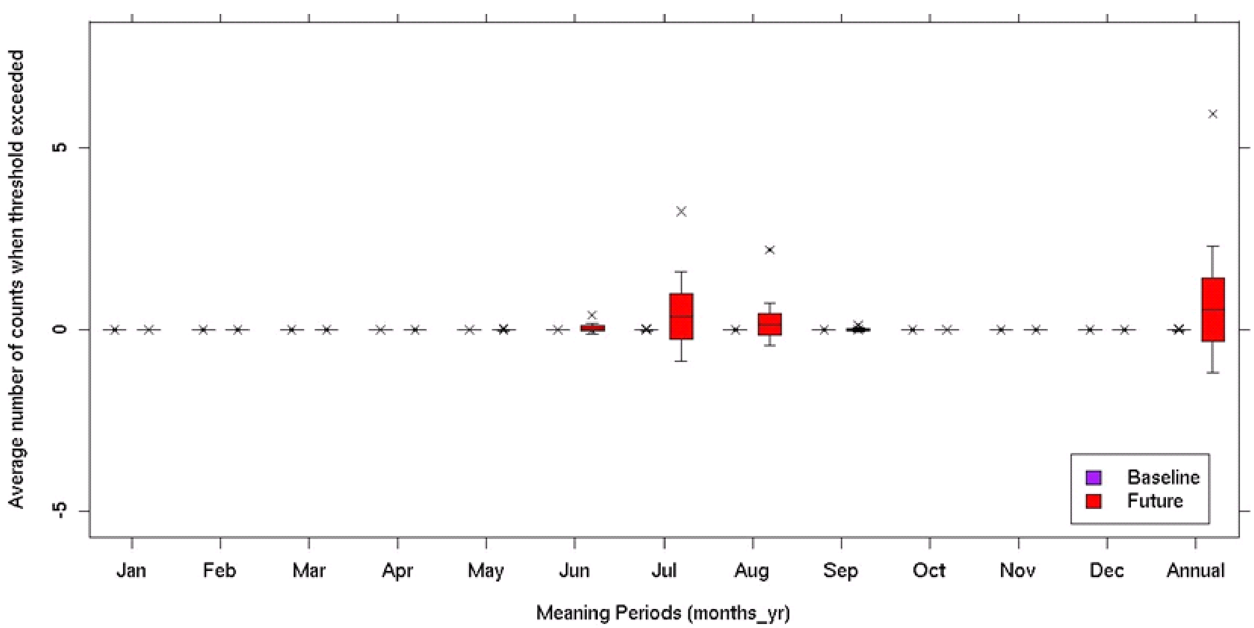
Under a high emissions scenario, the Royal Borough of Kingston will experience an average of approximately 0.1 heat waves a year during the 2030s (2020 – 2049) (Figure 26). It will average about 0.07 heat waves during the month of July and 0.03 heat waves during the month of August. The maximum number of heat waves that Kingston will experience is approximately 1.9 heat waves a year with a maximum of approximately 0.1 heat waves during the month June, 1.2 during the month of July, and 0.6 during the month of August.

Figure 26: Number of Heat Waves under a High Emissions Scenario during the 2030s (2020-2049)



Under a high emissions scenario, the Royal Borough of Kingston will experience an average of approximately 0.5 heat waves a year during the 2050s (2040 – 2069) (Figure 27). It will average about 0.4 heat waves during the month of July and 0.1 heat waves during the month of August. The maximum number of heat waves that Kingston will experience is approximately 6 heat waves a year with a maximum of approximately 0.5 heat waves during the month June, 3.3 during the month of July, and 2.2 during the month of August.

Figure 27: Number of Heat Waves under a High Emissions Scenario during the 2050s (2040-2069)



According to the figures above (Figures 26 and 27), the predicted average number of heat waves per year under a high emissions scenario is approximately 0.1 (1.9 maximum) during the 2030s, and there is a predicted average of 0.4 (6 maximum) heat waves during the 2050s. This means that there will be an average increase of 0.3 (4.1 maximum) heat waves per year from the 2030's to the 2050's.

Using this program, it is possible to find the frequency of hazardous events such as flooding and heat waves. These predictions in conjunction with hazard maps will help emergency planners understand what areas will be most affected by these changes in the future. This will allow planners to allocate resources more efficiently to help mitigate the effects of the increased frequency of these hazards.

6.0 Recommendations

This project focused on assessing the overall vulnerability of the Royal Borough of Kingston upon Thames, one of the thirty-two London boroughs. We produced two vulnerability maps that show areas of economic and social vulnerability. With confirmation from our sponsors, the Neighbourhood Team and the Borough Profile 2009, the vulnerability maps created are reasonable representations of social and economic vulnerability. However, it is believed that additional sources of information and data could supplement the maps created to further improve upon them. We were unable to accomplish this due to time and data restrictions. In the future this project is able to be expanded upon by taking advantage of additional time, data, and focus. Our team has recommendations on how to expand and refine our work moving forward.

Our team's primary recommendation deals with the data available to us while we were conducting our analysis. In order for our vulnerability maps to be as valid as possible, it is necessary to incorporate updated data as it becomes available. Due to the age of the current census data available, it is necessary to incorporate the 2011 census data into the analysis once it becomes available. This new data will provide a more recent snapshot of Kingston when analyzing vulnerability. Furthermore, since vulnerability is a constantly changing quantity it is necessary to use the most recent data in order to get a valid representation of vulnerability throughout an area.

Our team also believes that additional sources of data will allow the current analysis to have a greater resolution. This includes data on the population shift between day and night, access to transportation, English speaking skills, employment location, and overheating due to the heat island effect. Data on the day and night population shift is important, because current census data based on place of residence really only reflect the distribution of night time or weekend population and does not account for the large geographic shifts in population during the day. Cell phone mast data can help track the shift, but any other form of data on day and night population shifts which becomes available should be incorporated into a future analysis. Use of this data would be highly beneficial to the individuals responsible for emergency planning and response because it would allow them to view shifts in the population during the day and night. The access to transportation data currently available to Kingston is not in a format compatible with our analysis. In the future it is recommended that these data should be reformatted into a format which is compatible with our analysis. Due to time restrictions our team was not able to find any data on English speaking skills. Many sources agree that the inability to speak the native language greatly increases one's vulnerability. For this reason, that data should be incorporated. In order to increase the resolution of our economic vulnerability map, current employment data is available in the middle super output area and must be gathered into lower super output. Current data on overheating due to the heat island effect, produced by the LUCID Project, is currently unavailable but would be extremely useful when mapping the hazard of heart waves.

We recommend that a better hazard analysis of the Borough can be performed. Due to the scope of our project which focused on hazards related to climate change, we were not able to address all types of hazards the Borough may encounter. For emergency planning purposes as well as future analysis, it would be beneficial to perform a hazard analysis that includes petroleum station explosions, oil pipeline disruptions, fires, pandemic disease, and others. Furthermore, a more complete way for calculating a hazard score would be beneficial to this analysis. Our current method of calculating a hazard score is a course grained analysis and there may be a better way to perform a hazard analysis. In the future, groups should look at different ways to compute a hazard score, including: overlaying, open mapped hazard analysis, and a more broad analysis of applying a hazard score to an entire LSOA. Overlaying is an easy method, but makes the map difficult to interpret. Open mapped hazard scores are accurate but conversations with our sponsor suggest they may be too specific to incorporate into an approach that uses LSOAs. Applying a hazard score to a LSOA would give less resolution relative to open mapped hazard scores and overlaying, but it would allow for easy comparison with other LSOA based scores. Our team believes further research into hazard mapping would be beneficial to the advancement of this project. Through discussions with our sponsors, it is suggested that a group of university students work in conjunction with Rob Bell to investigate hazard mapping more comprehensively. Therefore, a more in-depth hazard analysis can be developed by introducing data on additional hazards and experimenting with alternate ways to calculate hazard scores.

To further explore hazard mapping in the Royal Borough of Kingston, it is necessary for the Borough to investigate a means of gaining access to a Spatial Analyst tools license for ArcGIS. The Spatial Analyst tools allow the user to convert a vector based GIS layers into a raster based GIS layer, which allows a risk score to be assigned to each 1 x 1 meter cell. They also allow for multiple raster layers to be combined using different mathematical calculations. In order to re-create and expand on our risk analysis, a copy of this add-on for ArcGIS is necessary.

Without the Spatial Analyst tools, overlaying the hazard and vulnerability map layers or using Excel to manually assign a hazard score to each LSOA individually are the only two methods we could find to generate a risk map. If the Spatial Analyst tools license is too costly to purchase directly, it would be beneficial to look into other means of obtaining access to the software, such as through a local university.

Resilience mapping is another aspect of the project we were unable to address due to time constraints. Resilience mapping would supplement the analysis of vulnerability throughout Kingston by showing the areas that will be the most resistant to the coming climate changes. Resilience mapping would consider variables such as the location of resources and the location of shelters. This analysis of resilience would help the Borough identify where to allocate resources and goes hand-in-hand with the vulnerability analysis we conducted. Resilience mapping is the next step in performing a risk analysis of the Borough of Kingston, and would be an appropriate way to continue this project in the future.

To further test the validity of our methodology, we suggest that our methodology be applied to another borough to prove that our methodology can produce accurate vulnerability analyses in other London boroughs and is not specific to Kingston. Due to Joe McFarland's familiarity with our work in Kingston, it would be logical to implement our methodology in Hounslow. If our methodology accurately represents vulnerability in Hounslow, it would be beneficial to apply our methodology to the other boroughs in London. This implementation must occur simultaneously in order for the quintile method to accurately categorize each class of vulnerability. This will allow for cross-borough comparisons of vulnerability which will be beneficial to London as a whole. To facilitate this, we have created a step-by-step guide on how to gather data from the ONS and format information using Microsoft Excel for other boroughs to use when conducting their own analyses in Appendix F.

It is important to have our methodology, maps, and data accessible to each group within the Kingston Council due to the far reaching applications of our project. Through the Interdisciplinary Spatial Information System (ISIS), the Kingston Council can share our data and maps, in a viewable format, with other groups in the Borough. Throughout the process of conducting our analysis, we have identified three groups within the council who are all interested in our project for their own applications. They are the Neighbourhood Team, Climate Change and Sustainable Travel Group, and the emergency planners who work for Kingston. This led us to believe that there may be other groups within the council who could use our research to assist them achieve their own goals.

In order for planning and policy groups to use our work most effectively via ISIS, we recommend that mapping groups conduct workshops or meetings with planning and policy groups to instruct policy-makers and planners on how to use ISIS to its full potential. This will allow planners and policy-makers to understand the capabilities of ISIS in conjunction with our map layers. As a result, planning and policy making groups can use our maps more effectively when creating policies. In order to allow policy-makers and planners to better understand the mapping group's instructions, we suggest implementing a common set of terms between the groups during such meetings or workshops. Therefore, this will bridge the gap between the language used by the mapping groups and the language used by planning and policy groups.

Finally, our vulnerability maps only display Kingston's vulnerability to current hazards that borough may face. It is important use future climate change prediction data to modify current hazard maps to model future hazard scenarios. These future hazard scenario maps can then be applied to current vulnerability maps to show future risk across the Borough assuming vulnerability remains constant. We suggest using the UK Climate Impacts Programme (UKCIP) to generate projection maps using variables such as increase in average summer surface temperatures. This data can then be input into the Geographic Information System (GIS) and properly formatted to create a layer file and respective scores. When heat island effect data becomes available in a format which can be input into GIS, the surface temperature projections layer can then be used in conjunction with this data to create a future hazard score for overheating via the heat island effect. This suggestion is not only limited to overheating, but can be applied to other climatic hazards as well. Such information can be used to shape policy and allow the Borough to adapt to climate change.

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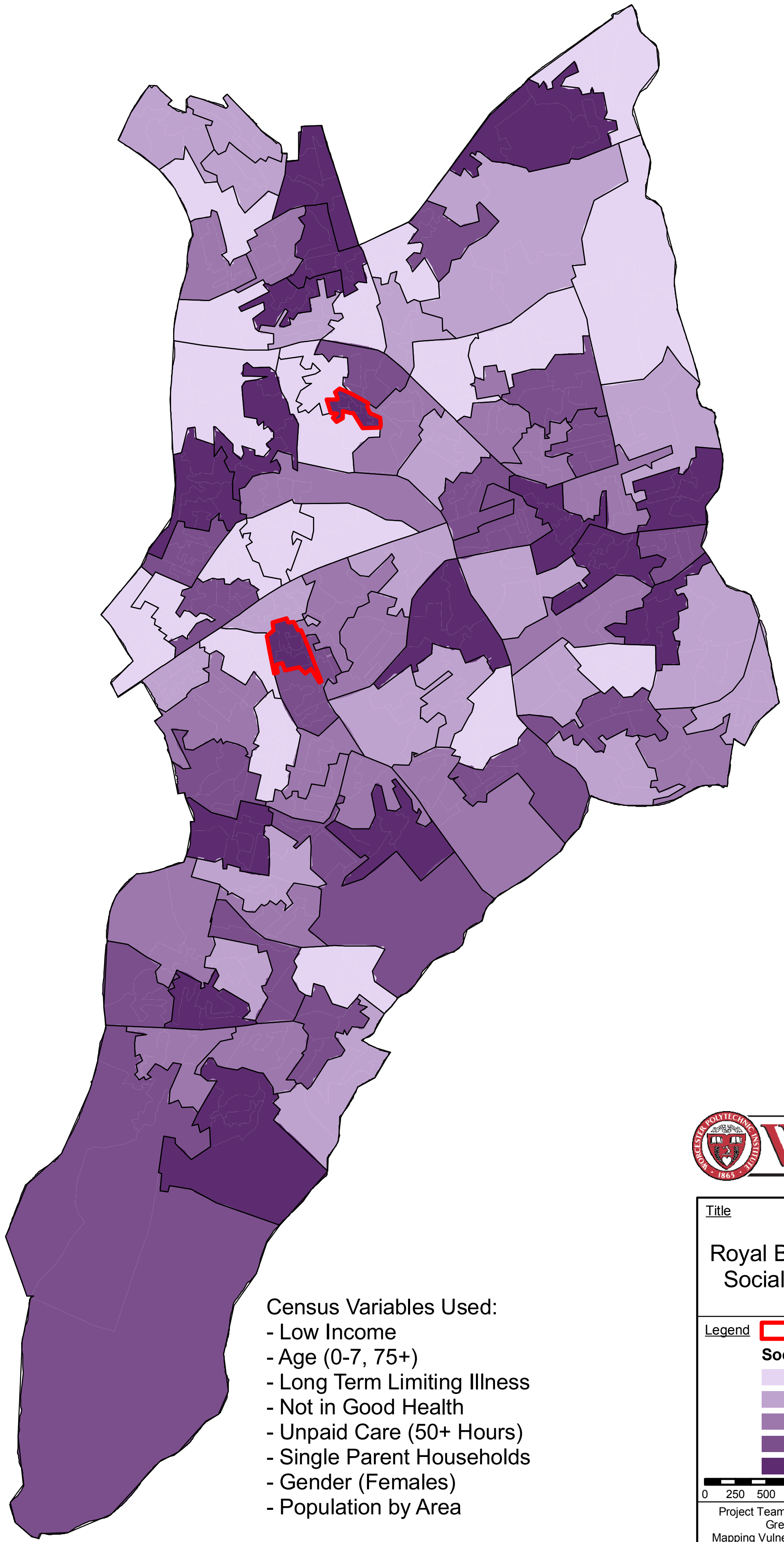
Appendix A: Collection of GIS-Based Maps Produced



Census Variables Used:
- Low Income
- Age (0-7, 75+)
- Long Term Limiting Illness
- Not in Good Health
- Unpaid Care (50+ Hours)
- Single Parent Households
- Gender (Females)
- Population by Area

(Source: Office of National Statistics (ONS))

Title

Royal Borough of Kingston Social Vulnerability Map

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

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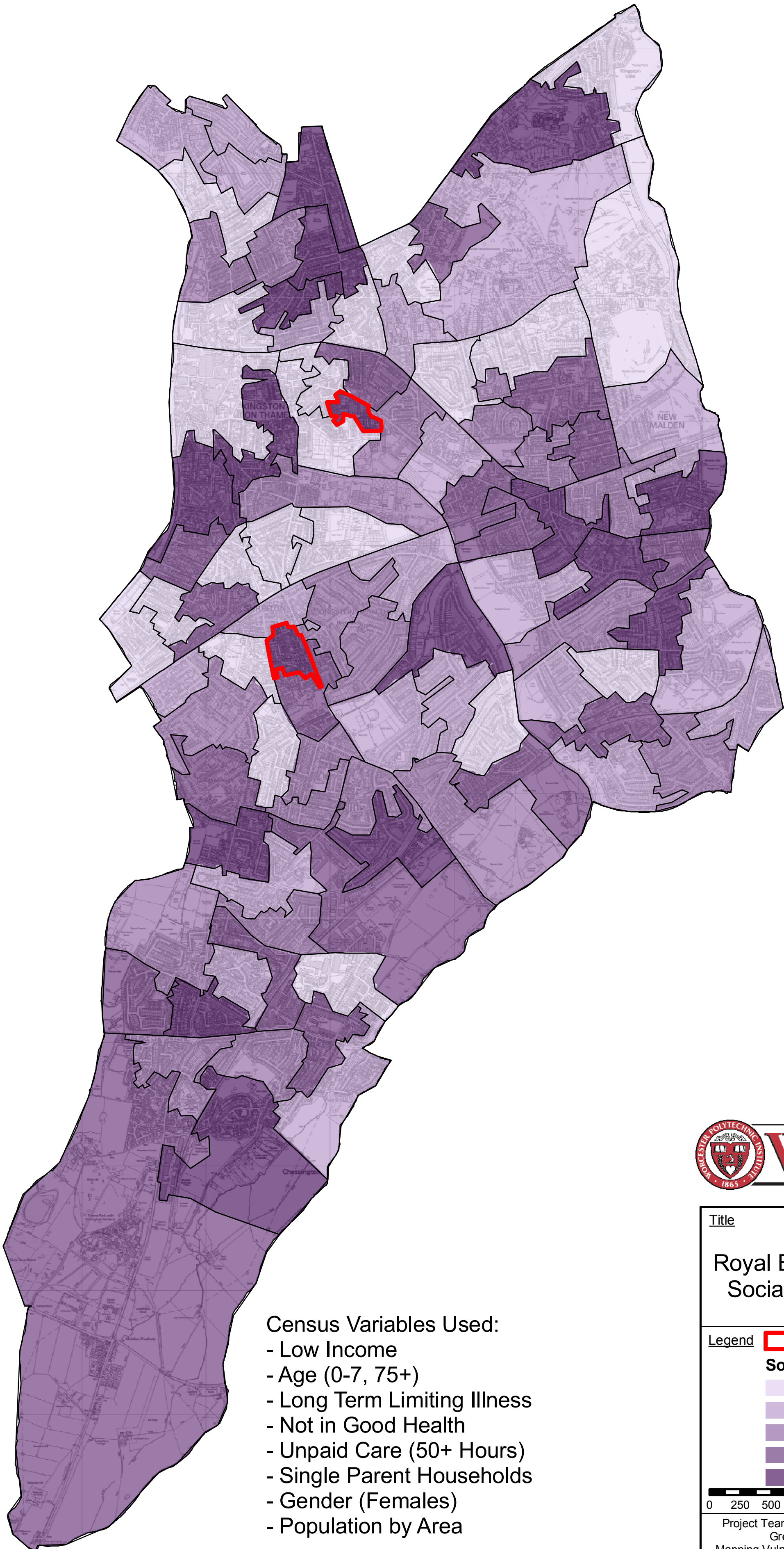

Census Variables Used:
- Low Income
- Age (0-7, 75+)
- Long Term Limiting Illness
- Not in Good Health
- Unpaid Care (50+ Hours)
- Single Parent Households
- Gender (Females)
- Population by Area

(Source: Office of National Statistics (ONS))

Title

Royal Borough of Kingston Social Vulnerability Map

Legend

Areas of Extreme Vulnerability

Social Vulnerability

Lowest

Moderate

Highest

0 250 500 1,000 1,500 2,000 Meters

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

Dwn: soc_vul_2

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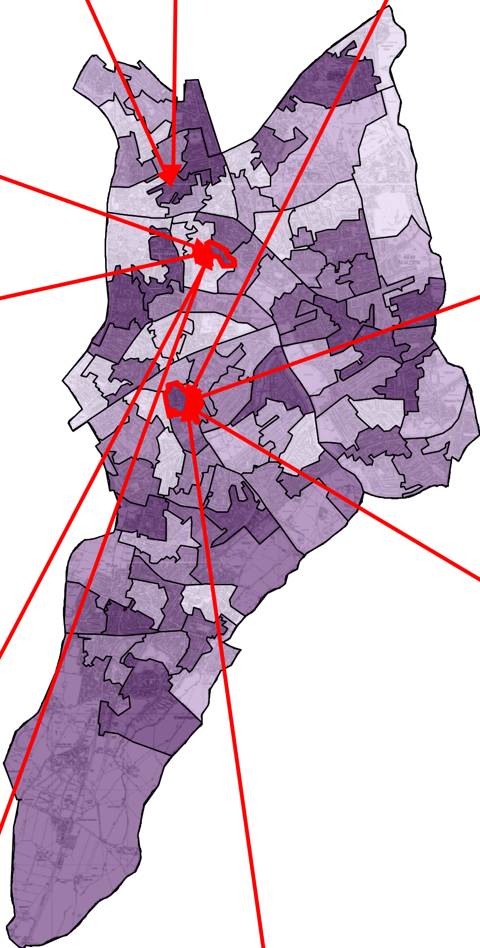

Title

Royal Borough of Kingston Social Vulnerability Map

Legend

Areas of Extreme Vulnerability

Social Vulnerability

- Lowest
- Moderate
- Highest

Meters

0 500 1,000 2,000 3,000 4,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

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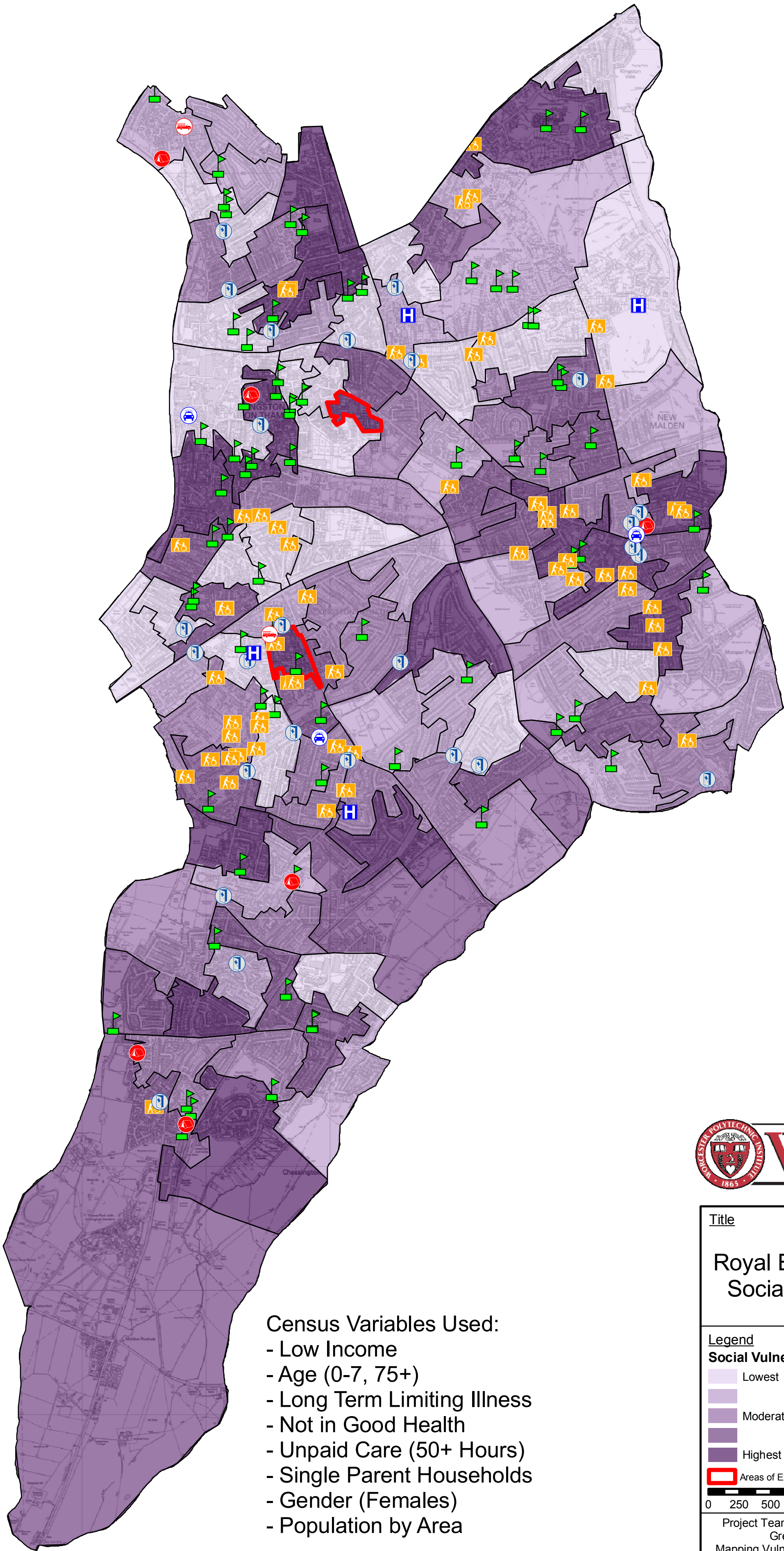

Census Variables Used:
- Low Income
- Age (0-7, 75+)
- Long Term Limiting Illness
- Not in Good Health
- Unpaid Care (50+ Hours)
- Single Parent Households
- Gender (Females)
- Population by Area

(Source: Office of National Statistics (ONS))

Title

Royal Borough of Kingston Social Vulnerability Map

Legend

Social Vulnerability

Lowest

Moderate

Highest

Areas of Extreme Vulnerability

Fire Stations

Police Stations

Hospitals

Medical Centres

Rest Centres

Community Care

Education Facilities

Meters

0 250 500 1,000 1,500 2,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

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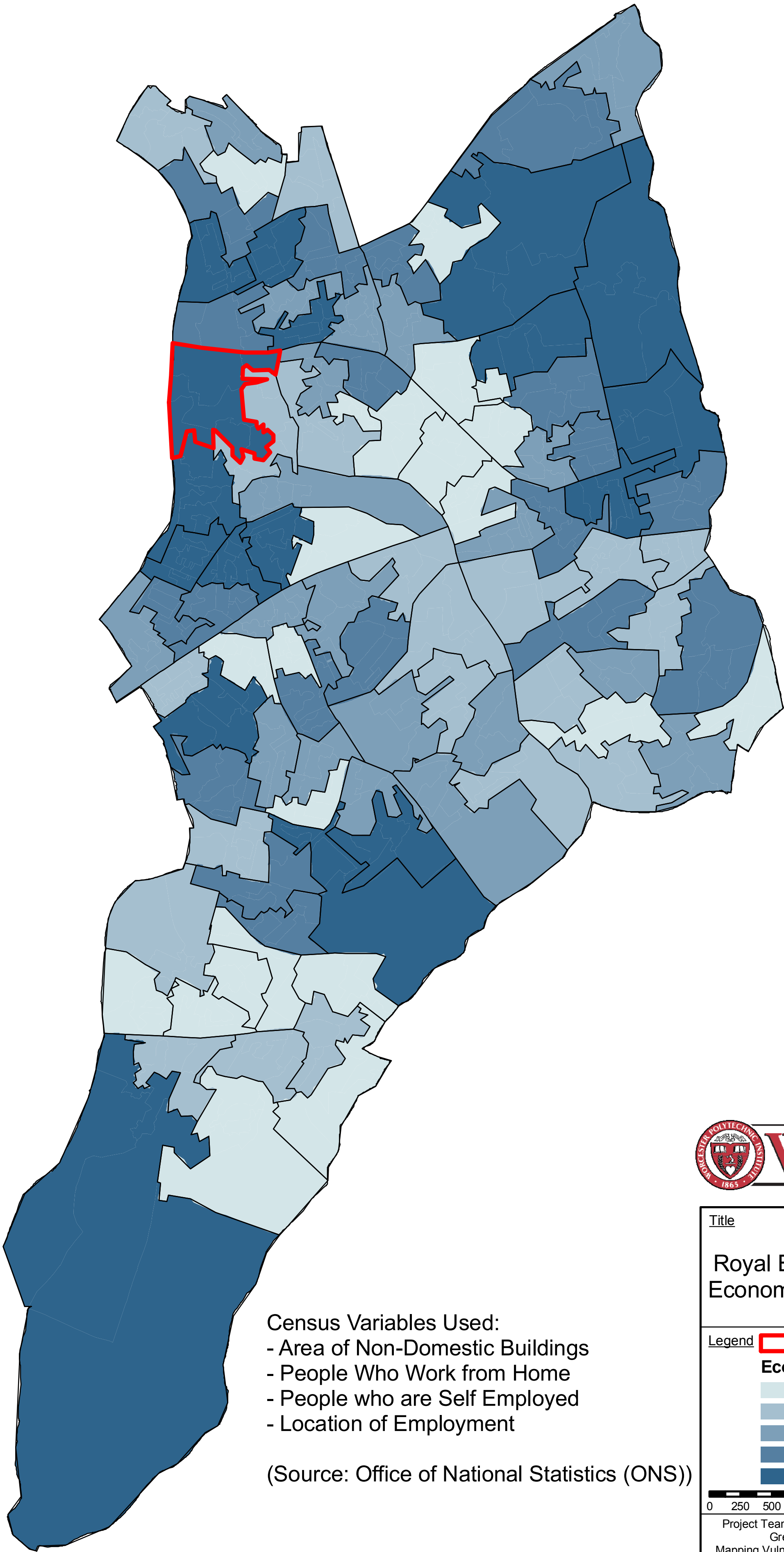

Title

Royal Borough of Kingston
Economic Vulnerability Map

Census Variables Used:
- Area of Non-Domestic Buildings
- People Who Work from Home
- People who are Self Employed
- Location of Employment

(Source: Office of National Statistics (ONS))

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

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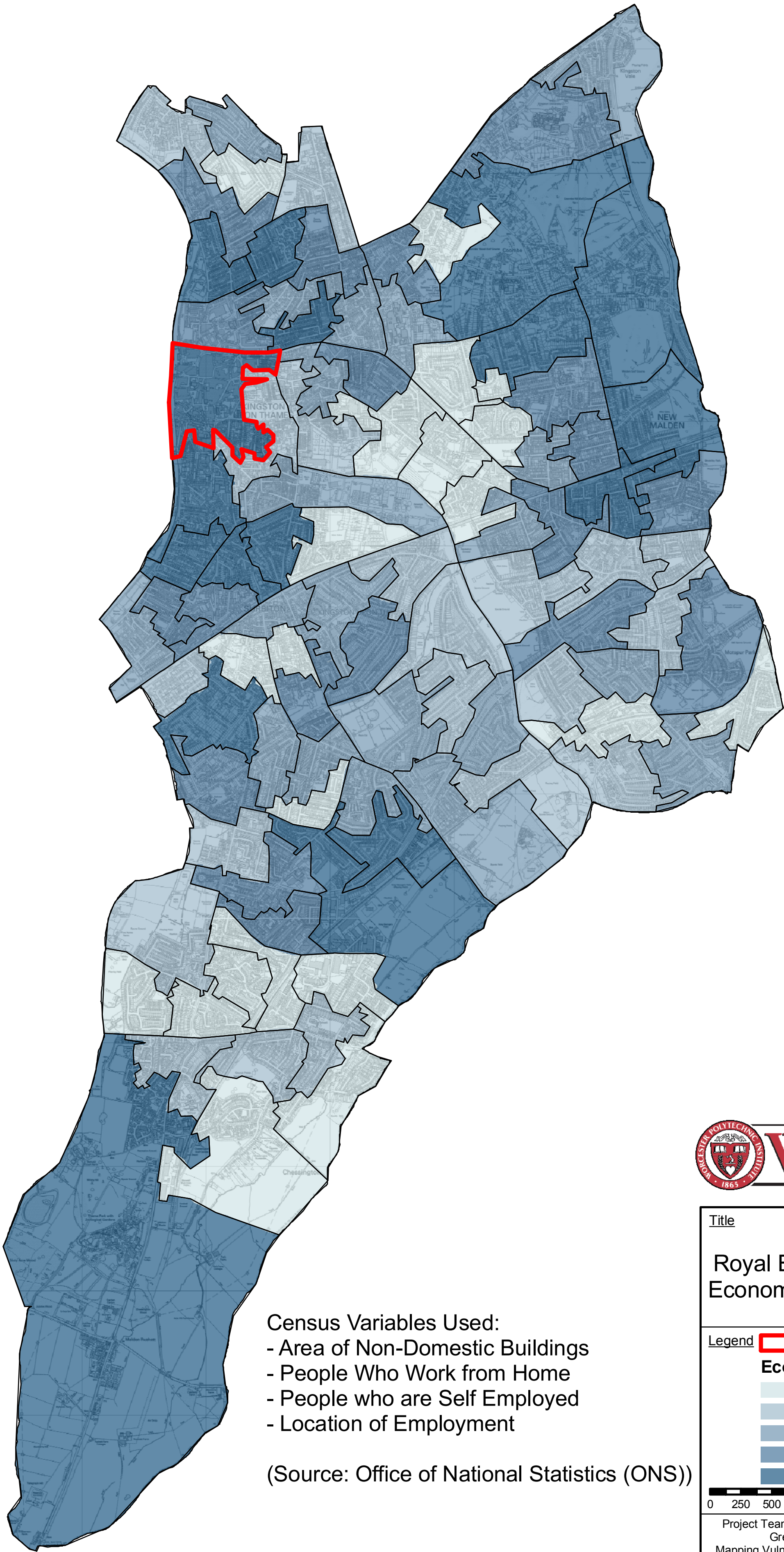

Census Variables Used:
- Area of Non-Domestic Buildings
- People Who Work from Home
- People who are Self Employed
- Location of Employment

(Source: Office of National Statistics (ONS))

Title

Royal Borough of Kingston Economic Vulnerability Map

Legend

Areas of Extreme Vulnerability

Economic Vulnerability

- Lowest
- (unlabelled)
- Moderate
- (unlabelled)
- Highest

Meters: 0, 250, 500, 1,000, 1,500, 2,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

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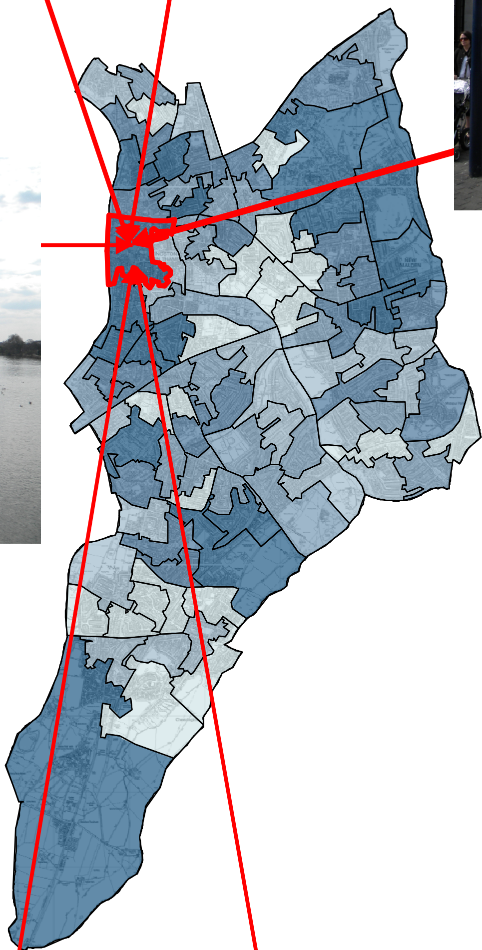

Title

Royal Borough of Kingston Economic Vulnerability Map

Legend: Areas of Extreme Vulnerability

Economic Vulnerability

- Lowest
-
- Moderate
-
- Highest

Meters: 0, 500, 1,000, 2,000, 3,000, 4,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

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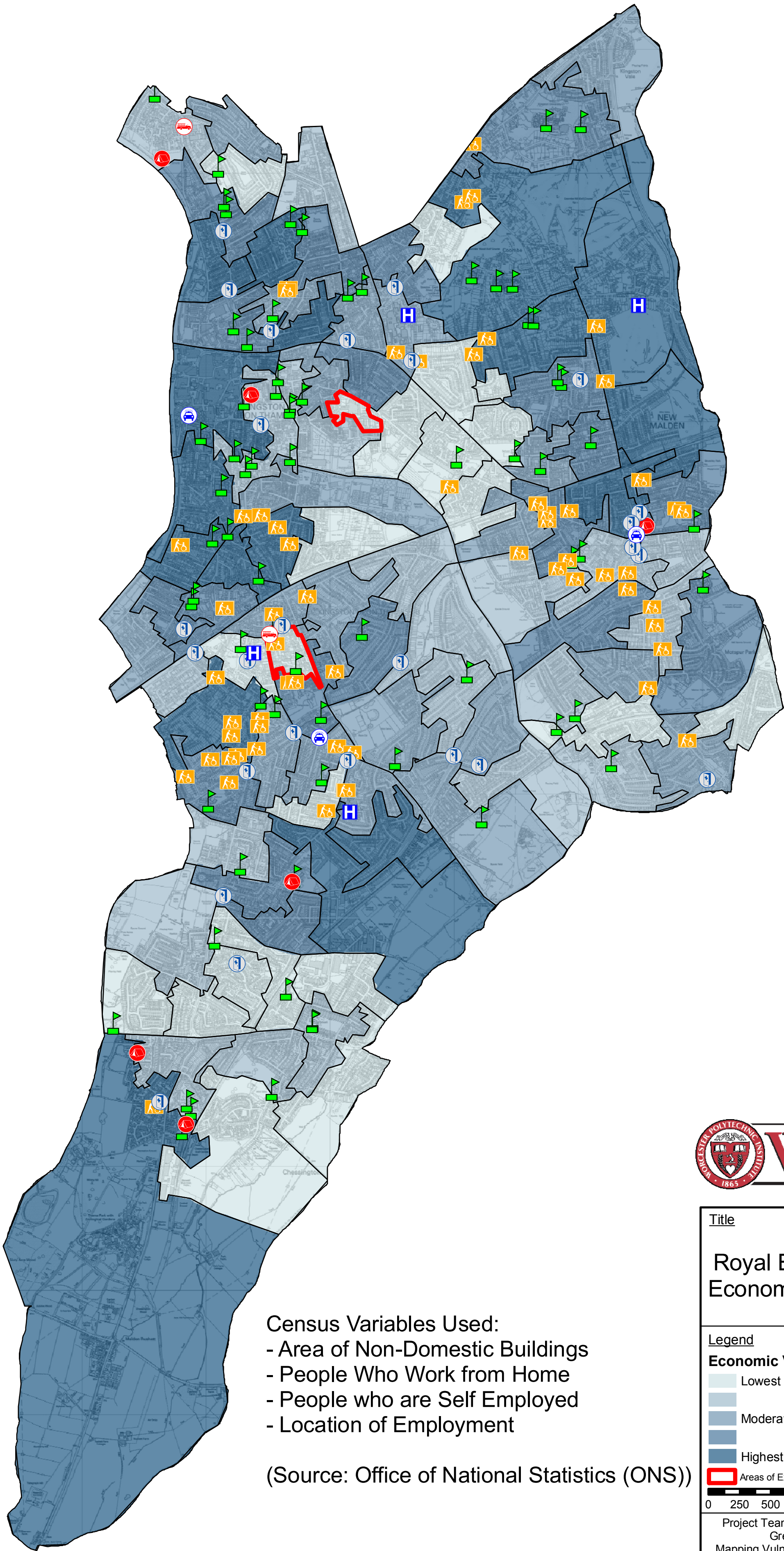

Census Variables Used:
- Area of Non-Domestic Buildings
- People Who Work from Home
- People who are Self Employed
- Location of Employment

(Source: Office of National Statistics (ONS))

Title

Royal Borough of Kingston Economic Vulnerability Map

Legend

Economic Vulnerability
- Lowest
- Moderate
- Highest
- Areas of Extreme Vulnerability
- Fire Stations
- Police Stations
- Hospitals
- Medical Centres
- Rest Centres
- Community Care
- Education Facilities

Meters
0 250 500 1,000 1,500 2,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

Dwn: eco_vul_4

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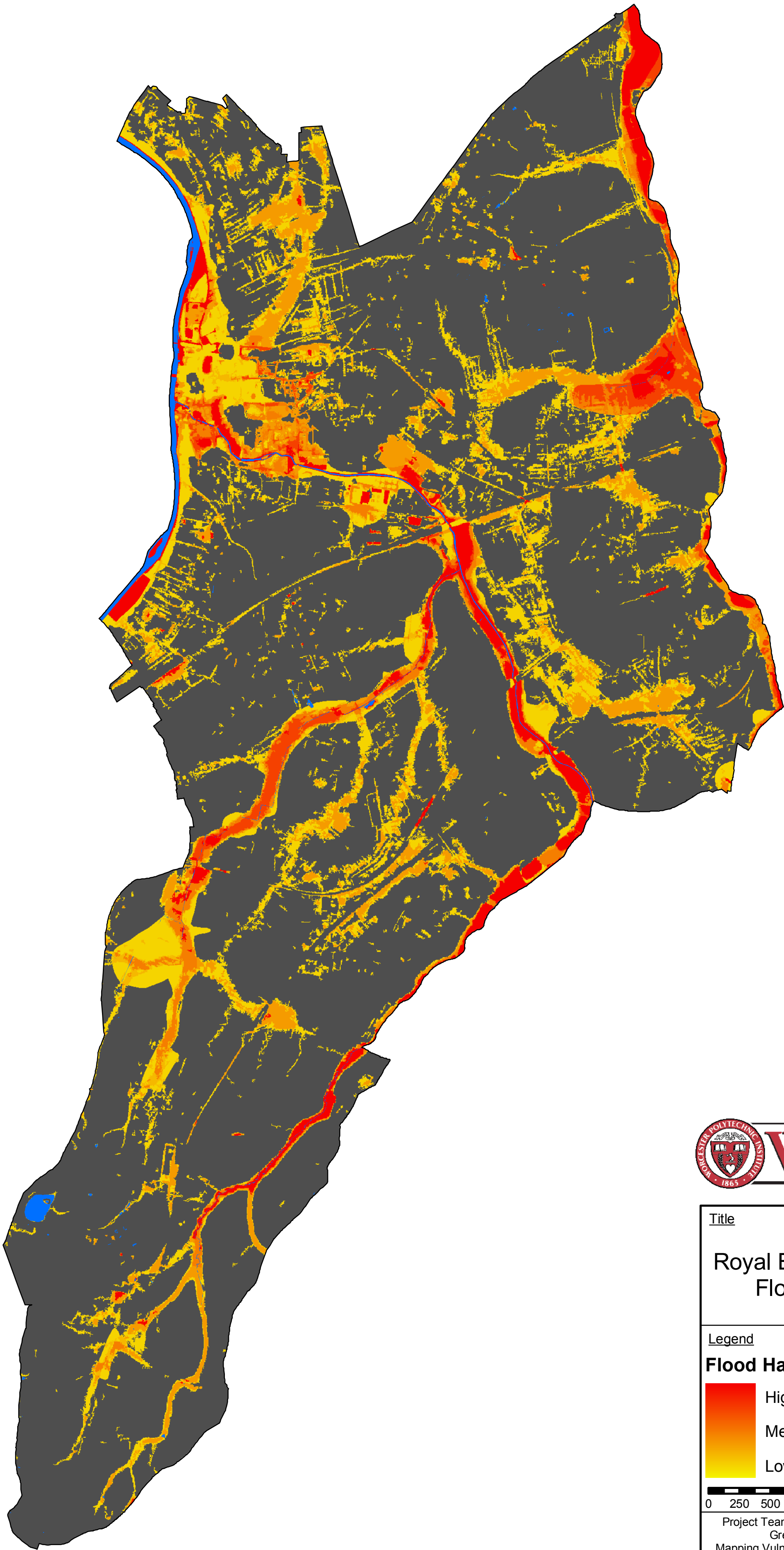

Title

Royal Borough of Kingston Flood Hazard Map

Legend

Flood Hazard

High

Medium

Low

Watercourses

Meters

0 250 500 1,000 1,500 2,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel

Mapping Vulnerability to Climate Change in the RBK

Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

Dwn: flood_haz_1

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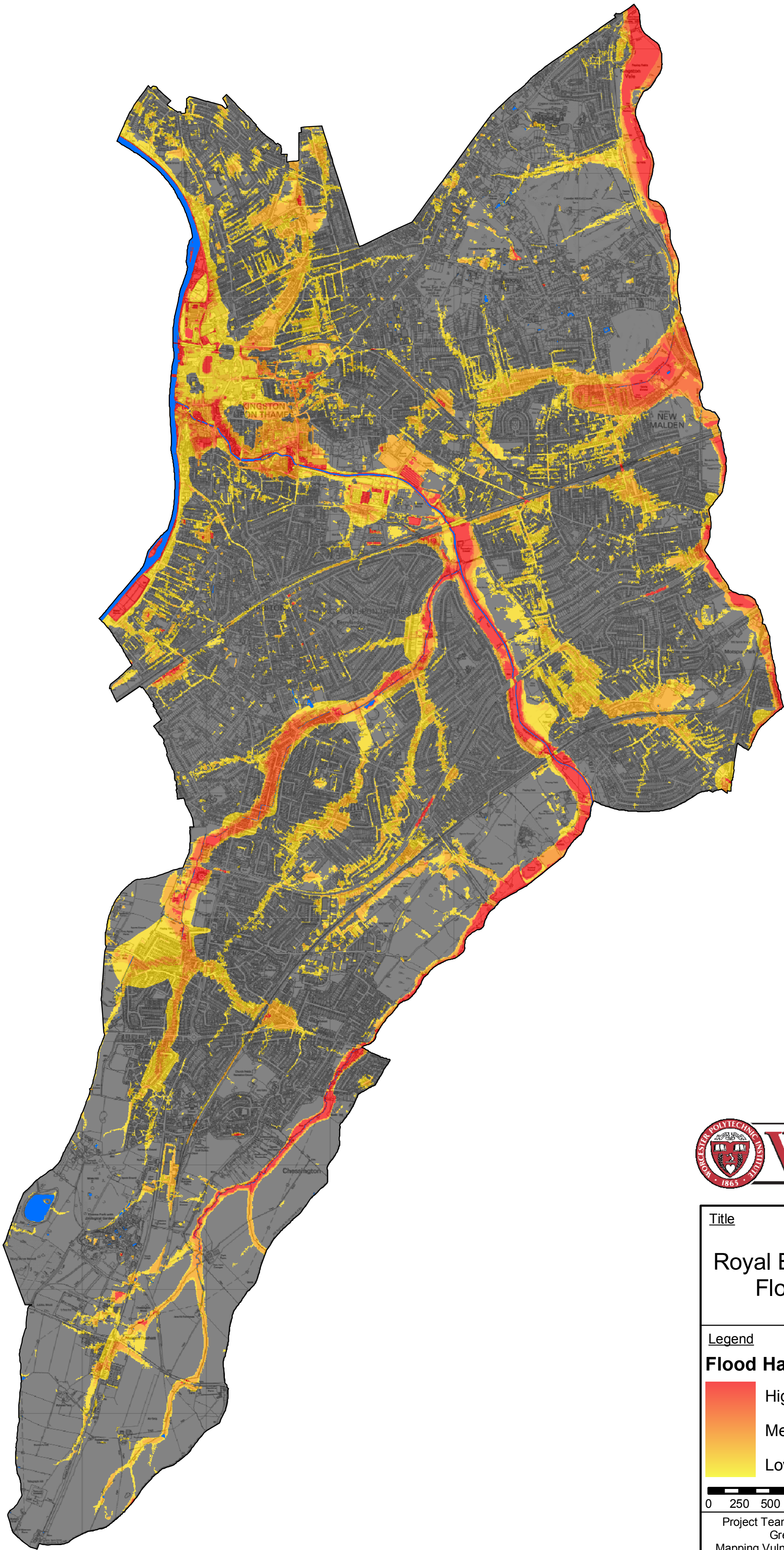

Title

Royal Borough of Kingston Flood Hazard Map

Legend

Flood Hazard

High

Medium

Low

Watercourses

Meters
0 250 500 1,000 1,500 2,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

Dwn: flood_haz_2

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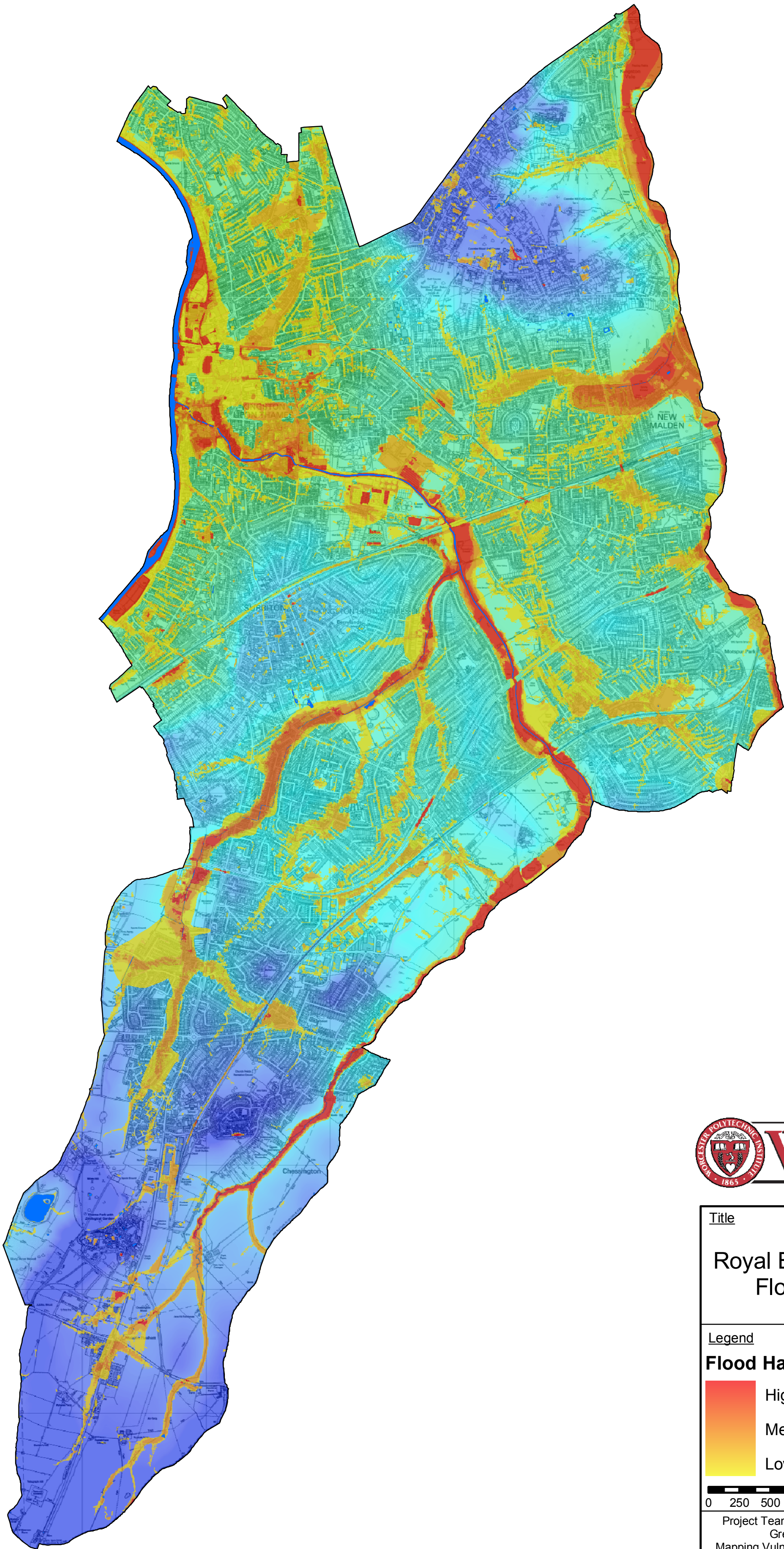

Title

Royal Borough of Kingston Flood Hazard Map

Legend

Flood Hazard
- High
- Medium
- Low

Watercourses

Elevation (m)
- High : 91.47
- Low : -1.75

0 250 500 1,000 1,500 2,000 Meters

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

Dwn: flood_haz_3

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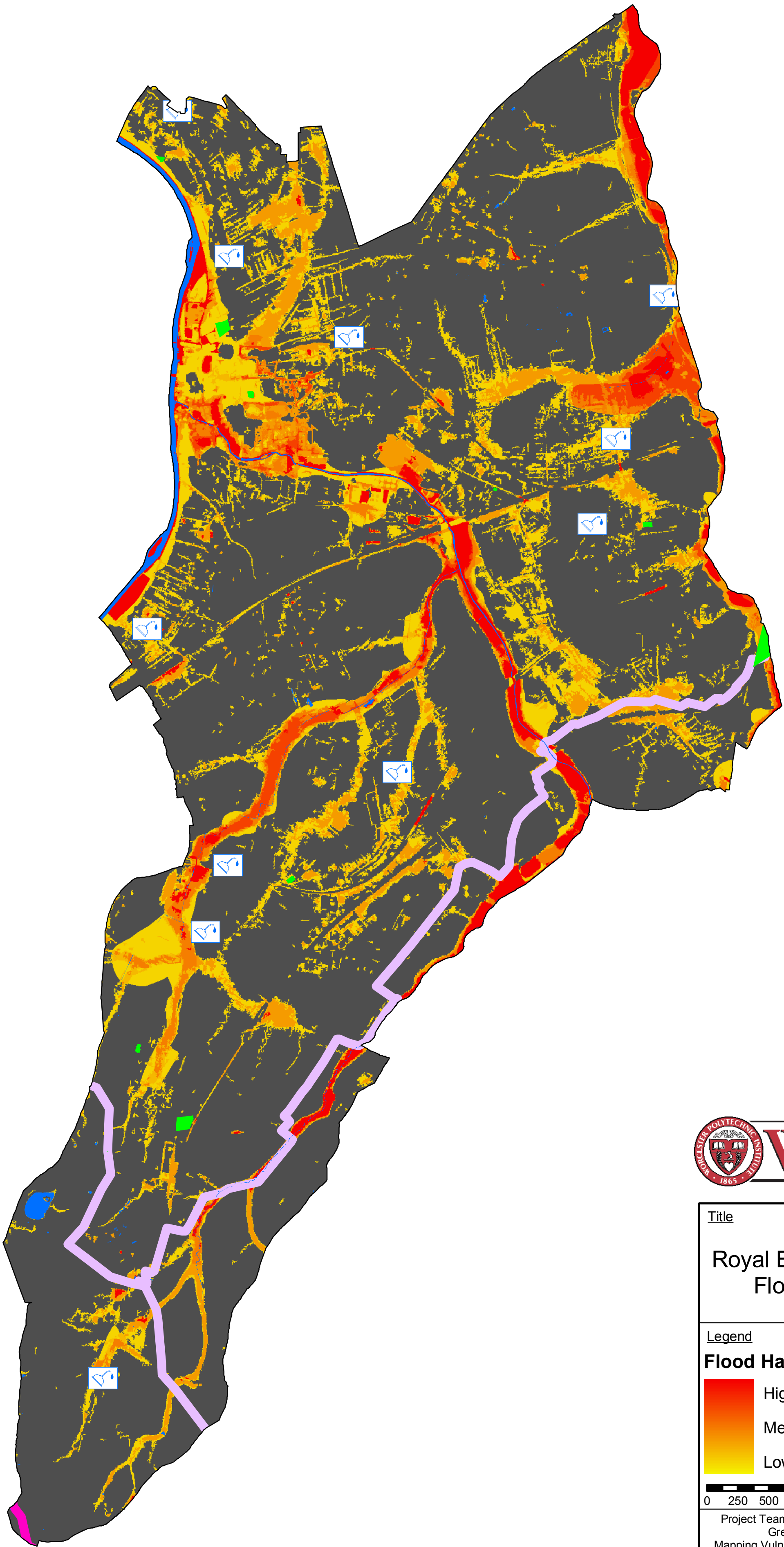

Title

Royal Borough of Kingston Flood Hazard Map

Legend

Flood Hazard

High

Medium

Low

Petrol Stations

Gas Holders

Gas Pipeline

Oil Pipeline

Watercourses

0 250 500 1,000 1,500 2,000 Meters

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

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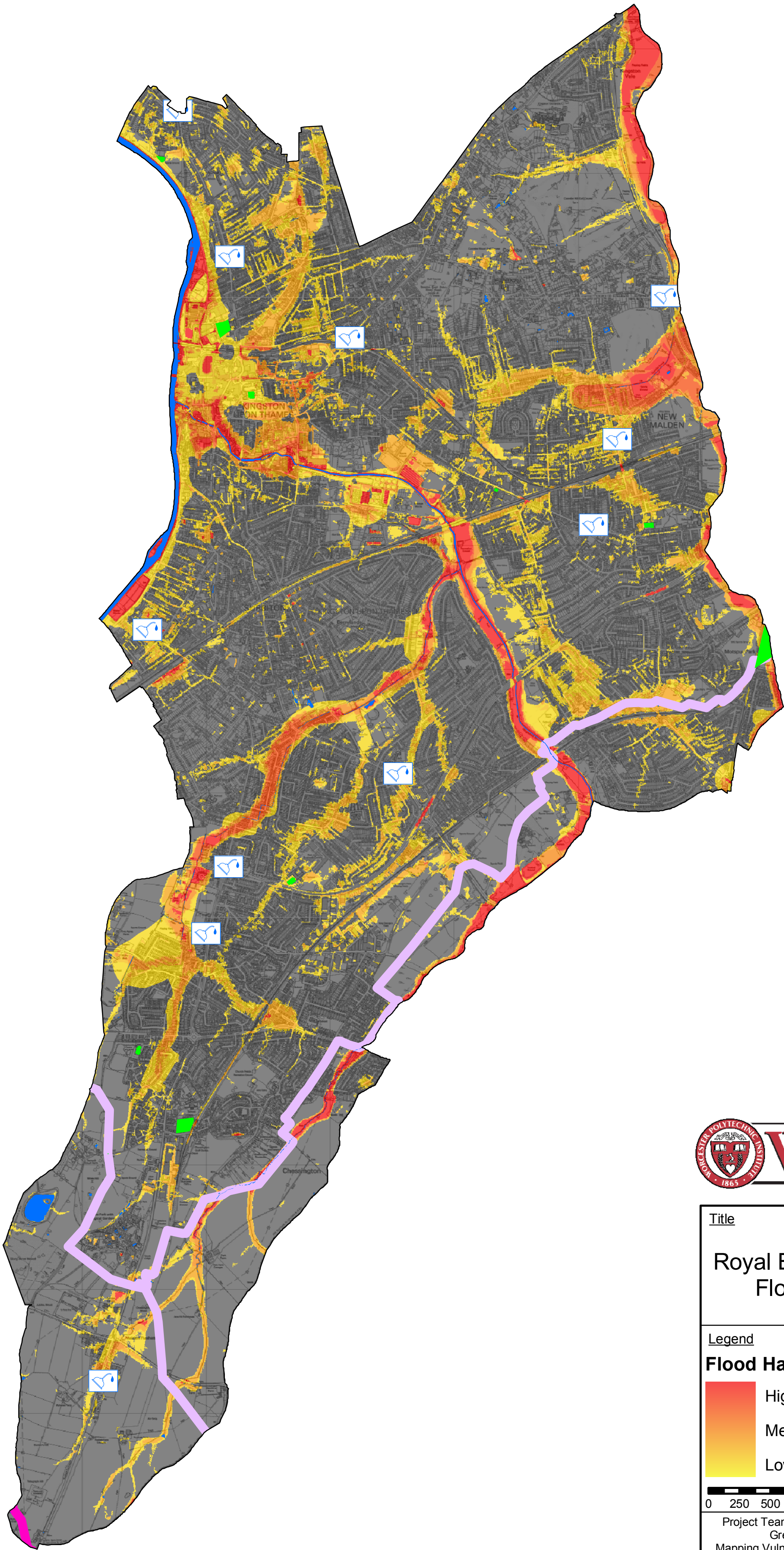

WPI Royal Kingston

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

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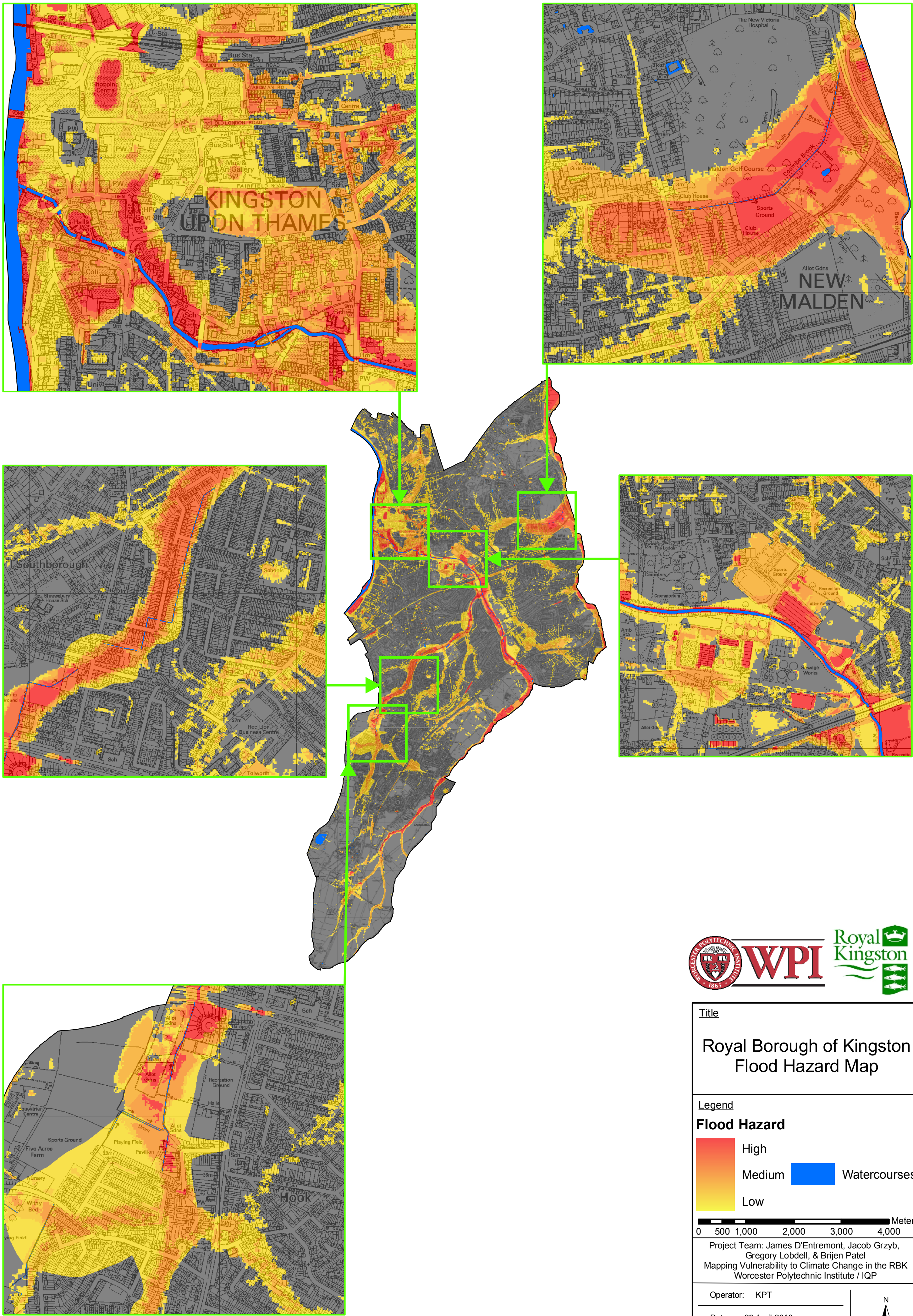

Title

Royal Borough of Kingston Flood Hazard Map

Legend

Flood Hazard

High

Medium

Low

Watercourses

Meters

0 500 1,000 2,000 3,000 4,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
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Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

Dwn: flood_haz_6

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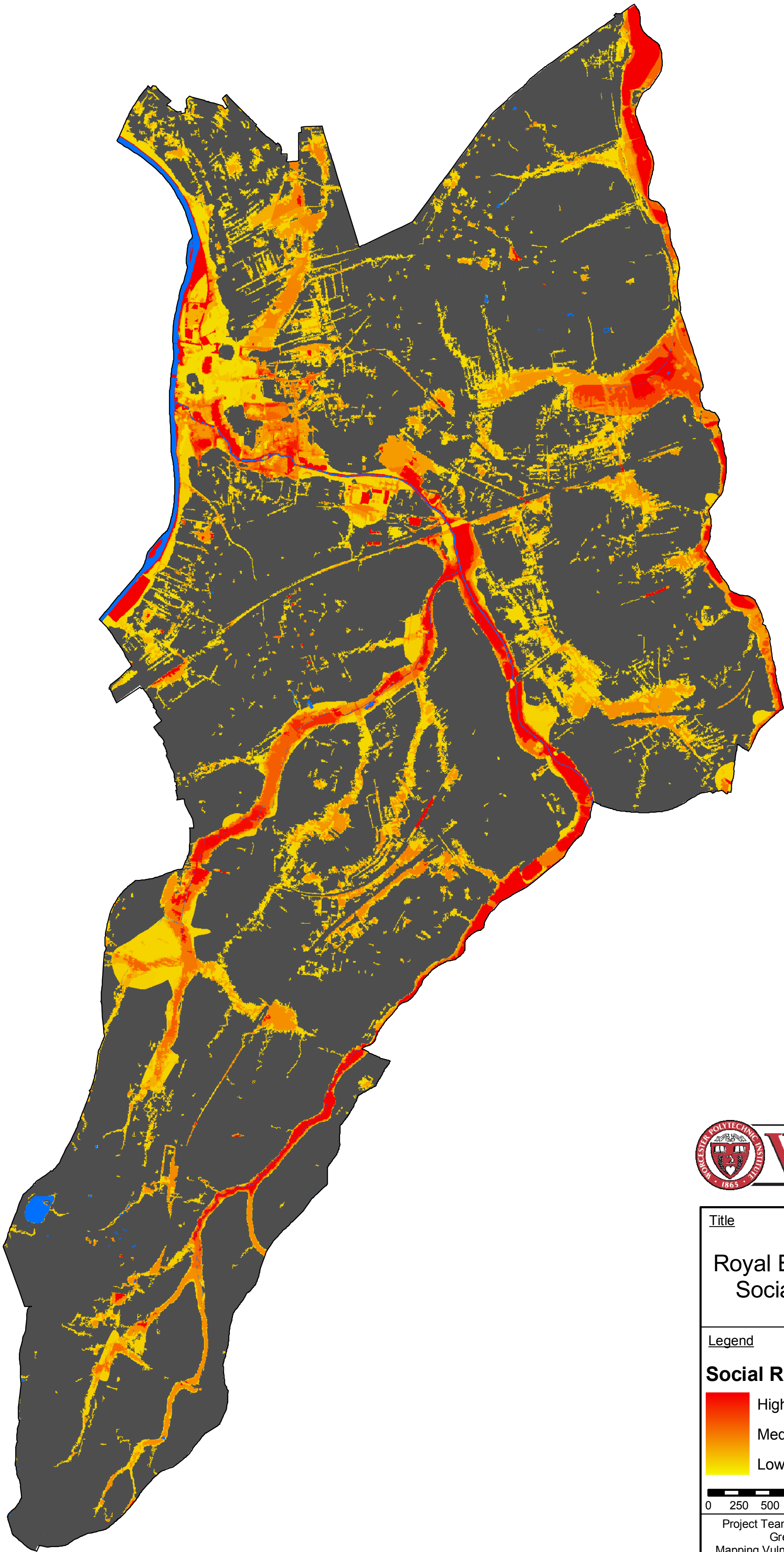

Title

Royal Borough of Kingston Social Flood Risk Map

Legend

Social Risk

High
Medium
Low
Watercourses

Meters
0 250 500 1,000 1,500 2,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

Dwn: soc_risk_1

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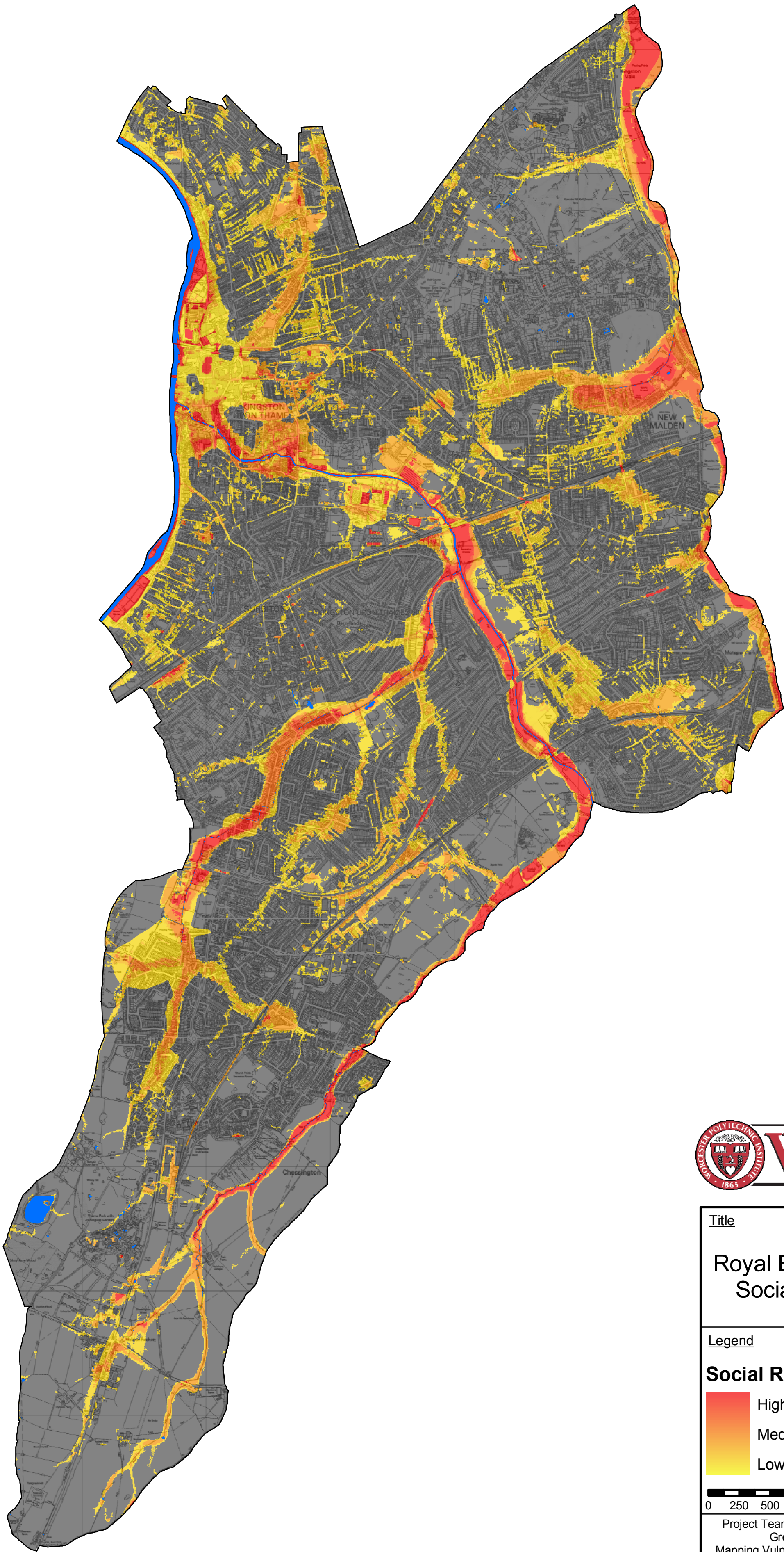

Title

Royal Borough of Kingston Social Flood Risk Map

Legend

Social Risk

High

Medium

Low

Watercourses

Meters

0 250 500 1,000 1,500 2,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
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Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

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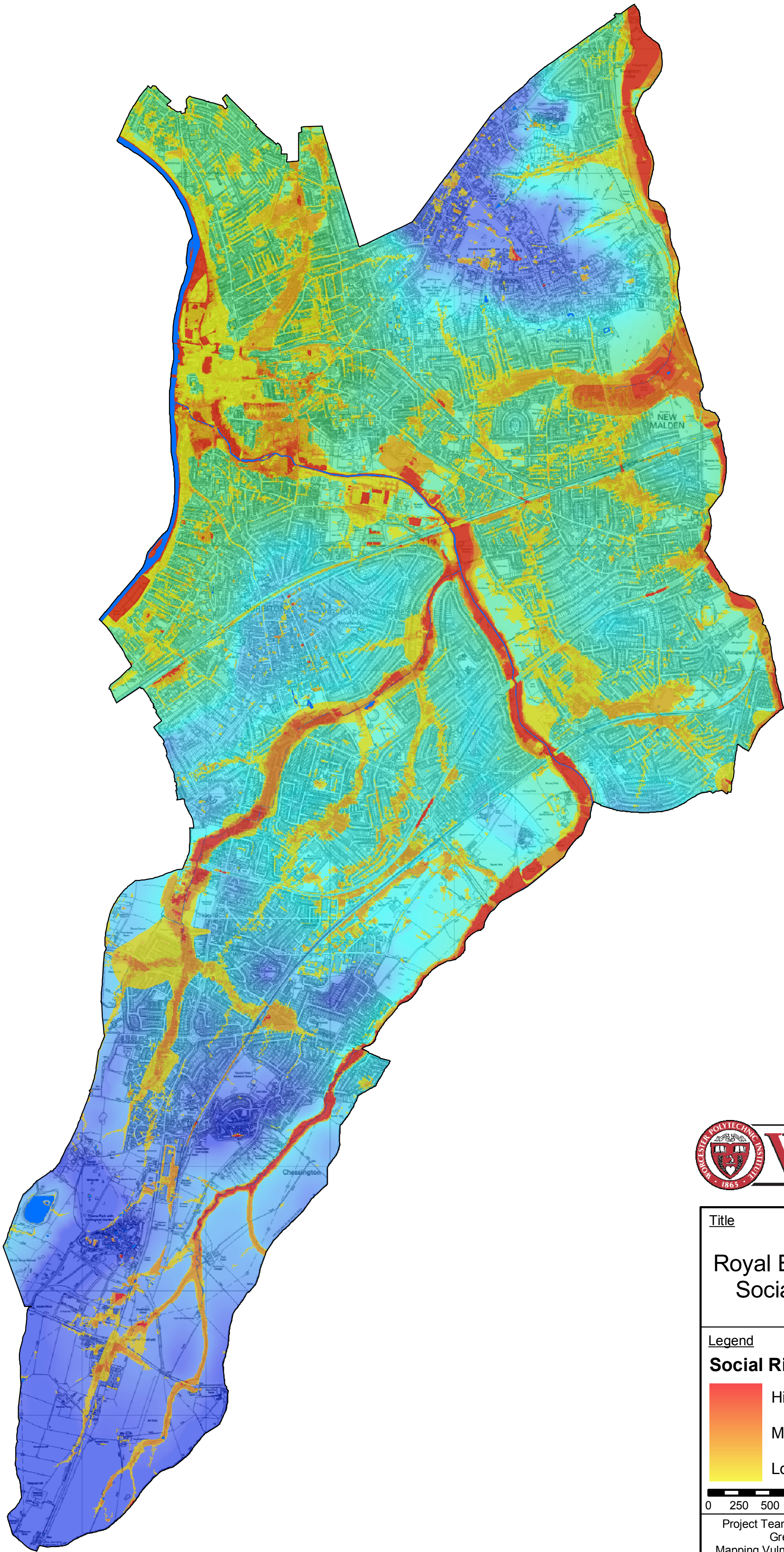

Title

Royal Borough of Kingston Social Flood Risk Map

Legend

Watercourses

Social Risk

High

Medium

Low

Elevation (m)

High : 91.47

Low : -1.75

Meters

0 250 500 1,000 1,500 2,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
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Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

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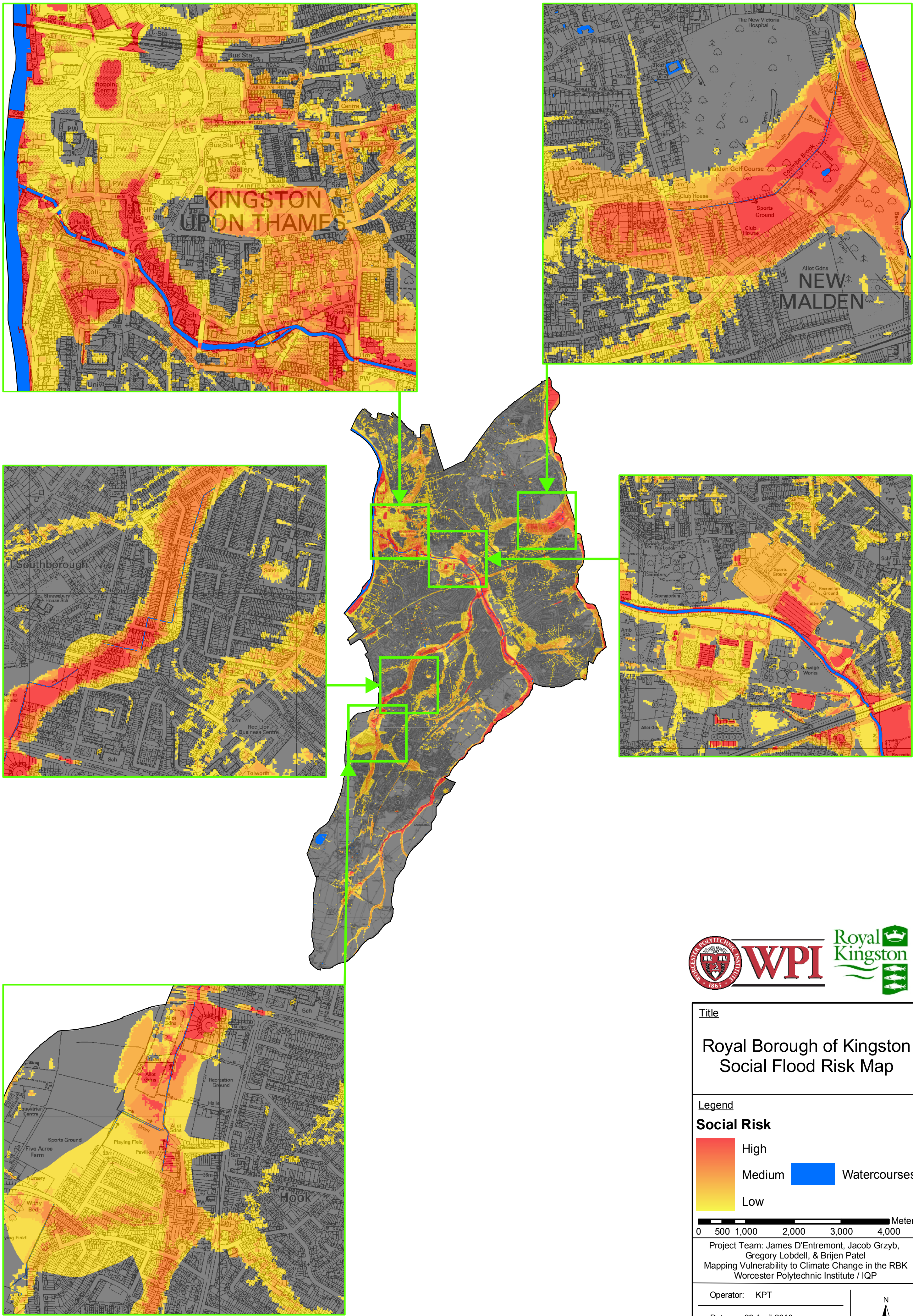

Title

Royal Borough of Kingston Social Flood Risk Map

Legend

Social Risk

High

Medium

Low

Watercourses

Meters

0 500 1,000 2,000 3,000 4,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel

Mapping Vulnerability to Climate Change in the RBK

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Operator: KPT

Date: 29 April 2010

Dwn: soc_risk_4

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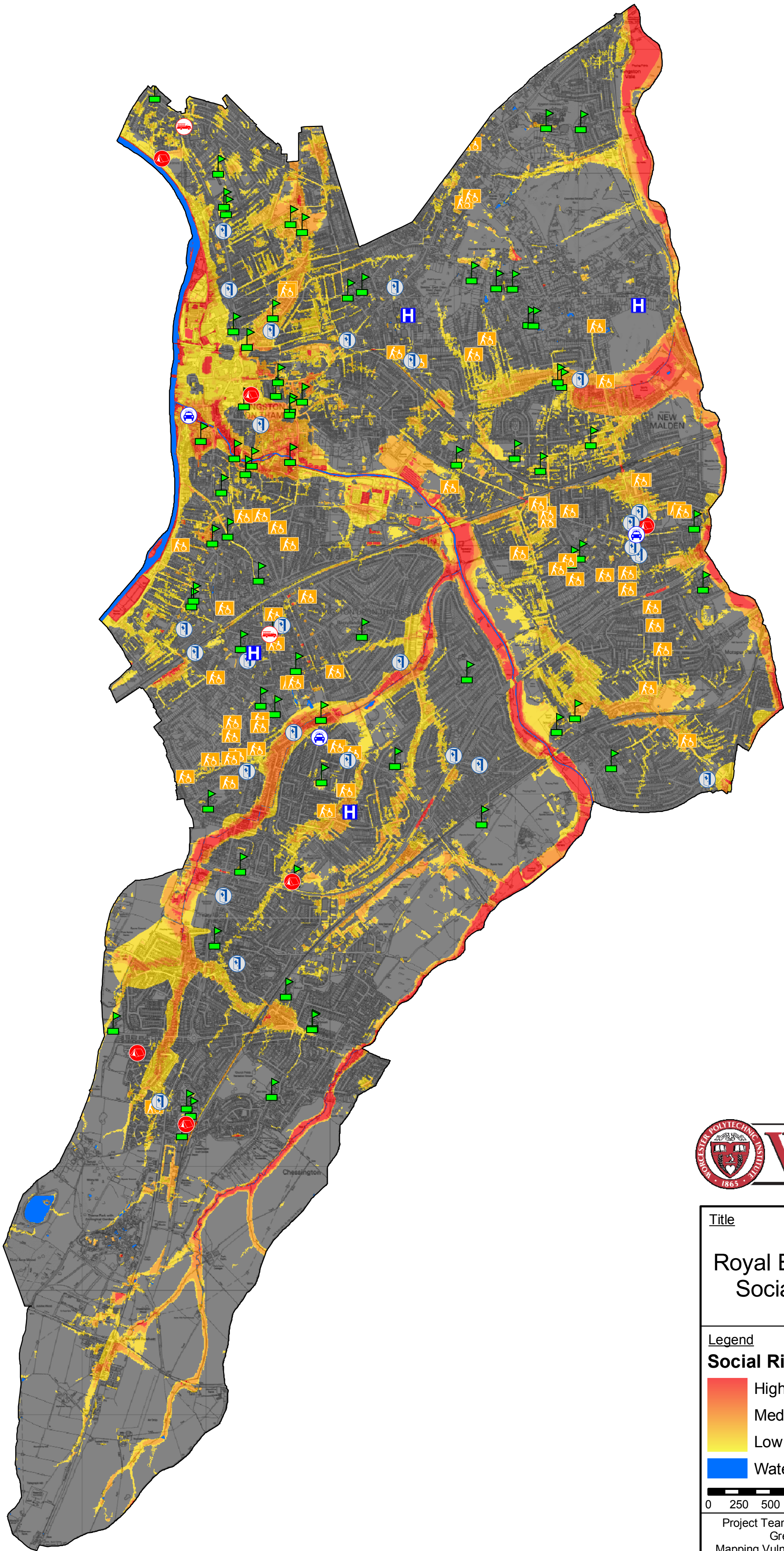

Title

Royal Borough of Kingston Social Flood Risk Map

Legend

Social Risk

- High
- Medium
- Low
- Watercourses

- Fire Stations
- Police Stations
- Hospitals
- Medical Centres
- Rest Centres
- Community Care
- Education Facilities

0 250 500 1,000 1,500 2,000 Meters

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel

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Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

Dwn: soc_risk_5

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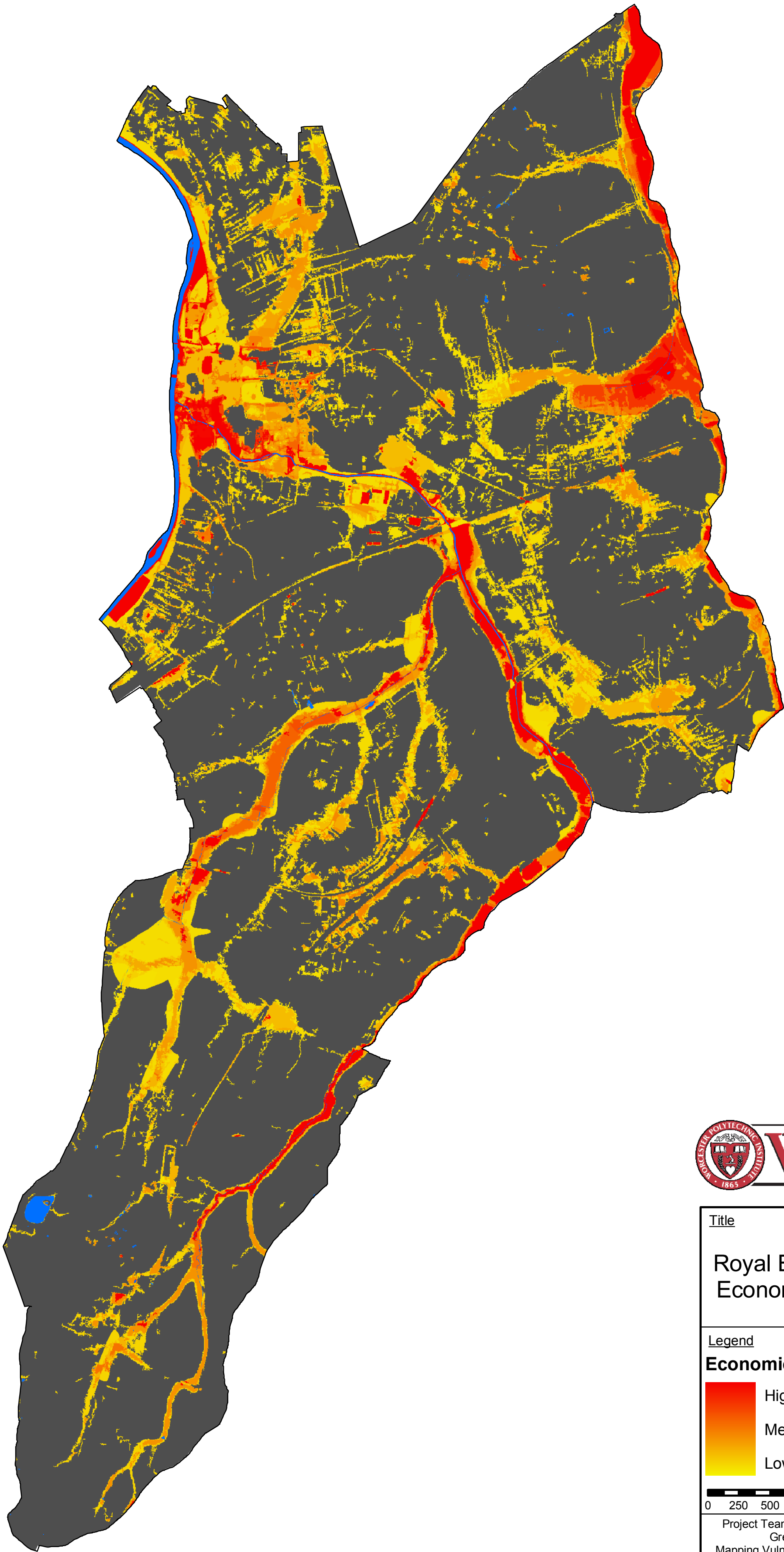

Title

Royal Borough of Kingston Economic Flood Risk Map

Legend

Economic Risk

High

Medium

Low

Watercourses

Meters

0 250 500 1,000 1,500 2,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel

Mapping Vulnerability to Climate Change in the RBK

Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

Dwn: eco_risk_1

N

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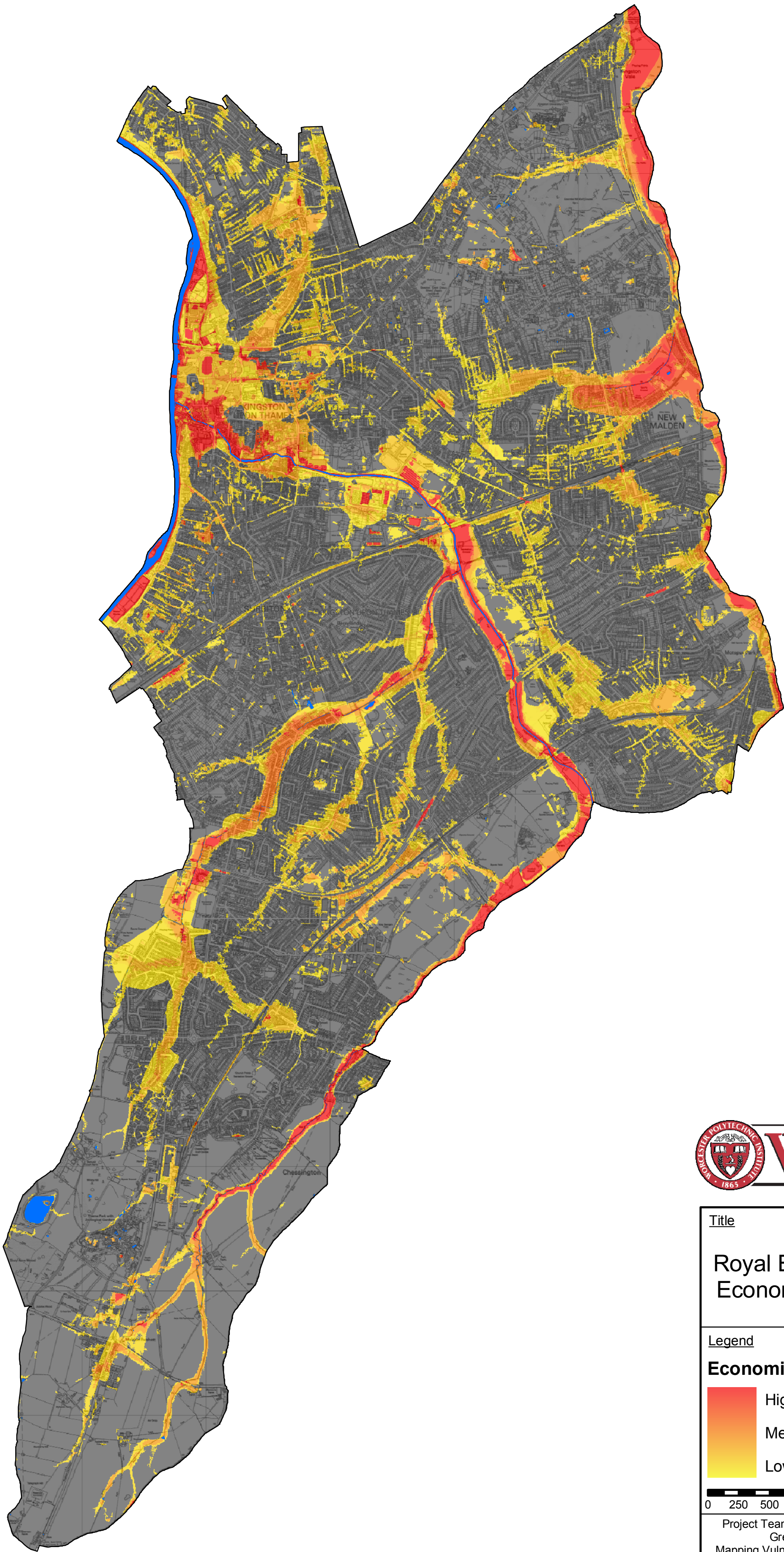

Title

Royal Borough of Kingston Economic Flood Risk Map

Legend

Economic Risk

High

Medium

Low

Watercourses

Meters
0 250 500 1,000 1,500 2,000

Project Team: James D'Entremont, Jacob Grzyb,
Gregory Lobdell, & Brijen Patel
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Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

Dwn: eco_risk_2

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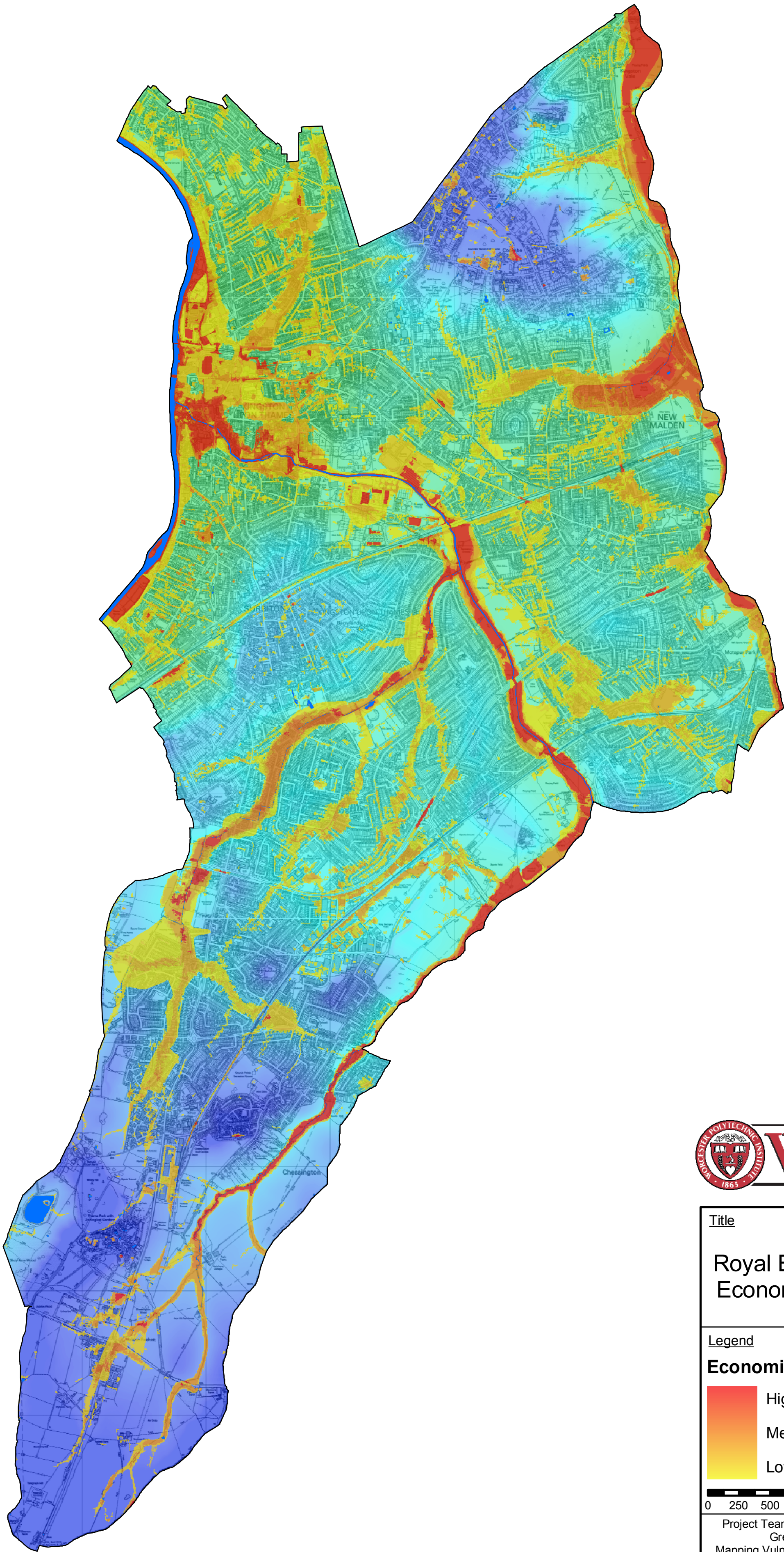

Title

Royal Borough of Kingston Economic Flood Risk Map

Legend

Economic Risk

High

Medium

Low

Watercourses

Elevation (m)

High : 91.47

Low : -1.75

Meters

0 250 500 1,000 1,500 2,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

Dwn: eco_risk_3

N

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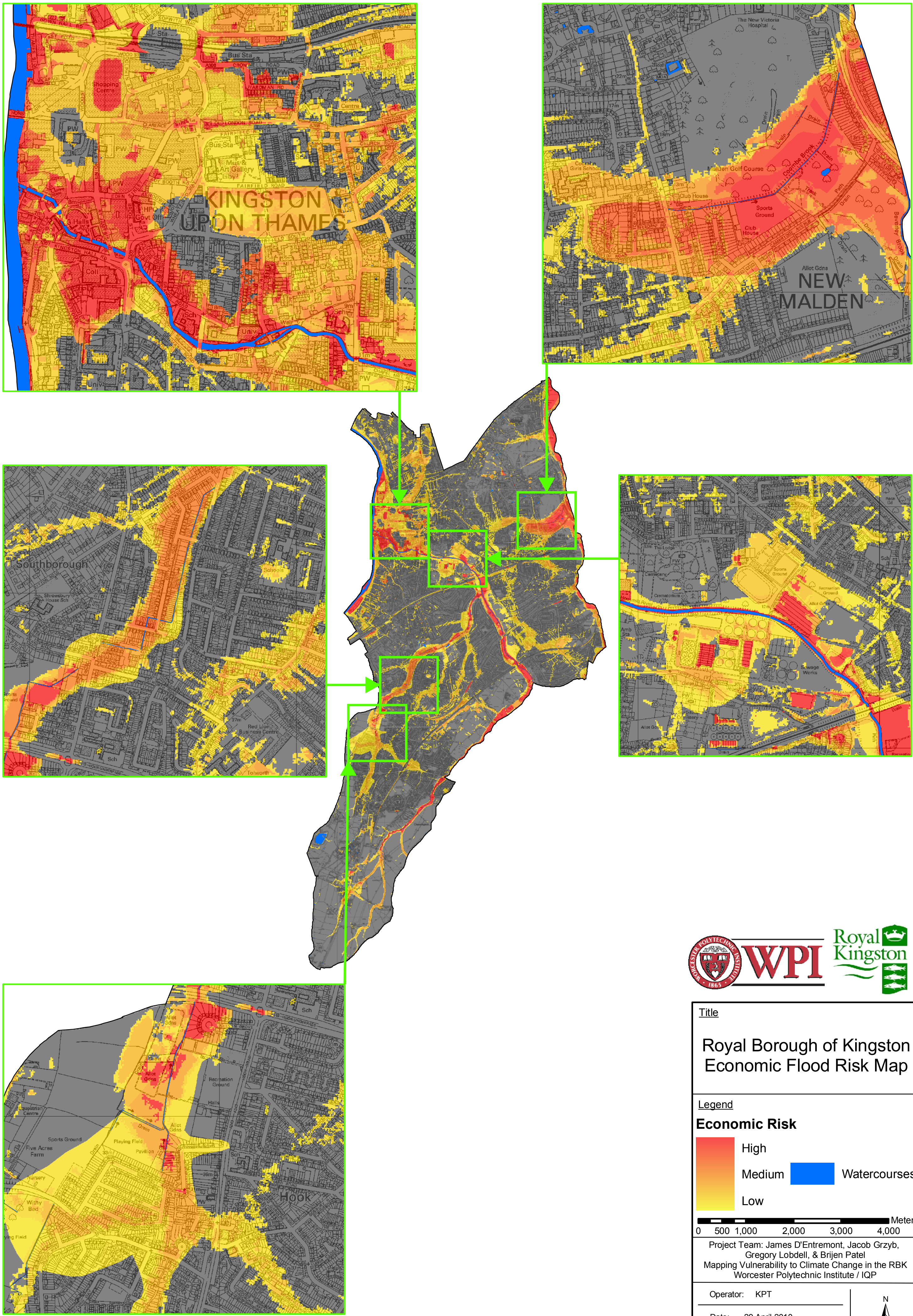


Title

Royal Borough of Kingston Economic Flood Risk Map

Legend

Economic Risk

High

Medium

Low

Watercourses

Meters

0 500 1,000 2,000 3,000 4,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

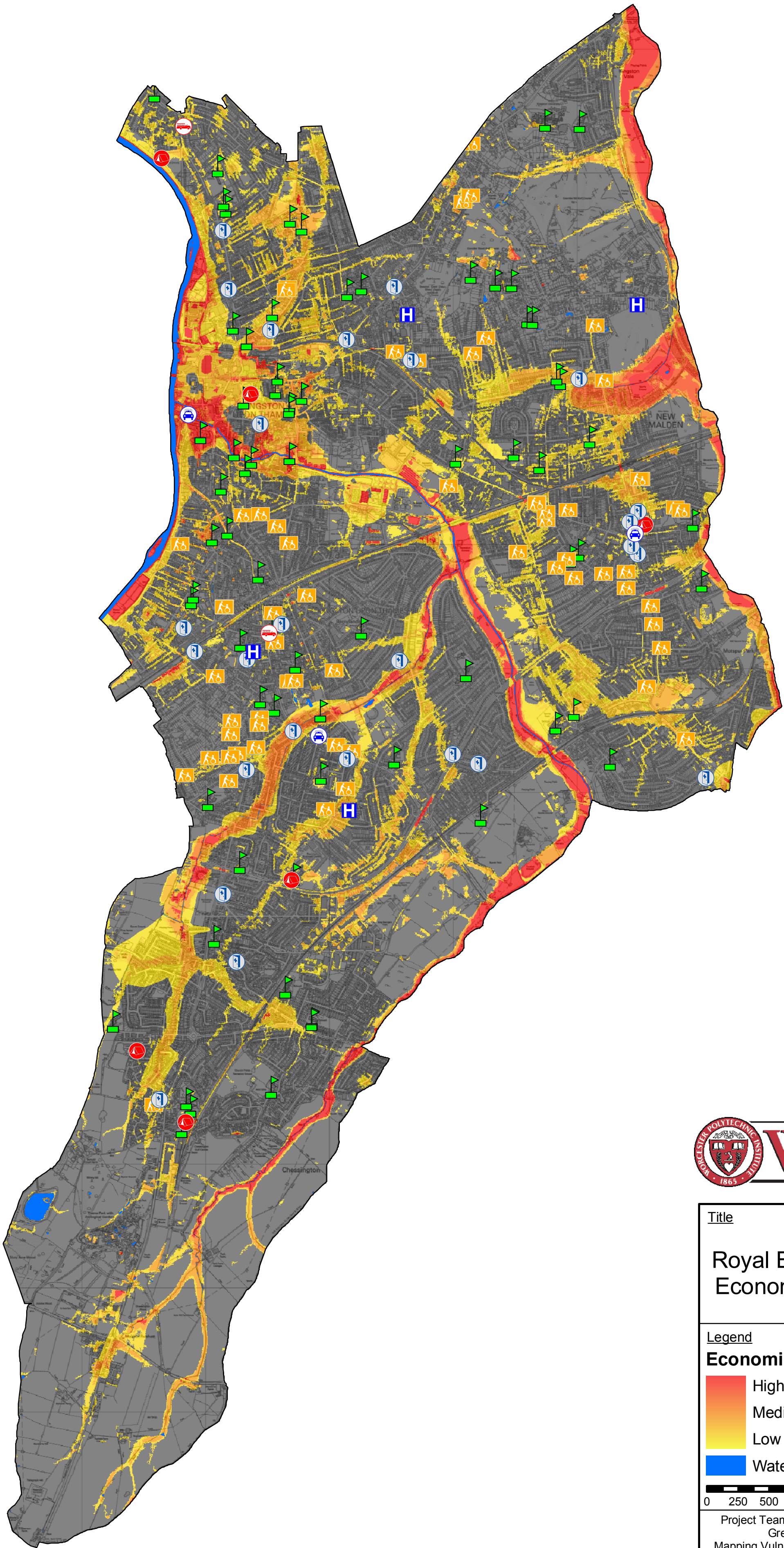
Operator: KPT

Date: 29 April 2010

Dwn: eco_risk_4

N

1:100,000



Title

Royal Borough of Kingston Economic Flood Risk Map

Legend

Economic Risk

- High
- Medium
- Low
- Watercourses

- Fire Stations
- Police Stations
- Hospitals
- Medical Centres
- Rest Centres
- Community Care
- Education Facilities

Meters: 0, 250, 500, 1,000, 1,500, 2,000

Project Team: James D'Entremont, Jacob Grzyb, Gregory Lobdell, & Brijen Patel
Mapping Vulnerability to Climate Change in the RBK
Worcester Polytechnic Institute / IQP

Operator: KPT

Date: 29 April 2010

Dwn: eco_risk_5

N

1:50,000

Appendix B: Vulnerability Map Iteration Tables

Iteration	Variables Used		Score Calculation Method	Data Display Method	Notes
First Iteration	Works from Home	Identified Health status as "Not Good"	Bell, McFarland, and Innerd (2008)	Equal Interval	
	Age (0-7, 75+)	Long Term Limiting Illness			
	Single Parent Households	Born in Less Economically Developed Countries			
	Low Qualifications (None - 1)	Provide 50+ Hours of Unpaid Care			
	Self-Employed				
Second Iteration	Works from Home	Identified Health status as "Not Good"	Chakraborty, Tobin, and Montz (2005)	Equal Interval	
	Age (0-7, 75+)	Long Term Limiting Illness			
	Single Parent Households	Born in Less Economically Developed Countries			
	Low Qualifications (None - 1)	Provide 50+ Hours of Unpaid Care			
	Self-Employed				

Iteration	Variables Used		Score Calculation Method	Data Display Method	Notes
Third Iteration	Income*	Disability**	Chakraborty, Tobin, and Montz (2005)	Equal Interval	*Income data not available and was supplemented by: on state benefit, unemployed, and lowest grade workers **Disability data not available supplemented by long-term limiting illness and health identified as not good ***Data inapplicable
	Age (0-7, 75+)	Households per LSOA			
	Population per LSOA	No Vehicle			
	No Telephone***	Mobile Homes per LSOA***			
	Institutionalized population in group quarters***				
Fourth Iteration	Income*	Disability**	Chakraborty, Tobin, and Montz (2005)	Equal Interval	*Income data not available and was supplemented by: on state benefit, unemployed, and lowest grade workers **Disability data not available supplemented by long-term limiting illness and health identified as not good ***Data not available (non-compatible format)
	Age (0-7, 75+)	Buildings Per Area			
	Single Parent Households	Provide 50+ Hours of Unpaid Care			
	Health Facility Density***				

Iteration	Variables Used		Score Calculation Method	Data Display Method	Notes
Fifth Iteration	Income*	Disability**	Chakraborty, Tobin, and Montz (2005)	Quintile	*Income data not available and was supplemented by: on state benefit, unemployed, and lowest grade workers **Disability data not available supplemented by long-term limiting illness and health identified as not good ***Data not available (non-compatible format)
	Age (0-7, 75+)	Buildings Per Area			
	Single Parent Households	Provide 50+ Hours of Unpaid Care			
	Health Facility Density***				
Final Social Map	Income*	Disability**	Chakraborty, Tobin, and Montz (2005)	Quintile	*Income data not available and was supplemented by: on state benefit, unemployed, and lowest grade workers **Disability data not available supplemented by long-term limiting illness and health identified as not good
	Age (0-7, 75+)	Population per LSOA			
	Single Parent Households	Provide 50+ Hours of Unpaid Care			
Final Economic Map	Area of Non-Domestic Buildings	Work From Home	Chakraborty, Tobin, and Montz (2005)	Quintile	*Data only available in MSOA format, converted to LSOA format but resulted in heavy groupings
	Self-Employed	Employment Location*			

Appendix C: Vulnerability Variable Commonality Tables

Economic Variables							
Variable	Data Source	Cutter	MLO	CTM	FEMA	Bell/McFarland	H+M
No Commonalities							
Location of Workplace (works at home)	Census					x	
High Number of Business Sole Traders	Census					x	
Employment Loss (Employment Density)	ONS Data	x					
Residential Property	Land Use	x					
Business Losses	N/A				x		
Cost of Replacement	N/A				x		
Rental Vacancy Rates	N/A				x		
Two Commonalities							
Work Facility Conditions	N/A		x		x		
Commercial and Industrial Density	Land Use	x				x	
Socioeconomic Status	Census	x				x	
Four Commonalities							
Buildings Per Area	Land Use	x		x	x	x	

Social Variables							
Variable	**Data Source**	**Cutter**	**MLO**	**CTM**	**FEMA**	**Bell/McFarland**	**H+M**
No Commonalities							
Economic Class in Country of Birth	Census					x	
Unpaid Care	Census					x	
Qualifications	Census					x	
Employment Density	Census (travel data)					x	
Financial Support	Benefits Layer					x	
Migrant Population Levels	Census					x	
Number of Voluntary Organizations	N/A					x	
Housing Conditions	N/A		x				
Homelessness	N/A (Unmappable)		x				
Occupation	Census	x					
Population Growth	Census	x					
Race and Ethnicity	Census	x					
Housing Type*	Census						x
Housing Construction Period	N/A						x
Two Commonalities							
Speak Local Language	N/A					x	x
Renters	Census	x					x
Education	Census	x				x	
Owns Vehicle	Census			x	x		
Social Dependency (Household Support)	Census	x	x				
Three Commonalities							
Population (Day/Night)	Census (Night only)			x	x	x	
Gender	Census	x	x				x
Four Commonalities							
Single Parent Households	Census	x	x			x	x
Income	Census		x	x	x		x

* (single detached, semidetached, row houses, detached duplexes, other single detached homes; mobile or moveable dwellings)

Health Variables							
Variable	**Data Source**	**Cutter**	**MLO**	**CTM**	**FEMA**	**Bell/McFarland**	**H+M**
No Commonalities							
Current Health	**Census**					**x**	
Level of Physical Activity (at work)	**N/A**		**x**				
Works Outside	**N/A**		**x**				
Use of Medication/Substances	**N/A**		**x**				
Three Commonalities							
Long Term Illness	**Census**		**x**			**x**	
Four Commonalities							
Disabilities	**N/A**	**x**	**x**	**x**		**x**	
Seven Commonalities							
Age	**Census**	**x**	**x**	**x**	**x**	**x**	**x**

Infrastructure Variables							
Variable	**Data Source**	**Cutter**	**MLO**	**CTM**	**FEMA**	**Bell/McFarland**	**H+M**
No Commonalities							
Shelter Locations	**N/A**				**x**		
Hazardous Material Sites	**Points of Interest**				**x**		
Location of Schools	**Points of Interest**				**x**		
Infrastructure and Lifelines **	**N/A**	**x**					
Two Commonalities							
Access to Transportation	**ATT Layer**				**x**	**x**	
Location of Emergency Facilities	**Points of Interest**	**x**			**x**		
Three Commonalities							
Health Facility Density	**N/A (Data incompatible)**	**x**			**x**	**x**	

** Loss of sewers, bridges, water, communications, and transportation infrastructure

Appendix D: Summer and Winter UKCIP Projections for Kingston

Summer UKCIP Projections for Kingston

Change in Temperature on the Warmest Day
High Emissions Scenario
Under a high emissions scenario, the central estimate of the change in temperature of the warmest day during the summer in Kingston is 2.1 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than -1.8 °C and a 90% probability that it will be less than 6.2 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the warmest day during the summer in Kingston is 2.9 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than -2.1 °C and a 90% probability that it will be less than 8.7 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the warmest day during the summer in Kingston is 4.2 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than -2.4 °C and a 90% probability that it will be less than 12.5 °C.

Medium Emissions Scenario
Under a medium emissions scenario, the central estimate of the change in temperature of the warmest day during the summer in Kingston is 2.0 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than -1.6 °C and a 90% probability that it will be less than 6.0 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the warmest day during the summer in Kingston is 2.4 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than -1.7 °C and a 90% probability that it will be less than 7.5 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the warmest day during the summer in Kingston is 3.2 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than -2.2 °C and a 90% probability that it will be less than 10.0 °C.

Change in Temperature of the Coolest Day
High Emissions Scenario
Under a high emissions scenario, the central estimate of the change in temperature of the coolest day during the summer in Kingston is 1.4 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than -0.2 °C and a 90% probability that it will be less than 3.1 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the coolest day during the summer in Kingston is 2.1 °C by the 2050s (2040-2069). There is a 90%

probability that it will be greater than 0.2 °C and a 90% probability that it will be less than 4.2 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the coolest day during the summer in Kingston is 2.9 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than 0.3 °C and a 90% probability that it will be less than 6.0 °C.

Medium Emissions Scenario
Under a medium emissions scenario, the central estimate of the change in temperature of the coolest day during the summer in Kingston is 1.3 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than 0 °C and a 90% probability that it will be less than 2.8 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the coolest day during the summer in Kingston is degrees 1.7 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than 0 °C and a 90% probability that it will be less than 3.6 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the coolest day during the summer in Kingston is degrees 2.4 C by the 2080s (2070-2099). There is a 90% probability that it will be greater than 0.1 °C and a 90% probability that it will be less than 5.0 °C.

Change in Temperature of the Warmest Night
High Emissions Scenario
Under a high emissions scenario, the central estimate of the change in temperature of the warmest night during the summer in Kingston is 1.7 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than -0.2 °C and a 90% probability that it will be less than 3.7 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the warmest night during the summer in Kingston is 2.7 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than 0.2 °C and a 90% probability that it will be less than 5.4 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the warmest night during the summer in Kingston is 4.5 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than 1.5 °C and a 90% probability that it will be less than 8.2 °C.

Medium Emissions Scenario
Under a medium emissions scenario, the central estimate of the change in temperature of the warmest night during the summer in Kingston is 1.8 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than -0.2 °C and a 90% probability that it will be less than 3.8 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the warmest night during the summer in Kingston is 2.5 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than 0.3 °C and a 90% probability that it will be less than 4.9 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the warmest night during the summer in Kingston is 3.3 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than 0.6 °C and a 90% probability that it will be less than 6.5 °C.

Change in Temperature of the Coolest Night
High Emissions Scenario
Under a high emissions scenario, the central estimate of the change in temperature of the coolest night during the summer in Kingston is 1.5 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than 0.2 °C and a 90% probability that it will be less than 3.1 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the coolest night during the summer in Kingston is 2.1 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than 0.5 °C and a 90% probability that it will be less than 4.3 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the coolest night during the summer in Kingston is 3.1 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than 0.7 °C and a 90% probability that it will be less than 6.5 °C.

Medium Emissions Scenario
Under a medium emissions scenario, the central estimate of the change in temperature of the coolest night during the summer in Kingston is 1.4 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than degrees 0.2 C and a 90% probability that it will be less than 2.9 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the coolest night during the summer in Kingston is 1.9 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than 0.4 °C and a 90% probability that it will be less than 3.9 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the coolest night during the summer in Kingston is 2.5 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than 0.6 °C and a 90% probability that it will be less than 5.2 °C.

Change in Precipitation on the Wettest Day
High Emissions Scenario

Under a high emissions scenario, the central estimate of the change in precipitation on the wettest day during the summer in Kingston is -3.0 % by the 2030s (2020-2049). There is a 90% probability that it will be greater than -24.2 % and a 90% probability that it will be less than 23.8 %.

Under a high emissions scenario, the central estimate of the change in precipitation on the wettest day during the summer in Kingston is -6.2 % by the 2050s (2040-2069). There is a 90% probability that it will be greater than -28.5 % and a 90% probability that it will be less than 22 %.

Under a high emissions scenario, the central estimate of the change in precipitation on the wettest day during the summer in Kingston is -13.1 % by the 2080s (2070-2099). There is a 90% probability that it will be greater than -38.3 % and a 90% probability that it will be less than 19.4 %.

Medium Emissions Scenario

Under a medium emissions scenario, the central estimate of the change in precipitation on the wettest day during the summer in Kingston is -0.2 % by the 2030s (2020-2049). There is a 90% probability that it will be greater than -22.1 % and a 90% probability that it will be less than 27.8 %.

Under a medium emissions scenario, the central estimate of the change in precipitation on the wettest day during the summer in Kingston is -7.0 % by the 2050s (2040-2069). There is a 90% probability that it will be greater than -28.9 % and a 90% probability that it will be less than 20.9 %.

Under a medium emissions scenario, the central estimate of the change in precipitation on the wettest day during the summer in Kingston is -8.8 % by the 2080s (2070-2099). There is a 90% probability that it will be greater than -31.9 % and a 90% probability that it will be less than 20.6 %.

Winter UKCIP Projections for Kingston

Change in Temperature on the Warmest Day
High Emissions Scenario

Under a high emissions scenario, the central estimate of the change in temperature of the warmest day during the winter in Kingston is 1.39 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than 0.49 °C and a 90% probability that it will be less than 2.42 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the warmest day during the winter in Kingston is 1.92 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than 0.78 °C and a 90% probability that it will be less than 3.32 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the warmest day during the winter in Kingston is 3.19 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than 1.58 °C and a 90% probability that it will be less than 5.29 °C.

Medium Emissions Scenario
Under a medium emissions scenario, the central estimate of the change in temperature of the warmest day during the winter in Kingston is 1.29 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than 0.38 °C and a 90% probability that it will be less than 2.32 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the warmest day during the winter in Kingston is 1.78 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than 0.78 °C and a 90% probability that it will be less than 3.04 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the warmest day during the winter in Kingston is 2.38 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than 1.16 °C and a 90% probability that it will be less than 4.03 °C.

Change in Temperature of the Coolest Day
High Emissions Scenario
Under a high emissions scenario, the central estimate of the change in temperature of the coolest day during the winter in Kingston is 1.41 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than -0.42 °C and a 90% probability that it will be less than 3.31 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the coolest day during the winter in Kingston is 2.08 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than -0.09 °C and a 90% probability that it will be less than 4.42 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the coolest day during the winter in Kingston is 2.43 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than -0.19 °C and a 90% probability that it will be less than 5.49 °C.

Medium Emissions Scenario
Under a medium emissions scenario, the central estimate of the change in temperature of the coolest day during the winter in Kingston is 1.52 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than -0.4 °C and a 90% probability that it will be less than 3.51°C.

Under a medium emissions scenario, the central estimate of the change in temperature of the coolest day during the winter in Kingston is degrees 1.81 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than -0.14 °C and a 90% probability that it will be less than 3.93 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the coolest day during the winter in Kingston is degrees 2.08 C by the 2080s (2070-2099). There is a 90% probability that it will be greater than -0.47 °C and a 90% probability that it will be less than 4.90 °C.

Change in Temperature of the Warmest Night
High Emissions Scenario
Under a high emissions scenario, the central estimate of the change in temperature of the warmest night during the winter in Kingston is 1.10 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than 0.07 °C and a 90% probability that it will be less than 2.27 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the warmest night during the winter in Kingston is 1.56 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than 0.26 °C and a 90% probability that it will be less than 3.16 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the warmest night during the winter in Kingston is 2.52 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than 0.64 °C and a 90% probability that it will be less than 4.92 °C.

Medium Emissions Scenario
Under a medium emissions scenario, the central estimate of the change in temperature of the warmest night during the winter in Kingston is 1.01 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than -0.11 °C and a 90% probability that it will be less than 2.24 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the warmest night during the winter in Kingston is 1.46 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than 0.20 °C and a 90% probability that it will be less than 2.95 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the warmest night during the winter in Kingston is 2.00 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than 0.52 °C and a 90% probability that it will be less than 3.91 °C.

Change in Temperature of the Coolest Night
High Emissions Scenario
Under a high emissions scenario, the central estimate of the change in temperature of the coolest night during the winter in Kingston is 2.15 °C by the 2030s (2020-2049). There is a 90%

probability that it will be greater than 0.38 °C and a 90% probability that it will be less than 4.02 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the coolest night during the winter in Kingston is 3.15 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than 1.04 °C and a 90% probability that it will be less than 5.5 °C.

Under a high emissions scenario, the central estimate of the change in temperature of the coolest night during the winter in Kingston is 3.87 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than 1.23 °C and a 90% probability that it will be less than 7.07 °C.

Medium Emissions Scenario

Under a medium emissions scenario, the central estimate of the change in temperature of the coolest night during the winter in Kingston is 2.18 °C by the 2030s (2020-2049). There is a 90% probability that it will be greater than degrees 0.37 C and a 90% probability that it will be less than 4.08 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the coolest night during the winter in Kingston is 2.86 °C by the 2050s (2040-2069). There is a 90% probability that it will be greater than 0.84 °C and a 90% probability that it will be less than 5.07 °C.

Under a medium emissions scenario, the central estimate of the change in temperature of the coolest night during the winter in Kingston is 3.42 °C by the 2080s (2070-2099). There is a 90% probability that it will be greater than 0.98 °C and a 90% probability that it will be less than 6.25 °C.

Change in Precipitation on the Wettest Day

High Emissions Scenario

Under a high emissions scenario, the central estimate of the change in precipitation on the wettest day during the winter in Kingston is 8.30 % by the 2030s (2020-2049). There is a 90% probability that it will be greater than -4.15 % and a 90% probability that it will be less than 23.0 %.

Under a high emissions scenario, the central estimate of the change in precipitation on the wettest day during the winter in Kingston is 11.29 % by the 2050s (2040-2069). There is a 90% probability that it will be greater than -2.50 % and a 90% probability that it will be less than 28.78 %.

Under a high emissions scenario, the central estimate of the change in precipitation on the wettest day during the winter in Kingston is 23.61 % by the 2080s (2070-2099). There is a 90% probability that it will be greater than 4.89 % and a 90% probability that it will be less than 50.69 %.

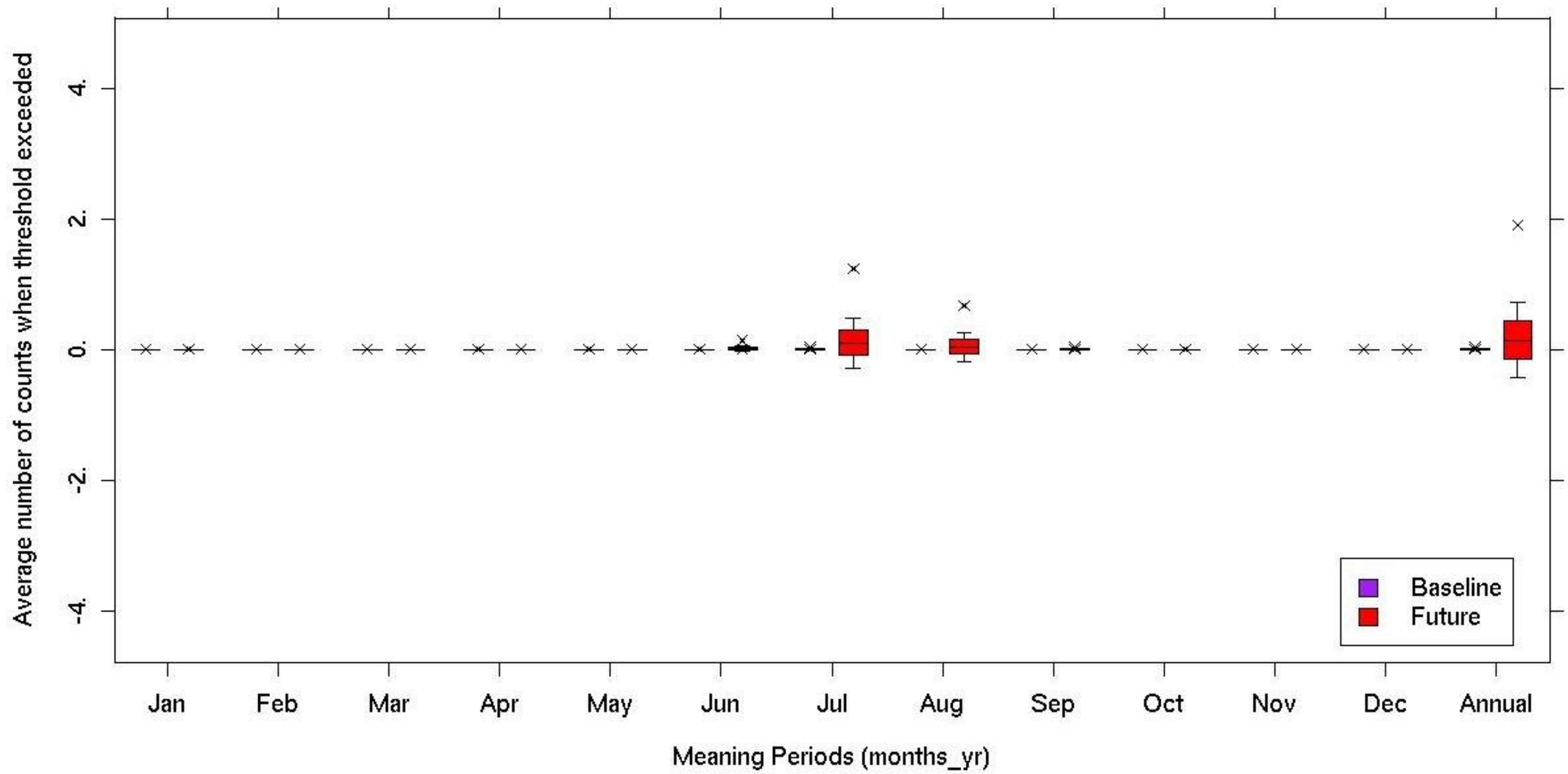
Medium Emissions Scenario
Under a medium emissions scenario, the central estimate of the change in precipitation on the wettest day during the winter in Kingston is 9.02 % by the 2030s (2020-2049). There is a 90% probability that it will be greater than -2.98 % and a 90% probability that it will be less than 23.15 %.

Under a medium emissions scenario, the central estimate of the change in precipitation on the wettest day during the winter in Kingston is 14.35 % by the 2050s (2040-2069). There is a 90% probability that it will be greater than 1.14 % and a 90% probability that it will be less than 30.97 %.

Under a medium emissions scenario, the central estimate of the change in precipitation on the wettest day during the winter in Kingston is 17.41 % by the 2080s (2070-2099). There is a 90% probability that it will be greater than 1.92 % and a 90% probability that it will be less than 38.82 %.

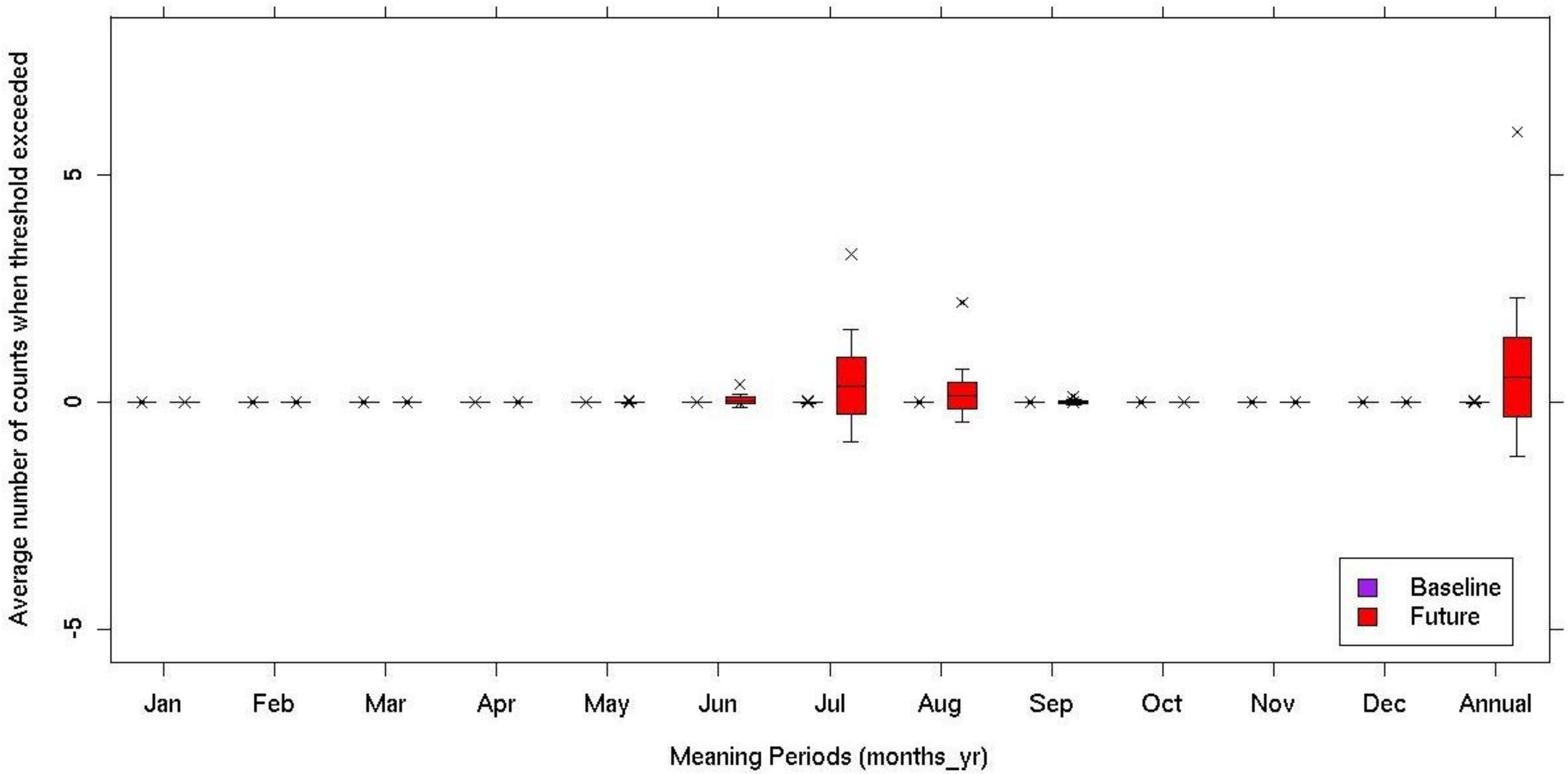
Appendix E: Weather Generator UKCIP Projections for Kingston

Number of Heat Waves under a High Emissions Scenario during the 2030s (2020-2049)



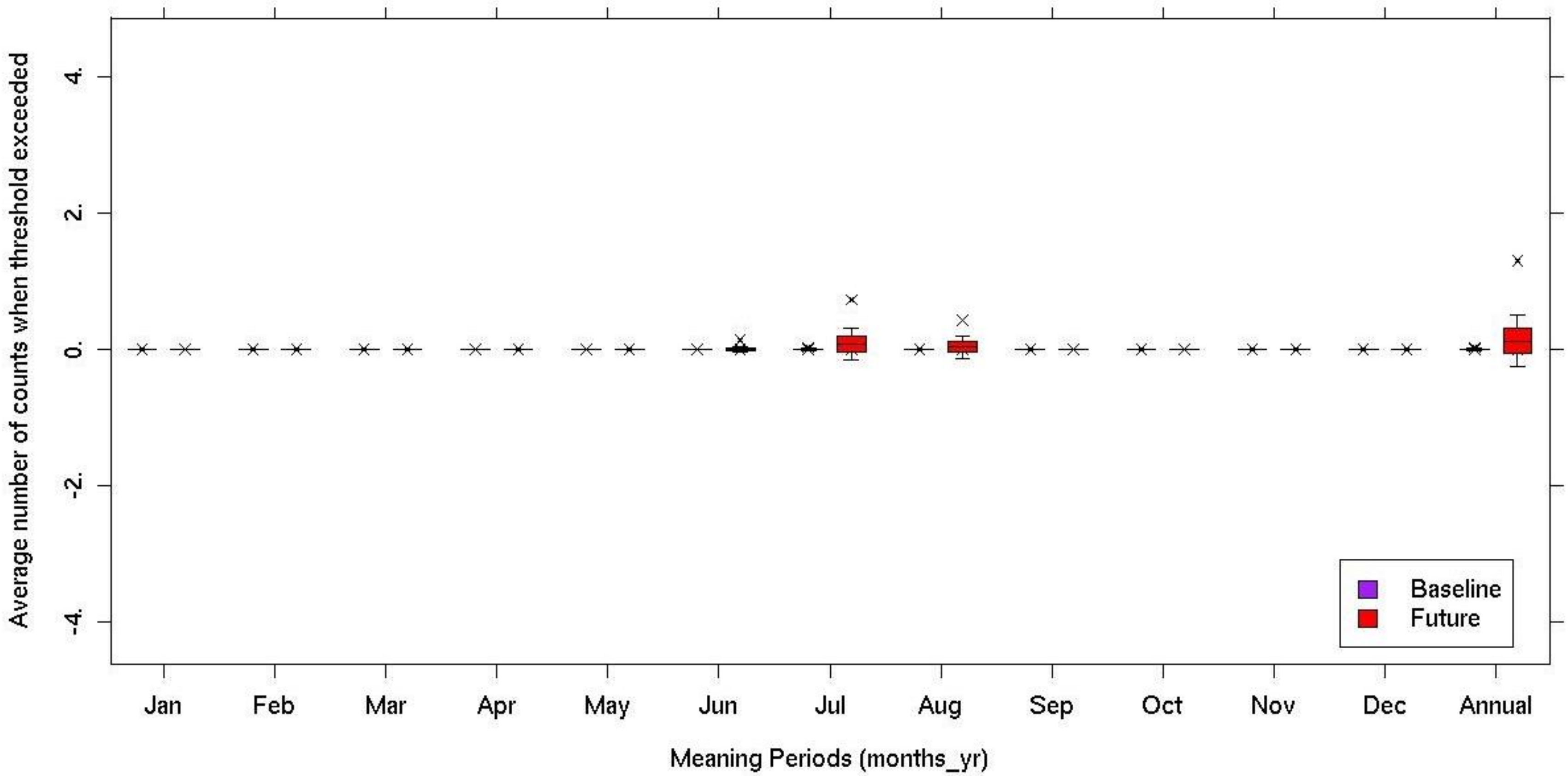
Under a high emissions scenario, the Royal Borough of Kingston will experience an average of approximately 0.1 heat waves a year during the 2030s (2020 – 2049). It will average about 0.07 heat waves during the month of July and 0.03 heat waves during the month of August. The maximum number of heat waves that Kingston will experience is approximately 1.9 heat waves a year with a maximum of approximately 0.1 heat waves during the month June, 1.2 during the month of July, and 0.6 during the month of August.

Number of Heat Waves under a High Emissions Scenario during the 2050s (2040-2069)

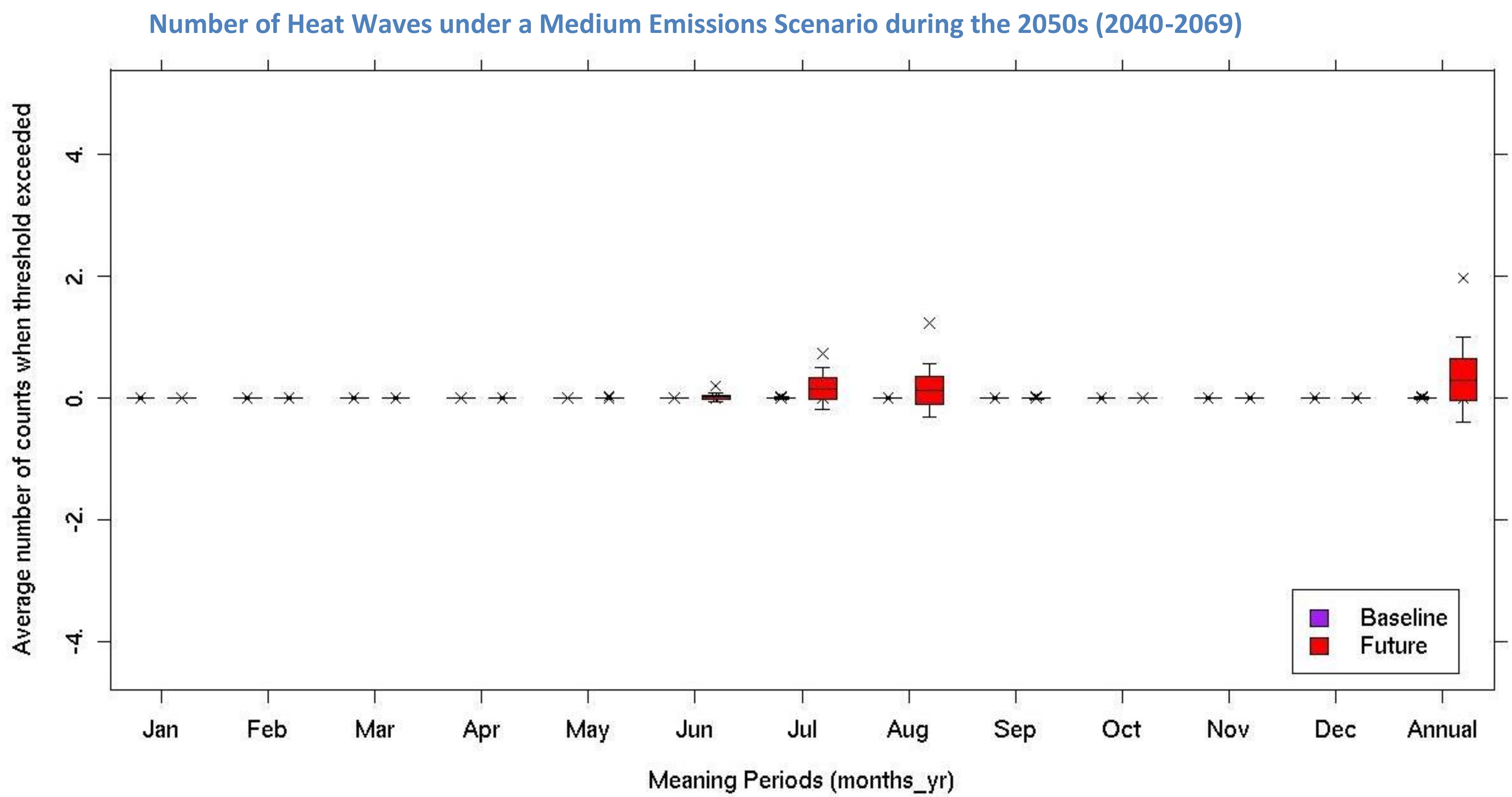


Under a high emissions scenario, the Royal Borough of Kingston will experience an average of approximately 0.5 heat waves a year during the 2050s (2040 – 2069). It will average about 0.4 heat waves during the month of July and 0.1 heat waves during the month of August. The maximum number of heat waves that Kingston will experience is approximately 6 heat waves a year with a maximum of approximately 0.5 heat waves during the month June, 3.3 during the month of July, and 2.2 during the month of August.

Number of Heat Waves under a Medium Emissions Scenario during the 2030s (2020-2049)

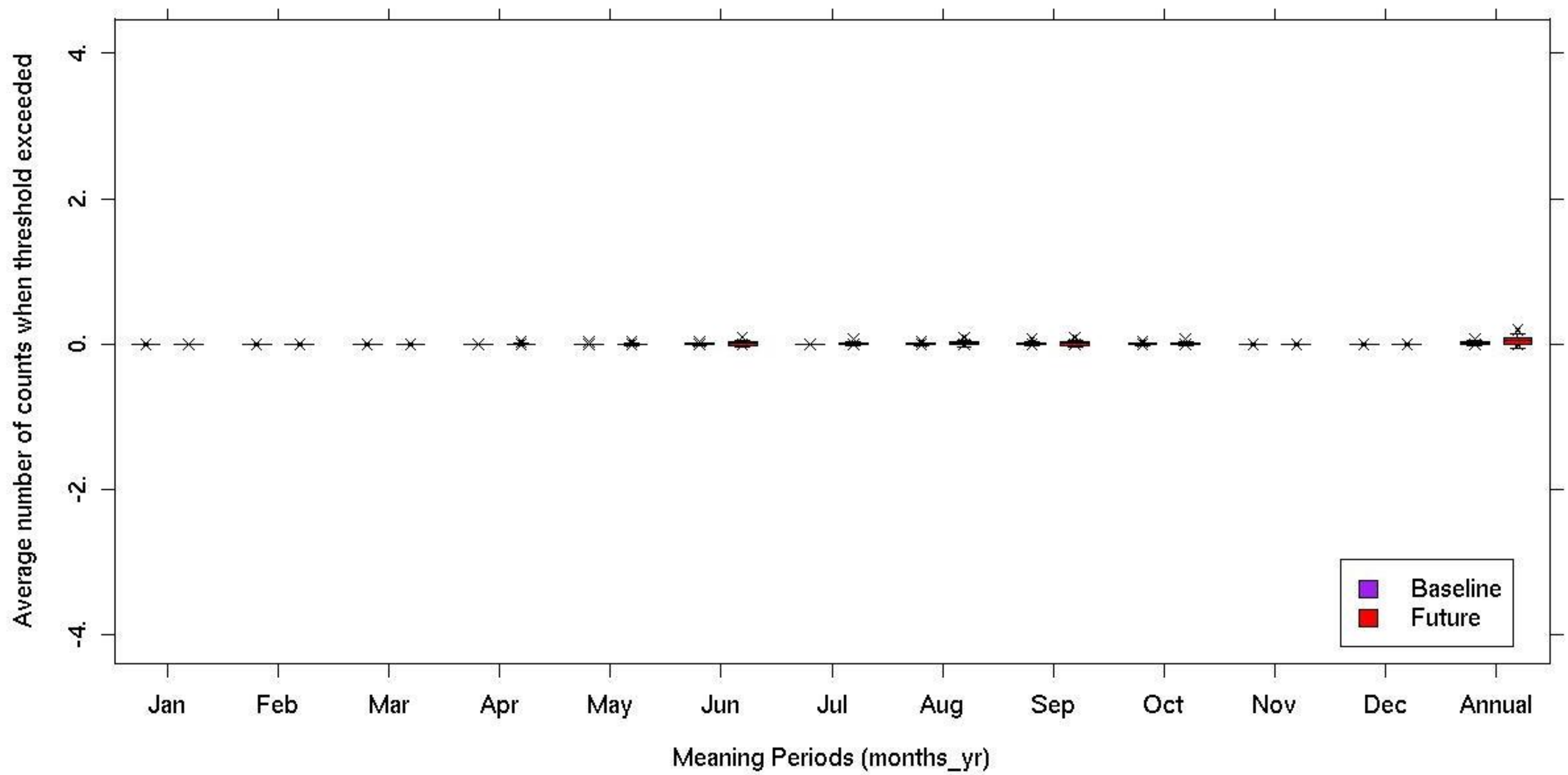


Under a medium emissions scenario, the Royal Borough of Kingston will experience an average of approximately 0.1 heat waves a year during the 2030s (2020 – 2049). It will average about 0.07 heat waves during the month of July and 0.03 heat waves during the month of August. The maximum number of heat waves that Kingston will experience is approximately 1.3 heat waves a year with a maximum of approximately 0.2 heat waves during the month June, 0.7 during the month of July, and 0.4 during the month of August.



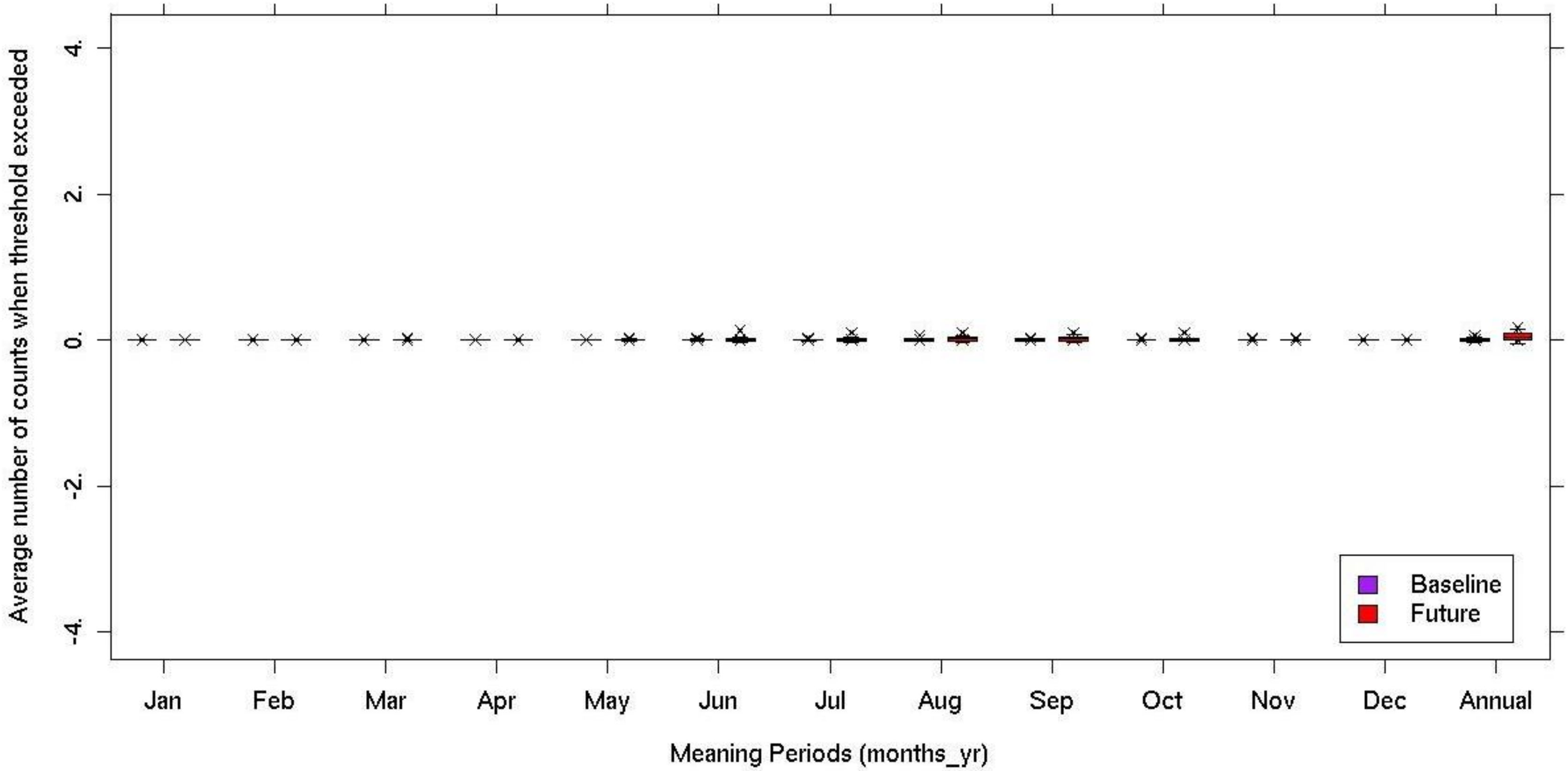
Under a medium emissions scenario, the Royal Borough of Kingston will experience an average of approximately 0.3 heat waves a year during the 2050s (2040 – 2069). It will average about 0.1 heat waves during the month of July and 0.2 heat waves during the month of August. The maximum number of heat waves that Kingston will experience is approximately 2 heat waves a year with a maximum of approximately 0.2 heat waves during the month June, 0.6 during the month of July, and 1.2 during the month of August.

Number of Floods under a High Emissions Scenario during the 2030s (2020-2049)



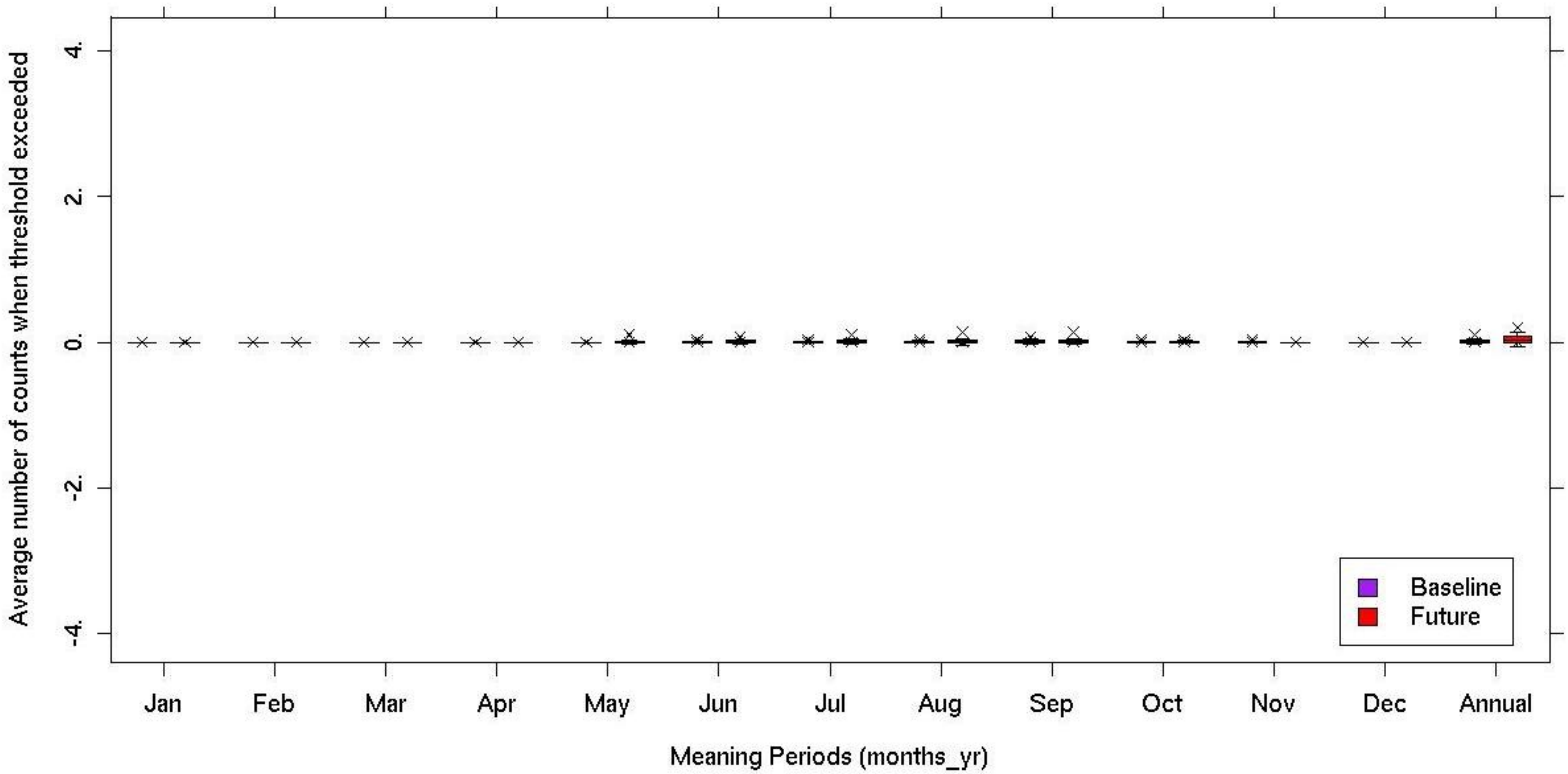
Under a high emissions scenario, the Royal Borough of Kingston will experience an average of approximately 0.03 floods a year during the 2030s (2020 – 2049), predominantly during the months of June, August, and September. The maximum number of floods that Kingston will experience is approximately 0.2 floods a year, predominantly during the same months.

Number of Floods under a High Emissions Scenario during the 2050s (2040-2069)



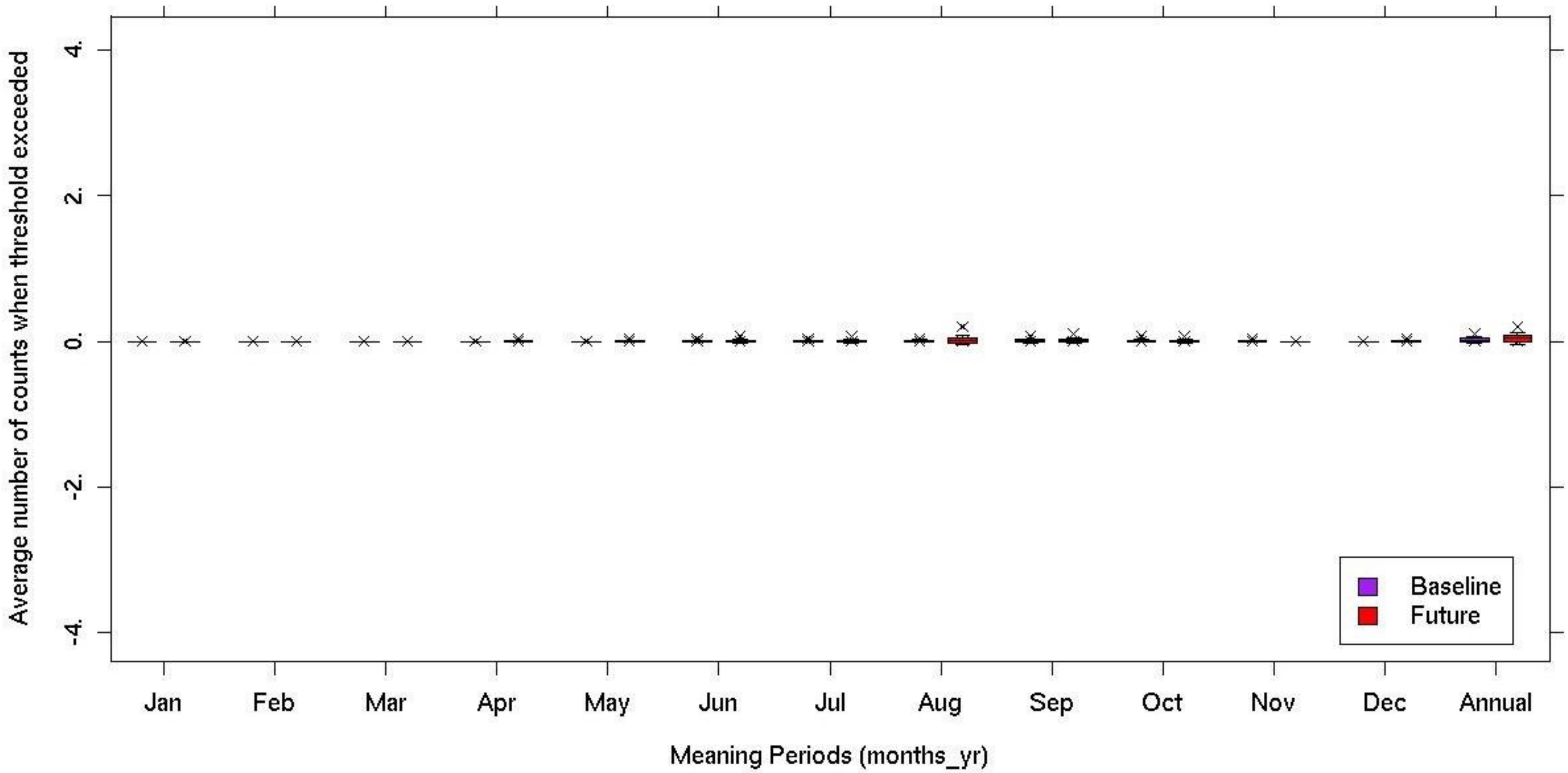
Under a high emissions scenario, the Royal Borough of Kingston will experience an average of approximately 0.05 floods a year during the 2050s (2040 – 2069), predominantly during the months of June, August, September, and October. The maximum number of floods that Kingston will experience is approximately 0.2 floods a year, predominantly during the same months.

Number of Floods under a Medium Emissions Scenario during the 2030s (2020-2049)



Under a medium emissions scenario, the Royal Borough of Kingston will experience an average of approximately 0.03 floods a year during the 2030s (2020 – 2049), predominantly during the months of May, July, August, and September. The maximum number of floods that Kingston will experience is approximately 0.2 floods a year, predominantly during the same months.

Number of Floods under a Medium Emissions Scenario during the 2050s (2040-2069)



Under a medium emissions scenario, the Royal Borough of Kingston will experience an average of approximately 0.05 floods a year during the 2050s (2040 – 2069), predominantly during the month of August. The maximum number of floods that Kingston will experience is approximately 0.2 floods a year, predominantly during the month of August.

Appendix F: Step-by-Step Guide to Mapping Vulnerability

Required Items

This guide will instruct the reader on how to replicate the vulnerability analysis conducted in the Royal Borough of Kingston upon Thames. In order to follow this guide one must have access to the following items:

1. The Excel file named "Kingston_Vulnerability_Scores_2010.xlsx
2. Internet connection and access to the Office of National Statistics Website(ONS)[4]
3. Super Output Area lookup codes provided by ONS either from website[5] or the file "Output Area Lookup Codes.csv"
4. ArcGIS Program and individual trained to use it

Disclaimer

Please note that this guide assumes the reader has very little Excel and GIS knowledge. Therefore, it contains very detailed steps. As a result, this guide is lengthy, but will become easier once the reader becomes more familiar with the process. If you are comfortable with Excel you may find it easier to read a few steps at a time to see what is happening, rather than reading one step at a time.

Contacting the WPI Team

If at any point you have questions about this guide you can always e-mail us and we will be happy to answer any questions or concerns you may have. We can be reached at the following e-mail addresses:

Primary: iqpkingston-d10

Secondary: grzybj@wpi.edu

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[4] http://www.neighbourhood.statistics.gov.uk/dissemination/Download1.do;jsessionid=ac1f930d30d6a29fa131559d4570afc09fcc3972a58f?$ph=60_61&nsjs=true&nsck=true&nssvg=false&nswid=1004

[5] http://www.ons.gov.uk/about-statistics/geography/products/geog-products-area/lookups/index.html (Located on the right side labelled "Output Area to lower Layer.....")

Common Terms

OA – Output Area

LSOA – Lower Layer Super Output Area

MSOA – Middle Layer Super Output Area

Updating the SVI scores

The follow steps instruct the reader on how to update the SVI scores:

1. Open the Excel file named "Kingston_Vulnerability_Scores_2010.xlsx"
2. Select the sheet labeled "SVIs"
3. The data you are looking to change is hidden. To unhide the data, select all of the vertical columns by dragging the mouse across the top bar. Once all columns are selected right click in the selected area and select "unhide" from the pop-up options
4. You should now be able to see columns A through AX
5. Open the OA Code Lookup file (WARNING: do not save any changes to this file)
6. Delete all rows not pertaining to your borough (to do this, select all rows not relevant to your borough, right click, and select 'delete' from the pop-up menu)
7. Delete columns A, C, D, and E
8. Delete Row 1. If asked if you want to shift cells up, select 'yes'
9. Select Column A
10. In the Excel Data tab select the "Sort" button
11. Click sort to get the LSOA's in numerical order
12. Select column A
13. In the Excel Data tab click "Remove Duplicates"
14. Select the remaining LSOAs and copy
15. Paste these LSOA's in Column A in the SVI sheet in Kingston_Vulnerability_Scores_2010. Make sure the list of LSOAs begins in row 7.

Each variable has three columns associated with it, a "DATA_VALUE" column, "Factor Ratio" column, and a "SVI column." You will only be editing the data located in the "DATA_VALUE" columns.

16. Open an internet browser and go to the ONS Neighbourhood Statistics website (Footnote #2 on the previous page)
17. Expand the selection labeled "2001 Census: Census Area Statistics"

The first variable to update is "On state benefit, unemployed, lowest grade workers." This variable is located in column D.

18. In the expanded area look for “Approximated Social Grade”
19. Select “Approximated Social Grade” by clicking the radial button in the same row on the right hand side
20. With the radial button checked click “Next” in the far lower right corner
21. Select the “Download” radial button and click “Next” again in the lower right corner
22. Select the radial button next to “NeSS Geography Hierarchy (London)”
23. Click “Next”
24. Click on “Microsoft Excel [*.xls]”
25. This will open a download window. Select “Save” and save this file in a location easily accessible (Making the save location the desktop might be the easiest as you will be doing this multiple times and the desktop takes the least amount of time to access)
26. Once the file has been downloaded, close the download window and go to the location of where the file was saved
27. Right click the file and select “Extract All,” this will open an Extraction Wizard
28. In the wizard click “Next” twice and then “Finish”
29. Open the Excel file in the folder that opens
30. Select the “LSOA” sheet in the Excel file

To make the document easier to read you can delete or hide columns A – H leaving just LSOA_CODE, LSOA_NAME and the data

31. Using the LSOA names column find the borough for which you want to do the analysis
32. Delete all rows not associated with your analysis (Note: make sure to leave rows 1-6)
33. Select column the data labeled “On state benefit, unemployed, lowest grade workers”, right click, and copy
34. Paste this column over column D in the Kingston_Vulnerability_Scores_2010 file

At this point the Factor Ratio and the SVIs will have updated to the new data, but there might be a complication. If you have a different number of LSOAs in your borough you must make sure the Factor Ratio and the SVI equations are filled to cover all the data. To fill the equation for all the data select the last cell in the Factor Ratio column and fill the equation down the column by clicking on the little box in the lower right hand corner of the cell, then drag down until your selected area matches with the data to the left.

If you wish to check if the equations are filled properly, there are two ways to check.

First select the cell directly under the last entry in the Factor Ratio column (the first empty one). Now click the “Sum” button on Excel (top right corner on the home tab) and hit “Enter.” This will sum all of the Factor Ratios and the sum should equal 1.

The second check is to quickly look through the SVIs and make sure that the SVI that has a score of 1 correlates with the maximum number from the data.

35. With the new data pasted and all the equations correct repeat these steps for all remaining variables except “Employment Location.” Paste the new data in the following columns:
    a. D
    b. G
    c. J
    d. M
    e. P
    f. S
    g. V
    h. Y
    i. AB
    j. AE
    k. AH
    l. AK
    m. AO
    n. AR
    o. AU

All of the data for these variables is located in Neighbourhood Statistics topics website. To get back to the topics click “Select Topics” on the top left side of the website. If you have any issue finding a particular variable use the search function on the website. For those people doing this with the new census data there is a hitch, these variables might not look the same in the new census as the questions change. If you cannot find the variable use your best judgment to find one that matches.

36. For employment location open the sheet named “Employment OA Transition”
37. Repeat the previous steps and paste the new data in columns B, D, F, and H, but note that this data will be in MSOA not LSOA format
38. You will now have and SVIs for all the MSOAs

The next part gets a bit complicated as the Employment Location Data is in MSOA format, not LSOA format, and must be converted. It is recommended to very carefully read two steps at a time.

39. If this analysis is being done on Kingston skip to “Kingston Continue Reading Here”
40. Open the LSOA and MSOA lookup file (Note: Do not save this file during the next steps as you will need it again later)
41. Delete all rows not associated with your borough
42. Delete columns A, C, and E
43. Select column B
44. Go to the Data table in Excel and select “Remove Duplicates” Make sure to select “Continue with Current selection”
45. With column B still selected, click the “Sort” button in excel. Select “Continue with Current selection” and make sure column B is selected as the column to sort by
46. Copy Column B and paste in into column A in “Employment OA Transition”. Make sure that the first MSOA code is in row 7
47. Close the Lookup code file and DO NOT SAVE
48. Repeat steps 29 through 31
49. Select columns A and B
50. In the Data tab on excel click Sort
51. In the ‘sort by’ selection select Column A
52. Now the values in column A are listed from smallest to largest, while the MSOA codes next to it will be the corresponding MSOA that matches to that LSOA
53. Select columns A and B and paste them into columns N and O in the “Employment OA Transition” sheet

Now comes the hard part. You must now turn all the MSOA codes in column O to the SVI score that matches that MSOA. We will walk you through the easiest way we found to do it, but if you know a shortcut to do this please do so.

54. Write down the code in row 7 column A exactly how it appears. Write down the very last MOSA code in column A exactly how it appears
55. Right click column A and select “clear contents”
56. Select column O
57. Press Control + F and select the replace tab to get to the “Find and Replace” option in Excel
58. Type the code you wrote down in the “Find” box and type “=L7” in the replace box

59. Click “Replace All” Excel will inform you that X changes have been made, click “Ok”
60. Now add 1 to both the find and the replace boxes (example: E02000598 will become E02000599 and =L7 will become =L8)
61. Click “Replace All”
62. Repeat this until you replace all the MSOA codes with scores. The end will be the last MSOA code you wrote down

Congratulations! You now have the employment data in LSOA form. In order to make sure this is accurately reflected in the SVI sheet, make sure the formula in column AX is filled until its length matches the length of the SVI in the column next to it. All cells should now have a score. The very last score in column AX should match the last score in Employment OA Transition column O.

Now comes the GIS part. Talk to your GIS contact and ask them if they have the Boundary files for the LSOAs or just the OA. If they have the LSOA boundary file you just saved some time. If they are in OAs only, we have to convert all the OAs as we did in Employment Transition. In either case, complete the following steps until otherwise noted.

63. Open the Total Scores sheet in Kingston_Vulnerability_Scores_2010
64. The Social and Economic scores for each LSOA are in columns B and C
65. You may need to fill B and C further down if you have more LSOAs then Kingston
66. If your GIS team has the LSOA boundaries you can skip to “LSOA Only Continue Here” below
67. If only have the OA boundary files then we need to convert the LSOA scores to OAs
68. Open the OA lookup File (again do not save this file in case you need the codes again in the future)
69. Delete all rows not relevant to your borough
70. Select columns A and B
71. Paste A and B in columns E and F in the Kingston_Vulnerability_Scores_2010 Total Scores sheet
72. Rename OA03CD to CensusOA
73. Rename LSOA04CD to Social

The following set of steps is the same as before to change the MSOAs into LSOAs.

74. Write down the first and last LSOA code in column A
75. Clear the Contents of Column A
76. Press Control+F and then go to the replace tab
77. In the Find box type the First LSOA code you wrote
78. In the Replace box write “=B2”

79. Replace all
80. Add 1 to the both the Find and Replace boxes (E01000001 becomes E01000002 and =B2 becomes =B3)
81. Repeat until you replace the final LSOA code you wrote down (This might take a while. Just remember, we had to do it too ☺)

Now with all of the Social scores matching the S1 scores you can select all of the Social scores and then fill the equation to the right to produce all of the economic scores. To do this:

82. Select all of the Social scores (not the Social name!), click the little black box in the lower right corner of the selection, and drag it all one column over.

Congratulations! We now have Economic and Social scores in LSOA and OA formats!

Kingston Continue Reading Here

LSOA Only Continue Here

83. Save this Excel file under a different name and submit it to your GIS team
84. Make sure they know that the scores are in the Total Scores sheet
85. The LSOA scores are located in the columns labeled S1 (Social) and E1 (Economic). You can always change these titles.
86. The OA scores are in the columns labeled "Social" and "Economic" (If you are using LSOAs only you can delete columns E, F, and G).
87. The GIS team will be able to "Join" this Excel sheet to a boundary file's attribute table
88. The GIS team should complete the following steps:
    a. Go to Symbology tab of the layer
    b. Go to classification section
    c. Click classify button
    d. Select Quantile Method
    e. Select 5 classes
    f. We made the Social map using a purple color ramp and the Economic map using a blue color ramp, but this is really up to you and your supervisor to decide on a color scheme.
89. Make the Social and Economic score two separate layers and you will have the completed Social and Economic vulnerability map
90. Celebrate!

Completing this Analysis for London as a Collective Unit

This is more of a quick suggestion section then a 'How To.' In order to complete this analysis for all of London use the same steps as above but we recommend the following:

- Complete the analysis in LSOA format – Unless you can find a better way to convert the LSOA scores to OAs (or any other format – i.e. wards), we recommend that you stick to the LSOA format as you will need to do the find and replace method thousands of times.
- Do not use employment location – Again, if you do not find a better way than the find and replace method using this variable might take a really long time to do for all of London.
- Make sure to do all of the analysis at one time and use one GIS layer for all of London- Due to the quantile method of classification you MUST input all of the scores into GIS at the same time.
- For analyzing all of London you might want to change the number of classes from 5 to 10. This will ensure that instead of each group containing 20% instead they will contain 10% and you will be able to see the top 10% most vulnerable LSOAs.
- Take your time – This might be a long process so it is essential to take your time in order to make sure you do not make a small mistake. A small mistake might throw off the entire analysis.