Worcester Polytechnic Institute (WPI)

Hazard, Vulnerability, and Risk Assessment in the London Borough of Hounslow using GIS

An Interactive Qualifying Project submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the degree of Bachelor of Science

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Abstract

The goal of the project was to produce hazard, vulnerability, and risk maps of the London Borough of Hounslow for improved emergency planning. The team collected hazard information from the Community Risk Register and emergency plans to identify and map hazards. We used 2011 UK Census data to identify and map vulnerable populations who might be more susceptible to harm and slower to recover from hazard events. The team combined several Census variables to produce composite indices of vulnerability ('Economic Stability,' 'Minority Status,' 'Evacuation,' and 'Public Health'). The maps of hazards, vulnerabilities, and risks will be used by the Contingency Planning Unit of the London Borough of Hounslow to better prepare for emergencies in the future.

Acknowledgements

We would like to express our gratitude to Twm Palmer, Fiona Hodge, Timothy Arnold, and Jyoti Sapkota (staff members of the London Borough of Hounslow Contingency Planning Unit) for all of their support and hospitality while we conducted our research with them.

We would like to give additional thanks to Khuram Awan and Vinesh Govind (staff members of the GIS team for the London Borough of Hounslow) for their assistance with generating the various maps presented in this work. Additionally, we would like to thank Richard Davill for his assistance with data management, Owen Kennedy for his help with data collection, and Ben Pearkes and Michael Lewis for helping us identify Hounslow border hazards.

Finally, we would thank our project advisors, Professors Dominic Golding and Patricia Stapleton for all of their guidance throughout our research and for their patience throughout the semester.

Executive Summary

The United Kingdom experiences numerous emergencies each year, resulting in many deaths, injuries, and damages to properties. As a result, the government passed the Civil Contingencies Act (CCA) in 2004. This act requires local authorities within the government to develop emergency plans for preparing, responding to, and recovering from hazardous events. In the London Borough of Hounslow, the Contingency Planning Unit (CPU) is the division responsible for preparing these emergency plans by assessing the local risks within the borough.

The overall goal of this project was to develop a suite of Geographical Information Systems (GIS) maps illustrating vulnerable groups of people, the most significant hazards, and the risks within the London Borough of Hounslow. We accomplished the goal of this work by completing the following set of objectives:

- identified the GIS map requirements desired by CPU staff members;
- mapped hazards and vulnerable populations within the borough; and
- interpreted hazard, vulnerability, and risk maps.

We conducted a detailed literature review to determine how hazard, vulnerability, and risk have been conceptualized and mapped in past research. We used internal sources of data, including emergency plans, risk registers, flood maps, and other data on the locations of petrol stations and transportation infrastructure to characterize the location and extent of hazards in the borough. We also used data on COMAH (Control of Major Accident Hazard) sites, which we supplemented and verified by interviews with emergency planners in neighboring boroughs, to identify additional hazards within and outside the borough. We developed a composite map of hazards affecting the borough (Figure A), which shows several areas of particular concern. For example, several petrol stations are located in flood-prone areas (areas C and D) and several areas may be affected by compound risks, such as the combination of chlorine storage facilities and petrol stations in close proximity, as at location A. With this detailed information, emergency planning officials may consider areas where multiple hazard types overlap when developing procedures for responding to incidents within the borough.

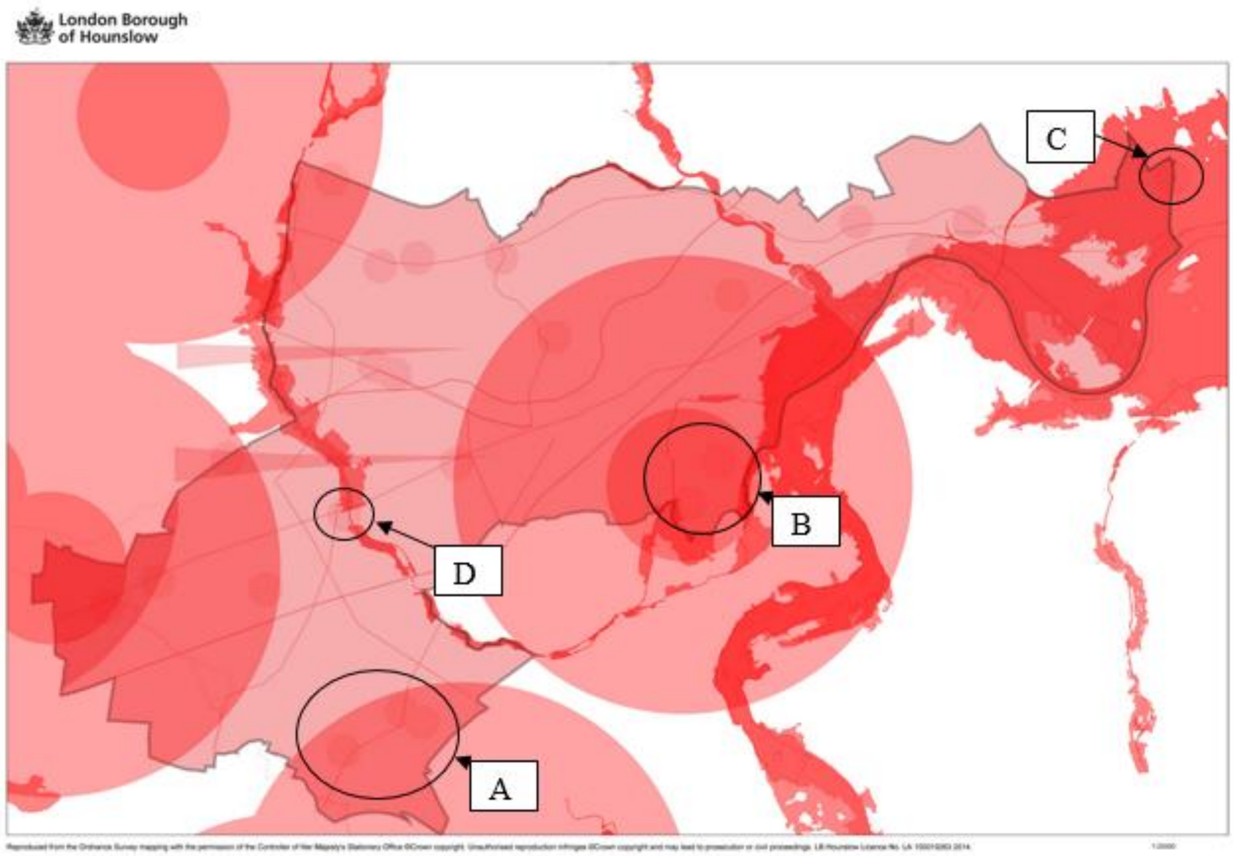

Figure A: Composite Hazard Map

We utilized the 2011 UK Census data in order quantitatively map various vulnerable populations. Based on the information obtained from the first objective and the literature review, the team identified the most relevant indicators of social vulnerability and placed them into composite indices that we called: ‘Economic Stability,’ ‘Public Health,’ ‘Evacuation,’ and ‘Minority Status.’ The table below shows the groups and associated indicators or variables from the Census data.

Group	Indicator
Economic Stability	• Education • Gender • Language • Occupancy • Occupation • Renting • Unemployment • Vehicles
Public Health	• Age • Disability • Health • Occupancy
Evacuation	• Age • Density • Disability • Gender • Health • Language • Migration • Occupancy • Vehicles
'Minority Status'	• Gender • Language • Migration

Table A: Grouping of Social Vulnerability Indicators

We calculated a vulnerability score for each indicator at the Lower Layer Super Output Area (LSOA) level. LSOAs are small geographic areas commonly used to analyze UK Census data. We chose to use LSOAs because they provided the best balance between resolution and ease of use. The team used Z-Scores in order to score every LSOA for each vulnerability indicator. We then summed the positive Z-scores within each group and LSOA in order to obtain a vulnerability rank for each composite group at the LSOA level. The team submitted a comprehensive spreadsheet to the London Borough of Hounslow's GIS Team who then imported our data into the local GIS system. We constructed vulnerability maps using the GIS system for each individual vulnerability indicator presented in Table A and generated maps for each composite group. An example of an individual vulnerability indicator map is presented in Figure B, and an example of a composite vulnerability map is presented in Figure C.

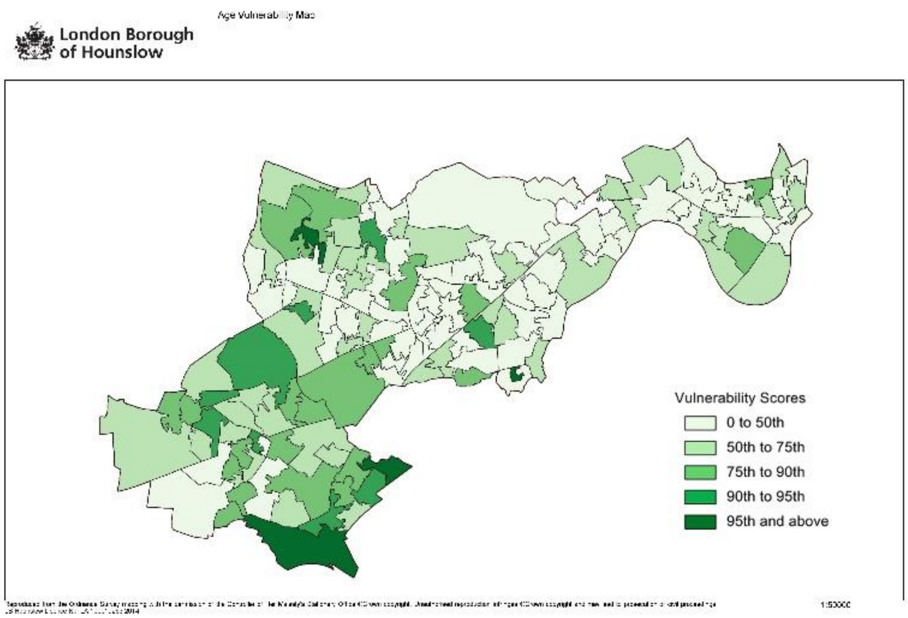

Figure B: Vulnerability by Age

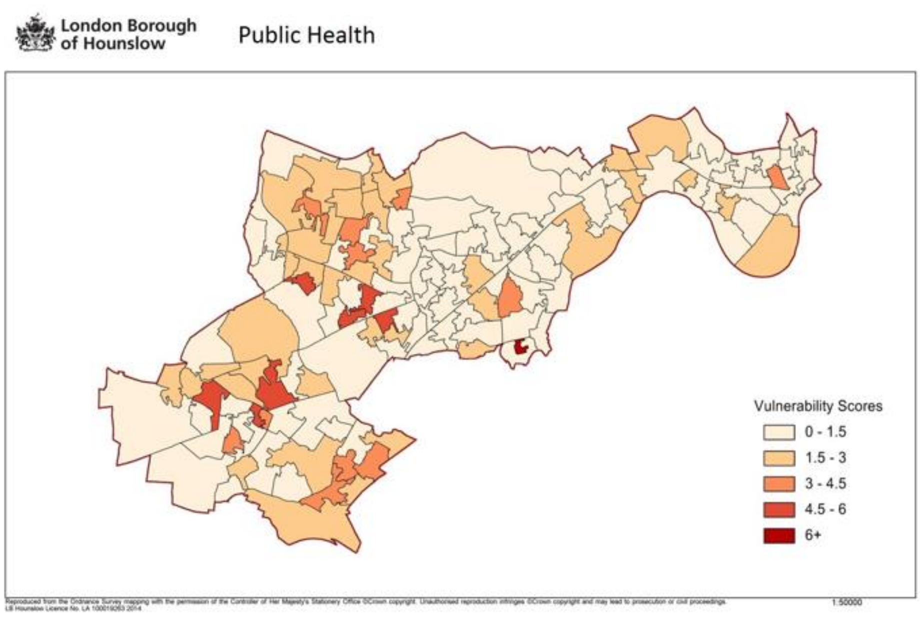

Figure C: 'Public Health' Group Vulnerability Map, Adjusted

The maps created in this project are intended for use by staff members of the CPU and emergency planners in order to identify vulnerable populations and areas at risk in an effort to improve emergency response plans and procedures. These maps show the hazards of greatest concern to the borough, the location of populations that may be the most vulnerable due to a variety of factors, and the risks associated with hazards and vulnerability. The team created 13 individual vulnerability maps, 4 composite vulnerability maps, 3 hazard maps, and 3 risk maps. Furthermore, the team developed a user guide which provides a detailed description on how to generate additional maps. This user guide will allow CPU staff members to generate new and revised vulnerability and hazard maps as the demographics of the borough changes.

We conclude that hazard and vulnerability mapping offers a way for the borough to better plan for future emergencies, but we recommend that the borough updates these maps as new information becomes available. Upon the release of the 2021 UK census data, we recommend using the guide we provided to replicate our process and adjust emergency plans accordingly to fit the new landscape of vulnerable populations in the borough. The team also suggests exploring hotspot and factor analysis to streamline and produce a more fine-grained breakdown of vulnerability within Hounslow. Lastly, we recommend producing a layer within the GIS system displaying the businesses of the borough to help minimize economic damage during an event as well as having a better idea where the working population is during the week day for planning purposes.

Authorship

The contributions to the writing and editing of this work are illustrated in the table below.

Section	Author (s)	Major Editors (s)
Abstract	SL	AL
Acknowledgements	AL	DL, SL
Executive Summary	AL	DL
1.0 Introduction	AL, DL, SL	AL, DL, SL
2.0 Literature Review	AL, DL, SL, AM	AL, DL, SL
2.1 Contingency Planning at the National Level	DL, SL	SL, DL, AL
2.2 Contingency Planning in Hounslow	DL, SL	AL, DL, SL, AM
2.3 Characterizing Vulnerability	SL	AL, DL, SL
2.4 Physical Vulnerability	AL	DL, SL
2.5 Social Vulnerability	AL, SL, AM	AL, DL, SL
2.6 GIS Mapping	AL	DL, SL
3.0 Methods	AL, DL, SL, AM	AL, DL, SL
3.1 Objective 1	DL	AL, DL, SL
3.2 Objective 2	AL, DL, SL, AM	AL, DL, SL
3.2.1.1 Hazard Data	AL	DL, SL
3.2.1.2 Generating Maps	AL	DL, SL
3.2.2.1 Census Data	DL, AL	SL
3.2.2.2 Selecting Vulnerability Data	AL, SL	DL
3.2.2.3 Vulnerability Grouping	DL	AL, SL
3.2.2.4 Scoring and Mapping Vulnerable Populations	AL, SL	DL
3.3 Objective 3	DL	AL, DL, SL
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4.1 Hazard Identification and Mapping	AL, SL	DL, SL
4.1.1 Flood Mapping in Hounslow	AL, AM	DL, SL
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4.3 Discussion	AL, DL, SL	AL, DL, SL
4.3.1 Interpreting Hazard Maps	DL, AM	AL, DL, SL

4.3.2 Interpreting Composite Vulnerability Maps	AL, DL	DL, SL
4.3.3 Integrating Vulnerability and Borough Hazards in the Form of Risk Maps	DL, AM	AL, DL, SL
5.0 Conclusions and Recommendations	DL, SL	AL, DL, SL
5.1 Conclusions	DL	AL, DL, SL
5.2 Recommendations	DL, SL	AL, DL, SL
7.0 Appendices	AL, DL, SL	AL, DL, SL
7.1: Appendix A: Basic Terminology	DL	AM
7.2 Appendix B: Discussion questions and points	AL, DL, SL	AL, DL, SL
7.2.1 For Richard Davill	AL, DL, SL	AL, DL, SL
7.2.2 For the GIS team	AL, DL, SL	AL, DL, SL
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1.0 Introduction

Every year, the United Kingdom faces a variety of potential civil emergencies such as influenza outbreaks, riverine and coastal flooding, chemical spills, and terrorist attacks. For example, in 2009 an outbreak of the H1N1 swine flu caused 1,550 deaths, and in 2005 bombings in central London killed 52 and injured more than 700 civilians. In 2007, floods damaged 48,000 households and 7,300 businesses. Two years later, flooding caused six bridges to collapse (United Kingdom Cabinet Office, 2013). In 2013 a heatwave resulted in more than 750 deaths in London alone. Experts and government officials worry that the growth in international travel, increased political instability, and a changing climate may exacerbate the frequency and severity of these kinds of events. In order to deal with these kinds of threats, the Civil Contingencies Act (CCA) 2004 requires local authorities to coordinate with other government agencies to develop specialized measures and emergency response plans.

In the Borough of Hounslow, the Contingency Planning Unit (CPU) is responsible for assessing risks and developing local emergency response plans. The CPU has drawn up plans to respond to a variety of threats to the borough, ranging from floods to major accidents associated with nearby Heathrow Airport. Given the social, economic, and ethnic diversity of the borough, the CPU is especially concerned about how best to identify and respond to the needs of those in the borough who may be more vulnerable based on differences in age, income, education, health, and other variables. Conceptual and operational definitions of vulnerability abound, but there is no standardized approach that local authorities can use to easily factor vulnerability into their assessment and planning processes.

The overall goal of this project was to identify innovative ways to assess and display data on hazards, vulnerabilities, and risks to emergency responders, planners, and policy makers by constructing a suite of Geographical Information Systems (GIS) maps using quantitative and qualitative data. The project team evaluated how the Borough of Hounslow, as well as other agencies in the US and UK, assess hazards, vulnerabilities, and risks. We then used that information, along with Census data and risk registers, to create a suite of GIS maps that can be presented to emergency planners, responders, and councillors. After creating the maps, the team developed a user guide for replicating our procedure and determined recommendations for further use of the GIS maps and potential improvements, as well as alternative means of displaying the data.

2.0 Literature Review

In this background section, we present a brief overview of the basic legislation behind emergency planning in the UK before describing the risk assessment and planning process in Hounslow in more detail. The section then presents an overview of the different approaches that have been used to assess vulnerability, with a special emphasis on the ways in which the spatial tools of geographic information systems (GIS) have been used to analyze and portray these kinds of data. The literature in this section provided a foundation for our hazard and vulnerability maps; the risk register was a key component of measuring the impact of particular hazards, and the social vulnerability indices and other vulnerability literature allowed us to determine the variables and thresholds needed to measure vulnerabilities.

2.1 Contingency Planning at the National Level

In 2004, Parliament implemented the Civil Contingency Act (CCA) to hold local governments responsible for the planning and recovery of a wide variety of civil emergencies. To do so, the Cabinet Office has provided a series of reports and guidelines for sub-levels of government to review and to use in order to fulfill their duties outlined in the CCA. In order to eliminate confusion, the Cabinet Office officially defines key terms such as emergency, vulnerable persons, and risk.

The Cabinet Office of the United Kingdom distinguishes between emergencies that affect people and those that affect the environment. Thus, an emergency is defined as "an event or situation [that] threatens damage to human welfare" that causes human death, injury, loss of property, or disruptions to essential services such as food and transportation (UK Cabinet Office 2011, p.11). An emergency can also be defined as "an event or situation [that] threatens damage to the environment" that contaminates air, water, or land, or destroys plant and animal life (UK Cabinet Office, 2011, p. 11)

In the event of a hazardous event or emergency, some individuals and groups in society may be more likely to experience harm, or the harm that they suffer may be more severe. Table 1 illustrates the groups that the Cabinet Office considers to be more vulnerable in a given emergency and who may need special protection or assistance. The classification includes a wide range of groups and individuals such as children, the aged, the infirm, people with disabilities, and those who speak minority languages. This typology reflects the findings from an extensive body of research conducted in the United Kingdom, United States, and elsewhere that we discuss later in this chapter. Local authorities are expected to compile and maintain lists of organizations that can serve as conduits to reach out to these vulnerable populations in the event of a civil emergency (Cabinet Office, 2008).

Potentially Vulnerable Individual/Group	Examples and Notes	Target through the following organisations/agencies
Children	Where children are concerned, whilst at school the school authorities have duty of care responsibilities. Certain schools may require more attention than others.	LEA schools through Local Authorities, and non-LEA schools through their governing body or proprietor. Crèches/playgroups/nurseries
Older People	Certain sections of the elderly community including those of ill health requiring regular medication and/or medical support equipment The "oldest-old" (aged 80 or over) are more likely to be widowed women, which may impact upon your planning.[6]	Residential Care Homes[7] Help the Aged Adult Social Care Nursing Homes
Mobility impaired	For example: wheel chair users; leg injuries (e.g. on crutches); bedridden/non movers; slow movers.	Residential Care Homes[7] Charities Health service providers Local Health Authorities
Mental/cognitive function impaired	For example: developmental disabilities; clinical psychiatric needs; learning disabilities.	
Sensory impaired	For example: blind or reduced sight; deaf; speech and other communication impaired.	Charities eg the Deaf Council Local groups
Individuals supported by health or local authorities		Social services GP surgeries
Temporarily or permanently ill	Potentially a large group encompassing not only those that need regular medial attention (e.g. dialysis, oxygen or a continuous supply of drugs), but those with chronic illnesses that may be exacerbated or destabilised either as a result of the evacuation or because prescription drugs were left behind.	GP surgeries Other health providers (public, private or charitable hospitals etc.) Community nurses
Individuals cared for by relatives		GP surgeries Carers groups
Homeless		Shelters, soup kitchens
Pregnant women		GP surgeries
Minority language speakers		Community Groups Job centre plus
Tourists		Transport and travel companies Hoteliers
Travelling community		LA traveller services Police liaison officer

Table 1: Vulnerable Persons (Cabinet Office, 2008)

The Cabinet Office defines risk as "the likelihood that a hazard will actually cause its adverse effects, together with a measure of the potential impact" (London Borough of Hounslow, 2015a). The CCA requires each level of government to produce an annual register of all the risks posed in their geographic area of jurisdiction (London Borough of Hounslow, 2015) and uses this information to develop the National Risk Register (NRR), which outlines the potential risks the United Kingdom may face in the next five years.

2.2 Contingency Planning in Hounslow

According to the Hounslow Resilience Forum, the major hazards of concern in the borough include influenza pandemic, small scale loss of utilities, regional power failure, and fluvial flooding. These hazards have the potential to impact the borough in varying ways. In the case of an influenza pandemic, up to half of the population of the borough could be affected. This will influence businesses and overwhelm health care services. A loss of utilities, such as gas, water, and electricity, for longer than a day but even at a small scale, can create severe difficulties for both residents and emergency services. Not only can there be issues at the source, but hazard events such as fires, flooding, or hurricanes can impact utilities, greatly increasing the likelihood of such an issue. Similarly, regional power failure can have a profound impact. Without backup generators, street lights, mobile phone towers, gas heating, and rail transportation would shut down. In the event of fluvial flooding due to “rapidly rising river levels”, thousands of homes and businesses may be damaged, and more would lose gas, electricity, and water (Hounslow Resilience Forum, 2015). In addition, flooding due to a period of sustained, heavy rainfall or snow melt can threaten hundreds of homes. Roads and rail lines would become impassible for several weeks or days, respectively. In the long term, severe flooding could strand several hundred people in need of shelter for up to a year, if large numbers of homes need to be repaired or rebuilt, and local businesses can be disrupted for months (Hounslow Resilience Forum, 2015). While Hounslow is located in close proximity to the River Thames, these events are unlikely to occur due to the flood barriers and other defenses put in place. However, due to the potentially great impact of the event, it is still a major concern to the borough.

Lastly, Hounslow contains the ExxonMobil (ESSO) West London Oil Terminal, located about a mile away from Heathrow Airport. This oil terminal is highly regulated to prevent ground water contamination. It serves areas such as Brighton, Swindon, the majority of London, and Milton Keynes. The terminal contains large bays for diesel, Maestro Oil and Gas Solutions (MOGAS), super unleaded oil, gasoil, and jet fuel. As seen from the Buncefield fire of 2005, shown in Figure 1, hazard events at these types of facilities can be catastrophic. The Buncefield oil depot, officially known as the Hertfordshire Oil Storage Terminal, was a major oil storage facility 25 miles northwest of London. After an accidental overfill of one of the oil tanks led to a series of explosions, a fire ensued at the depot for 5 days. The incident resulted in massive damages to the area, as the explosions shattered windows as far as 5 miles away, a loss of personal possessions, psychological trauma, and disruption to local services (The Major Incident Investigation Board, 2008). In addition to the short term losses, the Buncefield fire increased unemployment, resulting in approximately 265 initial job losses as well as a general increase of unemployment due to limited transportation in the area, job relocations, and the difficulties of older employees finding new jobs (Gardner, 2007). While the ESSO terminal in Hounslow is slightly smaller than the Buncefield depot, it still poses a major risk to the borough and also threatens major disruptions to Heathrow Airport which would have enormous ramifications in the borough. Additional safety measures were created after the incident, decreasing the likelihood of a similar event from happening, but the risk should still be considered due to the potential consequences (The National Archives, 2006).

Figure 1: The Buncefield Fire (static.guim.co.uk)

The Hounslow Resilience Forum is composed of the CPU, first responders such as the Metropolitan Police Service, Fire Brigade, 'Public Health' England, and transportation groups such as Transport for London and the Highway Agency. Together, these groups are in charge of producing the Community Risk Register in Hounslow. To create the register, the Hounslow

Resilience Forum uses the London Risk Register, produced by the Greater London Authority (GLA), to decide what hazards listed are relevant to the borough. Once those risks have been identified, the Community Register uses the same risk ratings and likelihood scores as the London Register. The register identifies the numerous emergency events that might have a negative impact on the Hounslow community, such as flooding. Each hazard subcategory is also given a risk rating (very high, high, medium, and low) based on an estimate of the likelihood of the event from 1-5, where 1 is 'limited' and 5 means 'catastrophic.' The final risk rating is produced using the GLA's Risk Matrix that combines the impact and likelihood scores as seen below in Figure 2.

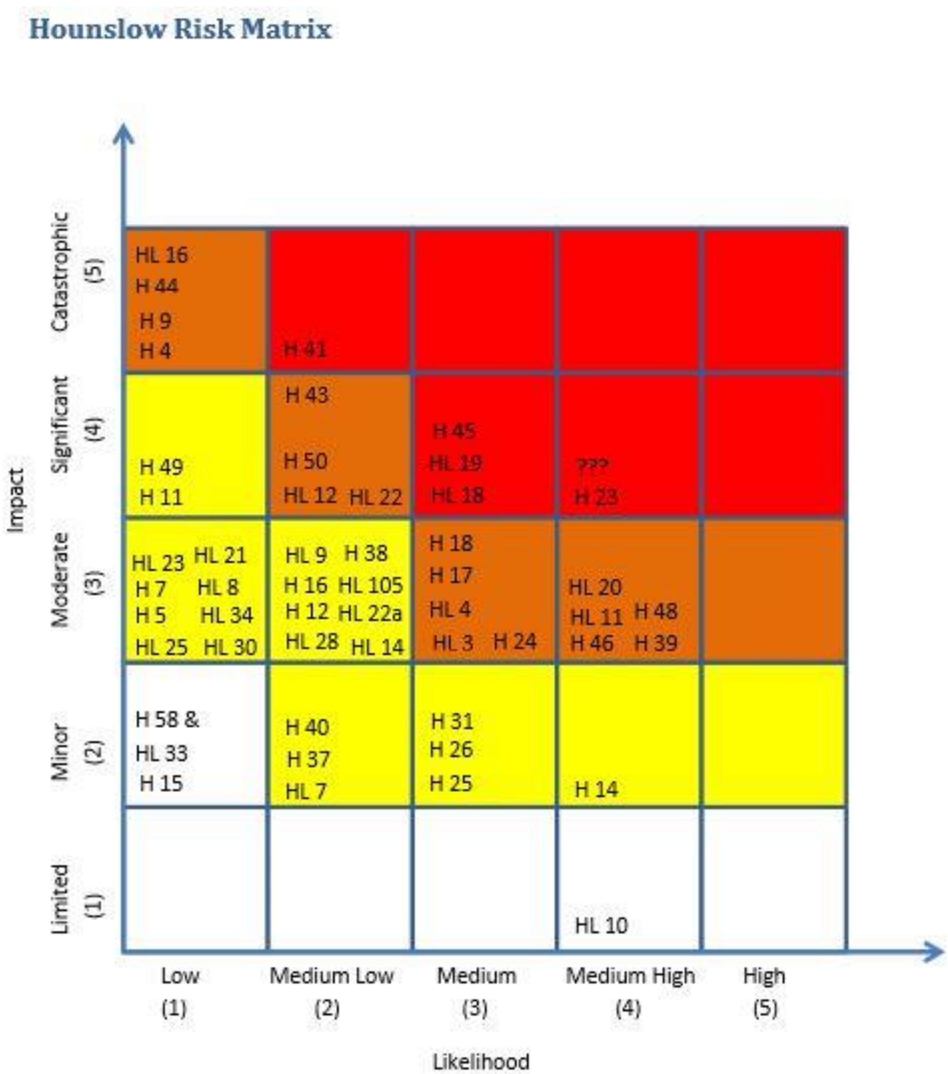

Figure 2: Risk Matrix (Hounslow Resilience Forum, 2015)

Through these registers (Table 2) local governments have a well-organized list of the possible scenarios the borough could face, the likelihood and impact of those scenarios, who should take the lead, and what government policies and guidance should be followed (Hounslow Resilience Forum, 2014). As the Hounslow Community Register was constructed using the London Register, so the London Register was produced based on the National Risk Register. Thus, Hounslow uses the listings in the London Register as a starting point to identify risks of potential concern in the borough and then 'scores' them based on local knowledge and information. Using a scoring method that combines impact and likelihood, the Hounslow Community Risk Register lists the following hazards with a risk rating of "Very High": Technical failure of electricity network at national/regional levels, influenza type disease, local and urban flooding/ surface runoff, and loss of utilities. We will focus on these four hazards most specifically when considering and mapping the vulnerable populations because they are the largest risks facing the borough in terms of frequency and severity.

Risk Ref.	Hazard Sub-Category	Outcome Description/Variation and Further Information	Likelihood	Impact	Lead Responsibility	Controls in Place
			Risk Rating			
H 43	Telecommunications infrastructure - Human error	**Outcome Description** Widespread loss of telecommunications (including public land lines and mobile networks) at a regional level, lasting for up to 5 days	2 (Rare)	4 (Significant)	London Fire Brigade (LFB)	Civil Contingencies Act 2004 Telephone provider demand and network capacity management strategies National Emergency Alert for Telecoms London Resilience Partnership Plans
			High			
H 49	Loss of drinking water supplies due to a major incident affecting infrastructure	**Outcome Description** Loss or non-availability of drinking water piped supply for 24 hours, lasting up to 2 weeks.	1 (Negligible)	4 (Significant)	Local Authority	Water Industry Act 1991 Security and Emergency Measures Direction 1998 Water companies mutual aid arrangements in place London Resilience Partnership Plans
			Medium			
???	Loss of utilities	**Outcome Description** Smaller scale loss of utilities (gas, water, electricity) for >24 hours at a site containing vulnerable persons.	4 (Possible)	4 (Significant)	Local Authority	
			Very High			

Table 2: Sample from Hounslow Risk Register (Hounslow Resilience Forum, 2015)

Risk assessments are used to create emergency plans and measures within the UK. Emergency responders must work together in order to identify risks and hazards within the community. Due to the changing nature of risks, risk assessment is done in 5 year intervals, with risk register updates every 2 years. In order to make communities more resilient, information on how to prepare for the effects of hazards must be communicated.

Figure 3 presents a map of the data obtained from the risk register in 2008 and how the risk scores are dispersed throughout the borough. To create the scores, different risks from the register were added to the map, and where risks overlapped their scores were added together. These overlapping areas are denoted by darker shading, so the darker the area the greater the risk. Some risks, such as a pandemic, affected the entire

borough, so those scores were added to every area (Hounslow Resilience Forum, 2014). The darker areas on the map indicate areas of greater risk. As indicated by the black annotations on the map, the dark, sinuous areas in the east and south of the borough represent the risk of flooding from the Thames River and its primary tributary, the Crane River. The overlapping semi-circular areas, indicated by the blue annotations, in the south and west indicate the risks of fires and/or explosions associated with oil storage depots supplying Heathrow, and situated outside the borough. The wedges in the central and western parts of the borough, annotated in green, indicate the risks associated with the dominant flight paths into Heathrow.

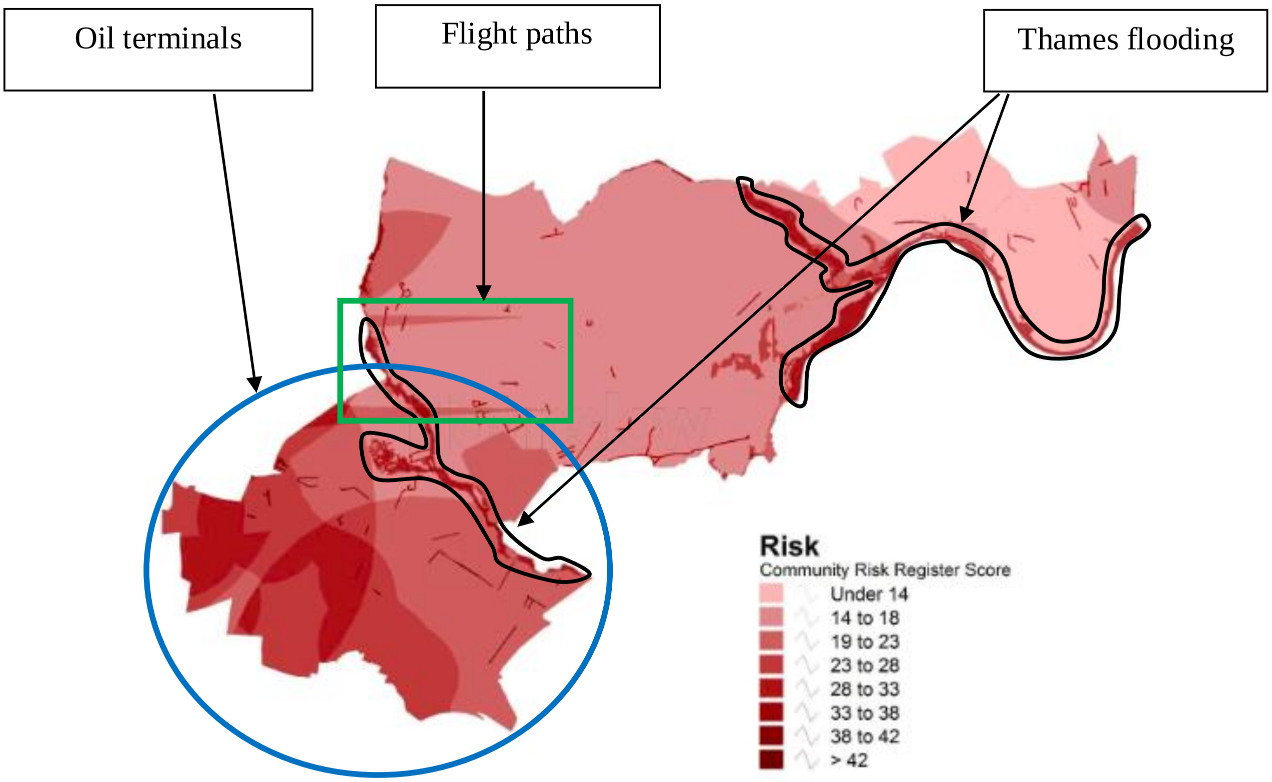

Figure 3: Risk Map of the London Borough of Hounslow (London Borough of Hounslow, 2015)

Given these hazards, the next task for the CPU and other emergency personnel in London is identifying, in advance, the portions of the population that are especially vulnerable in the event of an emergency so that special plans may be made to protect them or help them recover more quickly. Vulnerability is the potential for harm to people or things they care about (Cutter, Mitchell, & Scott, 1997, p. 6). Extensive research on vulnerability over the past twenty years has brought this key element of contingency planning to light. Below we summarize some of the key findings from this research.

2.3 Characterizing Vulnerability

The research on risk and vulnerability distinguishes broadly between physical and social vulnerability. Physical vulnerability is the increased risk due to exposure to a hazard. For example, people who live at lower elevations in a floodplain may be more exposed to the risks of flooding than people who live at higher elevations and further away from the river. Among those people who face the same physical risk of flooding by virtue of location, some are more likely to suffer harm or the harm may be more severe because of social vulnerability. For example, those who are old or infirm may be less able to deal with a flood event and the poor may be less able to 'bounce back' or recover following a flood event that destroys their property or displaces them for an extended period. Both physical and social vulnerability are important factors that local authorities must consider in planning appropriate responses before, during, and after an emergency. Figure 4 illustrates the various components of vulnerability, which will be discussed in this section.

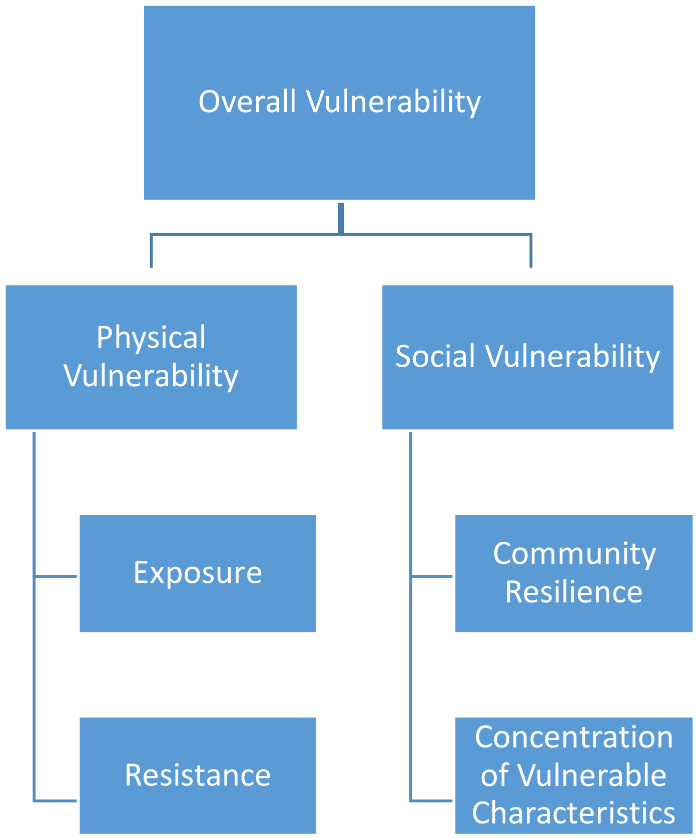

Figure 4: Vulnerability Tree

2.4 Physical Vulnerability

Douglas explains that the assessment of physical risks requires the consideration of the population's physical vulnerability (2007). Physical vulnerability represents the likelihood for an individual to suffer harm with respect to their *exposure* and *resistance* to an event or hazard. Peduzzi, Dao, Herold, and Mouton describe exposure as the "the frequency and geographical extent of each hazard" (2009). They used a combination of exposed populations and the average frequencies of hazards in order to quantify and illustrate the physical exposure of various populations in their studies (Peduzzi et al., 2009). Similarly, a team of WPI undergraduates mapped vulnerability to flooding for the Borough of Kingston. Those populations and businesses closer to rivers, located in or near flood plains, have increased exposure which in turn increases their vulnerability (Patel et al., 2010).

Resistance can be defined as the ability to withstand a physical hazard. For example, Clark et al. (1998) define resistance as "the ability to absorb impacts and continue to function." Cardona and Aalst (2012) use the definition of resistance to describe *sensitivity* in terms of risk management. They state that a lack of resistance increases the physical likelihood that humans, the environment, and infrastructure may be adversely affected by hazardous events (2012). For example, people who live in mobile homes may be less resistant to flooding than those who live in houses with substantial and secure foundations (Cutter, Boruff, & Shirley, 2003). Mobile or substandard homes may be rendered uninhabitable by flooding and residents may have to relocate for extended periods or even permanently, whereas residents of more resilient properties may need merely to clean up and engage in minor repairs to make their houses habitable again in relatively short order.

Physical vulnerability can be assessed using the identified risks and hazards in a given geographical area. For example, Rød, Berthling, Lein, Lujala, Vatne, and Bye (2012) developed a physical vulnerability index by using pre-existing risk maps in the central geographical area of Norway, which is called Trøndelag. They used existing quick clay slide risk maps and flood risk maps to develop their physical vulnerability indices by calculating the frequency and number of people affected by these risks. In order to create this index, the authors used another definition of physical vulnerability that concentrated on people's exposure to certain hazards, as opposed to dealing with "the value of threatened objects or their ability to withstand hazards." A more detailed explanation of the creation of these indices can be obtained from (Rød et al., 2012).

Focusing on exposure, Rød et al. (2012) designed their physical vulnerability indices to show the probability of a physical hazard affecting work places and residential locations. They scaled these indices to fit the social vulnerability indices, which will be discussed in the following section, by looking at the number of affected locations compared to the total number of residential locations present in a given ward of the geographical region. In order to reveal the total vulnerability toward specific hazards, the authors combined relevant hazards into specific groups (Rød et al., 2012). This technique of grouping various hazards can be utilized in our methodology as we identify the hazards that could present the greatest impact on the borough of Hounslow.

A combined physical vulnerability index was created after generating these indices. The team gave weights to the independent indices by predicting the amount of harm to the vulnerable population and the amount of property damage that would result from an event illustrated in the independent indices (Rød et al., 2012). In order to fully understand the extent of vulnerability of a given population, however, the social aspects of the population must also be taken into consideration.

2.5 Social Vulnerability

Social vulnerabilities are defined as characteristics of individual people such as age, race, and income, that make certain populations more susceptible to harm and loss (Cutter et al., 2003). Cutter et al. developed a social vulnerability index (SoVI) that was used to map and analyze patterns of vulnerable populations for creating programs and policies. Table 3 summarizes the factors or variables that contribute to social vulnerability according to various researchers. Blue cells indicate that the author uses that measure of vulnerability.

Factor	Description	Cutter et al. (2003)	Army Corps (2013)	CRN (2010)	Dwyer et al. (2012)	Rød et al. (2004)
Socioeconomic status (income, political power, prestige)	Lower socioeconomic status increases vulnerability due to a lack of available resources.	■	■	■	■	■
Gender	Due to statistically lower wages and family responsibilities, women are more vulnerable.	■	■	■	■	
Race and ethnicity	Ethnicity can create communication and cultural barriers that increase vulnerability.	■	■	■	■	
Age	The old and the young are both vulnerable due to dependence on others and mobility issues.	■	■	■	■	■
Commercial and industrial development	Commercial and industrial development increases vulnerability as damages will cause greater harm to the local economy.	■	■			■
Employment loss	The greater the employment loss, the longer the recovery process, which indicates a higher vulnerability.	■	■			■
Rural/urban	Dependence on local resources makes more rural areas more vulnerable, and urban areas are more vulnerable due to the evacuation problems of higher population densities.	■	■			
Residential property	Expensive homes and mobile homes are vulnerable due to the cost of replacement and lack of resilience, respectively.	■	■			■
Infrastructure and lifelines	A loss of infrastructure creates a large financial burden on the area, increasing vulnerability.	■	■	■		
Renters	Renters are more vulnerable due to their less permanent housing situations, as well as the indication of a lower socioeconomic status.	■	■		■	
Occupation	Some occupations may be impacted by a hazard event, be hazardous themselves, or result in a lower income, therefore increasing vulnerability. Other occupations may be less impacted or result in a greater income, resulting in a decreased vulnerability.	■	■		■	

Factor	Description	Cutter et al. (2003)	Army Corps (2013)	CRN (2010)	Dwyer et al. (2012)	Rød et al. (2004)
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.	■			■	■
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.	■	■			
Population growth	Rapid population growth leads to lack of resources and new immigrants, who likely lack social and physical resources in the area, which both increase vulnerability.	■				■
Population density	A higher population density increases vulnerability in a hazard event due to the number of impacted persons and difficulty of evacuation.	■	■			
Medical services	Health care providers are important post-event sources of relief. The lack of proximate medical services will lengthen immediate relief and longer-term recovery from disasters.	■			■	
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.	■	■	■		
Special needs populations	Special needs populations are very vulnerable due to their high dependence on others.			■	■	
Socially isolated	Social isolation increases vulnerability, as it reduces the availability of emotional and physical support.			■	■	
Tourists/travelers	Tourists are more vulnerable due to their unfamiliarity with the environment and lack of local resources.	■	■	■		

Table 3: Social Vulnerability List ((Cutter et al., 2003); (US Army Corps of Engineers, 2013); (Crisis and Risk Network, 2010); (Rød et al., 2012); (Dwyer, Zoppou, Nielsen, Day, & Roberts, 2004))

Evidently, many authors have identified similar attributes as important contributors to vulnerability, but they often use different thresholds in their analyses. For example, Cutter et al. (2003) viewed those younger than 18 and older than 65 as vulnerable because they are financially dependent on those who are of working ages; whereas Chakraborty et al. (2005) considered those younger than 5 and older than 85 as vulnerable because they lack physical mobility and will need help at the time of an emergency. In our analysis, we used 16 as the cutoff, because in the UK the legal age of an adult is 16, not 18. For each variable we used, the team determined the appropriate parameters using the same type of literary analysis.

Dwyer et al. (2004) grouped social vulnerable populations into four themes: Individual within Household, Community, Regional/Geographical, and Administrative/Institutional (Figure 5). Dwyer et al. (2004, p. 5) focused their study on the first theme of social vulnerability. We followed a similar approach in our analysis and used some of the same indicators (age, income, residence type, employment, English skills, household type, disability, gender, and debt and savings) as a baseline to determine vulnerable populations. Based on the work of Dwyer and others (Table 3), the team established a list of appropriate social vulnerability indicators that are relevant for the London Borough of Hounslow.

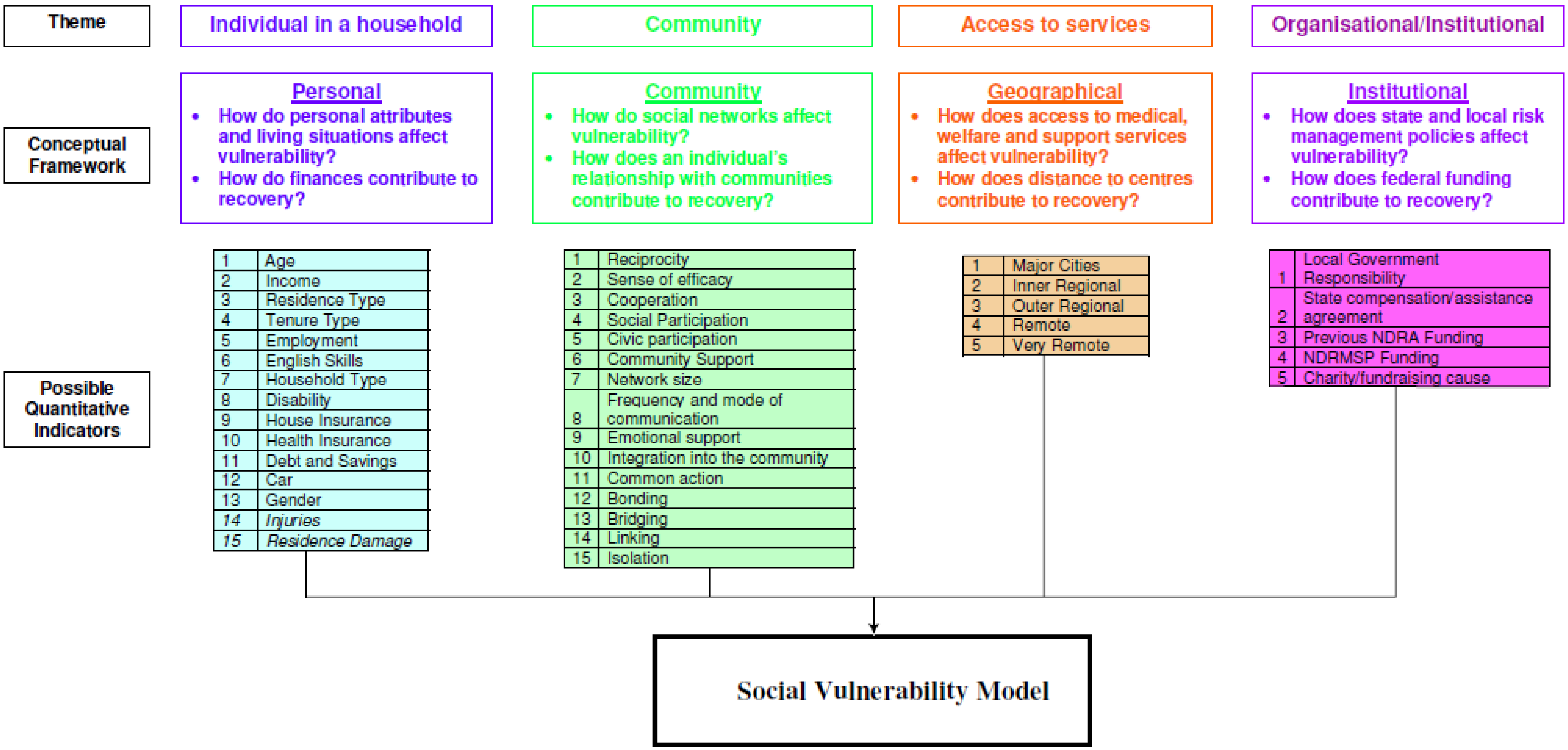

Figure 5: Dwyer et al.'s Social Vulnerability Breakdown (2004, p. 5).

Rød et al. (2012) indicated that the variables, as discussed above, overlap each other with respect to their contributions to overall vulnerability. When combining vulnerabilities, some variables are more important. To determine the importance of each variable, Rød et al. (2012) used factor analysis. These various factors are scored accordingly, and they are summed in order to obtain a measurement of social vulnerability. These social vulnerability indices can contain variation. This variation in social vulnerability results from the distribution of demographic and socio-economic characteristics, which results in the variation of response and resistance to hazards. Using a scoring system allows for the identification of vulnerability factors to be more location specific, as well as more detailed (Rød et al., 2012).

As described above, factor analysis is a key strategy used to collect various vulnerability factors into more manageable groups. Rød et al. used vulnerability analysis to group their identified vulnerability indicators into three separate groups. These groups included large numbers of immigrants who were vulnerable due to age, those who had a large amount of income, and those who live in single-parent households. See Rød et al. (2012) for more information on their factor analysis. Finally, the authors combined both the physical and social vulnerability indices in order to determine the overall vulnerability of the specific geographical areas presented (Rød et al., 2012).

A key aspect of social vulnerability is resilience. According to the National Health Security Strategy (NHSS) of the United States, community resilience is "the sustained ability of communities to withstand and recover from adversity" (2015). NHSS also states that a resilient community must have access to health care and the knowledge and resources to care for themselves and others (Assistant Secretary for Preparedness and Response (ASPR), 2012). The idea of resilience is similarly defined by Cutter et al. as "the ability of a social system to respond and recover from disasters" (2008, p. 599). This interpretation includes the pre-event preparedness conditions that affect the community's response and the actions taken after the event to both recover and better prepare for future events (Cutter et al., 2008). This means that a key element for a resilient recovery requires a community to not only rebuild, but to improve infrastructure and buildings that better prepare them for a similar event.

There are many different definitions for resilience, each modified depending on its use and context. The Community and Regional Resilience Institute (CARRI) analyzed these definitions, including their applicability across a wide range of social disciplines. The report outlines the key definitions of resilience, which includes the ability for a community to be dynamic and adaptive to emergency events over time. These adaptations help improve the functionality of the community. With these concepts, CARRI created their own definition of resilience: "Community resilience is the capability to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change" (2013). Much like the interpretation by Cutter et al. and NHSS, CARRI believes a resilient community is able to respond and recover to events adaptively in order to limit the impact of a similar event in the future.

Current research is developing a method to measure resilience in order to compare and rank communities. Meanwhile, a community's resilience can still be increased relative to its previous performance. In order to improve resilience, the people of the community must be more aware of the hazards and risks they face, and they must be prepared for events and defensive actions. Communities can improve public awareness and preparedness by signing up for flood warning services, volunteering in aid programs, and belonging to a neighborhood, through organizations or a watch (Bell, McFarland, Pole, & Innerd, 2008; Klein, Nicholls, & Thomalla, 2003).

The relationship between vulnerability and resilience is still widely debated. Some authors, including Klein, Nicholls, and Thomalla (2003), describe the relationship as a reciprocal: increasing resilience reduces vulnerability. Other authors state that vulnerability exists independent of resilience, and that resilience is the ability to recover from an emergency, no matter how vulnerable beforehand (Community and Regional Resilience Institute (CARRI), 2013; S. L. Cutter et al., 2008). While we have not directly taken resilience into account when mapping, we have taken the stance that increasing resilience reduces vulnerability, as we believe that preparing the public for emergencies and hazardous events makes them less vulnerable. In addition, we believe that a resilient population makes adaptation during its recovery in order to better mitigate future effects of hazards.

2.6 GIS Mapping

Because hazards and vulnerabilities can vary greatly across geographic areas, GIS maps have been used for emergency planning in the past. Presenting this information on a map makes the differences more comprehensible, because the maps illustrate clusters of vulnerable populations. These visual illustrations, in turn, prove beneficial for contingency planners because they allow officials to determine if locations are in the proximity of known hazards.

Additionally, it is crucial for a population to be prepared for many different kinds of hazards in order to remain resilient. As a result, providing maps of combined vulnerabilities and hazards allows populations to be aware of, and thus prepare for, dangers that are close to their home and place of work. For example, hazard maps use the extent of geographical impacts and the probability that they will occur in order to illustrate the risk of the hazard (Bell, McFarland, & Innerd, 2008b). In those maps, areas with a high risk can be looked at in terms of revising emergency plans and providing additional resources.

GIS maps can do more than just estimate damage. Emergency planners can move equipment or other resources before a potential event occurs, based on their visualizations of hazard exposure and vulnerability in order to better assist those who might be in need (Holdeman, 2014). Planners can also use the data provided from GIS maps to contact prospective local partners, such as local public schools, colleges, or stadiums that would be able to provide shelter, medical attention, or other aid in the event of an emergency. By using data from social media or Censuses, emergency planners can map socio-demographical areas and, thus, plan appropriate measures. Social media can also be used in conjunction with GIS maps during an emergency to show locations of hazards or helpful citizens in real time (Holdeman, 2014).

As noted, social factors play a significant role in determining vulnerability. In a case study in Georgetown County, South Carolina, Susan Cutter, Jerry Mitchell, and Michael Scott considered different social factors, then utilized GIS mapping to reveal vulnerable populations (2000). The authors used GIS to establish areas of vulnerability based on twelve environmental threats and eight social characteristics in the county. They generated composite maps of physical, social, and overall vulnerabilities using the appropriate vulnerability scores. Based on their research, those who have the resources to recover are considered to be less vulnerable, even if they live in an area of high physical risks. Also, those who live in areas that have less physical risk can still be considered vulnerable if the population does not have the necessary resources to recover (Cutter, Mitchell, and Scott, 2000). We followed a similar methodology by creating composite maps based on vulnerability scores.

Finally, GIS mapping techniques have been used previously in the London Borough of Hounslow. Bell et. al developed a series of GIS maps to aid in the development of community resilience to the changing climate in the United Kingdom (2008a). Figure 6 shows areas of multiple deprivation that are assumed to be vulnerable because they have lower levels of resistance and resiliency. Individuals and groups in in these areas are presumed to be less able to withstand a hazard event and less able to recover afterwards.

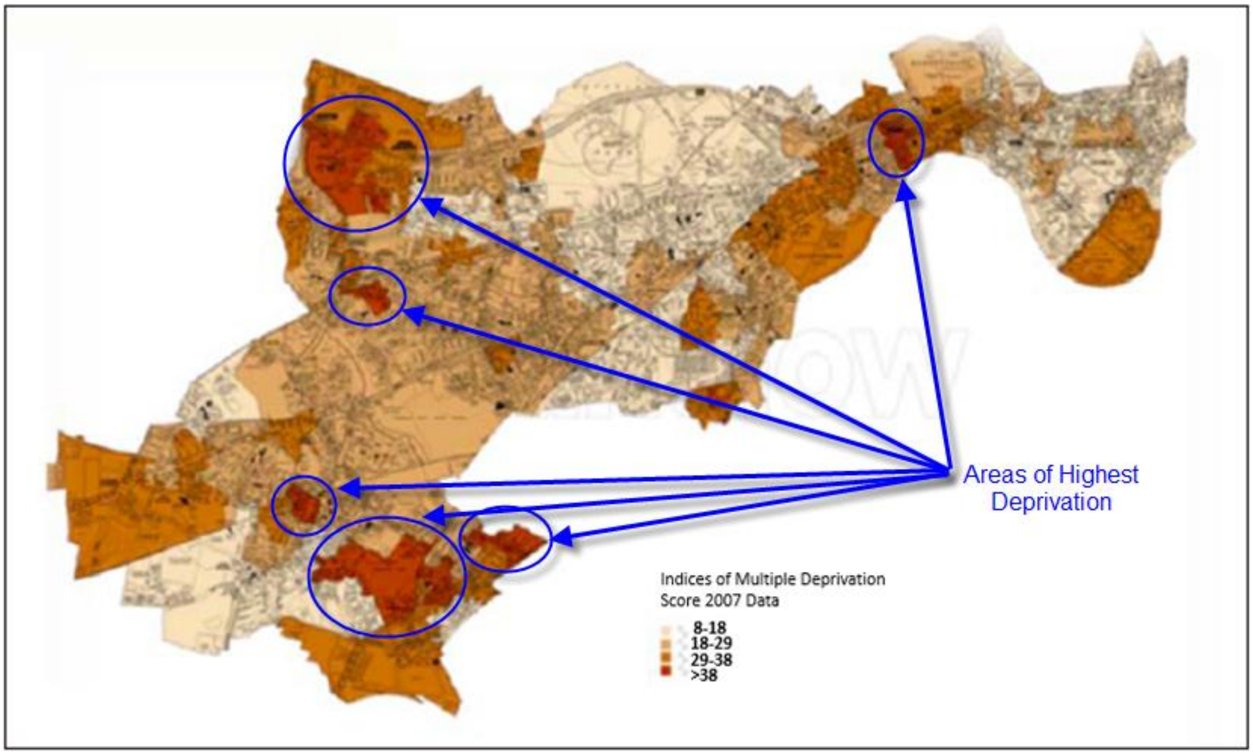

Figure 6: Indices of Multiple Deprivation (Bell et al., 2008a)

Bell et al. (2008a) also constructed an overall vulnerability map of the borough Figure 7 based on a composite overlay of five indicators or variables: those with limiting long term illness, those who are seeking employment, indices of multiple deprivation, population density, and individuals under the age of 5 and over the age of 70. The areas of highest vulnerability (with composite scores greater than 421) are shaded dark green and annotated in red. Areas that scored lower on the five indicators were given a lower overall vulnerability ranking and are shaded in light green.

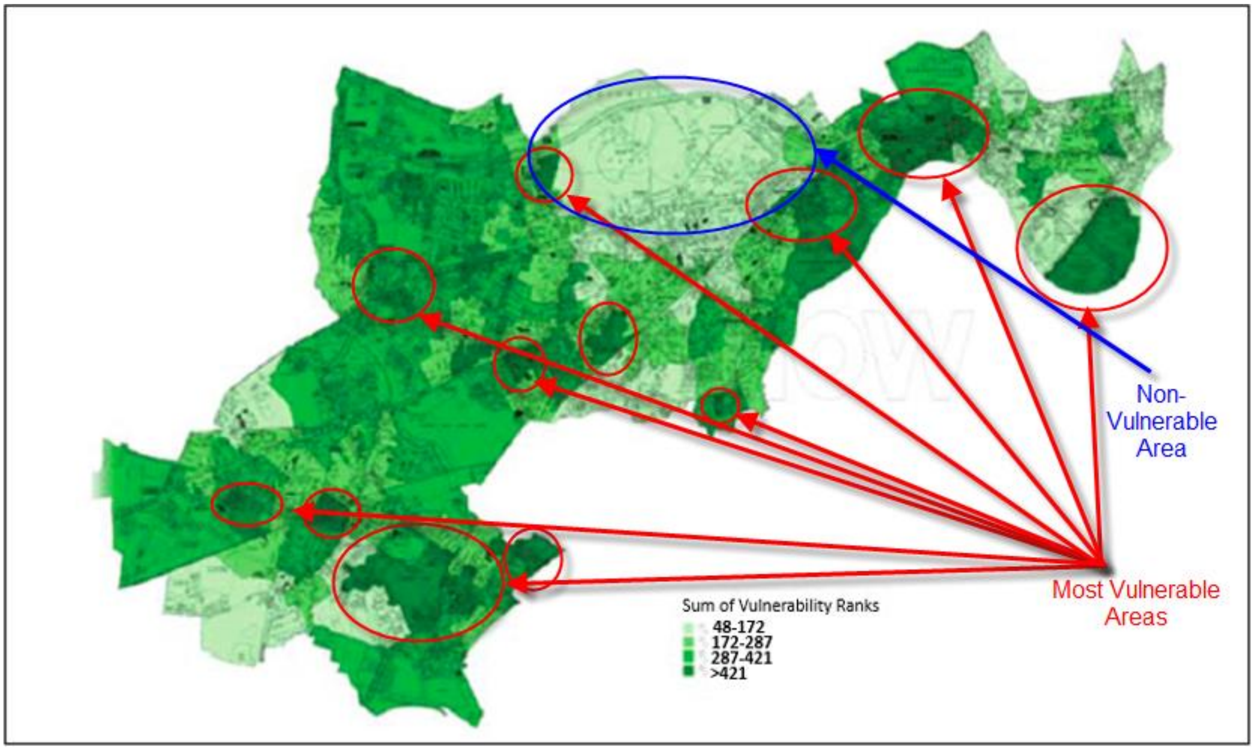

Figure 7: Combined Vulnerability Map for Hounslow (Bell et al., 2008a)

These maps provide useful information for emergency planners, responders, and policy makers because they isolate specific geographic sections of the borough that are considered to be the most vulnerable. Areas that have larger populations of elderly people could be given additional attention in terms of the number of responders. Additional responders may be needed to help elderly people who may have impaired mobility (Bell et al., 2008a). The hazard, and vulnerability maps created by Bell et al. provided useful information that we utilized in our methods to generate our own hazard, vulnerability, and risk maps of Hounslow (2008a).

3.0 Methods

The overall goal of this project was to create hazard, vulnerability, and risk maps to be used by emergency planners and responders. The team constructed a suite of GIS maps to display quantitative and qualitative data. In order to achieve this goal, the project team established three objectives.

- **Objective 1: Identified the map requirements desired by CPU staff members.**

The team consulted with members of the CPU and the GIS team to determine the design criteria and preferred content for the GIS maps (Figure 8).

- **Objective 2: Mapped hazards and vulnerable populations within the borough.**

The team determined the appropriate way to organize the collected information and developed a suite of GIS maps using the Earthlight software package. These maps include data on vulnerable populations, risks, hazards, and areas of concern.

- **Objective 3: Interpreted hazard, vulnerability, and risk maps.**

We created and analyzed maps in terms of use for emergency planning and response. While not comprehensive, our suite of maps provided a general set of maps for a variety of situations, as well as a foundation for the creation of more specific maps.

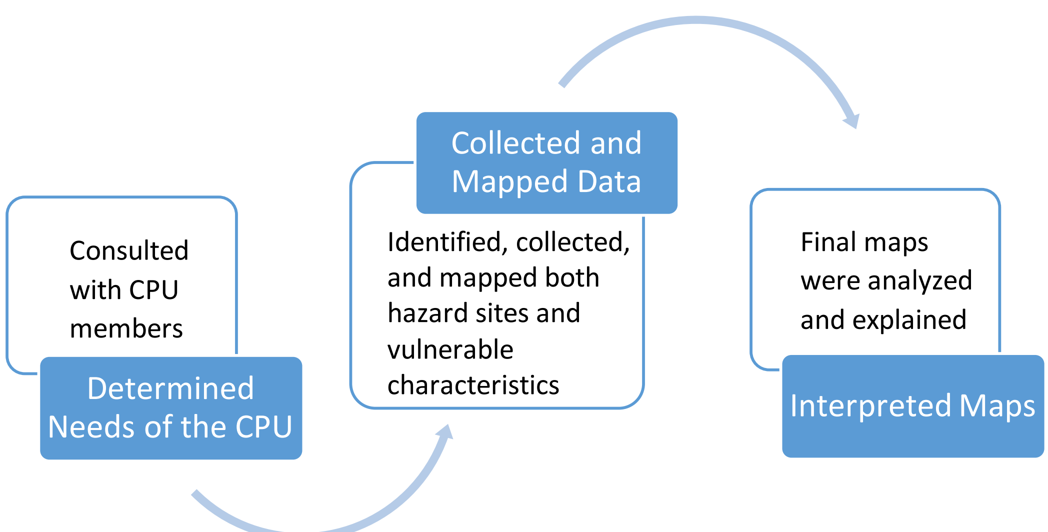

Figure 8: Flow Chart Displaying Progression of Our Objectives

3.1 Objective 1: Identified the map requirements desired by CPU staff members

The goal of this objective was to determine what information the CPU required in order to generate GIS maps. The project team began by conducting a comprehensive review of the hazards, vulnerabilities, and risks faced by the borough. We used informational sources such as risk registers and Census data to obtain this information. Additionally, we interviewed Hounslow officials to obtain confirmation of our goals and to determine what information emergency responders and planners, and the public, should know. Our interviews were informal, with several talking points and questions that led to a discussion on the topic. A list of questions and discussion topics is provided in Appendix D.

First, the team determined how risks, hazards, and vulnerabilities are defined by Hounslow and what data are used to operationalize these definitions. The team began this research by reviewing the various emergency planning and policy documents available through the Hounslow CPU. These documents included Census data and documents on responses to previous hazard events. Furthermore, the team reviewed the risk register for Hounslow in order to understand how risks and hazards are currently being analyzed and categorized. The information the team collected during this literature research was used as the background for interviews.

We interviewed professionals to obtain more detailed information that we were unable to access at WPI. After talking with the CPU, we interviewed Richard Davill, a master's student who previously worked with Twm Palmer and other members of the CPU. The team also conducted a meeting with Ben Pearkes, a Civil Protection Officer in the Borough of Hillingdon, because risks present in Hillingdon could affect vulnerable populations in Hounslow. A meeting was conducted with Michael Lewis, an emergency planning officer in Sutton, as suggested by staff members in Hounslow's CPU. A list of discussion points is presented in Appendix B, and Appendix D describes the meetings we held outside of the department in more detail. Figure 9 illustrates a map of London broken down into boroughs. This figure shows that Ealing, Hillingdon, Richmond, and Hammersmith and Fulham border the London Borough of Hounslow.

Figure 9: London Borough Map (Lambeth and Southwark Mind, 2015)

3.2 Objective 2: Mapped vulnerable populations and hazards within the borough.

3.2.1 Mapping Hazards

3.2.1.1 Hazard Data

The team used quantitative and qualitative sources in order to map hazards within the borough. Table 4 summarizes the sources of data that the team used throughout this project. The table shows what type of source it was, where the source was obtained, and how the source was used.

	Data	Type	Source	Application
Hazard Data Sources	Hounslow Risk Register	Online Document	• Fiona Hodge (CPU) • Twm Palmer	Identifying Hazard Types and Severity
	Contingency Plans	Documents	CPU Internal Records	Identifying Hazard Types and Severity
	Current Hazard & Risk Maps	Maps	CPU Internal Records	Identifying Hazard Locations

Table 4: Data Sources Used and Application

The team identified the relevant hazards within the borough by analyzing emergency planning documents within the CPU. We determined that Control of Major Accident Hazard (COMAH) sites were of particular concern. A COMAH site is a location that the Competent Authority (CA) has deemed hazardous under COMAH regulations, which allow businesses officials to limit the effects of a potential accident on the environment and people (The Competent Authority, 2013). The team used the Hounslow Multi-Agency Community Risk Register in order to identify borough-wide hazards, such as pandemic influenza and additional borough hazards that were not present in emergency planning documents (Hounslow Resilience Forum, 2015).

We determined the impact and likelihood of the identified hazards using the Risk Register and other identified documents. Finally, the team compiled a comprehensive spreadsheet including all of the data collected including hazard location, likelihood, and impact. The team sent this spreadsheet to the London Borough of Hounslow's GIS team, who then imported the information into the internal GIS system from which we were able to generated our comprehensive hazard maps (see section 3.2.1.2 Generating Maps).

3.2.1.2 Generating Maps

Members in the disaster management discipline currently use the well-established procedure of mapping hazards. Emergency planners have deployed resources to the necessary locations in the past using these maps, and preparedness activities have been used to educated populations who are at risk (The London Borough of Hounslow). Geographical hazard maps are useful because planners can place resources in appropriate locations using hazard maps that have impact zones represented by geographical boundaries. Furthermore, hazard maps allow members of the general public to plan accordingly because they can identify specific hazards within their vicinity (The London Borough of Hounslow).

The team generated GIS maps using the information described in the previous section. These maps illustrate the hazardous areas within the borough. We constructed geometric indicators on these maps in order to illustrate the likelihood and impact of a disaster if one were to occur at the various hazard site locations. Specifically, we used concentric circles on the hazard maps to represent areas with different scores of likelihood and impact.

3.2.2: Mapping Vulnerability

3.2.2.1 Census Data

The team developed a composite list of variables that various researchers have used to identify social vulnerability in the past (Table 3). Using this table as a starting point, we turned to the 2011 UK Census data. We obtained datasets from Nomis, which contains information such as age, language skills, gender, population density, occupation, and unemployment numbers, among other variables. Nomis provides free access to UK labor market statistics for the general public, and this service is provided by the Office of National Statistics (ONS). The team chose to use the UK Census data because the information is readily available, contains most of the relevant information needed to conduct the vulnerability analysis, and is available at an LSOA level. Specific sources of data can be selected by popularity, by theme, by area type, or by recent use (Office for National Statistics, 2015).

The UK Census uses a blocking method that starts with output areas that are a minimum of 100 persons and 40 households (Table 5). The output areas (OAs) are combined to produce lower layer super output areas (LSOAs) and middle layer super output areas (MSOAs). Below is a chart that displays the size of these two types of zones used by the Office of National Statistics (ONS). Not all information is organized at the OA level, so LSOAs are the smallest unit of area that displays most variables and are the most commonly used data for this kind of analysis by local government.

Zone	Min. Persons	Max. Persons	Min. Households	Max. Households
OA	100		40	
LSOA	1000	3000	400	1200
MSOA	5000	15000	2000	6000

Table 5: Size of Two Zones used by the Office of National Statistics (Office for National Statistics, 2011)

3.2.2.2 Selecting Vulnerability Variables

Given the data from Census, the team had to establish thresholds for some variables to label as vulnerable from literature review. In other cases, the team had to choose what categories would be deemed vulnerable based on the way the data was presented. Lastly, some variables were very straightforward requiring no such decisions.

One of the most common social vulnerability indicators used by previous authors is age. Due to a variety of factors such as dependence on others, physical weakness, and reduced mobility, the team decided to use age as a variable. We established numerical ranges in order to determine who is considered vulnerable due to age. Cutter et al. stated in their work that those above the age of 65 are considered vulnerable (2003). Other experts such as Dwyer used a similar cut-off, so the team chose to use the same threshold. The nationwide accepted age of adulthood in the United Kingdom is 16. The team established that those below the age of 16 are considered vulnerable, as we chose our threshold to be those dependent on others.

Occupation was also selected as a vulnerability indicator. Originally, the team wanted to use income, as reported by tax brackets, as an indicator because it was used by authors identified in the literature review and is a logical criteria for socioeconomic status (See Table 3). However, the Office of National Statistics does not provide data on tax brackets, but does provide data on the occupation of populations, organized by skill level (2010). For example, occupations that are in the highest skill level include corporate managers and directors, and those in the lowest level include those that are considered elementary trades and related occupations, as well as elementary administration and service occupations. The team selected those who had occupations in the lowest skill level to be considered the vulnerable population because that population would have a lower income (Office of National Statistics, 2010). A lower socioeconomic status indicates vulnerability because it makes recovery more difficult, in terms of access to resources.

Health was chosen as a vulnerability indicator because, due to their physical condition, less healthy individuals are more likely to sustain harm during a hazard event and are also less likely to recover. The 2011 UK Census data provided many of the necessary data sets needed for this work, asking its participants to rate the quality of their health as very good, good, fair, bad, or very bad (Office for National Statistics, 2015). The team selected those who indicated that their health was bad or very bad as vulnerable with respect to increased likelihood of sustaining harm during an event, and increased recovery time following an event. In addition, both Cutter et al. and Dwyer et al. believe that health care providers are necessary to recover from disasters; therefore, the team determined that populations of those with poor health are also vulnerable based on their dependency of health care providers and services.

Another vulnerability factor used was migration, which looked at the portion of the population that was new to the UK. The Census used the following ranges: less than two years, between two and five years, between five and ten years, more than ten years, and born in the UK (Office for National Statistics, 2015). For our index, we chose to consider those who have lived in the UK for less than two years as vulnerable because they are more likely to be non-English speakers, unfamiliar with the area, and have less of a support network to help them recover after an event. Areas with a high concentration of new immigrants also likely lack appropriate resources to accommodate the new population.

We chose to measure the variable ‘Access to transportation’ using the car availability data from the Census. This dataset was organized at the household level for each LSOA, which quantified how many vehicles each home owned. We identified those with zero cars or vans as the vulnerable portion of the population because they will be dependent on public transportation and less likely to be able to evacuate the area quickly. Ownership of vehicles is also a socioeconomic indicator, as many of those with no cars do not have the money to purchase one.

Family structure was another variable the team sought to use for our vulnerability index. Larger families in one household are considered more vulnerable because they are more likely to contain more children and elderly that are dependent on working age adults (Dwyer et al., 2004). The UK Census, however, records this data in the form of house occupancy. The data is given a ranking system that is determined by the number of rooms in a household compared to the number of people inhabiting it. A rank of 0 translates to there being the correct number of rooms for the amount of people living there, as defined by the ONS. A positive rank means the home has more room than necessary to house the occupants. Conversely, negative ranks indicate overcrowding. Thus the team chose to use the number of households that are overcrowded compared to the total homes in the LSOA as the indicator for family structure.

The ability to speak English is another important factor to consider when mapping vulnerability. Non-English speakers will have a harder time understanding warnings and evacuations, and have an increased chance of having a lower socioeconomic status (Dwyer et al., 2004). The UK Census has 'ability to speak English' data split into the categories: Native Language, Can Speak Very Well, Can Speak Well, Cannot Speak Well, and Cannot Speak at All.

We decided to use the number of people who answered Cannot Speak Well and Cannot Speak at All as the percentage of the LSOA who are vulnerable.

Education is another common social vulnerability variable that is a strong indicator of socioeconomic status, as those with higher education tend to be more financially stable. In the UK, the education system is broken down into nine levels, ranging from 'Entry Level' at the lowest tier and 'Level 8' (a Doctorate) at the highest. UK Census data provides data on this subject by listing the number of individuals whose highest level of qualifications is 4 or higher, 3, apprenticeship, 2,1, no qualifications at all, or other (Office of National Statistics, 2010). The team chose to consider those with only level 1 qualifications or fewer as those who are vulnerable because that population will more likely only have access to lower income jobs and in turn have a more difficult time gaining resources needed to recover from an event.

We found the variables of gender and population density to both be important factors, as well straightforward to collect in terms of how the Census data is classified. For the gender variable, we collected the ratio of women to the total population of each LSOA. As discussed in Table 3, women have greater difficulties recovering from hazard events because of family responsibilities and adverse economic conditions, meaning LSOAs with a higher proportion are more vulnerable. Population density for each LSOA was also readily available, which measured the number of people per hectare. Areas with a high density are considered vulnerable because more people can be harmed, as well as lose property, in the event of a hazard.

The team also used percentage of renters as an indicator for socioeconomic status. From the Census data gathered from Nomis, we identified the proportion of households that were privately or publicly renting their home. Renters tend to have less access to financial resources that are an important factor in recovering from an event and because of this, LSOAs with higher percentages of renters can be identified as more financially vulnerable.

Another socioeconomic variable in Table 3 we sought to include in our calculations was unemployment. Having a job provides an individual with a form of support network as well as the ability to make money; therefore, the LSOAs with high percentages of unemployment will have a more difficult time gaining the resources necessary to fully recover (Dwyer et al., 2004). For this reason, the team calculated the percentage of unemployed working age adults for each LSOA.

Disability and long term health problems increases an individual's vulnerability through a number of factors. Persons with these health conditions are more likely to be dependent on others for financial and mobility support as well as more susceptible to disease in the case of a pandemic depending on the infliction. The UK Census identifies the number of households in each LSOA that has at least one person suffering from a long term health problem or disability. The team used the percentage of households with these characteristics as an indicator for disability.

3.2.2.3 Vulnerability Grouping

Dwyer mentions in his discussion of vulnerable populations that no single measure of vulnerability will provide a complete answer to how vulnerable a population is; however, he also states that "there are aspects of vulnerability that can be explored and represented through the development and application of quantitative vulnerability indicators" (2004, p. 18). Most scholars and emergency planners only use individual vulnerabilities and determine which are necessary to use for each event. We wanted to provide more general vulnerability indices to aid in the planning process, as the faster a situation can be managed, the less harm is experienced. The team chose to group vulnerability indicators in an effort to aid the CPU with developing emergency plans. After considering literature on the conceptions of vulnerability and discussion with our sponsor, we determined that ‘Economic Stability,’ ‘Public Health,’ ‘Evacuation,’ and ‘Minority Status’ would be the most useful groups to use. Table 6 illustrates the selected vulnerability indicators and which group(s) they belong to.

Group	Indicator
Economic Stability	• Unemployment • Occupation • Education • Language • Gender • Vehicles • Renting • Occupancy
Public Health	• Disability • Age • Health • Population Density
Evacuation	• Disability • Age • Health • Population Density • Occupancy • Vehicles • Language • Migration • Gender
Minority Status	• Language • Gender • Migration

Table 6: Grouping of Social Vulnerability Indicators

We determined vulnerability factors that indicate a low socioeconomic status and grouped them into the 'Economic Stability' composite. The group 'Economic Stability' refers to the population's ability to recover financially after an event. 'Unemployment' and 'occupation' indicate those with low-paying or no jobs, and therefore do not have a large disposable income. Those who speak little to no English are denoted by the 'Language' indicator and are more likely to have a low-skill job. The percentage of females, shown by the 'Gender' indicator, also experiences more socioeconomic barriers. People who do not own cars, renters, and those living in high occupancy dwellings are also more likely to have a lower socioeconomic status.

We then created the 'Public Health' group, which indicates those who are dependent on health services, are more susceptible to harm and disease, and are slower to recover from an event. Persons who deemed themselves of poor health in the Census and those with disabilities are the most relevant to the category, but we also determined that the very old and young are by nature more vulnerable from a health perspective. We also included 'population density' in this group, as a pandemic will spread quicker in more densely populated areas, and problems can arise if there are too many people per health care provider.

The 'Evacuation' grouping is more general, and denotes those more dependent on services and others for mobility. We believe that this will be the most useful map, as it can be used for a variety of hazards. Vulnerabilities mentioned in the 'Public Health' are both less mobile due to their health as well as more dependent on services. 'Occupancy' can mark the locations of large families that live together, and will take longer to evacuate in order to stick together. It also indicates crowded buildings that can be more difficult to evacuate. Those without vehicles are more reliant on public transportation, which can be damaged, otherwise unavailable, or just overly crowded during a hazardous event. As a result, residents without cars might be stranded if they do not have other means to leave an area. Non-English speakers may not understand instructions and new immigrants may not be as familiar with the area, so both would require additional help during an evacuation. Women can also experience trouble leaving an area due to a variety of reasons, including cultural reasons (i.e. requiring additional clothing like a Burka), socioeconomic barriers, and family responsibilities. We developed the 'Minority Status' group using the same justifications.

Another alternative means of conveying general vulnerability would be to create a total vulnerability composite, which would be a combination of all of our vulnerability factors into one group, but we decided against it because many vulnerability factors are only relevant to certain hazards. For example, if shelter availability is a concern then having a low-skill job (occupation) becomes much less of a concern than being very old or of poor health. Weighting particular vulnerabilities within a more general group was also considered. The weighting process would entail multiplying each vulnerability factor by a certain 'weight,' or relevance to the group, and then adding those 'weighted' factors together. This would theoretically make the more important factors count for more, but there is no clear way to determine what weights to use. After talking with our sponsor and Richard Davill, as well as reading literature on vulnerability, we concluded that weights would be overly complicated and unnecessary. While the combination of multiple vulnerabilities is a better representation than an individual vulnerability, weighting skews the information and can be unreliable. According to Davidson, "no amount of clever mathematical manipulation will uncover the 'correct' weights for [vulnerability], because no single correct set of weights exists a priori" (Dwyer et al., 2004).

The combination of certain vulnerabilities will allow the CPU to better identify the most vulnerable areas of the borough. An example of these vulnerability maps can be seen in Figure 10. These previously created maps overlay plots of economic, social, and health vulnerability of LSOAs, which are different than the maps we presented in Figure 6 and Figure 7 created by (Bell et al., 2008a). The borough combined the data from three plots to make an overall vulnerability map illustrated in Figure 11. The darkest areas on the purple map illustrate the areas where populations are more vulnerable.

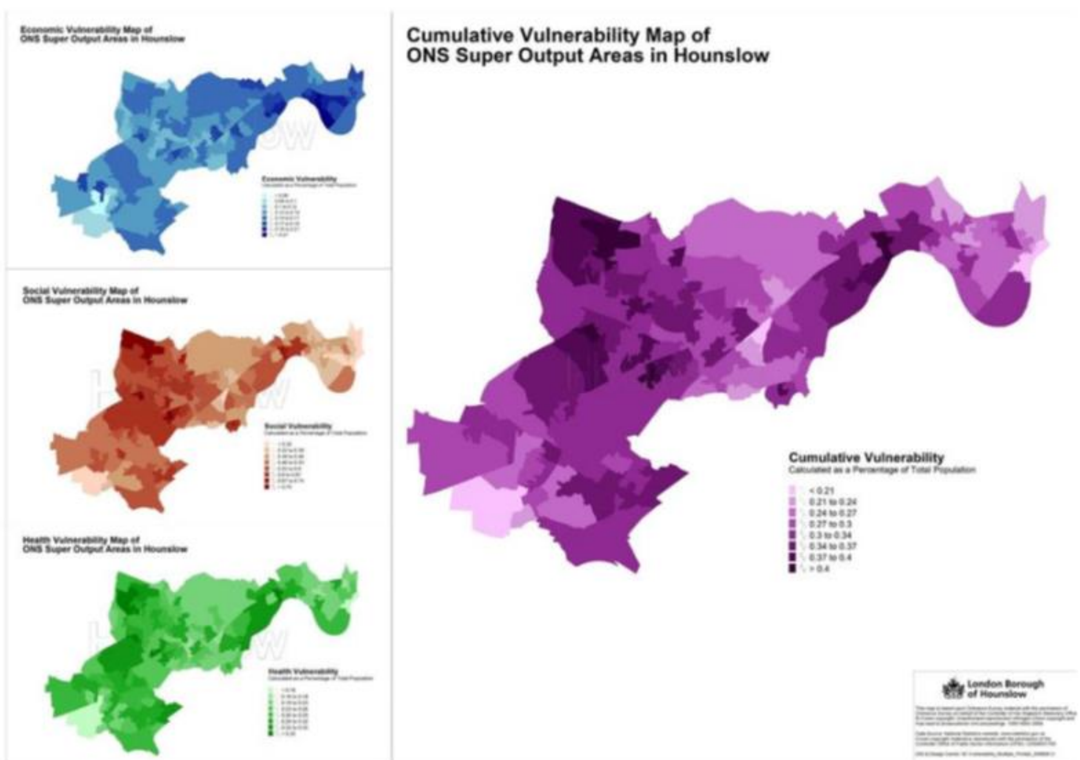

Figure 10: Composite GIS Map (The London Borough of Hounslow)

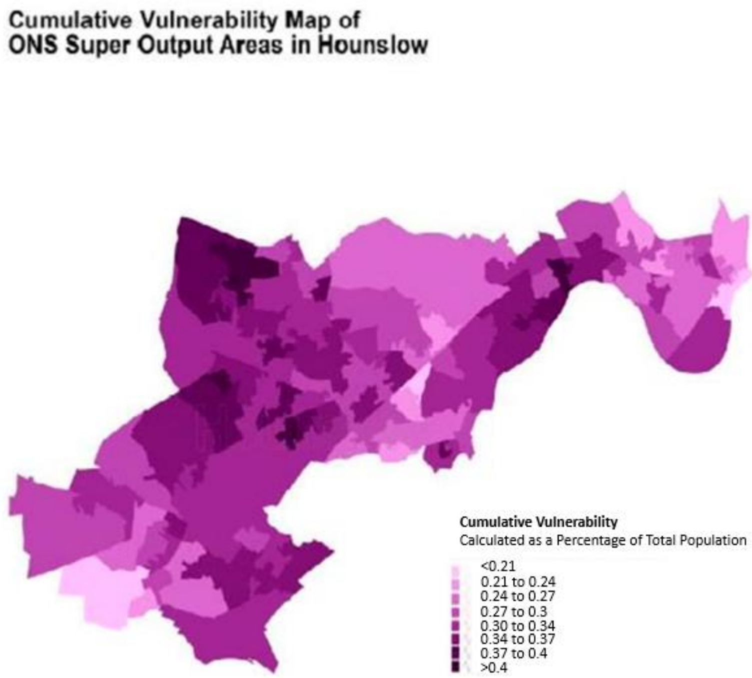

Figure 11: Cumulative Vulnerability in Hounslow (The London Borough of Hounslow)

3.2.2.4 Scoring and Mapping Vulnerable Populations

In order to create scores for these groups, the team combined the Z-Scores of the variables making up the composite. The combined score for each LSOA represents how vulnerable each LSOA is compared to the rest when considering a variety of factors. When combining scores for each LSOA, the team decided to exclude negative Z-Scores in order to prevent factors from cancelling each other out. For example, if one LSOA had a Z-Score of negative 1 for age then it would have a low percentage of youth and elderly compared to others. If the same LSOA had a Z-Score of 1 for general health, it would indicate that the area has a greater portion of its population with poor general health. In the 'Public Health' group, this particular LSOA would have a score of 0 after adding together the Age and Health scores (see Table 7).

LSOA	Age	Health	'Public Health'
Hounslow 1234	-1.0000	1.0000	0.0000

Table 7: Z-Score for Hypothetical LSOA to Illustrate Cancelling Effect

Such a score would be misleading because it does not indicate that the LSOA is vulnerable. Thus, the team omitted negative values from the composite because they would skew the results; a low vulnerability score in one category should not negate the presence of another vulnerability. For example, Table 8 shows the Z-Scores obtained for vulnerability indicators in the 'Public Health' Group for LSOA 'Hounslow 001C.' The unadjusted vulnerability score of -1.307 of this LSOA was calculated by adding the Z-Score of each of the individual indicators. A score that low is representative of an LSOA that is not vulnerable in comparison to the others. In reality the LSOA scored fairly well in disability and general health, but these variables, in turn, overshadowed the vulnerable age and density variables. Instead, the team omitted the negative scores, as seen in Table 9, where the LSOA receives an adjusted score of .7538 to better portray the vulnerabilities in the area.

LSOA	Disability	Age	Health	Density	'Public Health'
Hounslow 001C	-1.1112	0.2810	-0.9496	.4728	-1.307

Table 8: Unadjusted 'Public Health' Z-Scores for LSOA 'Hounslow 001C.'

LSOA	Disability	Age	Health	Density	'Public Health'
Hounslow 001C	0.0	0.2810	0.0	.4728	0.7538

Table 9: Adjusted 'Public Health' Z-Scores for LSOA 'Hounslow 001C.'

After meeting with Richard Davill we chose to deviate from the method of scoring found in the works of Rød et al. (2012). Following a discussion about hotspot analysis, the team found that using Z-Scores can better identify the LSOAs that are far more vulnerable than the rest. The team decided not to do hotspot analysis because it required software unavailable to the CPU, which would prevent the CPU from utilizing this method in the future. We instead combined the scores for each variable for all the LSOAs into one final spreadsheet. For further explanation of what a Z-Score represents, refer to Appendix C.

Using the Z-Scored Census data, we created a series of GIS maps to display the vulnerable populations in the borough of Hounslow. The staff of the Hounslow CPU will use the constructed maps to communicate which residents may need more attention to emergency responders, policy makers, the general public, and other professionals in the borough; this information will enhance emergency planning, preparedness policies, and practices. In order to portray the different types of vulnerabilities, the team produced separate maps depicting groups of related variables, as discussed above.

3.3 Objective 3: Interpreted hazard, vulnerability, and risk maps

The team identified areas of concern after creating the maps. We analysed both the hazard maps and composite vulnerability maps in order to identify these problem areas. The team also overlaid both hazard and vulnerability data to generate risk maps. Darker regions on the maps indicate areas of increased risks or vulnerability and are discussed further in the findings section.

4.0 Results and Discussion

During the completion of this research, the project team worked with members of the London Borough of Hounslow CPU to develop a suite of GIS maps that illustrate groups of vulnerable people and various hazards that are present in the borough. The GIS map construction process involved three key steps: identify hazards, group and score vulnerability data, and enter the data into the GIS. To begin the process, we first identified relevant hazards present in the borough and determined the areas of exposure for each using the Hounslow Multi-Agency Community Risk Register. The team then selected, scored, and grouped relevant Census data to display the social vulnerabilities of the borough. After grouping the data, we entered this information into the Hounslow GIS System and generated maps. This section further describes the results that the project team obtained while implementing the prescribed methodology.

4.1 Hazard Identification and Mapping

We gathered information on the location, likelihood, impact, and areal extent of hazards in and around the borough in addition to collecting data on vulnerability. The Hounslow Resilience Forum (HRF) keeps careful track of the hazards present and all associated contingency plans. This information can be found in various sources, including the Hounslow Risk Register (Table 2). As mentioned previously, hazards in the register are given a likelihood score, impact score, and risk rating. We noticed that higher likelihood incidents usually had a lower impact and lower areal extent, and vice versa. From these possible incidents, the team, chose one highest likelihood and one highest impact incident to represent each hazard. The incidents in the register include a 'reasonable worst case' area of effect, which we used for our maps. Our group gave these areas a score based on the likelihood and impact scores for the incident. This resulted in concentric circles surrounding the hazard sites, the different circles indicating different scores. For the high likelihood risk of COMAH sites, we used a 1km radius around the hazard point, which we determined from the risk register (HL 7 risk). We also used the risk register to find that the high impact areas of these sites (H 4 risk) are confined to a 3km radius circle around the center point. Included in these sites are the ESSO West London Oil Terminal and the Mogden Sewage Treatment Facility, which are represented as small blue dots in Figure 12.

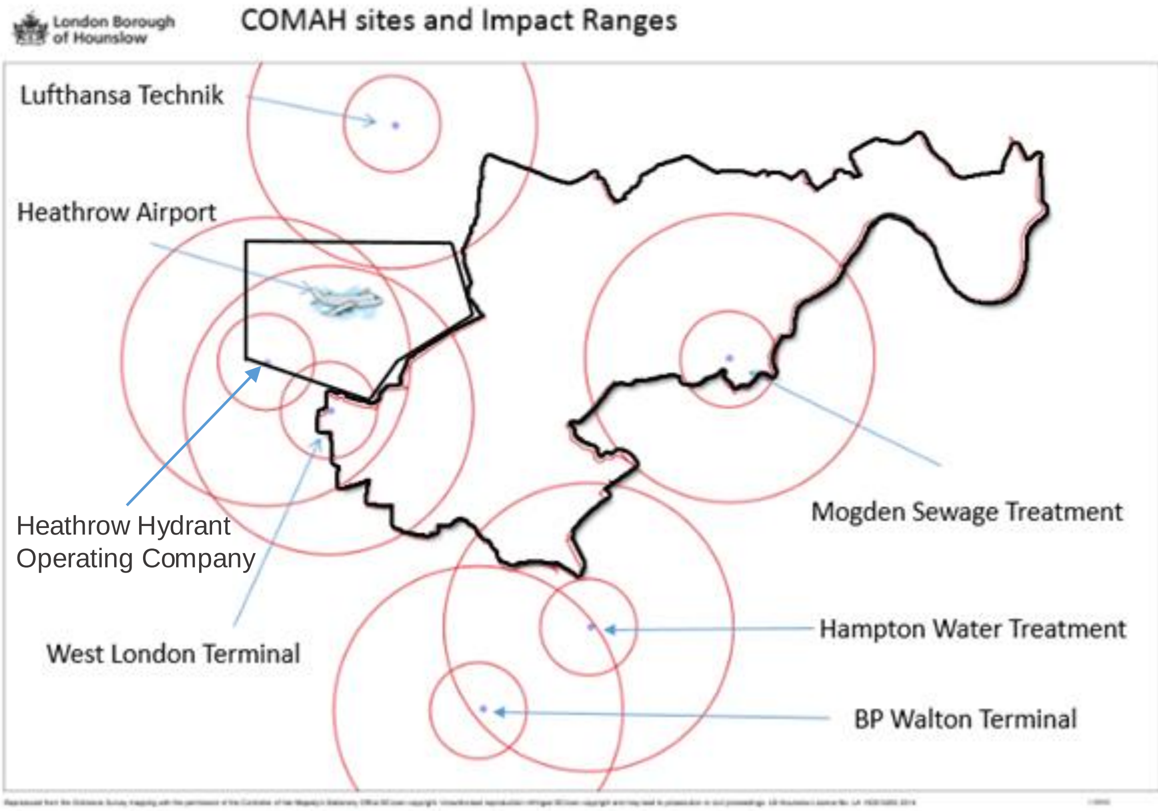

Figure 12: COMAH Sites and Impact Ranges

The ESSO West London Oil Terminal is located at the western most end of the borough and serves most of London. This terminal is at risk for several main hazard events ranging from small fires (HL 28 risks) to a major explosion (an HL 7 risk). The Mogden Sewage Treatment Facility treats sewage for over 2 million people and is located in the central part of the borough (Thames Water, 2015). To treat sewage, it stores large amounts of hazardous chemicals, which could cause an explosion or be released into the atmosphere (an H 4 risk), causing damages to the surrounding infrastructure and environment.

In addition to the COMAH sites contained within the borough, we also directed our attention to other hazards just outside the border, as the effects of an event at those sites would not be limited by political boundaries. Heathrow Airport lies on the western border of Hounslow, represented by the blue circle in Figure 12, and many planes fly over Hounslow during landing and takeoff. Heathrow hired a third party risk management company to assess the risk of aircraft incidents in the area surrounding the airport. This assessment resulted in a small area of effect, in the shape of two wedges across the western border of the borough (Civil Aviation Authority, 2015). The wedges' outlines represent a 1 in 100,000 likelihood per year of aviation incidents.

In an interview with Ben Pearkes, a Hillingdon official, we learned more about the hazards presented by Heathrow and the actions taken to protect the public. In addition to the risk of aviation accidents, there is also fuel stored on site. However, Mr. Pearkes assured us that the risks present are extremely well controlled and unlikely to affect Hounslow, as the response team on site is very good at containing incidents (Pearkes, 2015).

Another COMAH site outside of the borough is Lufthansa Technik Landing Gear Services (Figure 12), which is located a few miles to the North and West of Hounslow. They do repairs to landing gear that involves volatile chemicals. In the event of an explosion, or release of dangerous gasses, there is significant chance that the resulting cloud might pass into Hounslow airspace. This hazard was included on the Hounslow hazard map, even though the hazard site lies outside of the borough.

Petrol stations, as illustrated in Figure 13, are scattered throughout the borough, and are at risk for fire or leaks. However, they do not store enough fuel or flammable liquids to be considered under COMAH regulations, and as such the CPU does not have emergency plans for them. The team located the petrol stations manually since they had not previously been mapped. Based on the literature, we chose a 224m-radius to represent the area at risk of and affected by a major explosion, although in reality this risk area would be affected by prevailing winds (National Ground Itelligence Center, 2005).

Several major roadways run through the borough, including the M4 and A4. Given the volume of traffic, these roadways pose a substantial risk for a variety of accidents, including some that may involve hazardous chemicals. As such, the team mapped the major roads with a 45m on either side to represent the potential area affected (Standards for Highways, 2006)

Gas pipelines also pose a threat to the borough. National Grid pipes run through the north and eastern edge and BPA pipes run through the western edge, near the West London Terminal. Any damages, resulting in leaks or explosions, would be high impact for the borough, though relatively low likelihood. In order to map these hazards, the team used the reasonable worst case scenario distance from the pipelines, which is 190m (London Fire Brigade, 2013).

There are a number of hazards that could affect the entire borough, the most severe of which is a pandemic (an H 23 risk). Pandemics, or influenza type diseases, have both a fairly high likelihood and impact according to the Risk Register, and can affect up to half of the total population in a worst case scenario (Hounslow Resilience Forum, 2015).

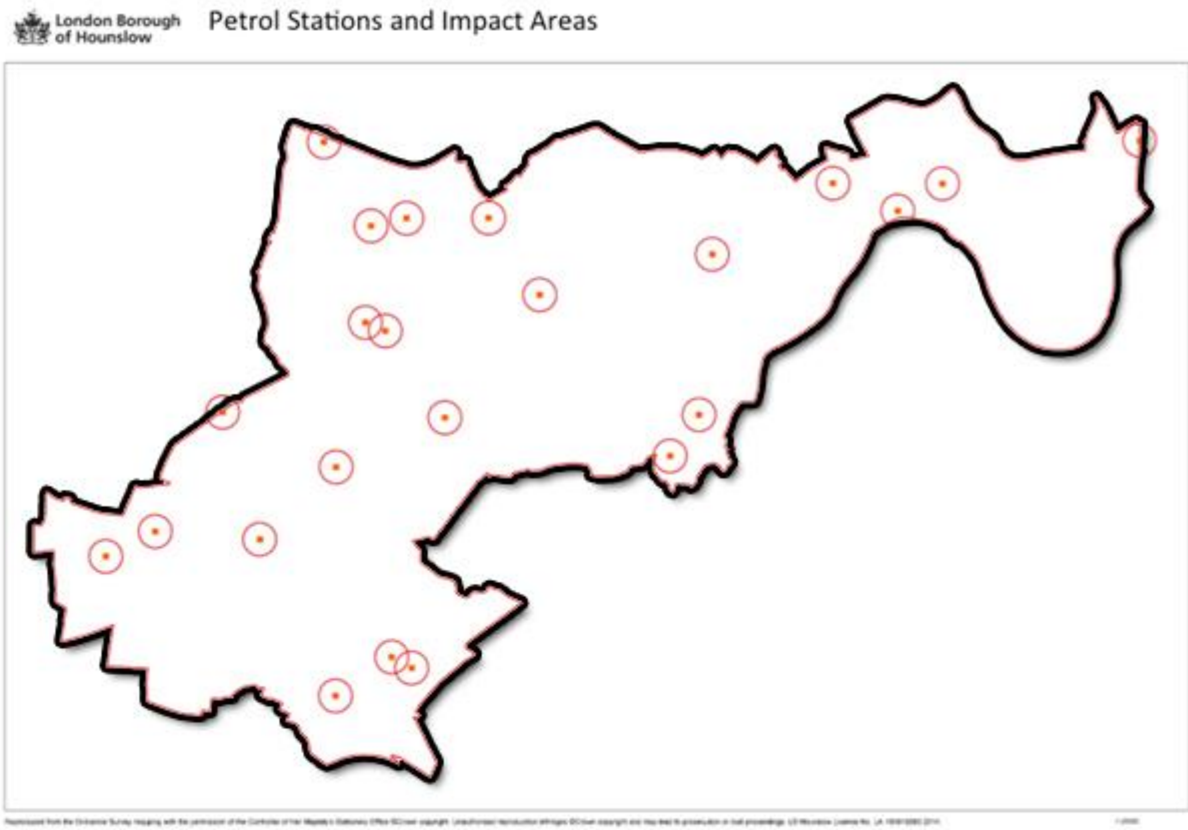

Figure 13: Petrol Stations and their Impact Areas in Hounslow

4.1.1 Flood Mapping in Hounslow

The Borough of Hounslow is extremely concerned with flooding, because the River Thames lies on its border, and two tributaries run through the borough. As such, Hounslow has different classifications for flooding depending on the source: river or fluvial, surface water, ground water, and reservoir. Ground water flooding is not included in our report, because it is generally less severe; it may result in only basement flooding and does not typically require evacuations. Reservoir flooding is a serious concern, but it also was excluded from our analysis because the data are confidential. The risk of reservoir flooding can affect property values, so the maps are only available for government use and cannot be presented in this paper.

Fluvial flooding is classified into three zones, according to likelihood (see Figure 14). Flood zone 1 has the lowest probability of flooding, and designates areas that may flood only every 1000 years or more. These areas are represented by the white shading in Figure 14. Flood zone 2 is shaded with the lighter blue and includes areas that are likely to be inundated every 100 to 1,000 years. Lastly, the darkest blue denotes flood zone 3 contains areas that are likely to flood every 100 years or less. A location in the 100 year flood plain, for example, has a 1% chance of one flood per year, but a 63.4% chance of one or more floods occurring within 100 years following the binomial probability formula ("Binomial Probabilities," 2015). Zone 3 is contained entirely within zone 2, and zones 2 and 3 are entirely within zone 1 (Mair, 2015).

The Environmental Agency (EA) originally created and mapped these zones, and the Hounslow Council later modified zone 3 to be more accurate based on historical records. Additionally, flood defenses have been constructed on the River Thames in the area of Chiswick. The EA does not take these into account when determining the flood zones; therefore, the actual risk in each flood zone varies and the defenses must be mapped separately. Below is a hierarchy, from highest to lowest, of those who are at risk of flooding with examples of each zone in Figure 14:

- Any area within flood zone 3 that does not benefit from flood defenses
- Any area within flood zone 3 that benefits from flood defenses
- Any area within flood zone 2, but not flood zone 3, that does not benefit from flood defenses
- Any area within flood zone 2, but not flood zone 3, that benefits from flood defenses
- Any area within flood zone 1, which covers the entire borough, excluding the areas listed above

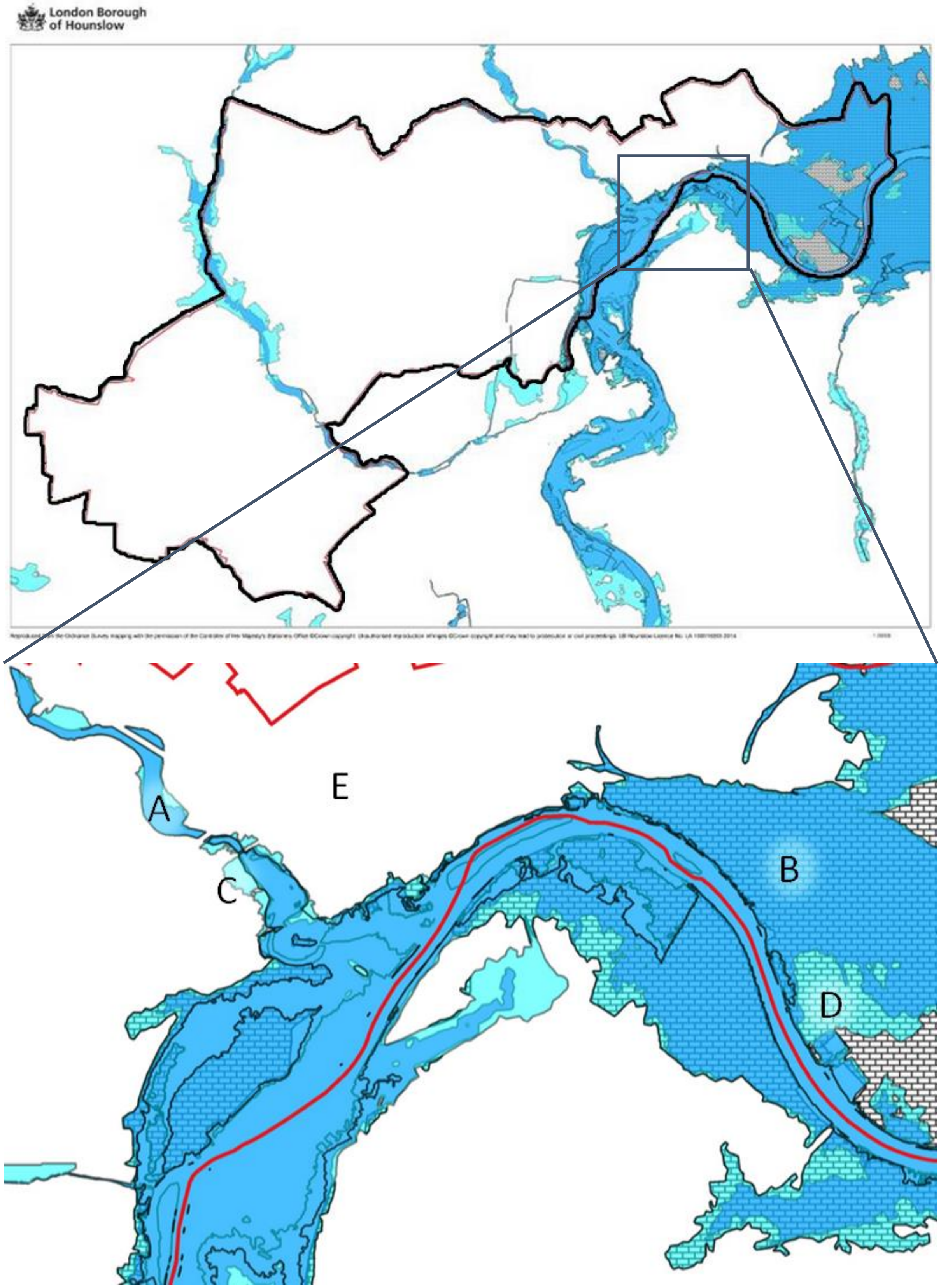

Figure 14: Fluvial Flood Zones

4.2 GIS Mapping of Vulnerable Populations

After generating the Z-Scores for both the individual indicators and groups and importing them into the GIS system, the team assembled the various vulnerability maps. For the ‘Public Health’ map, the team combined the indicators age, general health, population density, and disability. Our group graphed the individual variables in Figure 15, Figure 16, Figure 17, and Figure 18, where the darker LSOAs represent areas that have higher concentrations of the population that possess that vulnerability characteristic.

Using the scores from each of these factors, the team calculated ‘Public Health’ Group’ scores to produce a composite map, which can be seen in Figure 19. Areas in the central and southern parts of the borough are darker in each of the four maps above, which resulted in the darker shading in the composite maps. The darkness of an area is an indication of vulnerability, as shown in the scale. The higher the number is on the scale or the darker the color of the area is on the map, the more vulnerable the area is. Combining maps into composites adds the scores of each individual map, so areas vulnerable in several maps are very vulnerable in the composite, and areas less vulnerable in multiple maps are much less vulnerable in the composite. As shown in Figures 15-18, the LSOA in area A only has a high level of vulnerability in the age map, and it has low levels of vulnerability in the other maps; as a result, the composite has a low level of vulnerability. Likewise, the LSOA in area B has a medium level of vulnerability in all of the maps, so the result of adding those vulnerabilities is also a medium level. As noted in the section above, we omitted negative Z-Scores. In terms of mapping, leaving the negative Z-Scores in our composites would lighten (lower vulnerability) certain LSOAs that should be darker (higher vulnerability).

The team conducted the same procedure described above for all of the vulnerability groups listed in Table 6 (page 33) and generated the resulting composite maps illustrated in Figure 19: ‘Public Health’ Group Vulnerability Map, Adjusted, Figure 20: ‘Economic Stability’ Group Vulnerability Map, Adjusted, Figure 21: ‘Evacuation’ Group Vulnerability Map, Adjusted, and Figure 22: ‘Minority Status’ Group Vulnerability Map, Adjusted

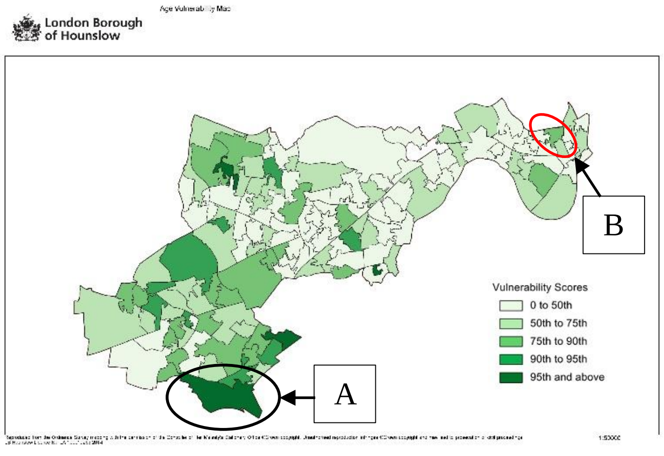

Figure 15: Vulnerability by Age

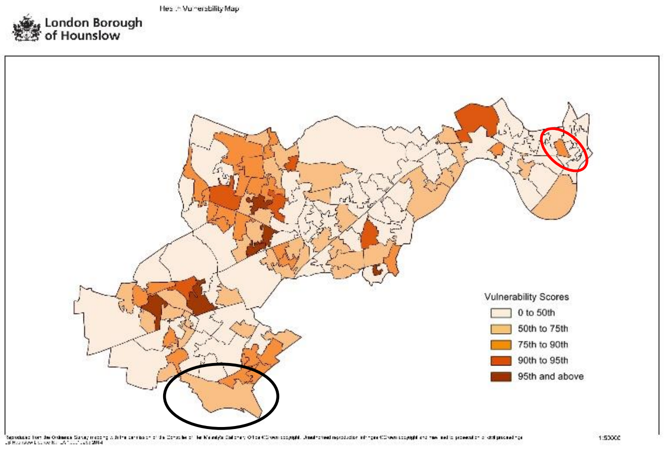

Figure 17: Vulnerability by Health

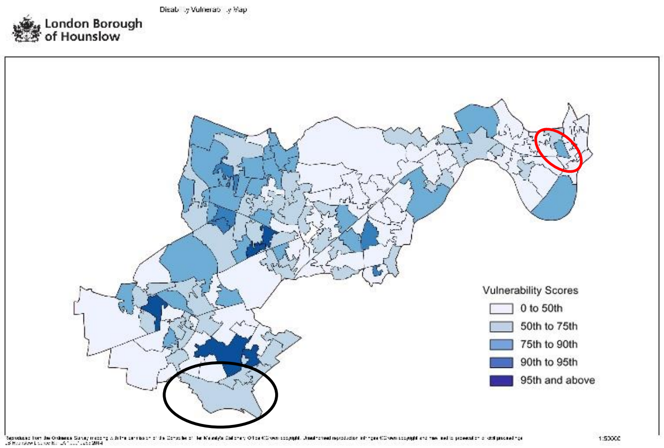

Figure 16: Vulnerability by Disability

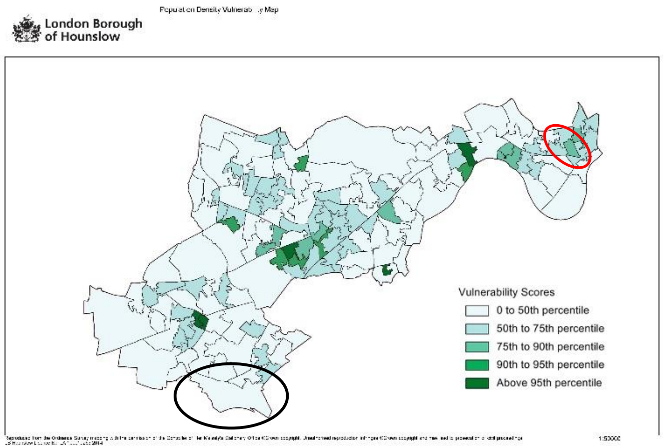

Figure 18: Vulnerability by Population Density

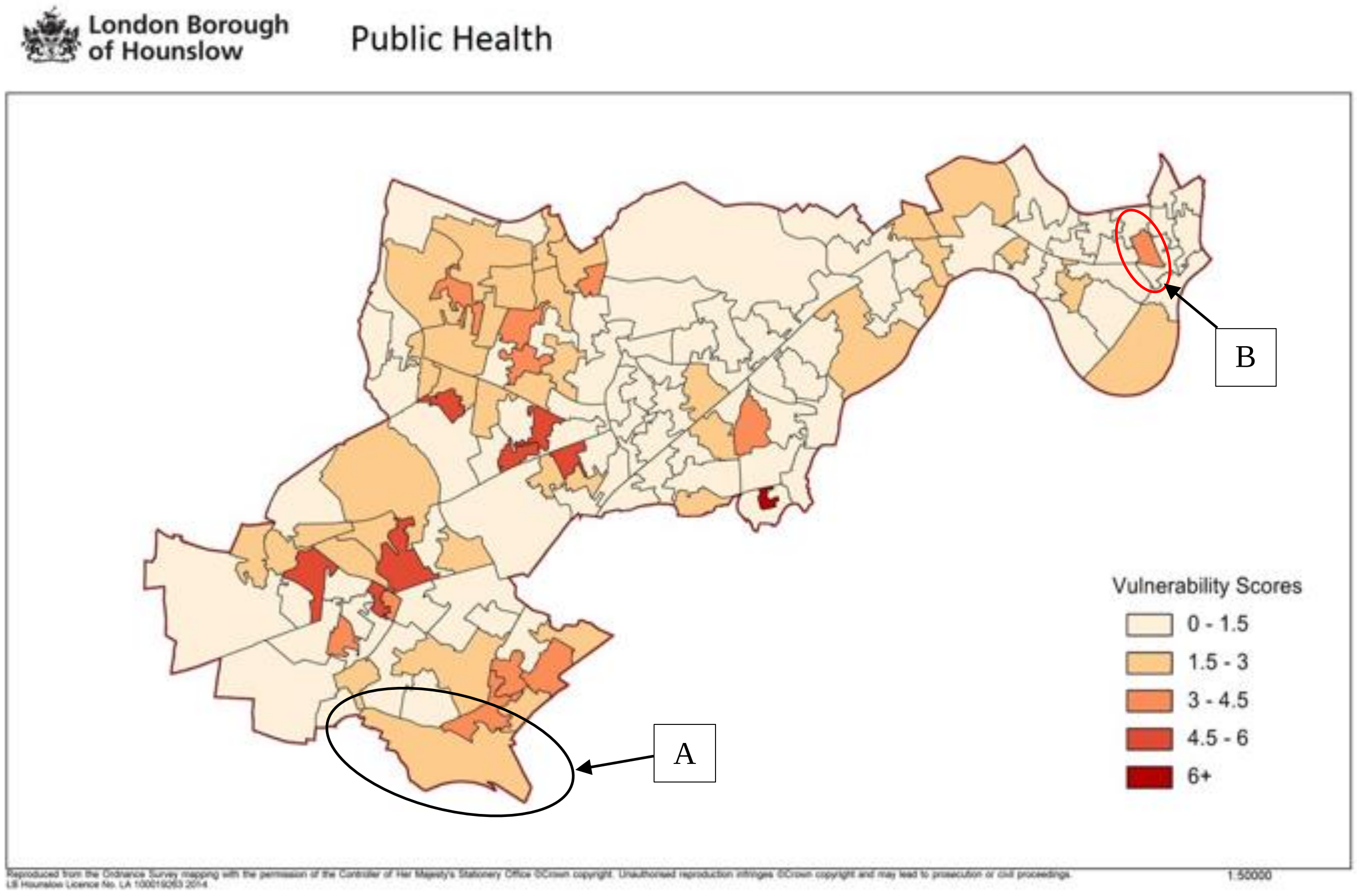

Figure 19: 'Public Health' Group Vulnerability Map, Adjusted

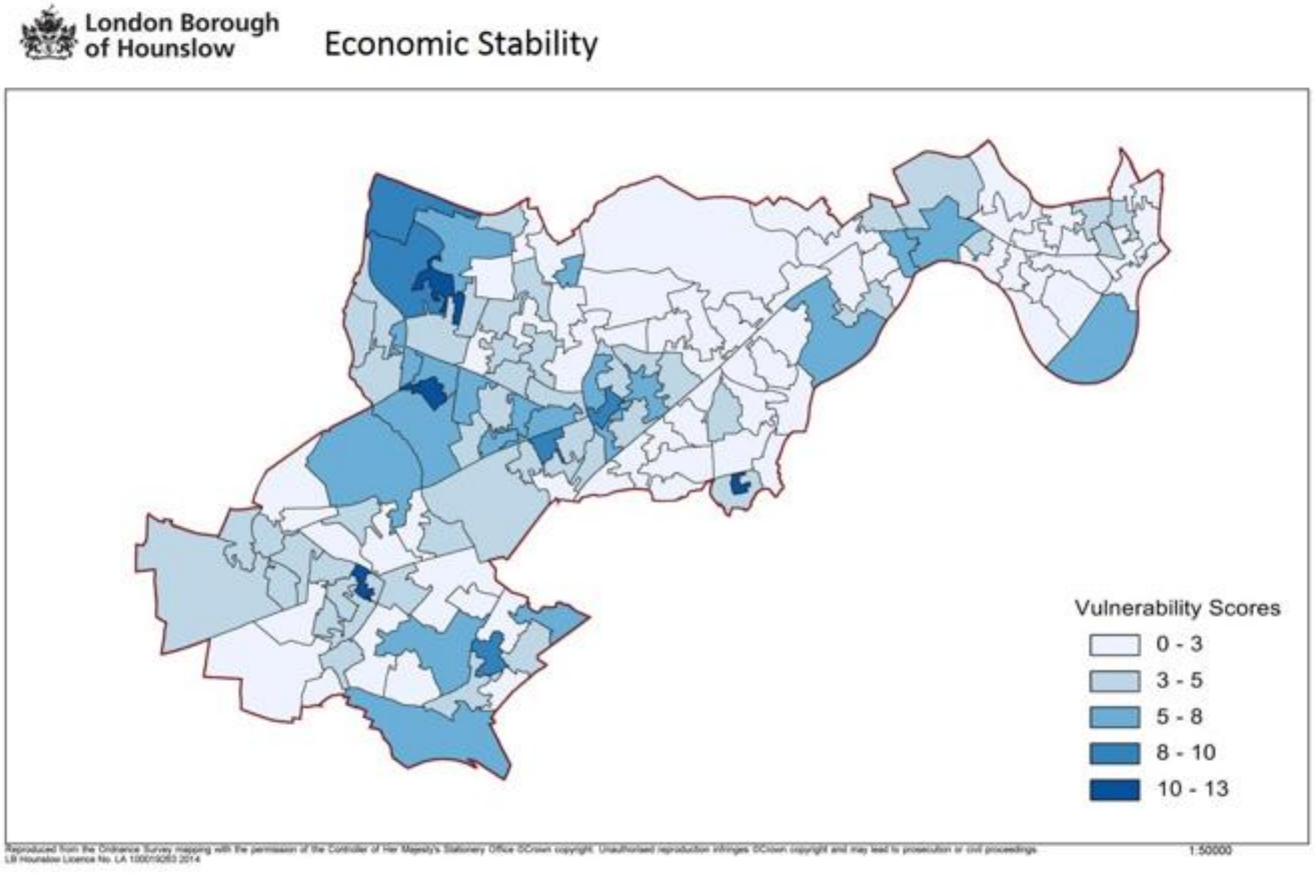

Figure 20: ‘Economic Stability’ Group Vulnerability Map, Adjusted

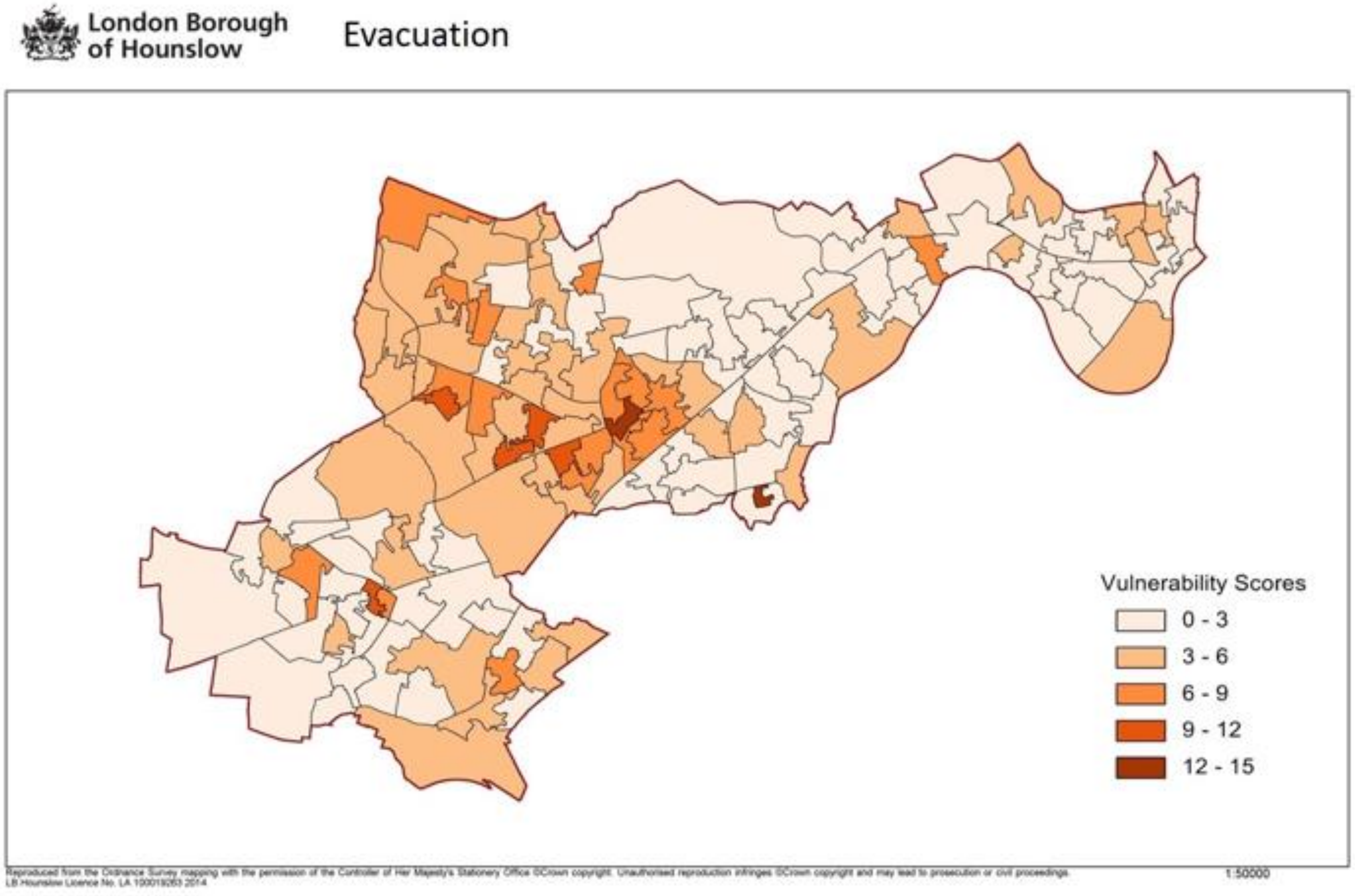

Figure 21: 'Evacuation' Group Vulnerability Map, Adjusted

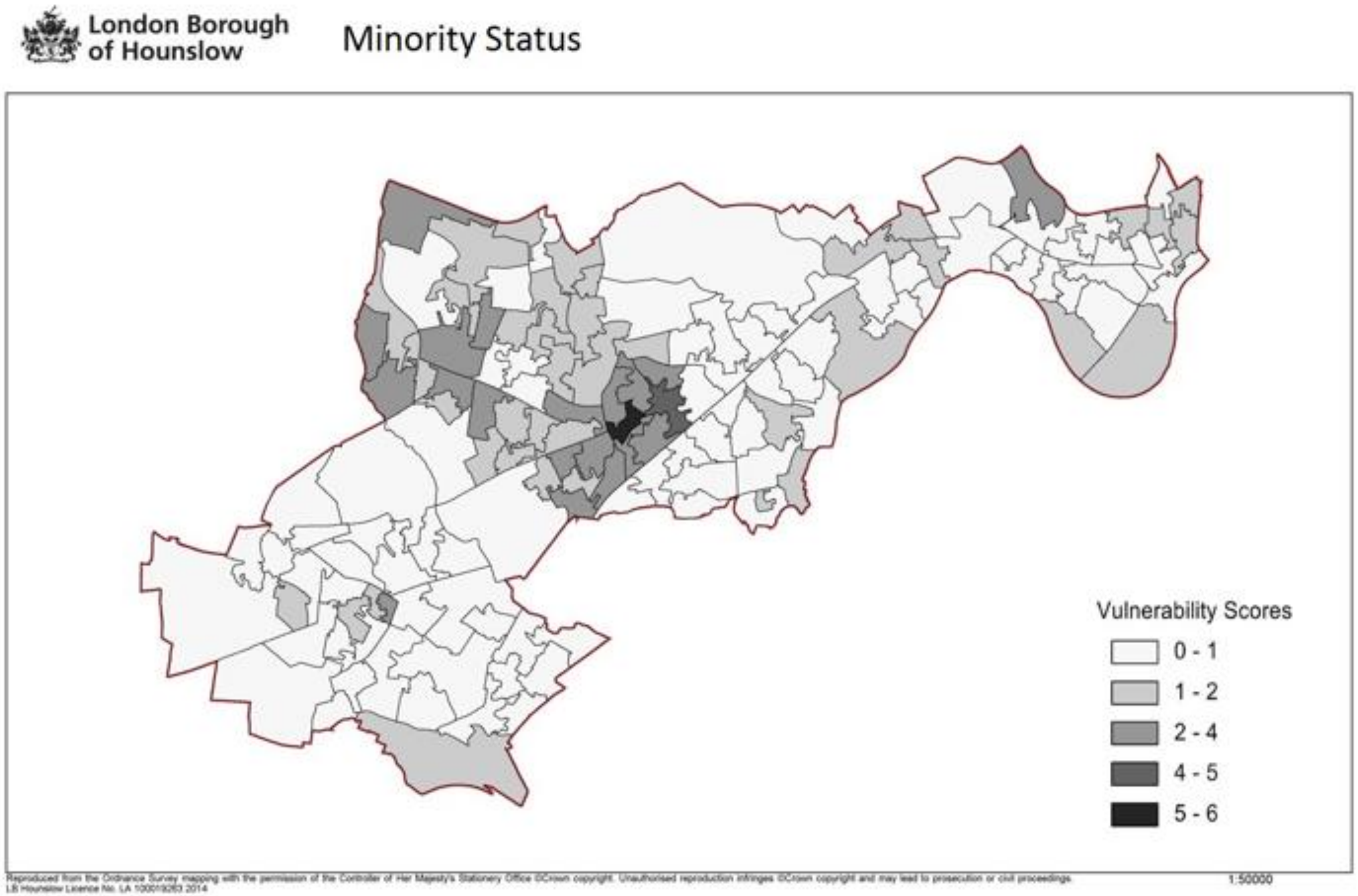

Figure 22: 'Minority Status' Group Vulnerability Map, Adjusted

4.3 Discussion

4.3.1: Interpreting Hazard Maps

A hazardous area poses a threat to the life, health, property, or the environment in and around it. Hazard maps allow the CPU and emergency planners to visualize the locations of hazards and plan accordingly. The team created 3 hazard maps: a map of COMAH sites (Figure 23), a map of petrol stations (Figure 13), and a composite hazard map (Figure 24) containing the major threats to the borough. As described in our methodology, two concentric circles are used for some of the hazards, with the smaller circle representing a more likely but less impactful event, and the larger circle representing a less likely but more impactful event.

Figure 23 shows COMAH sites affecting the borough: the Lufthansa Technik Landing Gear Service (TLGS), the Heathrow Hydrant Operating Company (HHOpCo), the West London Oil Terminal (ESSO), the Mogden Sewage Treatment Works, the Hampton Water Treatment Works (WTW), and the BP Walton Terminal. We shaded the map by levels of risk in order to highlight areas of concern, with darker areas indicating greater risk. The lightest shaded area, area A, indicates the base risk of the borough due to hazards like pandemics, which are independent of geography. We noticed a particular area of concern after mapping these hazards. In the southwest area of the borough, depicted by areas D and E, there are two major COMAH sites, the HHOpCo and ESSO, whose risk areas overlap. This means that a large scale event at one of these locations could affect the other and exacerbate the situation.

The petrol station map (Figure 13) shows the location of all petrol stations within the borough. These sites have relatively low likelihood and impact scores, but still require a response as hazardous events at these sites can still greatly affect the community. A petrol station explosion may be less significant than an oil terminal explosion, but to the immediately surrounding area it can be just as devastating.

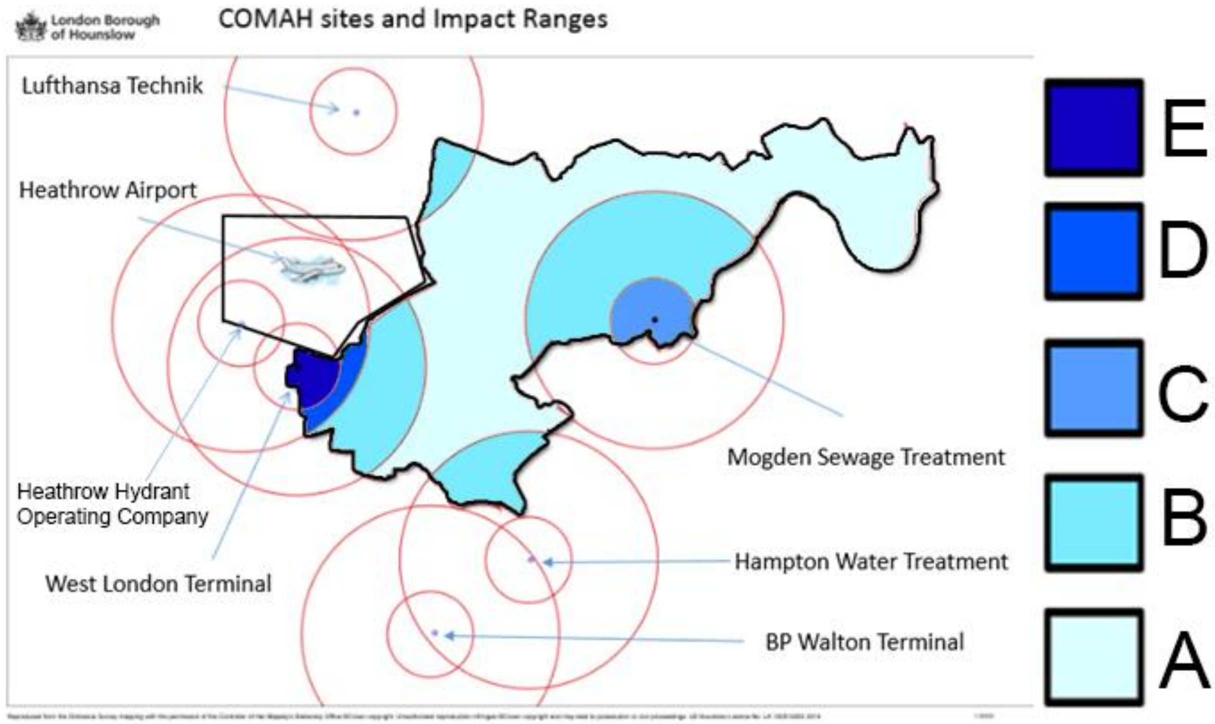

Figure 23: COMAH Site Hazard Map

The team also developed a composite hazard map (Figure 24) that contains COMAH sites (large concentric circles), petrol stations (small circles), transportation routes (lines), flooding, and Heathrow's public safety zones (triangles). As with most of our maps, darker areas are at greater risk, such as areas A, B, and C. Area A contains two overlapping COMAH sites, a petrol station, and several transportation lines. Similarly, area B contains a COMAH site, petrol site, transportation line, and risk of flooding due to the Thames River. Area C also contains several petrol stations, transportation lines; additionally, a large part of Area C is at risk due to flooding.

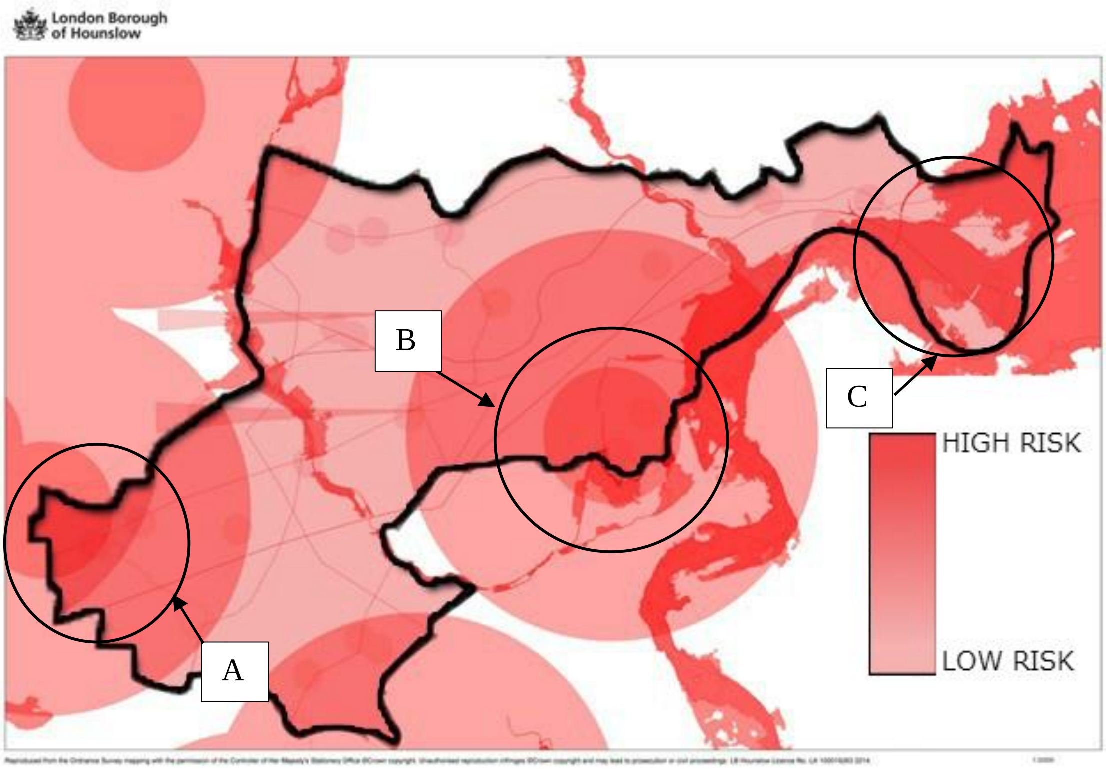

Figure 24: Composite Hazard Map

4.3.2 Vulnerability Map Comparison

The team identified several LSOAs throughout the borough that are considered vulnerable according to the individual vulnerability indicators presented in 7.5 Appendix E: Vulnerability Maps of Individual Social Vulnerability Indicator. As illustrated in Figure 25 the central region of Hounslow has an extremely high concentration of individuals who have spent very little time in the UK (less than 2 years), and it contains the largest number of people who live in overcrowded quarters. The central part of the borough also contains large numbers of immigrants who cannot speak English well. Furthermore, the northwestern part of the borough contains a large number of people who cannot speak English proficiently, and it contains a large population of people who work in jobs in low skill levels. Finally, the areas of the borough illustrated in Figure 28 contain large numbers of unemployed people who are also disabled.

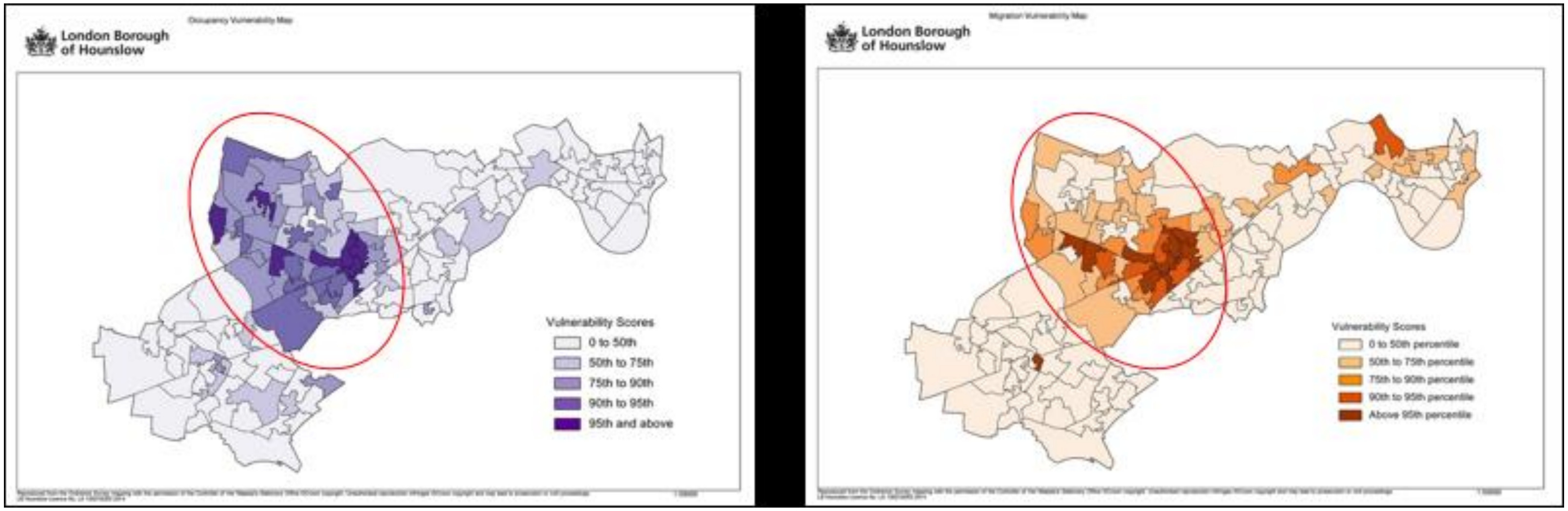

Figure 25: Household Occupancy and Migration Comparison

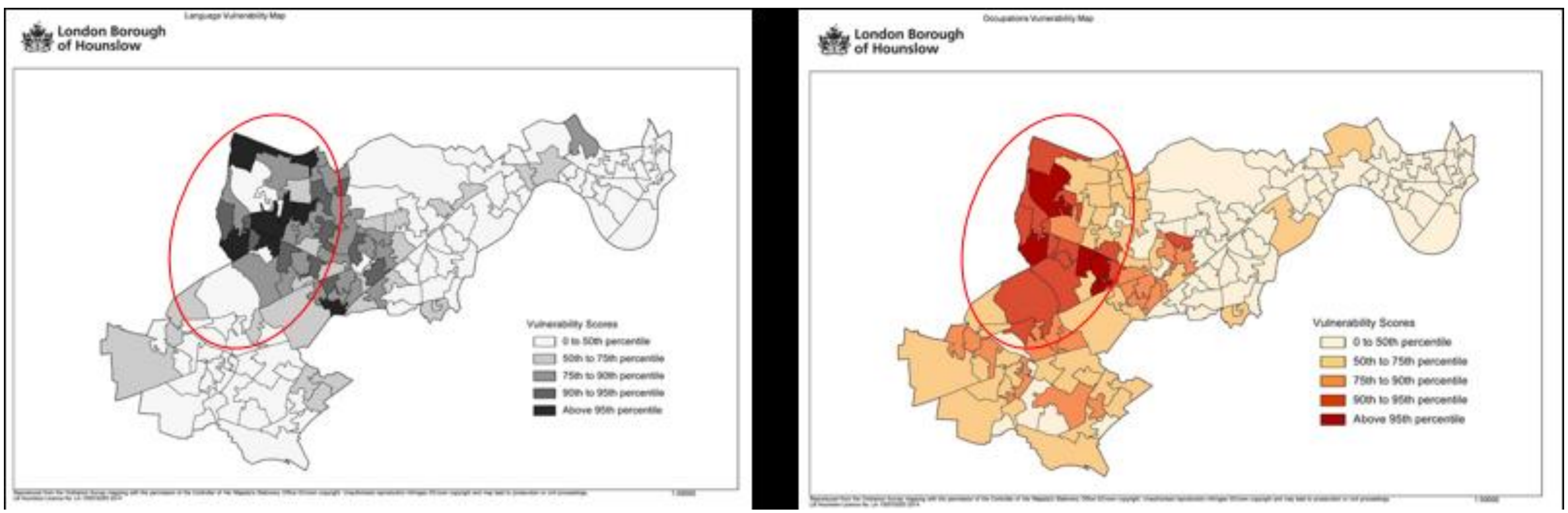

Figure 26: English Proficiency and Occupation Comparison

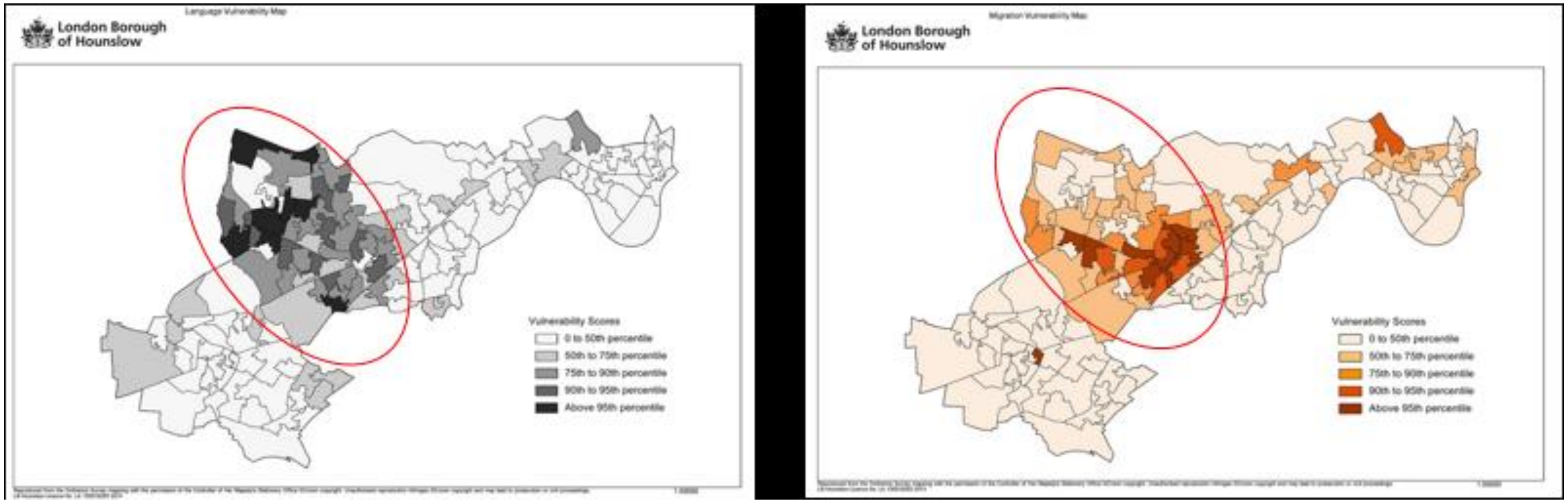

Figure 27: English Proficiency and Migration Comparison

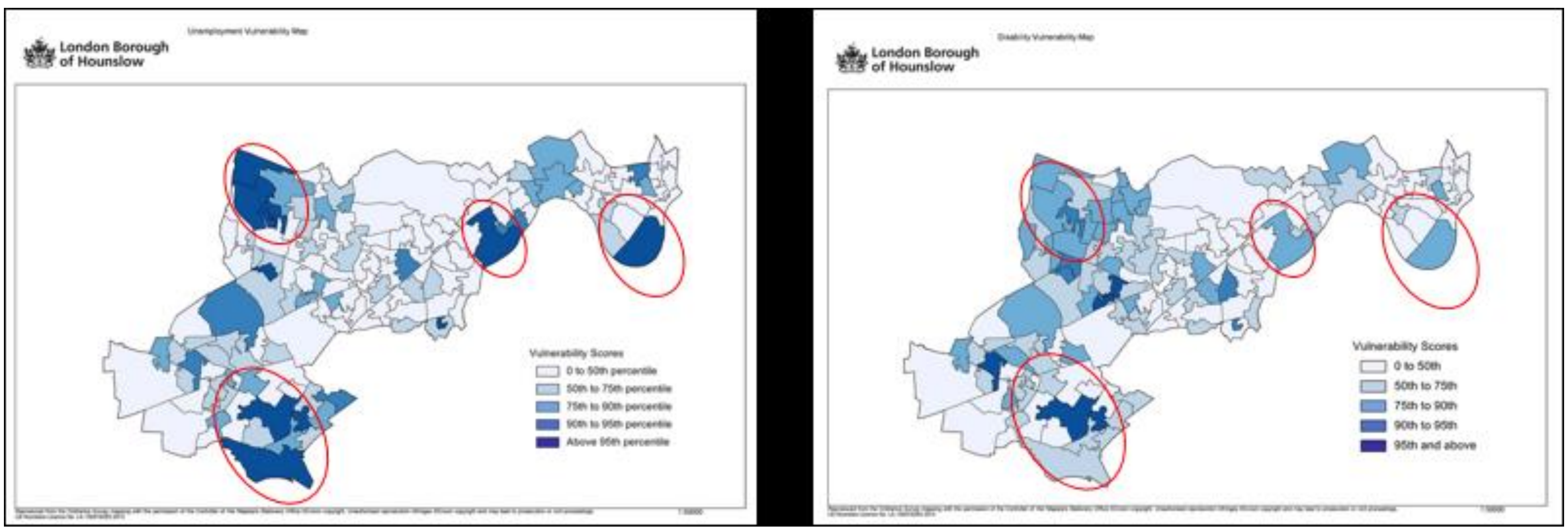

Figure 28: Unemployment and Disability Comparison

Figure 25 above shows that there is a strong relationship between Household Occupancy and Migration, indicating that many new immigrants live in more crowded areas. In terms of vulnerability, this means that there are concentrated areas of a population who are less familiar with the locale and would need more help with evacuation instructions. Figure 26 illustrates the strong relationship between the ability to speak English and occupation. It is clear that those who do not speak English well also work in low-skill jobs. The team has subsequently assumed that those who do not speak English well struggle to find decent work because they cannot speak the native language of the country, and thus must settle for less desirable work.

Figure 27 shows the relationship between English Proficiency and Migration Comparison. There is a large concentration of individuals in the center of the borough who are not proficient in English, and they have also been in the country for less than two years. We have assumed that many of the new immigrants to the country do not have a strong proficiency in English. Finally, Figure 28 shows the relationship between Unemployment and Disability. Many of the LSOAs that contain a large portion of unemployed people also contain a large portion of disabled people. Therefore, it can be assumed that many of these disabled people are also unemployed, indicating disabled persons may have financial troubles as well.

4.3.2 Interpreting Composite Vulnerability Maps

Identifying those in a population who are vulnerable during a large scale disaster is essential to providing an efficient response to the incident (The London Borough of Hounslow). Members of the Hounslow CPU can maintain a high level of preparedness by understanding the vulnerability characteristics of a population before a large scale disaster occurs (The London Borough of Hounslow). This section provides some examples on how the generated composite vulnerability maps could be interpreted. For example, LSOA 'Hounslow 020E,' in the south central area of the borough, (Figure 29), fell in the highest vulnerability range in the 'Public Health' vulnerability group. This LSOA contains many elderly homes, such as the Thirlmere House, Haweswater House, and Easedale House which house many elderly citizens in a very small area. Additionally, this LSOA can be considered more vulnerable because it is surrounded by an LSOA that is not vulnerable in the Public Health Group. The majority of the LSOAs that are vulnerable to public health characteristics are located in the central and western areas of the borough (Figure 29). Therefore, emergency responders and planners may focus their attention to these larger areas rather than 'Hounslow 020E.' It is possible that the population within

'Hounslow 020E' may have a lack of available resources, because it is geographically smaller and a greater distance away from the central and western areas of the borough.

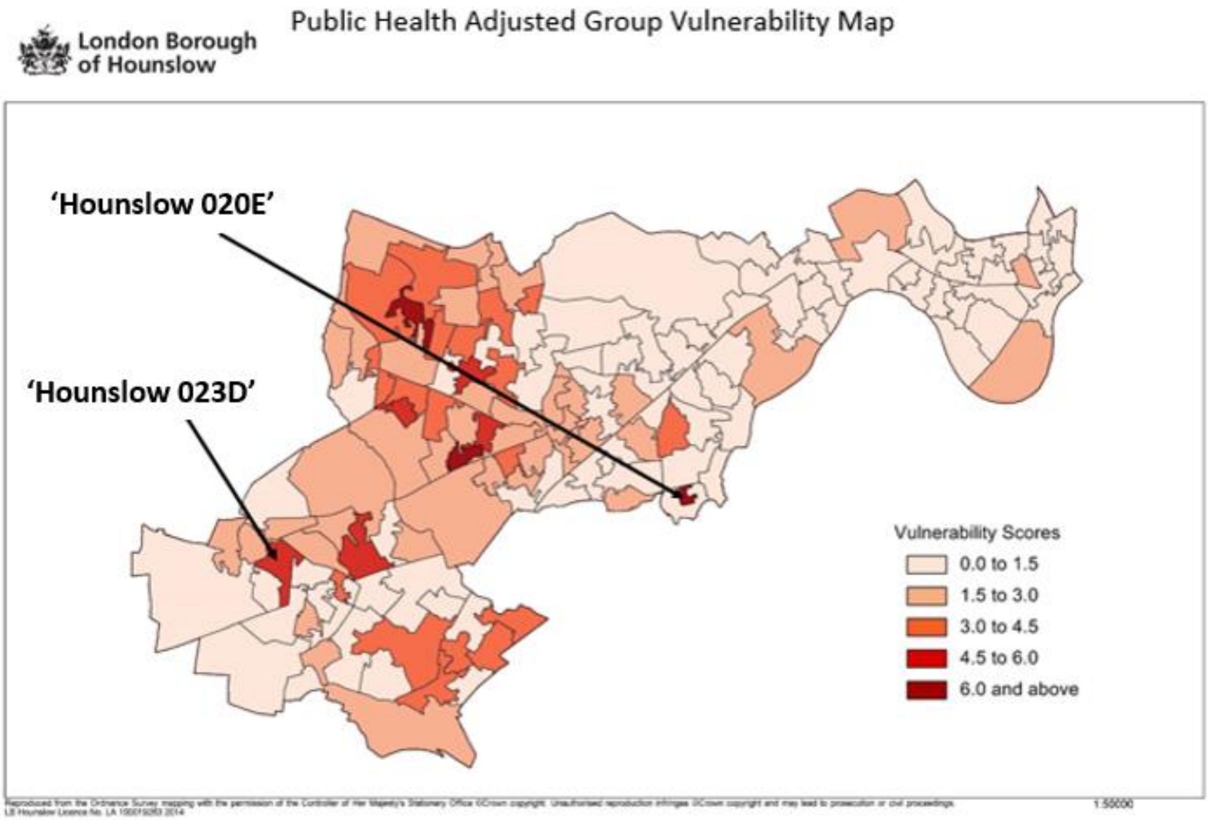

Figure 29: Location of LSOA 'Hounslow 020E' and 'Hounslow 023D'

Another example incorporates LSOA 'Hounslow023D' in the southwest area of the borough (Figure 29). This LSOA also ranked high in the 'Public Health' vulnerability group. Looking at Figure 29, it is evident that this LSOA fell in the highest range on the Disability vulnerability map. The team analyzed geographical sites and locations within this LSOA, and we discovered that there are additional elderly service homes present, such as the Sandbanks Resource Centre, and the Edward Pauling House. Therefore, it can be assumed that many of the tenants in these housing facilities are disabled, thus causing this LSOA to have the high disability vulnerability score. Interpreting the generated vulnerability maps in this manner will allow members of the CPU to identify what makes the populations living in these specific areas more vulnerable than others. Moreover, this method will allow CPU staff to determine if emergency response plans and procedures need to be revised and improved.

4.3.3: Integrating Vulnerability with Borough Hazards in the Form of Risk Maps

Vulnerability and hazard maps can be used independently, but can provide more useful information by combining the two into risk maps. Figure 30 shows the location of rest (or leisure) centers and other large public buildings (e.g., community halls, schools, churches) that could be used as evacuation sites in the event of an emergency. The map also shows the location of the social housing estates. Many of the people in social housing are likely to go to evacuation sites in the event of an emergency since they may lack the resources to go to alternative shelters, such as hotels within or outside the borough. These data are presented on a base layer showing the LSOA ratings on the composite vulnerability index for ‘Evacuation.’ Area A contains an LSOA with a vulnerable population and several social housing sites. There are also no evacuation sites within close proximity to this area. If a potential incident requires evacuation, a more dependent population must move a greater distance through a potentially hazardous area in order to reach shelter. Area B is also at risk due to the proximity of several vulnerable LSOAs, a multitude of social housing sites, and only having one evacuation site in the area.

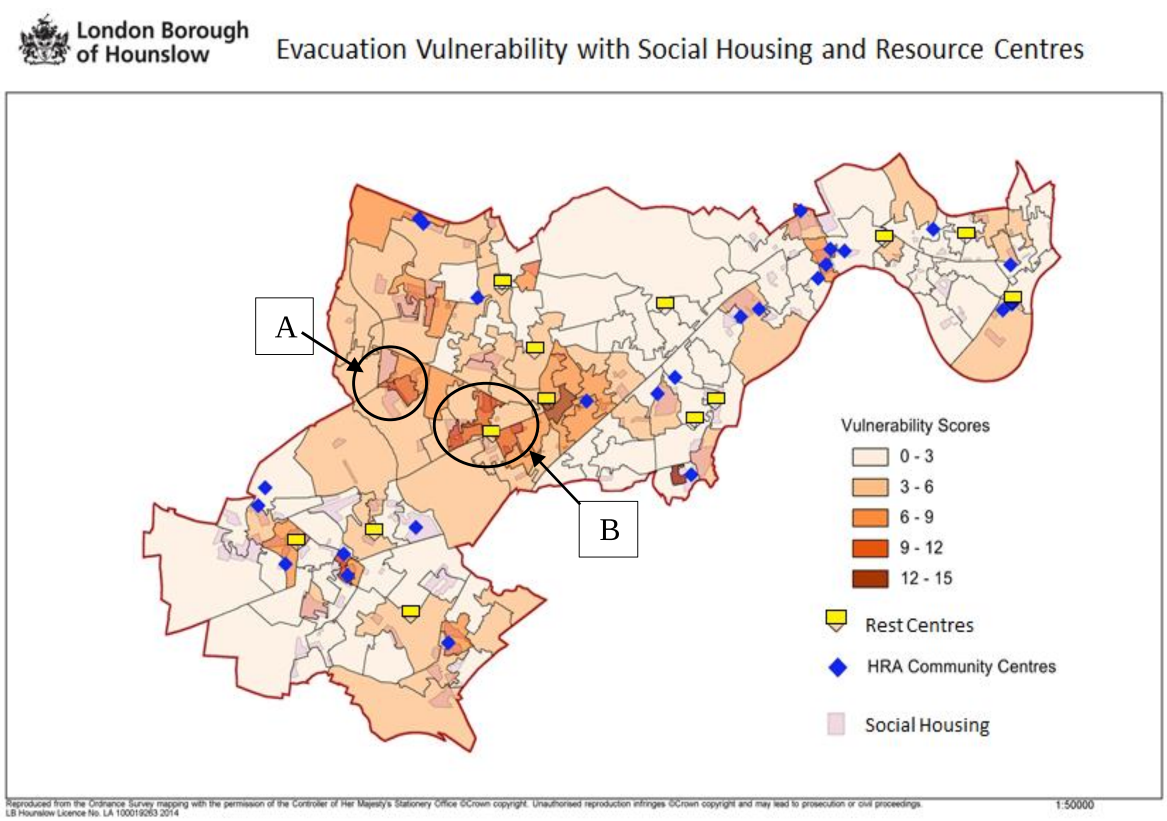

Figure 30: ‘Evacuation’ composite overlaid with evacuation sites and social housing

In order to obtain a better understanding of the risks present to those who are vulnerable in the 'Evacuation' composite group, the team mapped COMAH sites and petrol stations with fire stations, police stations, and evacuation centers Figure 31. This map illustrates where emergency services are located compared to the hazards and the availability of evacuation centers throughout the borough. For example, area A shows that a police station and a fire station are near the Mogden Sewage Treatment Works, which could quickly attend to an emergency. This area also contains numerous evacuation centers both inside and outside the zone of high likelihood. The shelters inside the zone can be used for immediate safe haven and also as a predetermined rendezvous point for rescue. The shelters outside the zone would be safer, though more difficult to reach.

In areas B and C, there are a number of COMAH sites, relatively few evacuation centers, and only one relatively close police and fire station. In the event of multiple emergencies at the same time, or in a short timeframe, emergency services would be sparse more than anywhere else in the borough. This could cause delays in emergency response. Additionally, the distance to evacuation centers in these areas could make it more difficult for citizens to get to refuge.

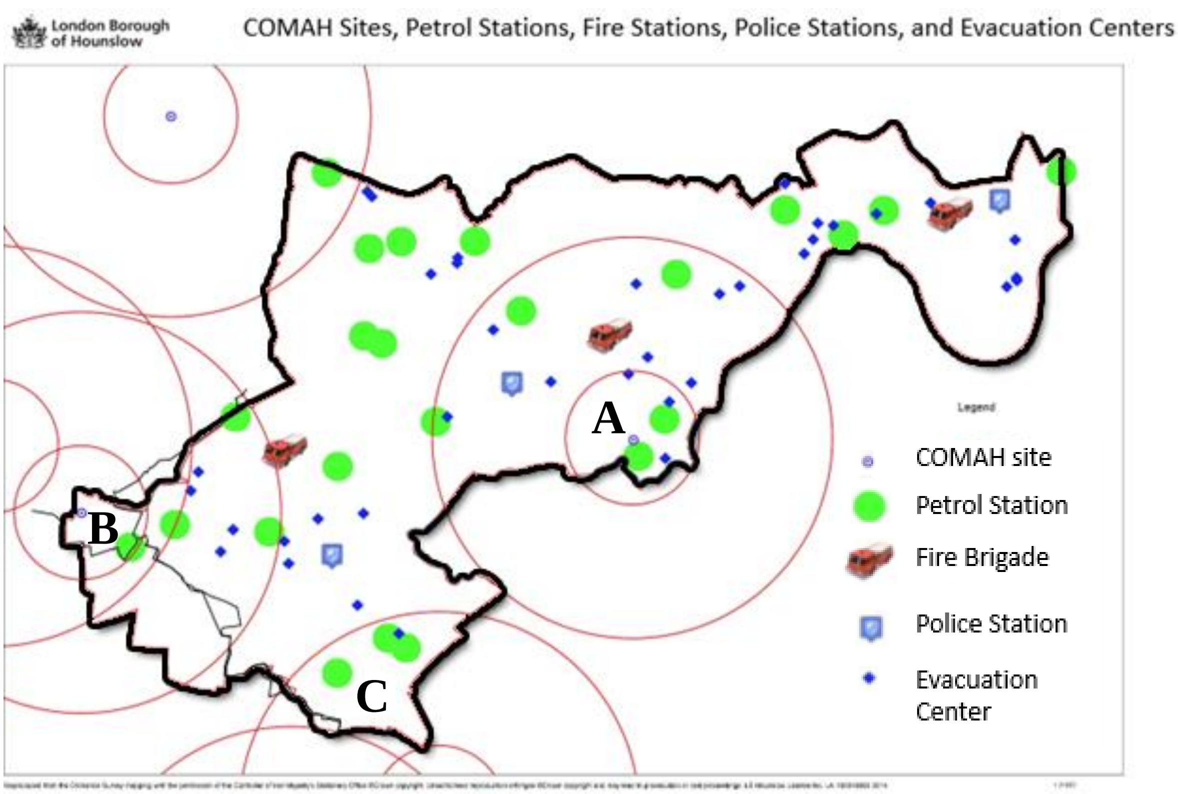

Figure 31: Map of COMAH Sites and other Emergency Response Locations

Finally, the team mapped the ‘Public Health’ vulnerability composite group with the locations of general practitioners (GP) and the location of the one hospital in the borough (Figure 32). We were able to compare the locations of several LSOAs with bad health to the proximity of facilities that could provide assistance by comparing the composite vulnerability layer with the locations of emergency response centers. In the areas labeled A and B in Figure 32, vulnerable LSOAs with numerous nearby GP centers are visible. These LSOAs may not need as much attention after an emergency given their close location to available medical resources. In contrast, the LSOAs in the southern part of the borough contain only three nearby GPs (see area C Figure 32). Residents in this area could have difficulty reaching a doctor in the event of pandemic, which emergency planners should take into account for the response and recovery process. Moreover, LSOA ‘Hounslow 020E’ (labeled D) is relatively isolated. The people living there during or after an emergency could experience a large degree of difficulty receiving medical attention.

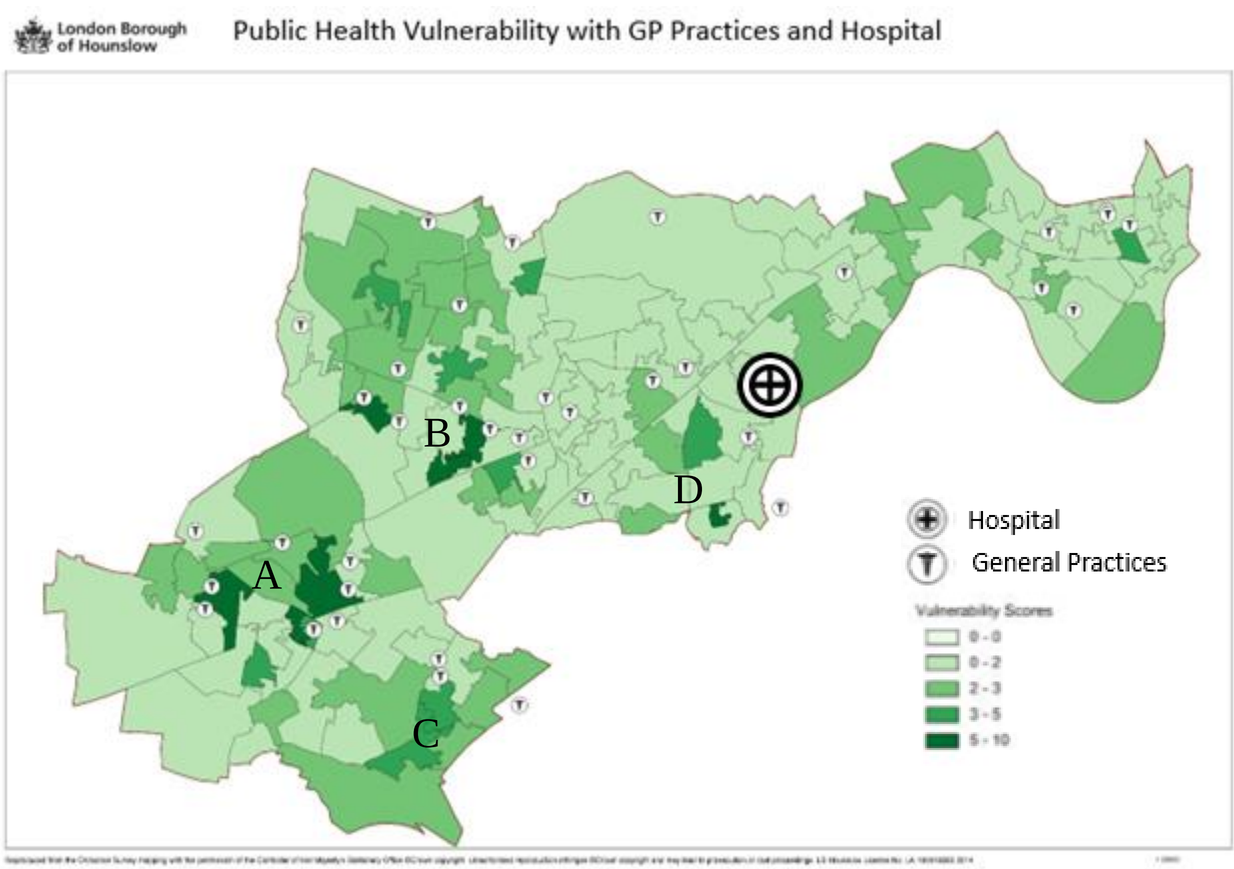

Figure 32: Public Health Vulnerability with GP Practices and Hospital

5.0 Conclusions and Recommendations

5.1 Conclusions

The goal of this project was to develop a suite of maps for use by the CPU and emergency planners and responders to indicate vulnerable populations and areas at risk. These maps show hazards and resource centers, vulnerabilities due to a variety of factors both by themselves and grouped into more general categories, and risks associated with these hazards and vulnerabilities. These data can show both available resources and areas in need of more resources, information which, in turn, can be used in the emergency planning process and relevant policy development.

The team created 13 individual vulnerability maps, 4 composite vulnerability maps, 2 hazard maps, and 1 risk map. We also developed a user guide detailing how to create more maps, allowing for the CPU to keep new vulnerable populations and hazardous areas up to date. The 4 composite maps each show a different type of vulnerability for the borough, and can be used for the risk assessment of different hazard events. For example, the 'Evacuation' composite map can be used to measure the ability of the population to leave an area after severe flooding and the 'Public Health' composite map can be used to look at the potential impact of a pandemic. The hazard maps show the locations of hazardous sites and their potential impact ranges. These can be used to locate spaces for resource sites that would allow for the fastest response that are still in a safe area. Our risk map shows a vulnerable population with respect to available resources and hazard sites. This map shows a clear picture of where resources need to be and if they are already there.

Hounslow faces a variety of hazards, ranging from flooding to regional power failures, and is especially concerned about hazards associated with its manufacturing industries and those that originate outside the borough but may affect Hounslow residents and businesses. Flooding, for example, is a major concern as it can disrupt transportation and cause damage to homes and businesses. Depending on the population, flooding can hit harder in certain areas or require more aid, so maps providing flood risk with information on the affected persons can minimize impact.

Hounslow is socioeconomically and demographically diverse, which poses a complex array of problems for the contingency planning unit and first responders in the event of an emergency. For example, an area with a low socioeconomic value may be more resistant to authority and ignore warnings, and an area with a large population of non-English speakers may require information provided in different languages to be understood effectively. Mapping such populations allows for a better understanding of the diversity present, which can provide insight for planning according to these issues, maximizing effective aid.

While the best way to develop emergency plans would be to analyze each vulnerability with respect to a particular hazard, that task is not feasible. To provide a more practical solution, we created a simple method of vulnerability analysis using readily available data and simple statistical analysis to create several general vulnerability maps. We determined individual vulnerability indicators and their thresholds based on our literature review, and while no agreement was found over the creation of composites, we used the characteristic vulnerabilities pertaining to certain hazards in order to develop our groups. Our group mapped vulnerabilities, per LSOA, by using Z-Scores of Census data to indicate concentrations of certain populations. We created these maps using existing GIS software and this process can be easily replicated when new data are available.

5.2 Recommendations

In addition to creation of the maps, we also provide a set of recommendations for how to use the information we have collected, and the maps themselves, as well as how to continue our project in the future. The CPU should update the maps when the new Census data is collected and released, and create new composite maps as new risks emerge in the borough. We had to narrow the scope of the project in order to complete a reasonable set of objectives in seven weeks, limiting the number of research goals we could pursue. As a result, the team has suggestions for further analyzing the data in greater depth, trying out other software, and using more variables when selecting vulnerable groups, which we were unable to achieve due to the limited time.

A growing population, changing climate, and immigration bring many difficulties to the area. One of these difficulties is accurately identifying vulnerable populations. While the Census provides an excellent source of information, the data becomes less relevant as it nears renewal. The team recommends exploring the usefulness of MOSAIC data[1] for a continuously updated

[1] MOSAIC is a set of geodemographical information, available at a household level, created by the Experian credit company. It is continuously updated and is a very accurate source of data that can be used to assess vulnerability through a variety of factors. Additional information can be found at the following URL: http://www.experian.co.uk/marketing-services/products/mosaic/mosaic-in-detail.html.

source of socio-demographic information at a household level. If it is deemed useful, data must be organized at an LSOA level in order to align with other variables provided by the Census, and then various factors can be chosen and analyzed to create a new vulnerability map. This data can be used in conjunction with Census data, which will also need to be updated, or can be used by itself depending on the application.

In addition to a changing population, hazards also vary over time. Airports can be expanded or oil terminals can be added; alternatively, these sites may shut down or move thus any changes in terms of risk to the safety of an area must be kept up to date. The council should update the hazard assessments and GIS mapping of hazards periodically to reflect the changing landscape of hazards in the borough. We have included columns for the impact, likelihood, and overall risk of a hazard in the table for our 'Hazard' layer on GIS, and they should be updated to match the latest version of the Community Risk Register.

Other analytical techniques can be used with more time or access to different software. Access to ArcGIS allows for hot spot and factor analysis. Hot spot analysis can be used to more rigorously study the clustering of vulnerable persons within the borough. Figure 33 shows a hot spot analysis of vulnerable age groups performed by Richard Davill using ArcGIS. The darker red LSOA's circled represents areas of high percentages of elderly and youth that are surrounded by other areas with high proportions as well. The method employed for this research project (described in section 3.2.2.2, page 26) is a simpler approach to portray regions with higher proportions of vulnerable persons, but with more time and access to ArcGIS, the team recommends that the borough to explore this type of analysis for a more fine grained vulnerability assessment.

In addition to hot spot analysis, we recommend exploring factor analysis to look at trends in vulnerability groups. Using this feature in ArcGIS, the borough will be able to better identify what indicators overlap in order to streamline the process. By identifying overlap, emergency planners can eliminate redundant characteristics considered, thereby eliminating 'noise' in the data. Instead of looking at more than a dozen of variables, factor analysis may suggest using only five key indicators to produce very similar visuals to the more complex maps.

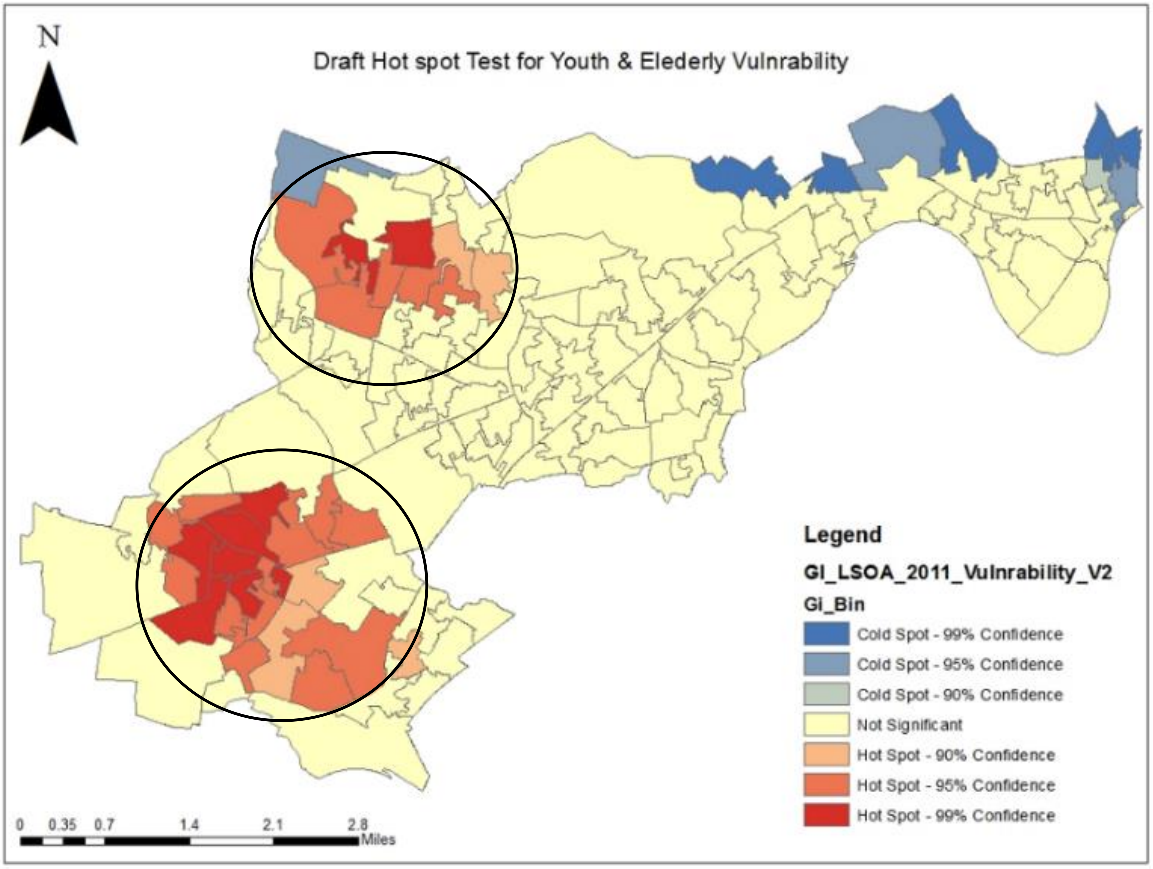

Figure 33: Hot Spot Analysis Example (Davill, 2015)

Other areas of the mapping procedure can be improved as well. The team recommends adding different shaped risk areas depending on the hazard to show a more accurate representation of the exposed area. For example, a prevailing wind would alter the shape of an airborne hazard into a teardrop shape. For further detail, analysis such as Gaussian distribution can be performed. More detailed hazard maps can also be created by including information such as gas and oil pipes leaving terminals.

We recommend producing an economic layer in GIS highlighting important areas of business in the borough such as the "Golden Mile" in Brentford, where some of the largest corporations in the area have headquarters. For these large operations, major economic supply lines could be disrupted if the headquarters needed to be shut down. Additionally, there are many small businesses that should be considered. The economic layer can help for planning in the case of an emergency during the work day to determine where large amounts of the working force will be located. This GIS layer also will allow the CPU to quickly recognize the location of key buildings to prevent more severe economic losses in terms of inventory and possibly jobs if the business needs to be shut down from damage.

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7.0 Appendices

7.1: Appendix A: Basic Terminology

Term	Definition
Risk	"[The] uncertainty of outcome, whether positive opportunity or negative threat, of actions and events. It is the combination of likelihood and impact, including perceived importance" (Office of Government Commerce, 2010).
Hazard	"A present condition, event, object, or circumstance that could lead to or contribute to an unplanned or undesired event." (U.S. Department of Transportation & Federal Aviation Administration, 2009).
Vulnerability	"[T]he potential for harm to people or things they care about." (Cutter et al., 1997, p. 6).
Physical Vulnerability	"…represents the likelihood for an individual to suffer harm with respect to their *exposure* and *resistance* to an event or hazard" (Douglas, 2007).
Social Vulnerability	"Characteristics of individual people such as age, race, and income that make certain populations more susceptible to harm and loss" (Cutter et al., 2003).
Exposure	"[T]he frequency and geographical extent of each hazard" (Peduzzi et al., 2009).
Resistance	"[T]he ability to absorb impacts and continue functioning" (Clark et al., 1998).
Resilience	"[T]he sustained ability of communities to withstand and recover from adversity" (National Health Security Strategy (NHSS), 2015).

7.2 Appendix B: Discussion questions and points

The team held several meetings throughout the duration of this research in order to obtain all of the necessary information. Many of these meetings were informal, and a specific set of interview questions was never used. However, the team developed a set of discussion points for several meetings, and these discussion points are presented in the following sub-sections. These discussion points do not reflect all of the meetings the team held, but they highlight several of the most important meetings.

7.2.1 Questions for Richard Davill

1. What is your previous experience with vulnerability mapping? What strategies have you used to map vulnerability data?

2. What do you feel are the most significant indicators of vulnerability when generating risk and hazards maps? How do you place a quantitative value on vulnerability data in order to map this information?

3. Other than Census data, where have you obtained data on vulnerability in the past?

4. What methods do you use when analyzing large amounts of data? Do you use specific mathematical procedures that we should be aware of?

5. Do you have any other suggestions for interpreting and handling big data that we have not already touched base on?

7.2.2 Questions for the GIS team

1. What maps on risks and hazards do you already have? Are all of these maps accessible on the Earthlight system?

2. How can we input new excel data into Earthlight?

3. How can we save our data into new layers?

4. How do we create different shades of severity?

5. What is your opinion on our vulnerability index in terms of mapping it? Do you have any suggestions on how we can improve it?

6. Will we be able to combine scores from multiple vulnerabilities into composites without making additional excel sheets?

7.2.3 Questions for the Intelligence Hub

1. We have developed a vulnerability index that groups different vulnerability factors into relevant groups, which we attached to our original email. Do you have any suggestions on how we can acquire the relevant population data in order to quantify our vulnerability index other than the basic Census data we already have?

2. What other information on vulnerable populations do you have?

3. Do you have a comprehensive list/map of risks and hazards that might be useful to us?

4. What are your suggestions for organizing this kind of data in order to improve visualization?

5. Do you use simple software packages such as Microsoft Excel to organize population data, or are there software packages we should be aware of that we could utilize during our research?

6. Do you use any statistical techniques to summarize or simplify data, such as filters, normalizing, averages, etc.?

7. Do you have any additional contacts that we could reach out to in order to help us obtain the necessary data needed for our research?

7.3 Appendix C: Z-Score Formulation

The team followed the procedure listed below in order to generate the vulnerability scores presented in this work.

1.) Identify the factor from Census that represents a vulnerable characteristic.
2.) Query data for all LSOA's within the borough from Nomis or a similar site.
3.) Import the raw data into Microsoft Excel, and determine what portion of the population is vulnerable from the given data.
    a. Determine a threshold from previous iterations presented in this work, or consultation with officials.
4.) Make a new column within Excel representing the portion of people or households that possess the vulnerable characteristic.
5.) Create a statistical table portraying the mean, standard deviation, minimum and maximum values of the new column of percentages.
6.) Using the formula $= \frac{x-\mu}{\sigma}$, calculate the Z-Score for each of the LSOAs.
    a. X represents the percentage of the vulnerable population within the given LSOA.
    b. μ represents the mean of the percentages across all of the LSOAs.
    c. σ represents the standard deviation of the percentages across all of the LSOAs.

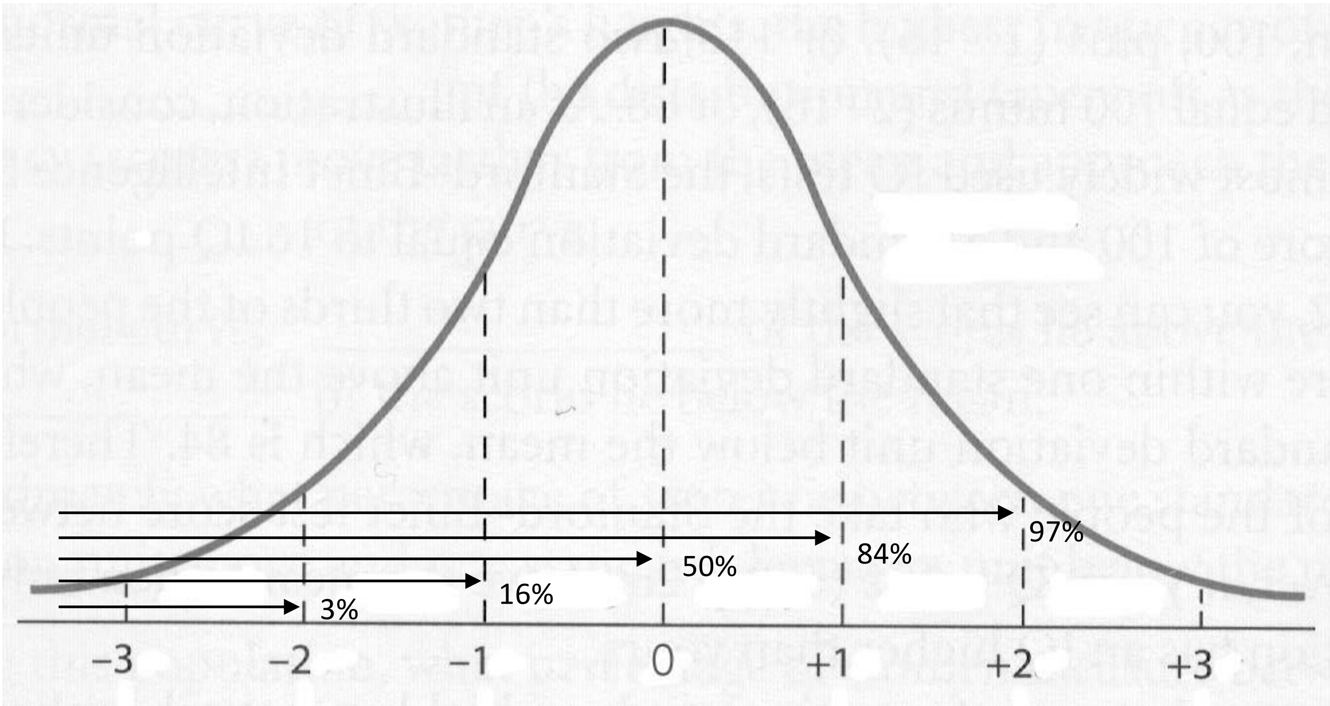

Figure 34: Bell Curve

The Z-Score indicates how from the mean the value is located in terms of standard deviations. As shown in Figure 34 above, a Z-Score of 0 represents the mean where 50% of the data set lies above and below it. In terms of vulnerability scores, if an LSOA has a Z-Score of 1, the LSOA's percentage of vulnerable persons is one standard deviation greater than the average. Using the curve above, a score of +1 indicates that the area is more vulnerable than 84% of the rest of the borough with respect to that variable.

7.4 Appendix D: Information on Contacts

Table 10 listed below illustrates information on the various individuals the team meet with. The team meet with these individuals either in person or by phone. The team held several meetings with Khuram Awan (marked with an *) throughout the term, and the table only lists the first meeting.

Contact	Position	Reason for Contact	Date of Meeting	Method of Contact
Richard Davill	Masters Student, Kings College	Experience with analysing large data	04/02/2015	In Person
Ben Pearkes	Civil Protection Officer-London Borough of Hillingdon	Determination of Hounslow Border Hazards	04/01/2015	By Phone
Michael Lewis	Emergency Planning Officer-London Borough of Sutton	Determination of Relevant Hazards in Sutton and hazard mapping techniques	04/15/2015	In Person
Own Kennedy	Analyst, London Borough of Hounslow	Advice on how to obtain data for mapping	03/31/2015	In Person
Fiona Hodge	Contingency Planning Officer-London Borough of Hounslow	Identification of the relevant hazards present in Hounslow	03/20/2015	In Person
Mike Mair	Project Officer	Obtain additional information on the flood zones in Hounslow	04/02/2015	In Person
Khuram Awan*	Assistant GIS Official	Techniques for organizing data and generating GIS maps	04/07/2015	In Person

Table 10: Information on Meeting Contacts

7.5 Appendix E: Vulnerability Maps of Individual Social Vulnerability Indicators

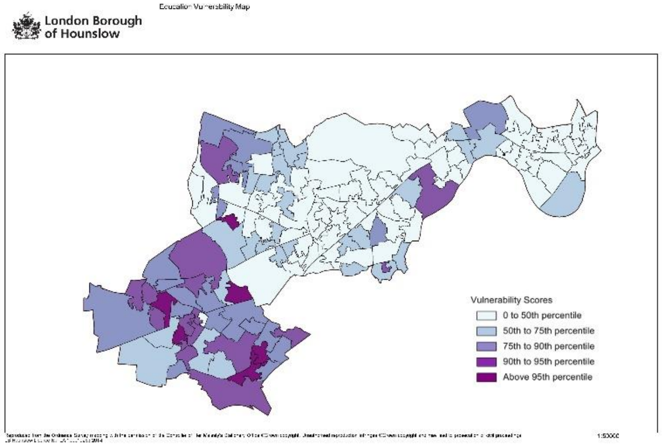

Figure 35: Vulnerability by Education

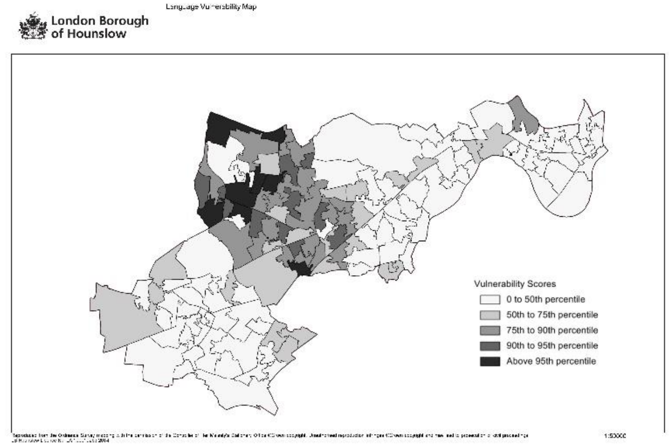

Figure 37: Vulnerability by Language

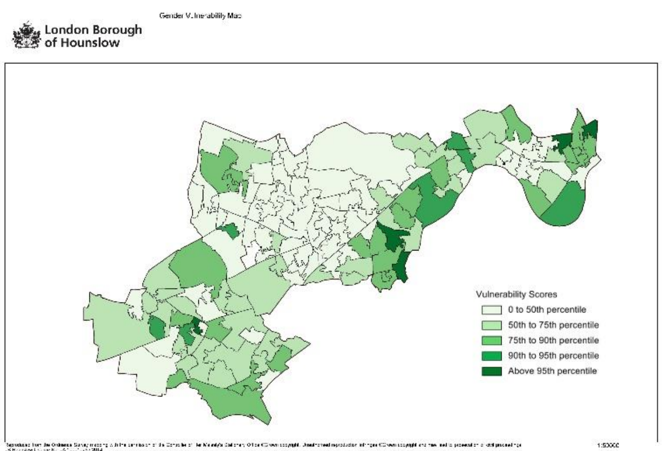

Figure 36: Vulnerability by Gender

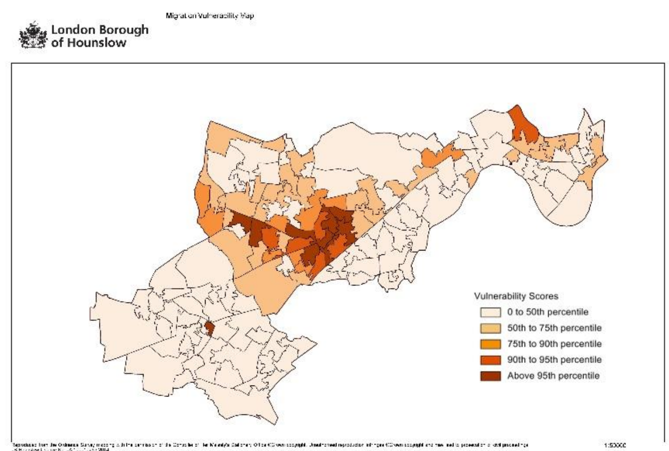

Figure 38: Vulnerability by Migration

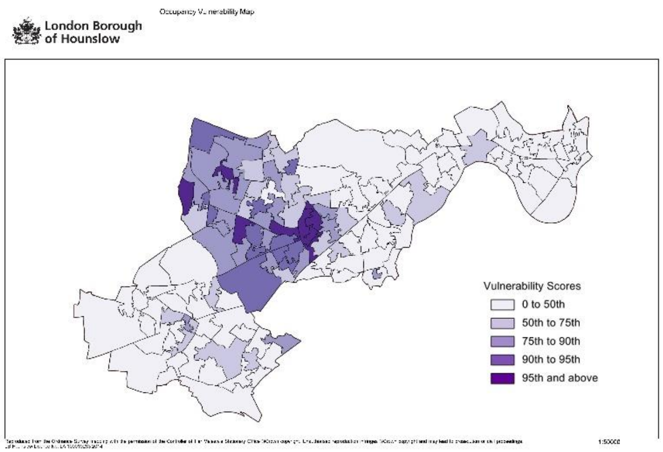

Figure 39: Vulnerability by Occupancy

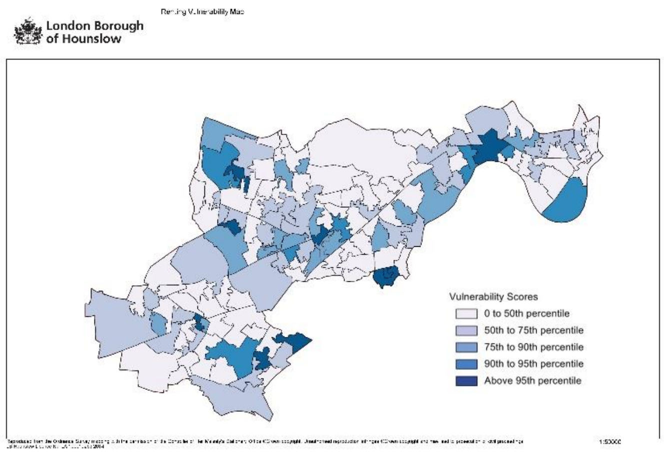

Figure 41: Vulnerability by Renting

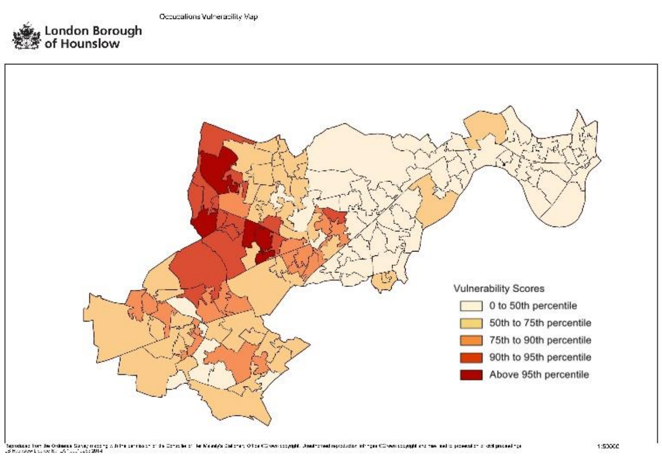

Figure 40: Vulnerability by Occupation

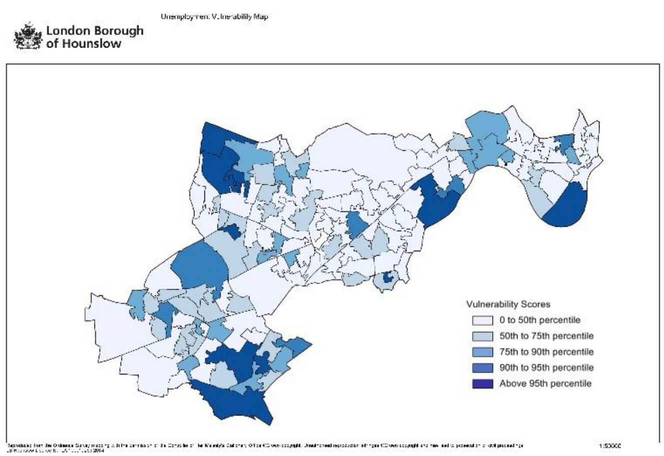

Figure 42: Vulnerability by Unemployment

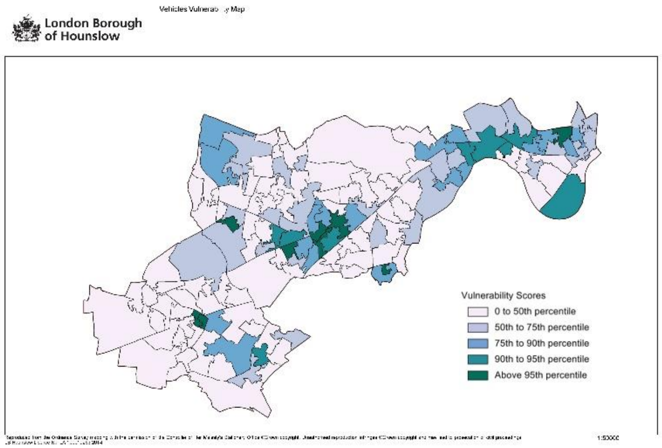

Figure 43: Vulnerability by Lack of Vehicle