

# VOLUME I

(i) Title Page.



## **Portsmouth Coastal Flood Vulnerability and Risk: Assessment and Mapping of Impacts at Microscale**

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The thesis is submitted in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy of the University of Portsmouth

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**(ii) Declaration.**

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'Whilst registered as a candidate for the above degree, I have not been registered for any other research award. The results and conclusions embodied in this thesis are the work of the named candidate and have not been submitted for any other academic award'

Sarah E Percival, 2016

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To Kenneth and Joyce Percival.

### **(iii) Abstract.**

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Within the UK, coastal community's risk to flooding has increased. Enclosed in these flood affected communities, people and areas suffer at different levels according to their vulnerability. This thesis describes the development of a new Coastal Flood Vulnerability and Risk methodology in order to understand, assess and map UK Coastal Flood Vulnerability for day and night time, at the most detailed level within the constraints of data protection. It also explores efficient visualisation of these results using three wards from the island city of Portsmouth: Hilsea, Eastney and St.Thomas. This subsequently led to an analysis of Coastal Flood Risk, via the combination of the newly developed, detailed Coastal Flood Vulnerability and Hazard Indexes, within ArcGIS, using accessible Ordnance Survey, 2011 UK National Census, and Environment Agency geoinformatic data.

The scale chosen for the analysis was Output Area (neighbourhood), representing the level where principal dimensions of vulnerability are founded. This resulted in a unique framework for measuring coastal flood vulnerability that operates at the level of detail necessary to truly deliver effective solutions and was able to distinguish the different risk levels to areas if a flood occurred at day or night. The detailed assessment provided by the Coastal Flood Vulnerability and Risk methodology developed here, pinpointed previously unidentified neighbourhoods to the northwest of Hilsea that have significant coastal flood risk levels, specifically at night. For Eastney, areas in the far western and eastern end of the ward were the most vulnerable and at-risk, whereas in St Thomas, coastal flood risk levels were primarily low.

The extra level of detail provided by the newly developed method, allows better targeting of interventions to improve resilience, reduce vulnerability and enhance recovery as well as assisting decision makers to deliver effective risk-reduction policies.

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## (x) Acronyms

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The following abbreviations were used in this dissertation.

AEP	Annual Exceedence Probability
ADL2	Address Layer 2
AOD	Above Ordnance Datum
CCO	Channel Coastal Observatory
CVI	Climate Vulnerability Index
CVI	Coastal Vulnerability Index
CoFH	Coastal Flood Hazard
CoFHI	Coastal Flood Hazard Index
CoFLR	Coastal Flood Limited Resilience
CoFLRI	Coastal Flood Limited Resilience Index
CoFPV	Coastal Flood Physical Vulnerability
CoFPVI	Coastal Flood Physical Vulnerability Index
CoFR	Coastal Flood Risk
CoFRI	Coastal Flood Risk Index
CoFSV	Coastal Flood Socio-economic Vulnerability
CoFSVI	Coastal Flood Socio-economic Vulnerability Index
CoFV	Coastal Flood Vulnerability
CoFVI	Coastal Flood Vulnerability Index
DEFRA	Department for Environment, Food and Rural Affairs
DRM	Disaster Risk Management
DTM	Digital Terrain Model
EA	Environment Agency
EcVI	Economic Vulnerability Index
EEA	European Environment Agency
EFO	Extreme Flood Outline
ESCP	Eastern Solent Coastal Partnership
FHRC	Flood Hazard Research Centre
FRA	Flood Risk Assessment
FRSA	Flood Risk Standing Advice
FVI	Flood Vulnerability Index
FZ2	Environment Agency Flood Zone 2

FZ3	Environment Agency Flood Zone 3
GIS	Geographic information Systems
GRVI	Global Risk and Vulnerability Index
HDI	Human Development Index
IPCC	International Panel on Climate Change
LPA	Local Planning Authority
LRF	Local Resilience Forum
MoD	Ministry of Defence
MOVE	Methods for the Improvement of Vulnerability Assessment in Europe
NSSMP	North Solent Shoreline Management Plan
NSSMP2	North Solent Shoreline Management Plan 2
OA	Output Areas
OP	Output Packages
OS	Ordnance Survey
PPS	Planning Policy Statement
PSMSL	Permanent Service for Mean Sea Level
PUSH	Partnership for Urban South Hampshire
SAC	Special Areas of Conservation
SEPA	Scottish Environment Protection Agency
SFRA	Strategic Flood Risk Assessment
SMP	Shoreline Management Plan
SoP	Standard of Protection
SoVI	Social Vulnerability Index
SPA	Special Protection Areas
SSSI	Sites of Special Scientific Interest
STWS	Storm Tide Warning Service
SVI	Social Vulnerability Index
UK	United Kingdom
UKCP09	United Kingdom Climate Projections 09
UNDRO	United Nations Disaster Relief Coordinator
UNISDR	United Nations for Disaster Risk Reduction

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## Chapter 1. Introduction

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## Chapter 1. Introduction

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Coastal zones are socially, economically and environmentally important: they attract settlements and economic activity. However, coastal zones are particularly susceptible to climate change, with impacts on physical and socio-economic vulnerability. There is an urgent need to assess and map coastal vulnerability, as the basis for reducing exposure and developing strategies for enhancing community resilience. DEFRA (2009) has estimated that climate change will increase vulnerability for ca. £130 billion of assets susceptible to coastal flooding. The Environment Agency (EA) (2009) stated that the expected annual damages to properties in England at risk of flooding from rivers and the sea, is estimated at more than £1 billion. The vulnerability assessment and mapping system developed in this research would give members of UK local resilience forums a better understanding of flood vulnerability and risk under our current climate, as well as the ability to model scenarios with possible future climate conditions.

### 1.1 Terminology: Hazard, Vulnerability and Risk

Climate change is likely to result in a substantial increase in extreme weather events (natural hazards) and this, combined with gradual change over long time-periods (such as sea-level rise), will be the cause of the most significant risks to humans and the natural systems they live in (Każmierczak and Cavan, 2011). In order to prepare for and adapt to these future threats, first we must understand the risk. Recent natural disasters (UK 2007 summer floods and winter 2013-2014 storm surges) have reminded us of society's increasing vulnerability to the consequences of population growth and urbanisation, technical and economic interdependence, and environmental change. Assessment of vulnerability and uncertainty is crucial for natural hazard risk management, not only in the evaluation of strategies to increase resilience, but also in facilitation of risk communication leading to successful mitigation (Rougier, Sparks and Hill, 2013). However, reducing risk from natural hazards is a major challenge that we face today, especially in the light of future global environmental change (Birkmann et al., 2013).

Rougier, Sparks and Hill (2013) commented that risk assessment and natural hazards are a complex subject. Natural hazards, like the environmental systems in which they occur, are full of many interactions and non-linearities: our understanding of their nature and our ability to predict their behaviour, is limited. Due to the impact they have on human society,

the effects of natural hazards needs to be managed. Choices have to be made in order to protect what we value, even though we have limited understanding of all the different components of natural hazard science. It is crucial that all data that is available to scientists is used where possible, in order to give us as detailed ‘a picture’ as possible, to assist our ability to inform decision-makers and create policies.

It has been increasingly recognised that risk associated with natural hazard and threats to human security cannot be reduced, by solely focussing on the hazard component of risk (Birkmann et al., 2013). Within this research project the meaning of **risk** is understood as an interaction of hazard and vulnerability. For coastal flood risk, a source – pathway – receptor model is used here to define the different elements (Crichton, 1999, 2007; DEFRA & EA, 2006; Kaźmierczak and Cavan, 2011). DEFRA and the Environment Agency (2006) developed this model in order to understand risks to people from flood events, therefore the flooding system was split into these three components; source, pathways and receptors. This model was then further developed by Kaźmierczak and Cavan (2011) by combining it with Crichton’s (1999, 2007) ‘risk triangle’ resulting in a surface water flooding risk triangle that formed the basis of the framework developed to analyse surface water flooding risk to urban communities. The ‘*source*’ relates to the hazard (coastal flooding), i.e. an extreme weather event such as an intense storm on a spring tide causing coastal flooding; the ‘*pathway*’ is defined as the nature and degree to which a pathway (i.e. physical/urban environment – including land and people) is exposed to the hazard; the ‘*receptor*’, is characterised as a degree of susceptibility or fragility of communities (coastal communities in this study), systems or elements at risk and their capacity to cope under hazardous conditions. **Vulnerability**, as defined by Birkmann et al. (2013), refers to the pre-event inherent characteristics of hazard receptors/pathways (e.g. people, buildings, infrastructure, local economies), and defines the extent to which these receptors/pathways are exposed or susceptible to harm from, or unable to cope with, hazards (Kazmierczak & Cavan, 2011). Therefore the magnitude of risk depends on the nature of the hazard, the level of vulnerability of the receptors and the physical characteristics of the urban environment. However in this research, **resilience** is also considered a crucial component of flood risk analysis and taken as the ability of a socio-economic system to respond and recover from disasters, and includes those conditions that allow the system to absorb impacts and cope, as well as post-event, adaptive processes that

assist the social system in re-organising, adapting, and learning from an event (Cutter et al, 2008).

### 1.2 Aim, Research Questions and Objectives of the Study

The aim of this research is:

*To develop an effective methodology for the assessment and mapping of flood vulnerability and risk for UK coastal communities.*

The following research questions were considered:

- Can neighbourhood-level coastal flood vulnerability and risk be analysed and quantified via accessible geoinformatic data, within a risk, hazard, vulnerability model i.e. one framework?
- Can neighbourhood-level coastal flood vulnerability and risk be quantified and mapped for different times of day?

Answering the research questions involved the following objectives:

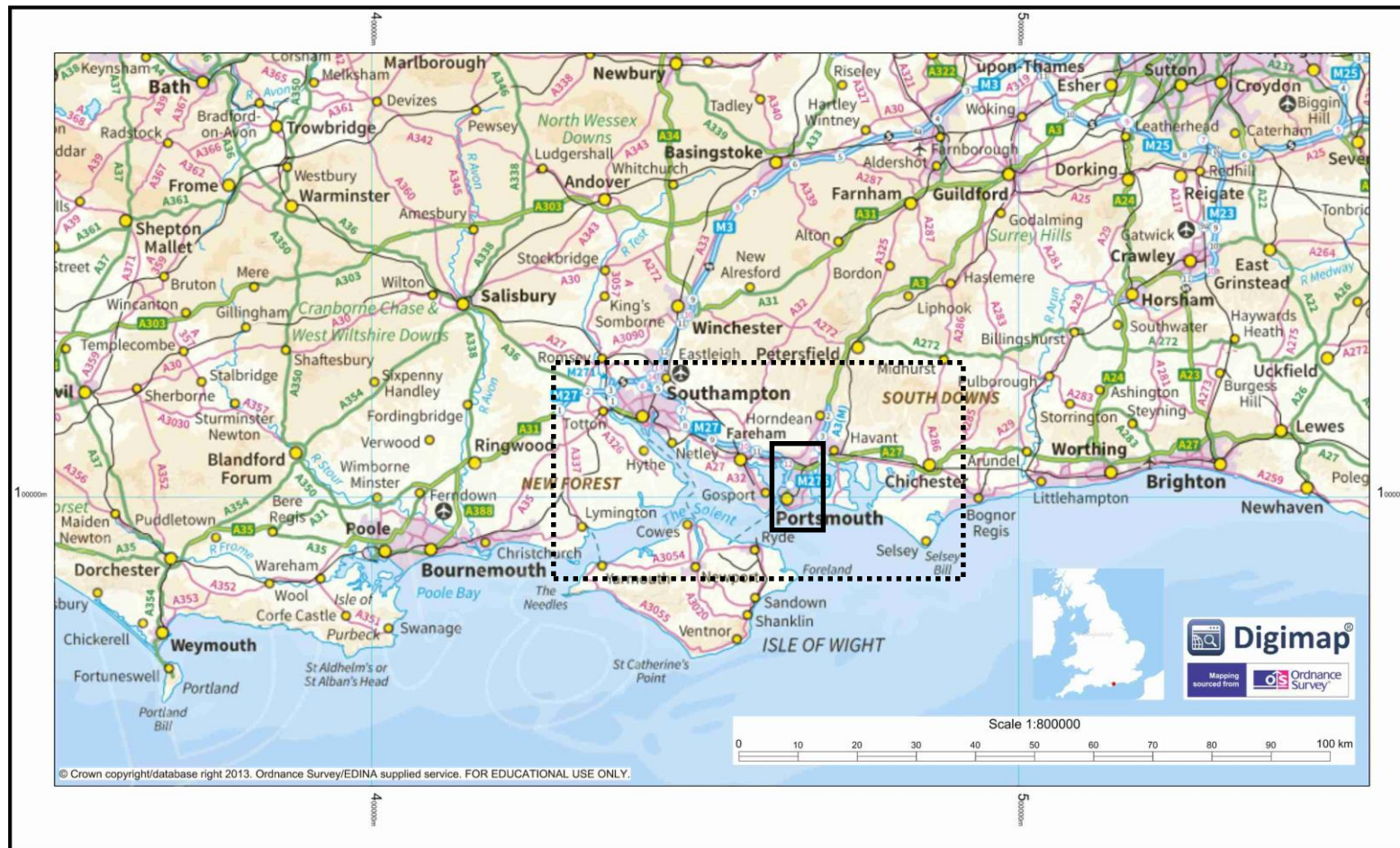
1. To establish a vulnerability analysis framework for coastal flooding
2. To create a set of vulnerability factors (that must relate to the risk equation (Chapter 2)) to measure coastal flood vulnerability at high 'resolution' level, incorporating the latest climate change projection data, socio-economic data physical/topographic data and visual data into the framework
3. To create a natural hazard themed land use classification scheme, to assist the measurement of some of the vulnerability factors
4. Assess the Coastal Flood Vulnerability and Risk, via an index approach, at the most detailed scale possible in the UK (OS Output Area level); for floods of different magnitude; and for day-time and night-time.
5. Incorporate the final Coastal Flood Vulnerability Index and Coastal Flood Hazard Index results into a Coastal Flood Risk Index, enabling the creation of neighbourhood-scale maps of coastal flood vulnerability and risk
6. Create new visualisation techniques to maximise the potential of 3D mapping for communicating coastal flood vulnerability and risk.

7. Improve links between UK geoinformatic datasets that inform the decision making processes for coastal management, emergency planning, crisis management and disaster recovery.

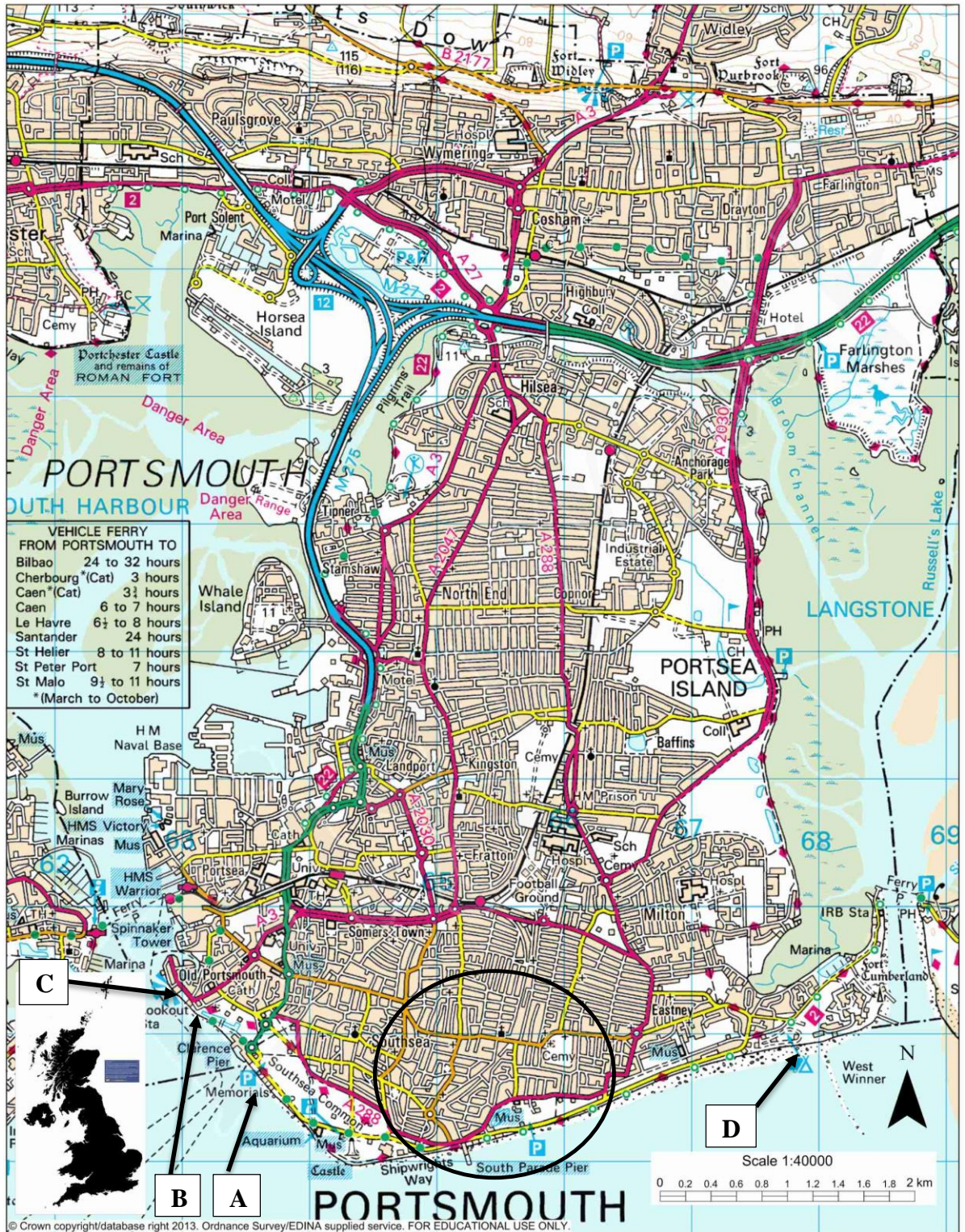
### 1.3 Location of Study: Region and Test Area

The Solent (Figure 1.1) is the body of water that lies between the central south coast of England and the Isle of Wight. It is a low energy, sediment dominated estuarine complex, consisting of 12 separately defined estuaries and harbours, draining a catchment of approximately 3000km<sup>2</sup> (Fletcher et al, 2007; Solent Forum, 2011). It is a densely populated area that has a long history of coastal development, commercial activities and marine and coastal recreation. The coastal zone has a high nature conservation value, and has many dedicated commercial and military ports. The Solent is an area that is shaped by the sea, both in terms of the physical environment and the prevailing economic and social conditions (Fletcher et al, 2007; Solent Forum, 2011). This has given the area a long history of reconciling conflicting coastal activities.

The island city of Portsmouth sits within the Solent (Figure 1.1) and is the test area for this research project due to a number of factors. Portsmouth has 45 km of open coastal frontage, and lies in the east of a sub-region of the Partnership for Urban South Hampshire (PUSH) which covers a total area of approximately 40 km<sup>2</sup>, split between the mainland and Portsea Island (Figure 1.2). 32 km of the coastal frontage is around Portsea and 11.5 km on the mainland, Portsmouth has a population of just over 197,000 (Environment Agency, 2010a), the majority of which live on Portsmouth island. It is a densely populated, highly developed, urbanised, low-lying, coastal region. It is of major economic importance for industry, commerce and, tourism, as well as being the primary naval port of Britain. It has two harbours; to the west lies Portsmouth Harbour, to the east is Langstone Harbour. The Environment Agency (2010a) states both harbours have numerous conservation designations awarded, due to their important inter-tidal habitat. Portsmouth has a long naval history and has had a significant naval port for centuries, it also contains an important commercial port, which serves destinations in France and Spain for both freight and tourist/passenger traffic.



**Figure 1.1.** Location map of Portsmouth. Inset box shows the location of the Solent and Portsmouth within the UK (Crown Copyright/database right. Ordnance Survey/Edina supplied service, 2013).



**Figure 1.2.** The island city of Portsmouth in greater detail (source Ordnance Survey, scale 1:40000) (black circle pinpoints Grand Morass and black arrows with letters refer to Figure 1.3) (Crown Copyright/database right. Ordnance Survey/Edina supplied service, 2013).

In the Solent region, there is the potential for coastal flooding along 250km of intertidal shoreline. If coastal defences are not considered, in a 1 in 200 year (greater or equal to 0.5% chance) coastal flood; more than 24,000 properties are exposed in the region (NFDC, 2009; Wadey et al., 2012, 2013). Over 15,000 of these properties are situated in Portsmouth, making it the third most exposed city to coastal flooding in the UK after London and Hull (NFDC, 2009; RIBA and ICE, 2009; Wadey et al, 2012, 2013). A national assessment of flood risk found, that the Solent would experience some of the largest increases in flood risk during the 21<sup>st</sup> century (Evans, 2004).

Portsmouth's primary source of flood risk is from the sea (Atkins, 2007; Portsmouth City Council, 2011a; b; c; Wadey et al., 2012): approximately 47% of the city's land area is designated as within the Environment Agency's Flood Zones 2 and 3 (Atkins, 2007; Atkins, 2011), compared to 11% of Southampton's. Physically, Portsmouth's topography ranges from sea level to approx. 125 m above Ordnance datum (mAOD), however on the island very few areas are higher than 10 mAOD. On the mainland, the southern part of Portsmouth is equally as low lying, it is only when approaching Portsdown Hill the land rises up to 125 mAOD (Atkins, 2011). 87% of Portsmouth is covered by existing development (Atkins, 2011). Future developments will have to occur on Brownfield sites, with intensification of dwellings likely because approximately 8% of the city is within environmentally designated areas. That further constrains development in the city and increases pressure on flood risk management. The South East Plan has allocated an additional 14,700 homes to be built in the Portsmouth area before 2026 (Environment Agency, 2010a).

To summarise, Portsmouth has had many past coastal flood incidents (Ruocco et al, 2011) and has potential for serious coastal flooding events according to the local SFRA - PUSH assessment (2007). It is a vibrant city with many diverse socio-economic 'pockets' in a densely populated geographic area, and it is also easily accessible for the 'ground truth' surveys required within the study.

#### 1.4 Coastal Flooding in Portsmouth

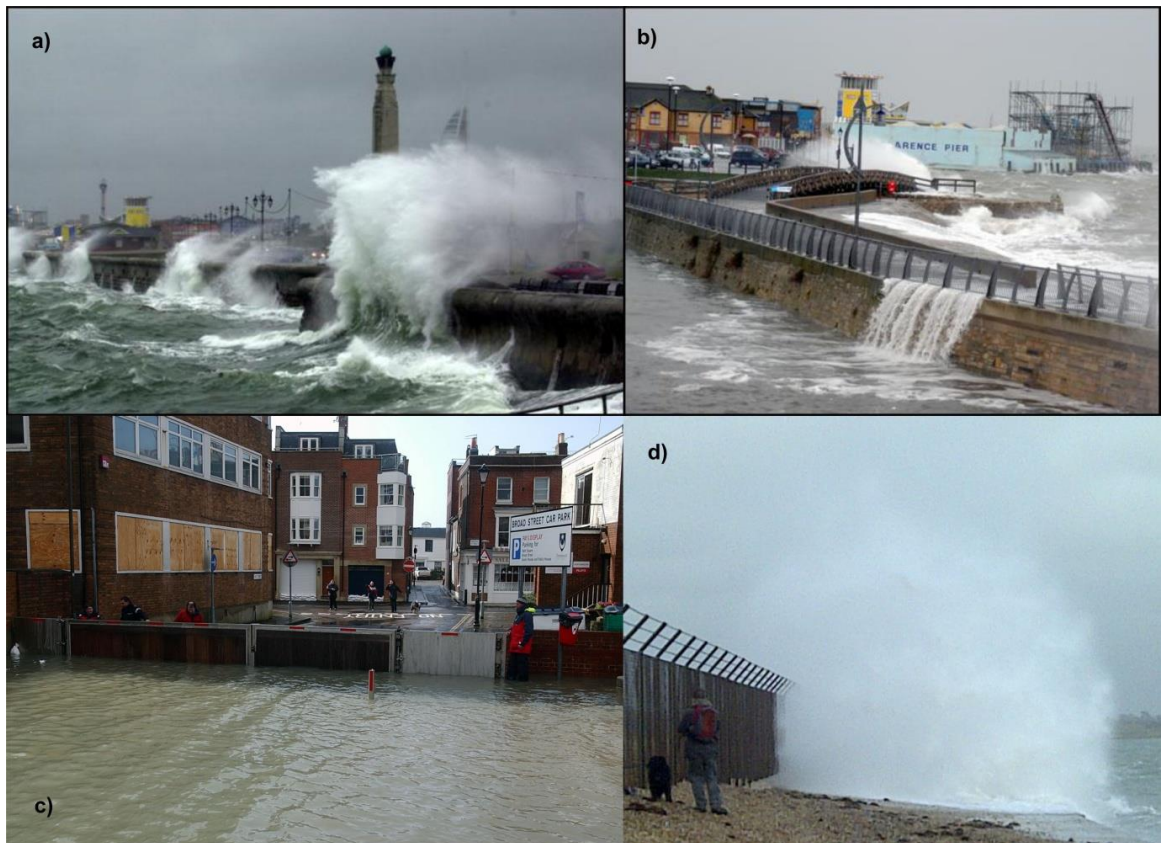
Portsmouth is the UK's only island city. All coastal parts of the city are at risk of coastal flooding, especially to the north east of Portsea Island, Southsea and large parts of the

mainland around Highbury, Farlington and Hornsea Island (Portsmouth City Council, 2011a); see Figure 1.2. Presently 1,755 residential properties are at risk from a 5% Annual Exceedence Probability (AEP) flood event, 3,805 residential properties from a 1.3% AEP flood event and approximately 4,211 residential, 364 commercial and 48 Ministry of Defence (MoD) properties are currently at risk from a 0.5% AEP of flooding by breaching of the existing coastal defences (Portsmouth City Council, 2011a).

From climate change predictions, Portsmouth City Council (2011a) have stated the number of properties at risk from flooding in 2109 (again a 0.5% AEP) rises to 9,355 residential, 950 commercial and 117 MoD. The areas in Portsmouth that have had historical flooding during storm tides include; Old Portsmouth near the Town Quay, Broad Street, Eastern Road near Great Salterns Quay and Southampton Road (A27) to the north west of Port Solent (see Figure 1.2) (Atkins, 2011). Photographs of recent flooding events are shown in Figure 1.3 and pinpointed in Figure 1.2.

The southern part of Portsmouth has the most exposed part of the shoreline, it is around 8 kms long. Most of the coastal fringes of Portsmouth are low-lying and flat. However, in some areas (particularly on the southern shoreline) the land tends to dip behind the shoreline gravel beaches and then gradually rise towards the centre of the city. This particularly occurs inland from South Parade Pier, which according to Atkins (2011), was historically known as the Great Morass (Figure 1.2). There are many properties in this area that have floor levels 4 m below the current sea wall crest height Atkins (2011). If a breach occurred here, there would be a torrent of fast-flowing water in an area that is mostly urbanised (i.e. with low natural resistance (no green spaces) and low permeability to flood waters in the area), resulting in extensive flooding to hundreds of properties (Portsmouth City Council, 2011b).





**Figure 1.3.** Photos of past flooding/storm/overtopping events in Portsmouth - locations highlighted in Figure 1.2; **(a)** Overtopping on Southsea Promenade (heading west towards Clarence Pier) (ESCP, 2013); **(b)** Overtopping and breaching past Clarence Pier moving further towards Old Portsmouth (ESCP, 2013); **(c)** Old Portsmouth flood gates in action (ESCP, 2013); **(d)** Overtopping at Eastney.

The Portsmouth coastal defences are designed to protect the city from a storm surge of a 1 in 5 to a 1 in 200 year return period. There is also the possibility to close floodgates within Old Portsmouth, thereby reducing the risk further of overtopping from a storm surge that is greater than a 1 in 200 year return period (shown in Figure 1.3, Image C). The coastal defence frontage of Portsmouth extends over 27 km and incorporates many different types of coastal defences, including sea walls, groynes and breakwaters. 14 km of these defences only have a residual lifespan of another 10 years and another 6.5 km of defences provide a Standard of Protection (SoP), that is less than the indicative range for the land use type behind them. Portsmouth City Council (2011a) have predicted with the sea-level rise values for Portsmouth in the next 50 years, this will increase to 11.5 km of defences. Floodwater after a severe inundation event in Portsmouth, will be present for some time. This is due to the floodwater not able to drain away naturally, and in some areas pumping

will be necessary as well. Therefore the affects from a severe flood event could last a long period of time (weeks or perhaps months). The total value of assets at risk from flooding in Portsmouth is over £1.25 billion, based on damages that are expected over the next 100 years (Portsmouth City Council, 2011a). These include the 9,335 residential, 950 commercial, and 117 MoD properties mentioned previously. It also includes the Historical Dockyards that contain the famous *HMS Victory*, *HMS Warrior*, and the *Mary Rose*. There is also the HM Naval Base on Whale Island, continental ferry ports in Nelson's ward, main roads and railway lines that come on and off the island. There are also the landfill areas (15 are known), hospitals, Eastney Pumping Station, schools, university, colleges, power supplies, utilities, emergency services, 40 monuments, 450 listed buildings, 70 archaeological sites, 2 large Sites of Special Scientific Interest (SSSI), Special Protection Areas (SPA), Special Areas of Conservation (SAC) and Ramsar sites. It is important to note that much of the Portsea Island coastline has been artificially altered through the reclamation of waste material. Therefore there is also the risk that the environmentally designated areas mentioned previously, are in danger of being contaminated if coastal defences were to fail.

The current defence assets along the coastal frontages of Portsmouth are almost entirely for protection against wave over-topping or coastal flooding. Three quarters of the present coastal assets have a crest level that is higher than a 1 in 200 year flood. Areas that are below the minimum standard of protection required for new development include the frontage from the east of Stamshaw to the east of Hilsea, the Langstone Harbour Frontage (west of the Milton ward), the northern frontage of Portsea Island along Ports Creek, and lastly the frontage that borders the Fareham Borough on the mainland (Figure 1.2) (Portsmouth City Council, 2011b). The Portsmouth coastal defences are likely to be susceptible to climate change: the predicted sea-level rise by 2100 would cause them to fail to offer protection from a 1 in 20 year tide.

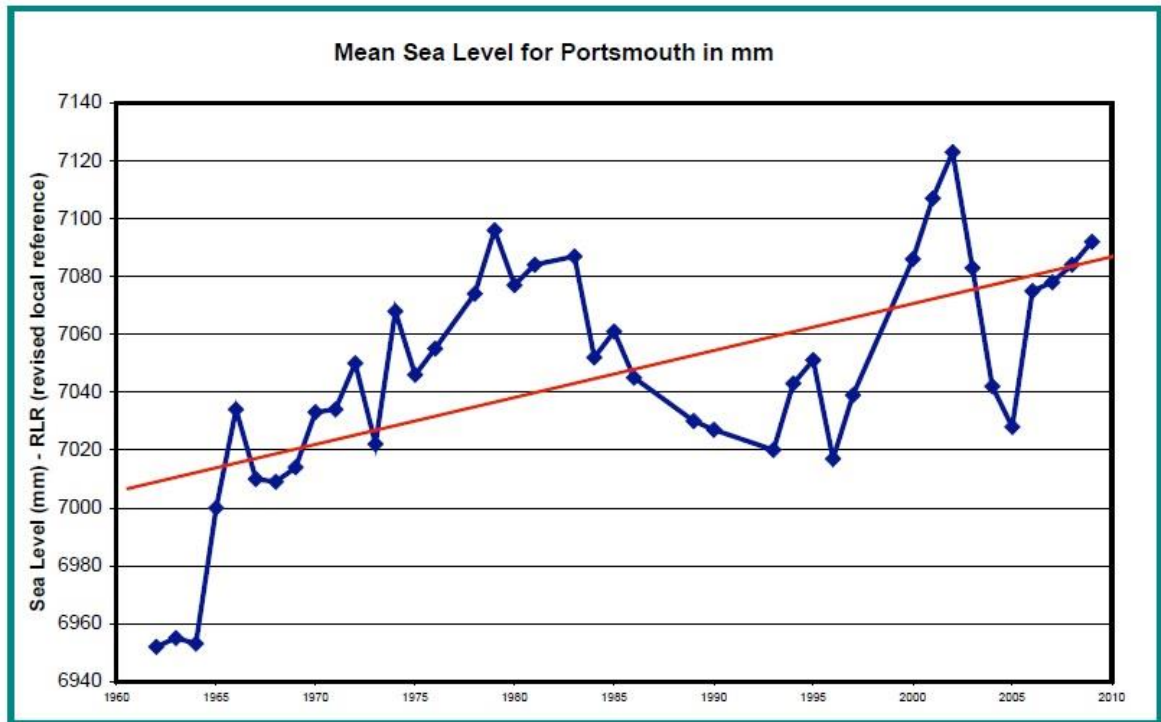
There are few embankments or similar features within Portsmouth that could act as natural barriers to reduce the spreading of floodwaters, once a breach or serious over-topping of the local defences has occurred (Portsmouth City Council, 2011c). The Environment Agency hope to warn the residents of Portsmouth, 8 hours in advance of the coastal defences being over-topped. However Portsmouth City Council (2011b) have commented

that by its nature a breach, is very difficult to predict, and therefore it should be assumed that no long advance warning would take place. Therefore a serious breach would result in a torrent of floodwater affecting the area directly behind the defence, damaging buildings in this vicinity. Other additional hazards could include large floating objects, such as cars and debris; and hidden obstacles, such as manholes. For Portsmouth the meteorological conditions (alone or in combination) that would pose a significant risk of breaching/overtopping the defences include:

- High tide to be 5 m Chart Datum or more
- Gale force winds from the south, south-east or the south-west
- Lastly pressure dropping below 980 mb

Previous flood modelling from the SFRA has identified 7 discreet areas of flooding within Portsmouth (Portsmouth City Council, 2011a). There is no interdependency of flooding between these 7 areas and no shared benefits, meaning the preferred defence strategy has been chosen on a cell by cell basis, ensuring compatibility with neighbouring coastal processes and in accordance with the North Solent SMP2, which incorporates the outputs from the PUSH SFRA (2009). The policy for Portsea Island is to 'Hold the Line', thereby reducing risk to the communities, and reducing the risk of contaminating the harbours from the erosion of the landfill sites that are present in Portsmouth. The options within this policy, are either maintaining, sustaining (new sea walls, embankments, revetments or splash walls), or improving (raising seawall crests, providing splash walls, or even replacing the sea wall or the embankment).

The Portsea Island Coastal Strategy have proposed improvements to Flood Cells 1 and 2 as their current SoP has a 100% AEP, it must be raised to 0.5% AEP, this would potentially protect >4000 properties in the next 100 years. For Flood Cells 3, 4, 6 & 7 the current flood defences will be sustained in order to provide suitable flood protection in the next 100 years, meaning raising the flood defences at times, keeping time with sea-level rise (Figure 1.4). This will include raising crest heights of sea walls and embankments, also replacing existing structures (end of life cycle) with enhanced designs (Portsmouth City Council, 2011a). Lastly Flood Cell 5 is recommended to maintain its current AEP, this would stop any contamination within the harbour. Portsmouth City Council (2011a) have



**Figure 1.4.** Mean Sea Level Rise for Portsmouth from the Permanent Service for Mean Sea Level (PSMSL) (Solent Forum, 2011).

stated this strategy has been approved by the Portsmouth City Full Council, but is now awaiting DEFRA’s approval, as the complete cost will be £372 million (without inflation but including £131 million contingency).

Flood Cells 1 (located in the southwest of Portsea Island) and 4 (located in the north of Portsea Island) are the most critical within Portsmouth due to their potential high flood risk and their very high capital costs (compared to the other Flood Cells they are predicted to be at least ten times more expensive). They require a large capital grant each in the next 10 years as the cost for the life cycle of Flood Cell 1 is £39.9m (£47.8m with inflation) and Flood Cell 4 £42.9m (£53.7m with inflation). Risk to life assessments have predicted that under a ‘Do Nothing’ strategy Flood Cell 1 given a 100% AEP event 6 fatalities could occur, raising to 14 in a 0.33% AEP event. Flood Cell 4 given a 100% AEP event 4 fatalities could occur, raising to 13 in a 0.33% AEP event (Portsmouth City Council, 2011a).

Coastal flood vulnerability assessments within flood risk analyses have the most scope for improvement. It is this area of hazard/risk science that this research will examine:

particularly how coastal flood vulnerability and risk is quantified, analysed, mapped and visualised. For a single type of hazardous event (source), this research analyses, quantifies and integrates into one framework, the main components of vulnerability: the physical environment (pathways) and socio-economic features (receptors). A Geographical Information System (GIS) is then used to integrate and process the many diverse layers of data involved in the analyses, displaying the results as maps and 3D visualisations.

Impacts from recent climate-related extremes, i.e. floods, droughts, wildfires and heat waves; reveals significant vulnerability of many human systems to current climate variability (very high confidence) (IPCC, 2014). Portsmouth has a high risk of future coastal flooding events. The land is low-lying, heavily urbanised; large numbers of commercial, industrial and historical areas, are protected by many different types of old flood defences that will not present significant protection to future storm events, especially with sea-level rise. Two areas in particular are susceptible, in Flood Cells 1 (Southsea area) and 4 (Hilsea area). The cost of maintaining and improving current coastal defences in these areas is very high, combined with notable potential loss of life. It is essential that we measure and map vulnerability to hazard events, in order to highlight areas of high risk, allowing better mitigation and adaptation. The methodology presented here will quantify different types of vulnerability and combine them into a geospatial model. The resulting flood vulnerability and risk maps will assist the development of climate change adaptation measures, emergency planning, crisis management and resilience strategies.

### 1.5 Synopsis

The thesis is presented in the style of monograph, rather than a series of papers, as this was deemed most appropriate for the study: the methodology and data needed to be presented together, for comprehensive comparisons. The layout of the thesis is as follows:

**Chapter 2** presents a literature review describing the different disciplines of this research project. Firstly, coastal flooding in the UK, and the Solent. Secondly, coastal flood vulnerability, the focus of this research - however: why concentrate on vulnerability? Chapter 2 examines this, and explains what vulnerability means in the context of this project, and how this has morphed into the term Coastal Flood Vulnerability. It also examines previous vulnerability analyses within scientific and Governmental literature.

The data analysis and mapping methodology has been split into three parts within Chapter 3. **Chapter 3** discusses Stages 1, 2, 3, and 4 of the methodology, which involves the organisation, integration and analysis of the source, pathways, and receptors datasets. This chapter discusses the steps taken to organise and analyse the Ordnance Survey, Census, Environment Agency, Strategic Flood Risk Assessment, and estate agent datasets. The Coastal Flood Vulnerability analysis is presented in **Chapter 4**, which consists of *Part A*, reducing the complexity of the Coastal Flood Vulnerability Index; and *Part B* the final Coastal Flood Vulnerability and Risk analysis and results. The main tool used to perform the vulnerability analysis is a Geographical Information System (GIS), the results of which are vulnerability maps. Previous coastal flood maps for the Solent area are discussed in **Chapter 5**, along with how that has led onto the other main component of this project: exploration of visualisation. The methodologies of innovative mapping visualisation techniques and processes are described, in order to improve flood vulnerability and risk mapping (stage 5 of the methodology). **Chapter 6** contains the Discussion, reviewing the research aims and the objectives achieved, applications of the study, along with its strengths, weaknesses and limitations. **Chapter 7** describes the conclusions and key findings of the project and includes a section on recommendations for future research. Finally there are the **References** and **Appendices A-N**.

## Chapter 2. Literature Review

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## Chapter 2. Literature Review

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The purpose of this literature review is to examine recent literature on the hazard, vulnerability and risk of coastal flooding. This chapter is divided into two main sections, *hazard (source)* (section 2.1) and *vulnerability (pathways/receptors)* and risk (section 2.2). Section 2.1 examines the hazard/source coastal flooding, and coastal flooding events in the UK and the Solent. Section 2.2 describes interpreting and defining risk, hazard and vulnerability. Furthermore the creation of the risk, hazard and vulnerability model and equation used within this research to develop the coastal flood vulnerability and risk methodology framework (Chapter 3). This is not an exhaustive literature review, but rather a selection of those studies that have the most relevant understanding of the evolution, measurement and application of vulnerability and risk, its relationship to flooding, and their influence on the development of the framework used to assess coastal flood vulnerability and risk within this study.

### 2.1 Coastal Flooding

#### 2.1.1 Hazard (Source) Coastal Flooding

One of the most dangerous and frequent challenges to human settlements comes from the flooding of areas that are not designed to cope with such inundations, i.e. flooding (Lamond, 2012). Extreme floods are among the most destructive forces of nature (Rougier et al, 2013). Notable examples include the 2004 tsunami flooding in Asia, the 2005 storm surge flooding of New Orleans due to Hurricane Katrina, the summer 2007 floods in the United Kingdom (UK), and the 2010 Pakistan flood disaster; together it is estimated that around 20 million people were affected by these events (Lamond, 2012). In 2007 it was estimated globally, that 520 million people are affected annually by flooding, with a death toll of approximately 25,000 people in any given year (Rougier et al, 2013). Disaster statistics present flooding to be the most frequently occurring and significant natural disaster, in terms of people affected (Jonkman, 2005).

The impacts to flooding events can encompass loss of life, damage to built and natural environments and extreme disruption to the lives of the population affected. However, in the long term, the immediate recovery and post recovery phases can cause disruption, distress, health problems and financial hardships that can last many years. Meteorological



events cannot be changed, but the manifestation of a flood event as a result of weather extremes is to some extent mitigable. The land, built environment and society can make a large contributing factor to the vulnerability to such events. Therefore, understanding the level of vulnerability in an area that has high probability to hazard events, is key to mitigating and thereby increasing resilience resulting in reducing the risk. The aim of this research is to focus on the assessment of flood vulnerability and risk for coastal communities in the UK. The flood risk of coastal communities in the UK has increased, primarily due to climate change, urbanisation and extension of infrastructure. Climate change is expected to increase the frequency and magnitude of storms and flood events, with coastal communities bearing the brunt of those impacts.

According to the International Panel on Climate Change (IPCC), climate change and global warming are a reality (IPCC, 2014). Coastal areas are perceived as particularly vulnerable to the impacts of climate change because they are subject to changes in the marine environment and in the terrestrial environment (European Environment Agency, 2011). They would be affected by sea level rise, severe storm surges and wave heights (Evans, 2004; Hansen, 2010). The IPCC (2007) made predictions of 21<sup>st</sup> century global average sea-level rise ranging between 0.22 m and 0.44 m, with accelerated rise towards the end of the 21<sup>st</sup> century. Hansen (2010) states that sea-level rise is one of the most apparent consequences of climate change. Predictions of global mean sea level rise can be made with more confidence than many other aspects of climate change science. This study focuses on the projected hazards that can result from sea-level rise on the coast. Eustatic sea level changes are worldwide and due to global changes in the Earth's climate. Major changes of sea level are caused by isostatic mechanisms or by the addition/subtraction of water from the oceans (typically to/from ice-sheets during glacial/inter glacial periods); changes in the configuration and capacity of the ocean basins; or a combination of all of those factors (Bird, 1969). Water from the oceans which is lost must be gained either by the atmosphere or the land. Therefore if the volume of water in the ocean remains the same (constant), sea level changes may be the result from variations in the density of ocean water through changes in temperature. There is growing evidence that so-called greenhouse gas emissions are changing the atmosphere significantly (Hosking & McInnes, 2002). In 2007 the IPCC concluded that most of the observed increase in Global average temperatures since the mid-20<sup>th</sup> century is due to the observed increase in anthropogenic

greenhouse gas concentrations. As oceans warm, they expand, this has been the primary contributor to the historic sea-level rise which has recently accelerated from 1.7 mm per year over the 20<sup>th</sup> century, to 3 mm since the 1990s (IPCC, 2007; RIBA & ICE, 2009). The United Kingdom Climate Projections 09 (UKCP09) forecasts sea-level rise to be in a range up to 76 cm by 2095, however, a revised 'extreme' figure for vulnerability testing of 190cm (RIBA & ICE, 2009). Increase in sea-level rise will heighten the amount of wave energy that reaches the shoreline: wave overtopping, surges and breaches will result in damage to coastal management structures beyond their initial design conditions. Sea level rise will increase the exposure of low-lying coastal populations and their infrastructure to storm surges and storm waves. Adapting to climate change is therefore an essential part of ensuring our coastal communities to remain safe, desirable places to live and work (Hansen, 2010).

A storm surge is caused by a combination of high tidal elevations plus a positive surge (wind blowing onshore), which usually comprises of four main components. These include a barometric effect caused by a variation in atmospheric pressure from its mean value; a wind set-up – in shallow seas such as the North Sea, strong winds can raise sea levels very quickly; high tide levels (spring tides); and lastly a dynamic effect – this is due to the amplification of surge-induced motions caused by the shape of the land (EurOtop, 2007; Hampshire and Isle of Wight Local Resilience Forum, 2013).

To summarise; a coastal flood is defined as an event where any part of the land becomes inundated by sea water, contrary to normal conditions (Ruocco et al., 2011; Rougier et al, 2013), this can be by storm surges, breaching, overtopping, sea level rise or tsunamis. When one of these components are at an extreme level, they can temporarily push water levels across a threshold, or cause a breach/failure of a coastal defence structure, resulting in significant inundation of coastal areas (Rougier et al, 2013). The South coast is at risk of coastal inundation via storm surge, sea level rise, overtopping or breaching. The predicted risk impacts of coastal flooding are (Hampshire and Isle of Wight Local Resilience Forum, 2013):

- The risk to life (people and animals)
- Damage to property, businesses, agricultural land, roads, structures and infrastructure

- Contamination and pollution of the local environment
- Long term damage to the local economy via tourism, businesses and agriculture
- Damage to national critical infrastructure
- The consequences of these risk impacts include:
  - Foremost – flooding of properties
  - Evacuation of local residents
  - Major disruption of local utilities (e.g. electricity and water supply)
  - Moving to – short, medium and long-term accommodation of those who have lost their homes to flooding
  - Unrecoverable damage to local businesses
  - Long term health and psychological impacts
  - Long-term recovery and restoration issues for homes and businesses

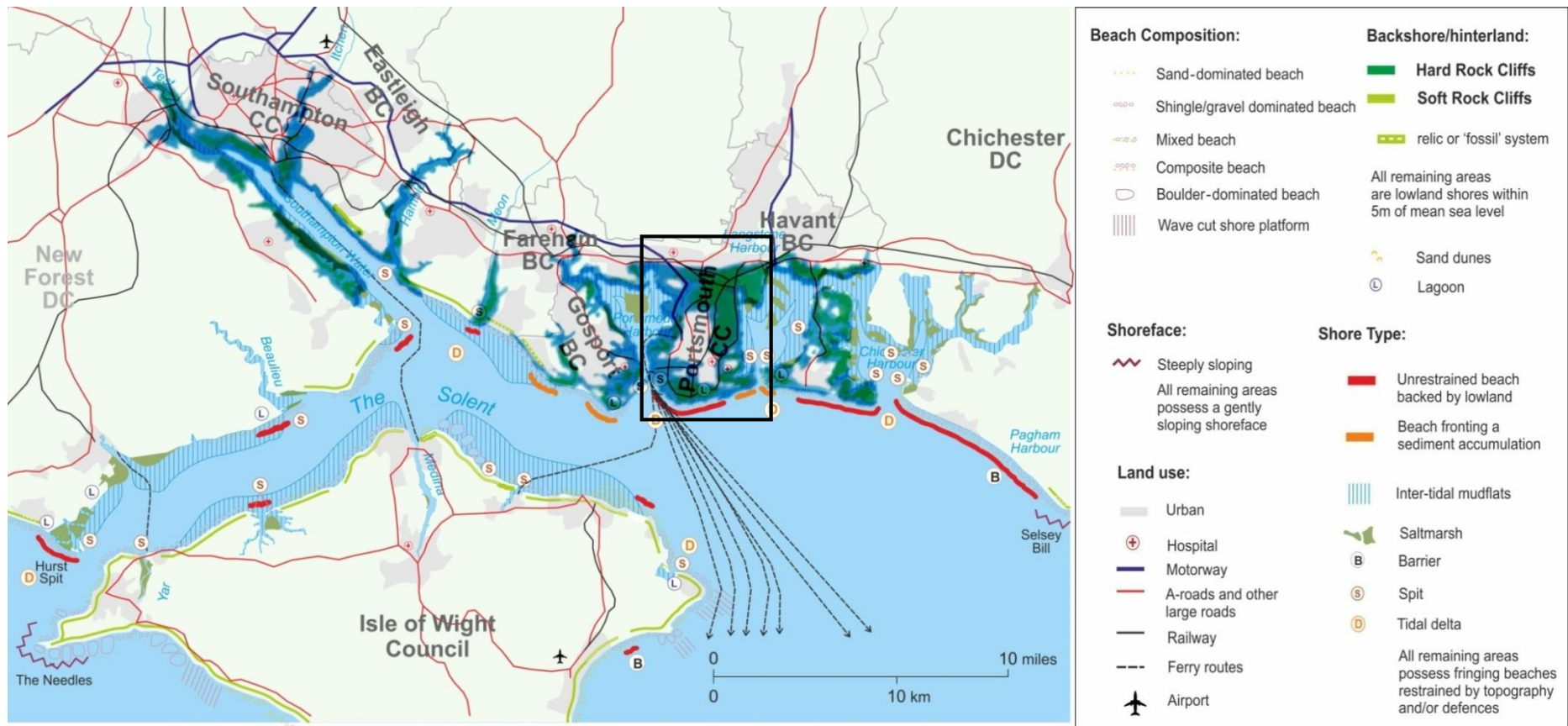
### 2.1.2 Coastal Flooding in the United Kingdom (UK)

The UK has a long history of severe coastal flooding events. The first recorded in 1570, where a large North Sea storm surge might have caused the deaths of between 100,000 and 400,000 people (Lamb, 1991; Ruocco et al, 2011). Nevertheless, in 1607, coastal floods within the Bristol Channel caused the greatest loss of life from a natural catastrophe in the last 500 years. The number of people drowned was between 500-2000, on low-lying coastlines around the Severn Estuary and Bristol Channel in isolated villages (Horsburgh and Horritt, 2006; RMS, 2007; Ruocco et al., 2011). In 1703 Brighton's lowest street of houses, was washed away by a storm (RMS, 2007). The 1953 storm surge killed 1836 people in the Netherlands, a further 307 in the UK and 17 in Belgium (Wadey et al., 2013). According to Ruocco et al (2011) 24,000 people fled their homes in the UK during the 1953 event. It was the 1953 event and a further one in 1962 on the German Bight that were the catalysts that led to agreement on the need for a coordinated response to understand coastal flood risk then and to provide protection for people and the environment they inhabited from events such as these (Ruocco et al., 2011; Wadey et al., 2013). It was the 1953 storm that led to the development of the national Storm Tide Warning Service (STWS) and the Thames Storm Surge Barrier in London, without which, London's continuation as the nation's capital would be precarious (Dawson et al, 2005; Ruocco et al., 2011).

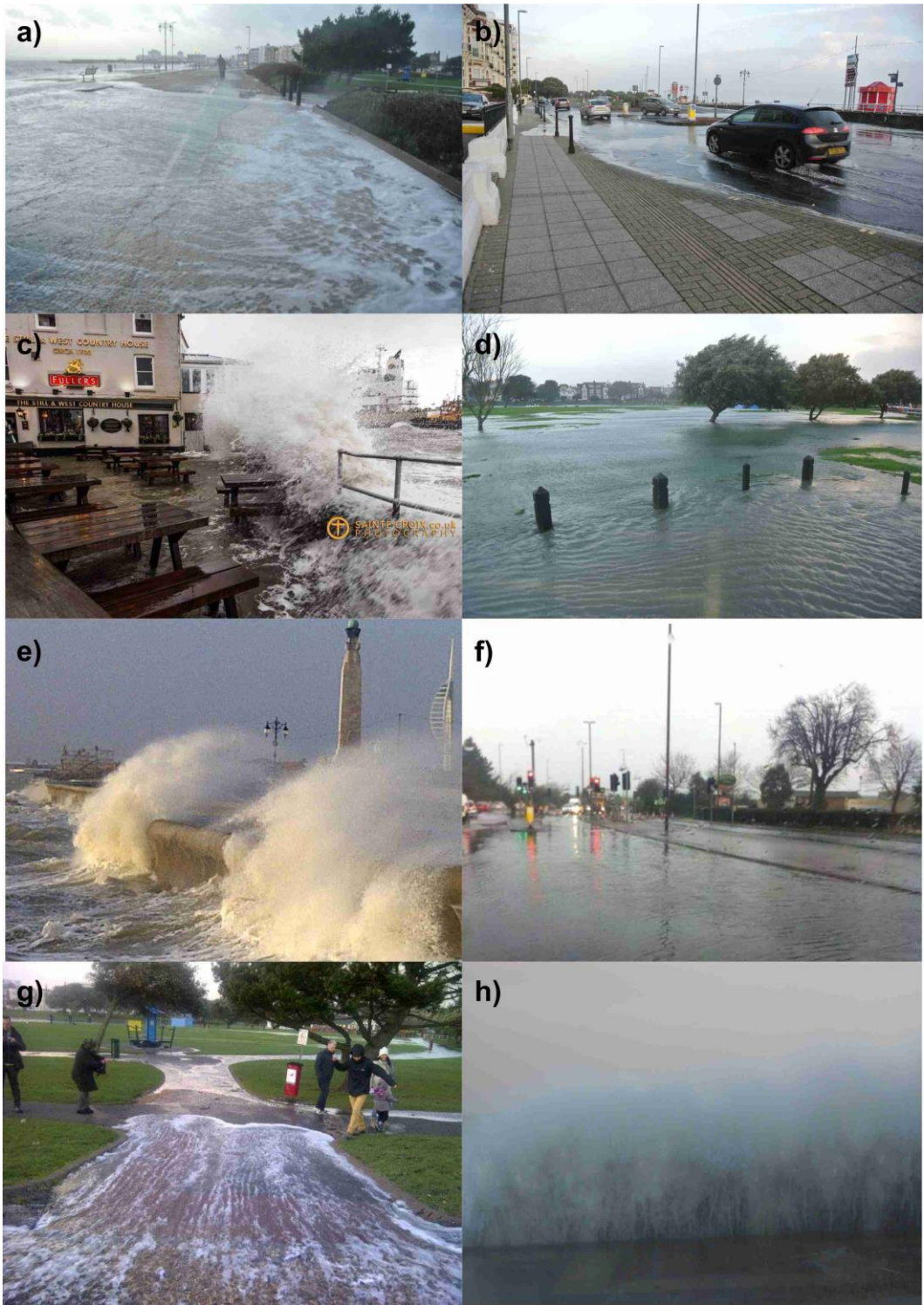
The EA (2011) stated that around 490,000 properties today in England face a 1 in 75 chance, in a given year, of flooding from rivers and the sea. The EA have also predicted, in their Investing for the Future Report (2009) that if overall investment remains at 2009 levels and if there is no additional development in the areas at risk, by 2035 there will be an additional 350,000 properties in areas with  $\geq 1$  in 75 probability of annual flooding. The expected annual damages to residential and non-residential properties in England at risk of flooding from rivers and the sea is estimated at more than £1 billion. Floods can also cause serious indirect impacts, including damage to important energy, water, communications and transport infrastructure. They can also interfere with basic public services, such as schools and hospitals (Environment Agency, 2009).

### 2.1.3 Coastal Flooding in the Solent

The Solent (Figure 2.1) is an estuarine complex lying on the south coast of the UK, it comprises of 12 estuaries and harbours along the Hampshire, West Sussex and Isle of Wight coastlines. The form of the estuary has been influenced by sea level change as the Solent was once a river (Solent Forum, 2011). Another flood risk factor in the Solent region is the progressive development of the two main cities in Southampton and Portsmouth. There are now over one million inhabitants in these two cities (Wadey et al., 2013). The Solent is within the Environment Agency's Southeast Region, which contains two Shoreline Management Plan (SMP) areas the mainland and the Isle of Wight; North Solent and South Solent (Wadey et al., 2012). The SMP studies provide a framework for dealing with flooding and erosion by dividing the shoreline into sections based on the coastal processes and their related defences. Much of the Solent's shoreline is sheltered from large waves by the Isle of Wight and shingle barrier Hurst Spit (Wadey et al., 2013). According to Pugh (1987) the Solent is known for its complex tide system and has a range of 2m in the west (Hurst) to 5m in the east (Selsey). There are double high waters in Southampton water and extended high waters in the eastern part of the Solent (Wadey et al., 2013). Storm surges occur in the region because of low-pressure systems that have moved eastward from the Atlantic over to southern England (Haigh et al, 2004). Smaller surges occur as a result of large North Sea storm surge events that are transmitted into the English Channel via the Dover Strait (Wadey et al, 2013), as in the case of December 2013 and early January 2014 (see Figure 2.2).

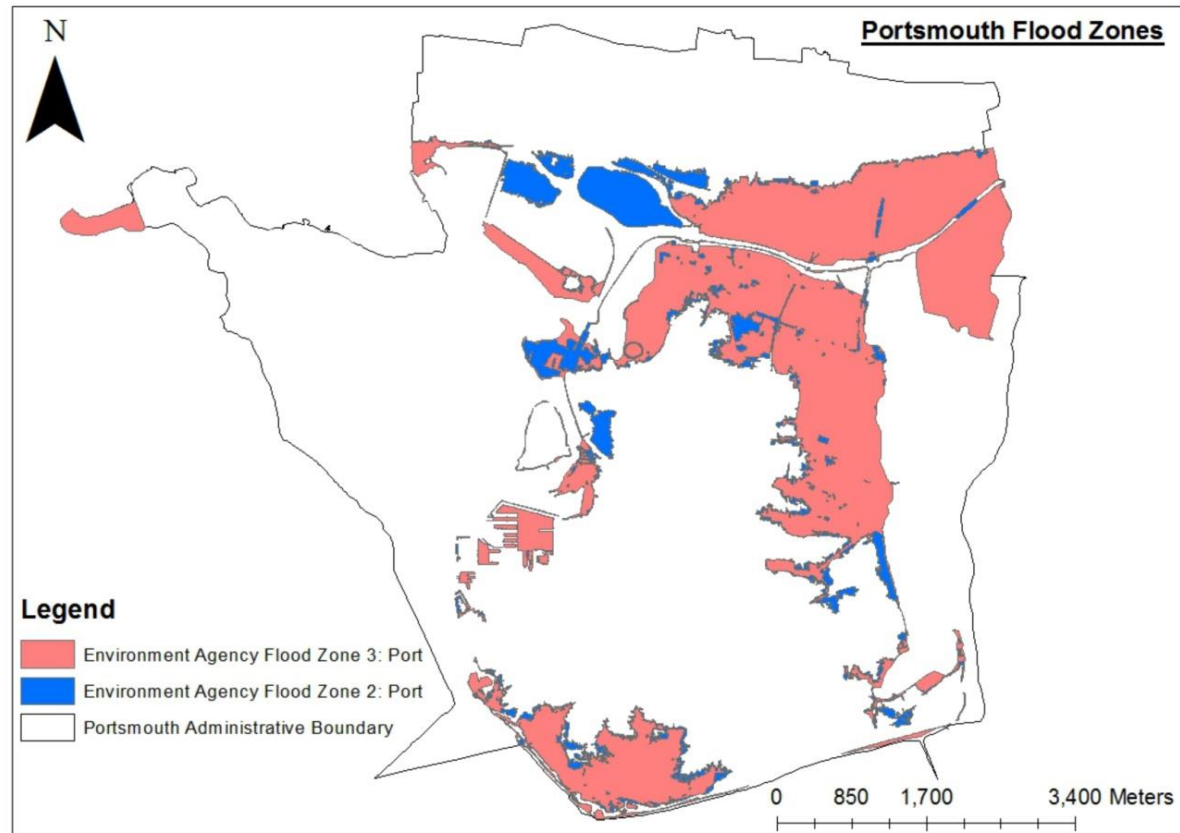


**Figure 2.1.** Map of the Solent based on the geographical area used by the Solent Forum (2008). Incorporating data from SCOPAC, The Solent Forum and Google Maps, the map includes coastal landforms, urban distribution, important points of infrastructure (e.g. Roads, railways, hospitals, etc). The black rectangle indicates the study area, the island city of Portsmouth.



**Figure 2.2.** Photographs of the December 2013 and January 2014 flooding around Portsmouth. Images **a**, **b**, **d**, **e**, **g** and **h** are from Southsea and my own. Image **c** is from Old Portsmouth and **f** is from Copnor (LoveSouthsea.com, 2014).

Coastal flood events in the Solent have been studied by Ruocco et al (2011). Combining wave and tidal data from Haigh et al (2009) and corresponding newspaper recordings from 1935 (Southampton) and 1961 (Portsmouth). Flooding occurs frequently in the Solent region, especially in Portsmouth (24 events), Hayling Island (26 events), Southampton (12 events), Fareham (22 events) and Cowes (38 events). They are mostly minor events with no loss of life. The most significant event was a storm that took place between the 13-17<sup>th</sup> December 1989, where high water levels persisted over eight tidal cycles (Wadey et al., 2013). Figure 2.3 presents predicted future EA flood zones (2 and 3) in Portsmouth. The next section considers risk, hazard and vulnerability definitions and how these have been defined and applied within this research.



**Figure 2.3.** Environment Agency Flood Hazard Zones 2 (an area with the chance of flooding an any one year between a 1000 to 1 and a 200 to 1; 0.5% coastal. The outer edge of this zone is known as the ‘Extreme Flood Outline’ (EFO)) and 3 (areas with a higher probability of flooding in any one year – a 200 to 1 chance; equal or greater to 0.5% coastal flood) (2010) laid over Portsmouth Administrative Boundary.



## 2.2 Vulnerability and Risk

The aim of this research is to provide a Coastal Flood Vulnerability analysis and mapping system that assists Coastal Flood Risk analysis, for flood management, based on UK geoinformatic datasets. However, vulnerability has not always been at the forefront of risk and hazard assessment. Vulnerability has now become a central concept in disaster research and in mitigation strategies, at all scales. Assessing and mapping vulnerability is increasingly seen as a key step towards effective risk reduction and the development of promoting a culture of disaster resilience (Birkmann, 2006b; Menoni et al., 2012). Measuring vulnerability is paramount to help science support our move to a more sustainable society, especially in the light of climate change increasing the frequency of meteorological disasters.

Coastal vulnerability assessments still focus mainly on climate change aspects, such as sea-level rise, flooding potential and overall risk. Less attention is paid to other dimensions of climate change such as the influence of economics, to the extent it is often completely ignored (Nicholls et al, 2008). *What does vulnerability mean, and how does it factor within risk?* This section reviews risk and vulnerability within the literature and discusses risk, hazard, and vulnerability concepts that form the basis for the methodology presented in this research.

### 2.2.1 Definitions and Interpretations

The concept of risk combines the probability of an event occurrence with the likely impacts or consequences that are associated with that event (see Equation 2.1) (Ramieri et al, 2011; IPCC, 2014). A risk assessment should therefore incorporate the interaction between the nature of the event (subject) and the inherent characteristics of the area or population at risk (Green, Parker and Tunstall, 2000; Cancado et al, 2008). A risk assessment provides the information or measurement of society and environment at the ‘pressure point’, when and where the disaster unfolds (Wisner et al, 2004; Cancado et al, 2008) (Equation 2.1):

*Equation 2.1*

$$\mathbf{Risk} = \text{Hazard} \times \text{Vulnerability}$$

Hazard refers to the possible future occurrence of natural events (e.g. storm surges and tsunamis) or human-induced physical events that could have serious adverse effects on exposed and vulnerable elements, including loss of life, injury, other health impacts, damage and loss to property, infrastructure, livelihoods, ecosystems and environmental resources (Birkmann, 2006b; Ramieri et al, 2011; Cardona et al, 2012; IPCC, 2014). The origins of hazard vulnerability theory go back to the 1970s (Torry, 1978; O’Keefe et al, 1976), where dissatisfaction was felt with natural hazard assessments, due to their focus on geophysical or climatic causality (Menoni et al., 2012). It was an expert group from United Nations Disaster Relief Coordinator (UNDRO) in 1979 that highlighted the need for vulnerability analysis according to Menoni et al (2012). Since then the theory of vulnerability has evolved into many different fields; geography, systems engineering, structural engineering, policy, ecology, and sociology. However, Cutter et al (2006) noted that the multi-disciplinary contribution to vulnerability theory has left us with a wide range of definitions of vulnerability, but little consensus.

There is no clear cut definition for vulnerability, as it has been attached over time to many different categories. The ordinary use of the word vulnerability refers to the capacity to be wounded, or due to the exposure from a hazard, the degree to which a system is likely to experience harm (Turner II et al, 2003). In science, vulnerability is primarily used in geography and natural hazards research, however today it is now a central concept in a large variety of other research subjects. For example; sustainability, land use, public health, poverty and development, climate impacts and adaptation, ecology etc (Füssel, 2007). Vulnerability has been related or equated to many concepts, such as marginality, susceptibility, resilience, fragility, adaptability, risk, sensitivity, coping capacity, exposure, criticality and robustness (Liverman, 1990; Füssel, 2007). Kaspersen et al (2005) stated there is no single ‘correct’ conceptualization of vulnerability that would then fit all assessment contexts. The main reason for the diversity in the conceptualizations of ‘vulnerability’ is it being used in so many different policy contexts, i.e. different systems being exposed to different hazards. The concept of vulnerability *‘has been a powerful analytical tool for describing states of susceptibility to harm, powerlessness, and marginality of both physical and social systems, and for guiding normative analysis of actions to enhance well-being through reduction of risk’* (Adger, 2006). Bogardi et al

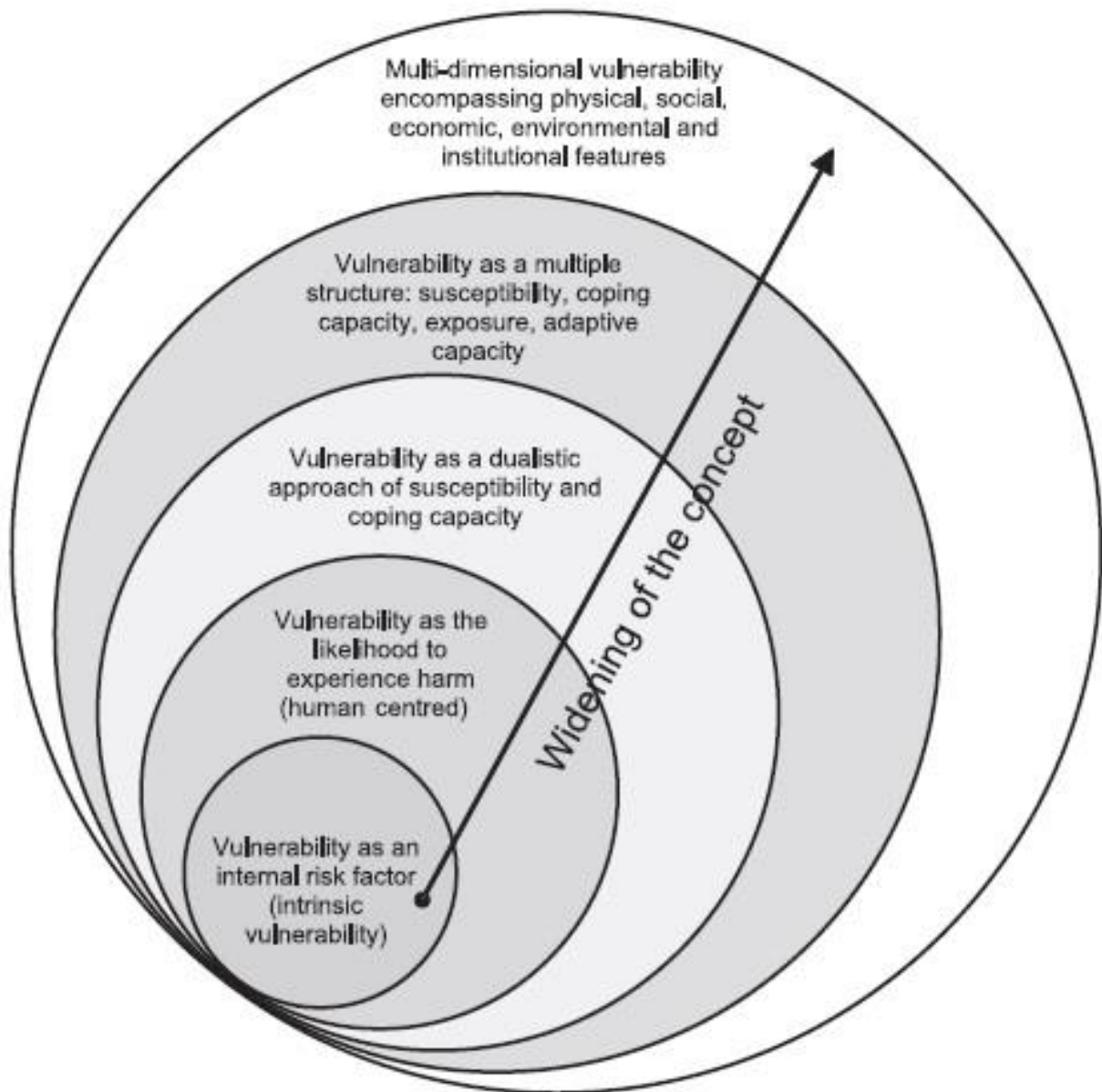
(2005) states the 'starting point' of vulnerability is a general characteristic of societies generated by different social and economic factors and processes.

Within climate change science, the 'end point' definition of vulnerability is seen as the residual of climate change impacts minus adaptation (the remaining segments of the possible impacts of climate change that are not targeted through adaptation). The more classic and universal definition of vulnerability is that by UNISDR (United Nations for Disaster Risk Reduction) (2004) in which vulnerability is identified as the condition determined by the physical, social, economic and environmental factors of a group or area, that make them less likely to survive the impact of a serious hazardous event. However, even when vulnerability factors such as these are applied, there still needs to be a starting point of identifying vulnerability. Since hazard can be viewed in a number of significantly different perspectives, it is not surprising that vulnerability can be open to such a varied definition.

Vulnerability to environmental hazards can simply or generally mean the potential for loss that varies over space and time (Cutter et al., 2003). Cutter et al (2003) states that there are three main themes in environmental hazard vulnerability research: firstly there is the identification of conditions that make people or places vulnerable to extreme natural events, an exposure model; secondly there is the measurement of societal resistance or resilience to hazards; and lastly, the integration of potential exposures and societal resilience with a specific focus on particular places or regions.

Birkmann et al (2013) states that the concept of vulnerability underscores the social construction of risk and is empirically supported by a range of studies applying vulnerability to help understand risk to hazards, this also includes ones which focus on climate change. As mentioned above, vulnerability has been defined many times. The MOVE (Methods for the Improvement of Vulnerability Assessment in Europe) project (2013) have developed a vulnerability framework that underlines that the key factors are related to exposure of a society or system to a hazard or stressor, the susceptibility of the system or community exposed, and its resilience (adaptive capacity). This framework has been used to define vulnerability in recent studies by Menoni et al (2012), Birkmann (2006b) and Tate and Cutter (2010).

This overview reveals that although the concept of vulnerability has achieved a high degree of recognition in many fields, the concept is still unclear. Birkmann (2006b) states that it could be misleading to try to establish a universal definition of vulnerability, a concept that is still evolving (Figure 2.4).



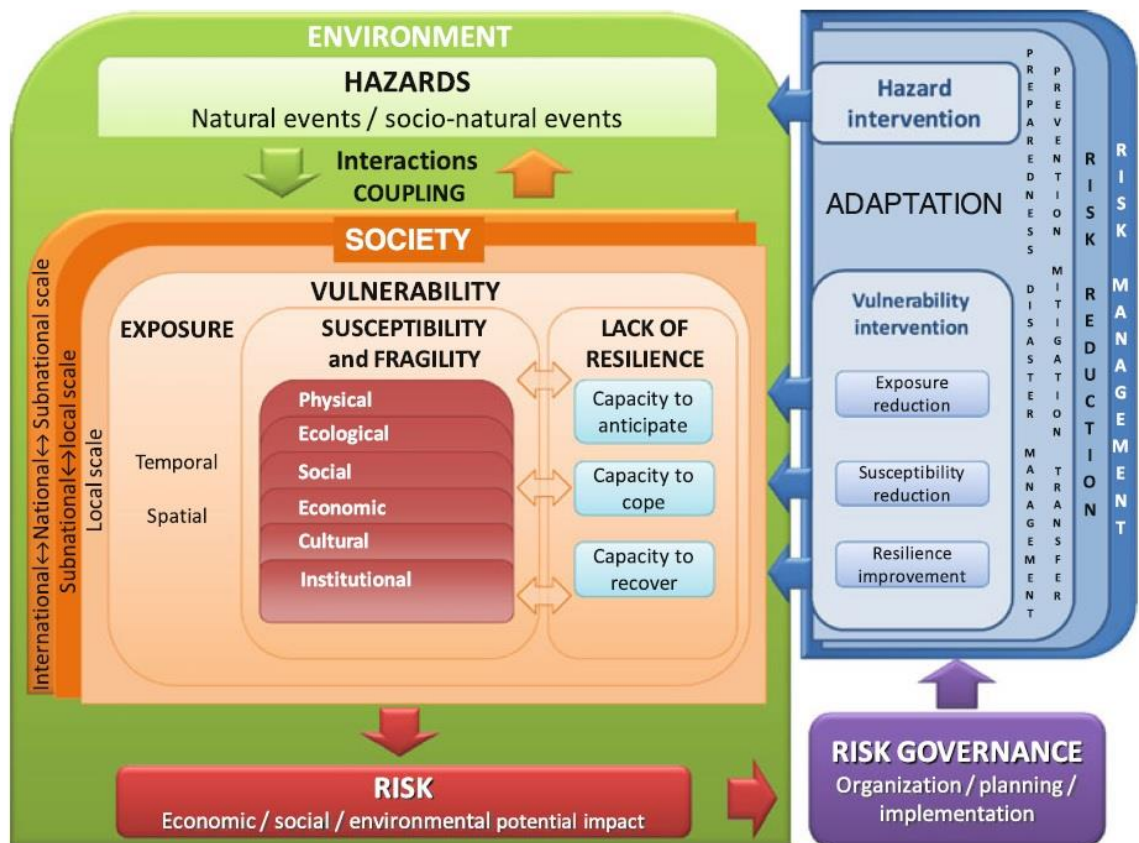
**Figure 2.4.** Key spheres of the concept of vulnerability (Birkmann, 2006b).

### 2.2.2 Coastal Flood Risk and Vulnerability

Birkmann et al (2013) described four distinct frameworks that have been created to systematise and define vulnerability. This research falls within the school of thought that

has emerged via the context of Disaster Risk Management (DRM). This approach differentiates exposure, susceptibility, and societal response capacities or limited resilience (Cardona, 1999a, b, 2001, 2011; IDEA, 2005; Birkmann, 2006a; Carreno, 2006; Carreno et al, 2007a, b, 2012; Birkmann and Fernando, 2008; Barbat et al, 2011; Menoni et al, 2012; Birkmann et al, 2013). The core element of this vulnerability, is dynamic, and cannot be limited to the identification of deficiencies (Birkmann et al, 2013).

For the purpose of this research, *Disaster risk* associated with climate and weather signifies the possibility of adverse effects in the future (Cardona et al, 2012). While risk and vulnerability can be seen as continuous, a *disaster* is a materialisation ('this is happening now'/ 'real event') of these underlying conditions (Renn, 1992; Adam and Van Loon, 2000; Beck, 2000, 2008; Cardona et al, 2012; Birkmann et al, 2013). The concept of vulnerability underscores the social construction of risk and is supported by many studies applying vulnerability to help understand risk of disaster (Aysan, 1993; Blaikie et al, 1996; Wisner et al, 2004; Birkmann et al, 2013). The hazard event is no longer seen as the sole driver of risk, there is high confidence that the adverse effect levels are also determined by the vulnerability of societies and their socio-economical systems (intrinsic factors) (UNDRO, 1980; Cuny, 1984; Cardona, 1986, 1993, 2011, 2012; Davis and Wall, 1992; UNISDR, 2004, 2009; Birkmann, 2006a, b; van Aalst, 2006). Vulnerability is a composite outcome of exposure, susceptibility and limited resilience, its definition is based upon the MOVE framework (Figure 2.5) (Birkmann et al, 2013) and the risk, hazard, vulnerability equation (Equation 1, page 50). Vulnerability in this framework, refers to the degree of exposure and susceptibility (or fragility) of communities, systems or elements at risk, as well as their capacity to cope (adaptive capacity/resilience) under adverse or hazardous conditions (Menoni et al, 2012). Vulnerability refers to the intrinsic characteristics of the hazards' pathways and receptors, which include human beings (society), their livelihoods (economic), assets (structures), that are exposed, susceptible to harm from, or unable to cope with, hazards. Vulnerability is related to predisposition, lack of capacities, exposure, susceptibilities, weaknesses, or fragilities that would favor the adverse effects from hazardous events (UNDRO, 1980; Cardona, 1986, 1990, 1993, 2012; Liverman, 1990; Maskrey, 1993; Cannon, 1994, 2006; Blaikie et al, 1996; Weichselgartner, 2001; Bogardi and Birkmann, 2004; UNISDR; 2004, 2009; Birkmann, 2006; Janssen et al, 2006; Thywissen, 2006; Kaźmierczak and Cavan, 2011).



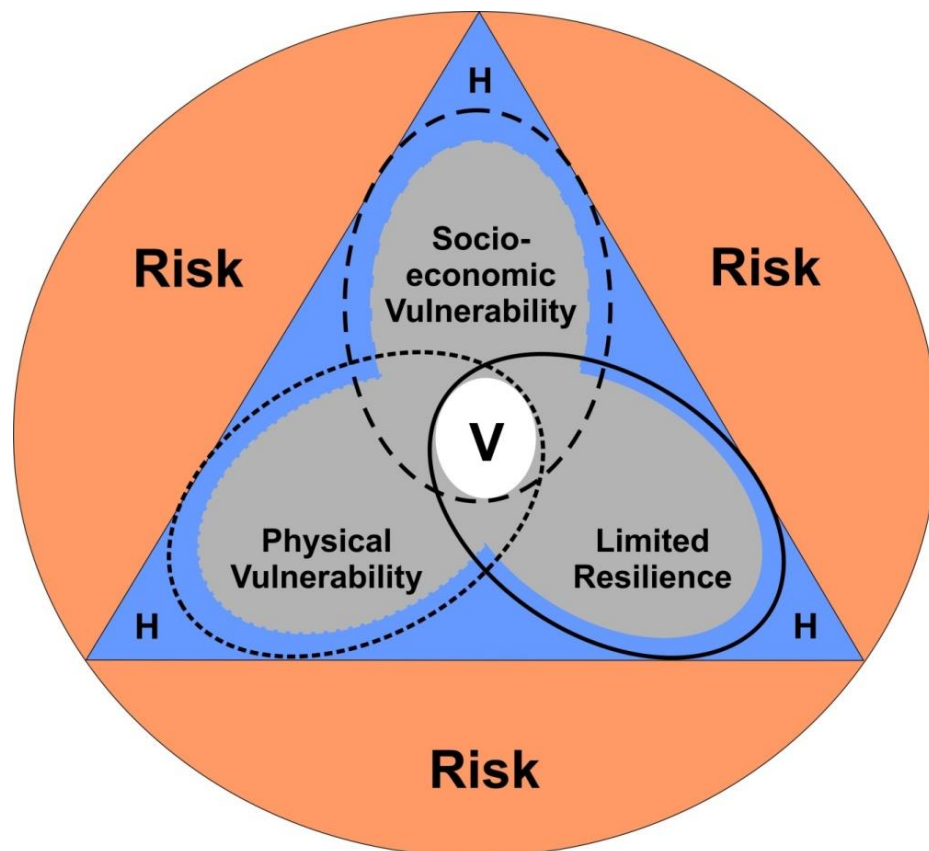
**Figures 2.5.** The MOVE Framework (Birkmann et al, 2013).

In summary, flood risk assessments (which occur all over the English coastline in the form of SFRA's) occur in order for the appropriate coastal and emergency management strategies to be applied and therefore decrease risk, improve resilience and help sustain a sustainable environment. Large populations are found in coastal areas where the exposure to coastal flooding is high (Small and Nicholls, 2003). This exposure is likely to increase due to the continual coastal net migration across the globe (Bijlsma et al, 1995; Balica et al, 2012). It is also likely that coastal changes of the twentieth century are to continue through to the twenty-first century. Therefore, to better support climate and coastal management policy development, more integrated assessments of climatic change in coastal areas are required, including the significant non-climatic aspects (Nicholls *et al.*, 2008). Portsmouth is an area that has substantial potential risk of future coastal flooding occurrences, due to its low lying nature, high population density, different land use and social deprivation areas across the city. This study aims to measure and map vulnerability to the hazard coastal flooding at high definition, to highlight areas of high risk, allowing better mitigation and adaptation. The methodology that has been developed within Chapter

3 is based upon the original risk, hazard, vulnerability equation (Equation 2.1, pg 49). However, now with the additions of vulnerability from Birkmann et al (2013) and Menoni et al (2012), including physical vulnerability (exposure), socio-economic vulnerability (susceptibility) and limited resilience. The following equation and model of that equation has been constructed (Equation 2.2 and Figure 2.6):

*Equation 2.2*

$$\mathbf{Risk = Hazard \times Vulnerability (Physical Vulnerability + Socio-economic Vulnerability + Limited Resilience)}$$



**Figure 2.6.** Model of risk, hazard, vulnerability equation (H = Hazard and V = Vulnerability).

The model of the risk, hazard, vulnerability equation (presented in Figure 2.6) is a combination of elements from Kaźmierczak and Cavan’s (2011) surface water flood risk triangle, the source – pathways – receptors model (DEFRA & EA, 2006), Crichton’s (1999, 2007) risk triangle, IPCC’s (2012) core concepts illustration, and Lindley et al’s (2011), Birkmann et al’s (2013) and Menoni et al’s (2012) vulnerability assessments. These characteristics have been adapted and combined in a model (Figure 2.6) to visualise

the risk, hazard, vulnerability equation and model (on which the methodology framework is based), used to assess coastal flood vulnerability and risk in this research.

Within this model, the hazard/source relates to an extreme natural event; in this case coastal flooding. The 'exposure' contributes to vulnerability (Cutter, 2006; Lindley et al, 2011; Menoni et al, 2012; Birkmann et al, 2013; Climate Just, 2015) and is defined by physical assets (inventory of elements) - here the urban communities are exposed to a meteorological hazard. These assets include buildings, roads, power stations, critical infrastructure, land, ecosystems, individuals, households etc (Menoni et al, 2012).

Kaźmierczak and Cavan (2011) stated, exposure can be related to a flooding' pathway', i.e. the urban environment. In summary, the characteristics of the urban environment (i.e. land use/cover) and the population density of Portsmouth, can either exacerbate or reduce the hazard's impact (Kaźmierczak and Cavan, 2011). Socio-economic vulnerability (receptors - susceptibility) reflects the fragility in the face of external stress. Susceptibility equates to intrinsic and physical predisposition of human beings, to be affected by a dangerous phenomenon (Cardona et al, 2012). Limited resilience, includes capacity to anticipate, cope and recover. Meaning limitations in access to and mobilization of human beings resources, their incapacity to anticipate, adapt and respond in absorbing the impact (socio-ecological and economical) (Cardona et al, 2012; Birkmann et al, 2013).

To conclude, flooding is a continuous danger and challenge community's face, especially in the UK. The recent storm surges in 2013/14 highlight the extent of damage to property, the environment and people's lives due to the impacts and resulting long term recovery processes. Meteorological events cannot be changed, but the severity of impacts via a flood event as a result of weather extremes, is to some extent mitigable. Within flood affected communities, people and areas suffer at different levels according to their degrees of susceptibility or fragility (i.e. their vulnerability) (Birkmann et al, 2013). Therefore, understanding levels of vulnerability in an area, is key to mitigation and adaptation in order to reduce risk. Although vulnerability was not always at the forefront of risk and hazard assessment (Birkmann, 2006b; Menoni et al, 2012). It is now increasingly seen as a key step towards effective risk reduction and promoting the concept of disaster resilience. To be sustainable it is paramount we measure vulnerability in order to identify and reduce risk.



According to IPCC (2014), coastal areas are particularly vulnerable and in the UK the Solent contains many urban coastal communities of varied sizes, and physical and socio-economic 'make-up'. Portsmouth particularly has flooded frequently historically and is principally urbanised on an island that is now extremely densely populated, contains only three evacuation routes, has large areas of deprivation, and the possibility of almost 50% of the island to be severely inundated. It is an area that vitally needs detailed coastal flood vulnerability and consequently risk analysis.

A risk assessment should incorporate the interaction between the nature of the event (subject/source - hazard) and the inherent characteristics of the area or population at risk (pathways and receptors - vulnerability). There is however, no single or clear cut definition for vulnerability and this is due to its continual evolution as a concept (Figure 2.4). Coastal flood vulnerability assessments still mainly focus on aspects of the hazard, however the MOVE framework developed by Birkmann et al (2013) and vulnerability assessments by Lindley et al (2011); describe vulnerability as a composite outcome of exposure, susceptibility and limited resilience (or lack of resilience). Both of these research projects falls within the Disaster Risk Management (DRM) school of thought and differentiates these elements. Therefore, the concept of vulnerability underscores the social construction of risk and can be applied to assist our understanding of risk of the disaster. The hazard event is consequently no longer the sole driver of risk, in fact adverse effect levels are also determined by the vulnerability of societies and their systems, and this can be defined by three distinctive components - exposure, susceptibility and limited resilience.

Through review of the literature the source - pathways – receptors model and the original risk, hazard, vulnerability equation (equation 2.1). This can be developed further (equation 2.2) to determine vulnerability and risk effectively and in detail, by separating it into three distinctive components; physical vulnerability (exposure), socio-economic vulnerability (susceptibility) and limited resilience. Thus establishing a model (Figure 2.6) on which the methodology framework is based (Chapter 3 and Chapter 4, part A). The next chapter describes the steps required to measure Coastal Flood Vulnerability and Risk, and the factors selected for the vulnerability assessments.

### Chapter 3. Identification of Vulnerability Factors

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### Chapter 3. Identification of Vulnerability Factors

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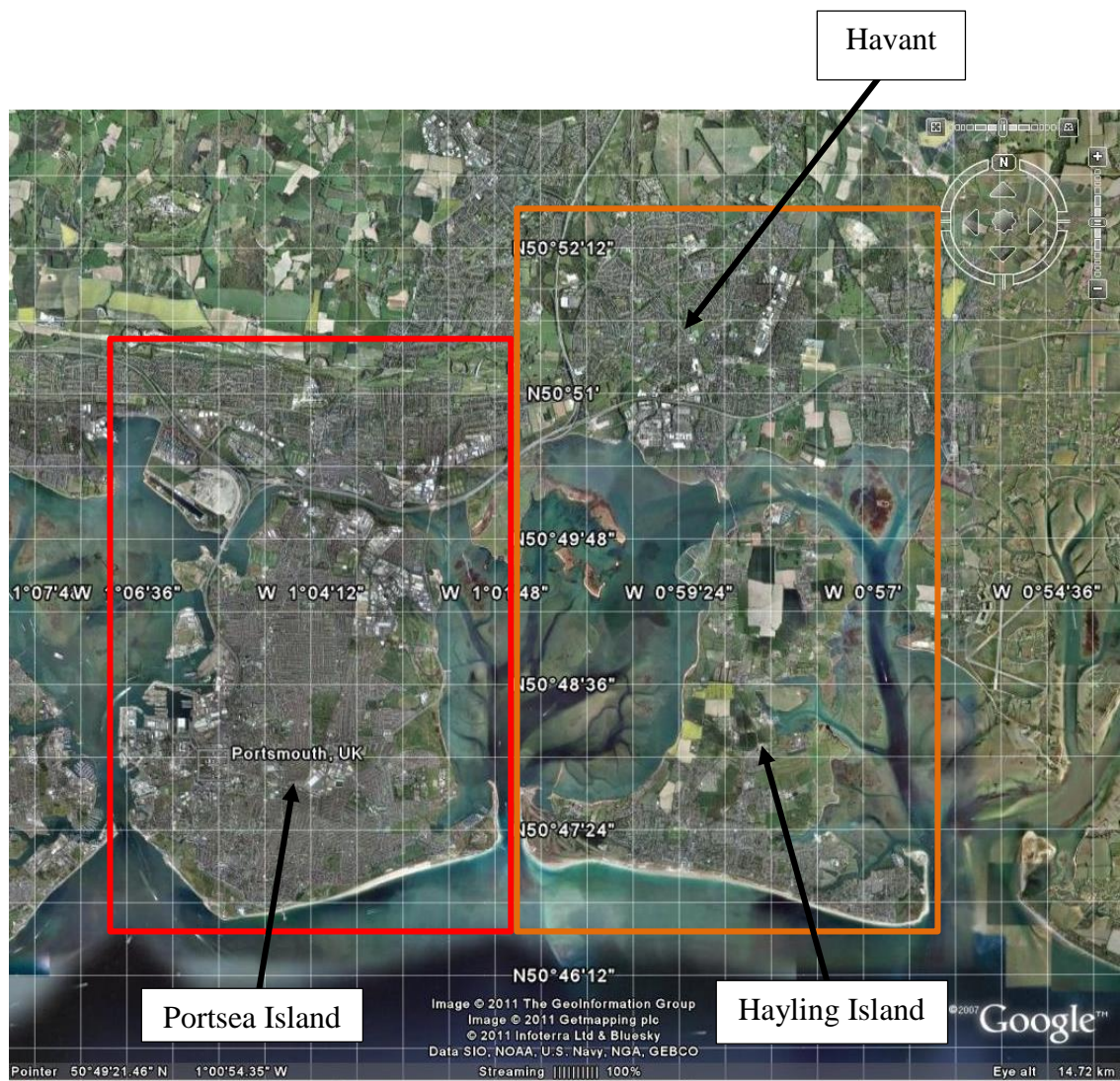
This chapter outlines in detail the components that form the methodology of the Coastal Flood Risk (CoFR) analysis, and the identification of the factors chosen to analyse them. This includes the Coastal Flood Hazard (CoFH) analysis, and the Coastal Flood Vulnerability (CoFV) analysis (physical vulnerability, socio-economic vulnerability and limited resilience analyses). There are four parts to this chapter; 3.1, 3.2, 3.3, and 3.4. They each describe the integral stages of specific dataset insertion, manipulation and creation for the CoFH and CoFV analyses. Prior to these four sections, the first 13 pages of this chapter describe the initial data inception phase. This involved a review of the data available for the CoFR analysis, and the scale chosen for assessment. Figure 3.1 provides visualisation of the methodology framework used. Section 3.1 describes the stages involved within the CoFH analysis, the available data and the resulting flood zones used for this assessment. Section 3.2 to 3.4 recounts the development of the analysis of each CoFV component; coastal flood physical vulnerability (section 3.2), coastal flood socio-economic vulnerability (section 3.3) and coastal flood limited resilience (section 3.4). These sections include the selection of factors chosen for each vulnerability component, the data selected and methods used to populate these factors, and where required accuracy clarification. The reduction of the Coastal Flood Vulnerability Index (CoFVI) complexity, the index results for each component, and the final CoFV and CoFR analysis and results are described in Chapter 4.

As stated, prior to the four main stages of the methodology, there was an initial data inception phase. This involved a review of the available data, the identification of appropriate outputs (hazard and vulnerability factors) and constructing the methodologies to deliver the desired outputs. The datasets used, represent the hazard and the three components of vulnerability: physical (exposure); socio-economic (susceptibility); and limited resilience. The hazard is coastal flooding, which is analysed via data received from the Environment Agency and local councils Strategic Flood Risk Assessment (SFRA), described as PUSH. The physical data represents the physical environment, this has been analysed from many Ordnance Survey Map layers, mainly Mastermap, Integrated Transport Network (ITN), Address Layer 2 and the new Land Use Reclassification which was created for this project using the primary Ordnance Survey layers identified above.

The socio-economic data and limited resilience data, which identifies a community's intrinsic and physical abilities to cope with a natural disaster, have been acquired from the UK National Census (2011, but updated in 2013), estate agent websites (Rightmove.co.uk and Zoopla.co.uk), and identified primary Ordnance Survey layers.

This research will examine the city of Portsmouth at the highest definition level possible. Although the data provided by Ordnance Survey is at building level, Census data at higher levels of detail, such as individual houses, breaks the Data Protection Act. Therefore, the analysis will be at Output Area (OA) level, which is the smallest geographical area in the UK. This scale will facilitate a detailed analysis and all the data chosen for analysis is now available at this level. OAs were created for Census data, specifically for the output of census estimates. OAs are the lowest geographical level that census estimates are provided, and were provided in the UK at the 2001 Census (Office for National Statistics, 2013). They are roughly the size of a neighbourhood. In 2001 the Census OAs were built from clusters of adjacent unit postcodes and designed to have similar population sizes. A minimum size was required ensuring confidentiality of data. As of 2011 the total number of OAs in England and Wales is 181,408, Lower Super Output Areas (LSOAs) 34,753 and Middle Super Output Areas (MSOAs) 7,201 (Office for National Statistics, 2013). The 2011 Census OAs and Super Output Areas (SOAs) align to local authority boundaries. All OAs have a unique nine character code provided by ONS.

Ordnance Survey (OS) had already provided a substantial amount of their Mastermap datasets for the Portsmouth and Havant Borough areas (under an Ordnance Survey Research Data Licence). Originally there was to be a comparison of a coastal flood vulnerability assessment between areas in Portsmouth and Hayling Island of Havant Borough. That was due to the different socio-economic settings of these adjacent islands (Portsmouth being a densely populated city, and Hayling a mostly rural district: see Figure 3.1), both having several historical flood events and a high probability of future inundation (shown in Figure 2.1, Chapter 2). However during early stages of the project, the Coastal Management Officers of Portsmouth City and Havant Borough recommended concentrating solely on Portsmouth, due to the social and economic significance of the city, the dense urbanisation and population, evacuation problems (only three exits present on the island, two likely to be inundated), many pockets of high deprivation and the rapid



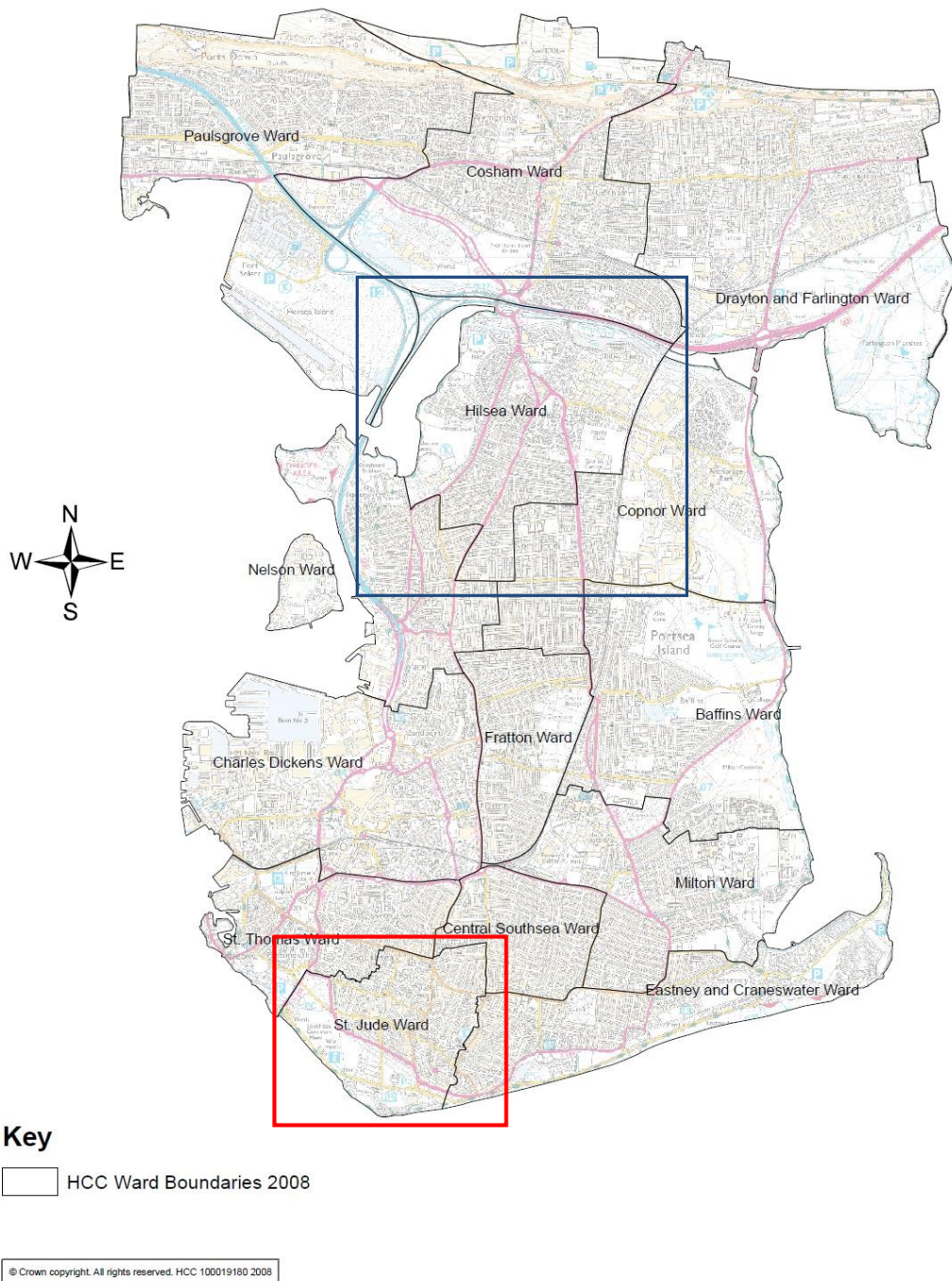
**Figure 3.1.** City of Portsmouth (red rectangle) and Havant Borough (orange rectangle) areas, UK (Google Earth, 2014).

change of land use in small areas. Also, the main aim of the research is to develop an effective methodology for the assessment and mapping of flood vulnerability and risk for UK coastal communities. Therefore, rather than comparing CoFV and CoFR results for two islands, focusing on the assessment methodology was critical within the time constraints of the project.

All the primary Ordnance Survey data for Portsmouth was displayed within ArcGIS 10, and posed an initial problem due to the size of the datasets. Displaying, moving, zooming and editing any layer was time consuming and difficult. The datasets needed to be cut into smaller sizes for ease of analysis and interpretation. Therefore, the initial Mastermap, Integrated Transport Network, and Address Layer 1 for the city of Portsmouth, was subdivided into its 14 electoral wards (Figure 3.3); St Jude, Eastney and Craneswater, Milton,

Central Southsea, St Thomas, Charles Dickens, Fratton, Baffins, Copnor, Nelson, Hilsea, Drayton and Farlington, Cosham and Paulsgrove, following the boundaries defined by the 2011 National Census (OS Boundary Line data is released under the OS OpenData Licence and available at <http://www.ordnancesurvey.co.uk/business-and-government/products/opendata-products.html>).

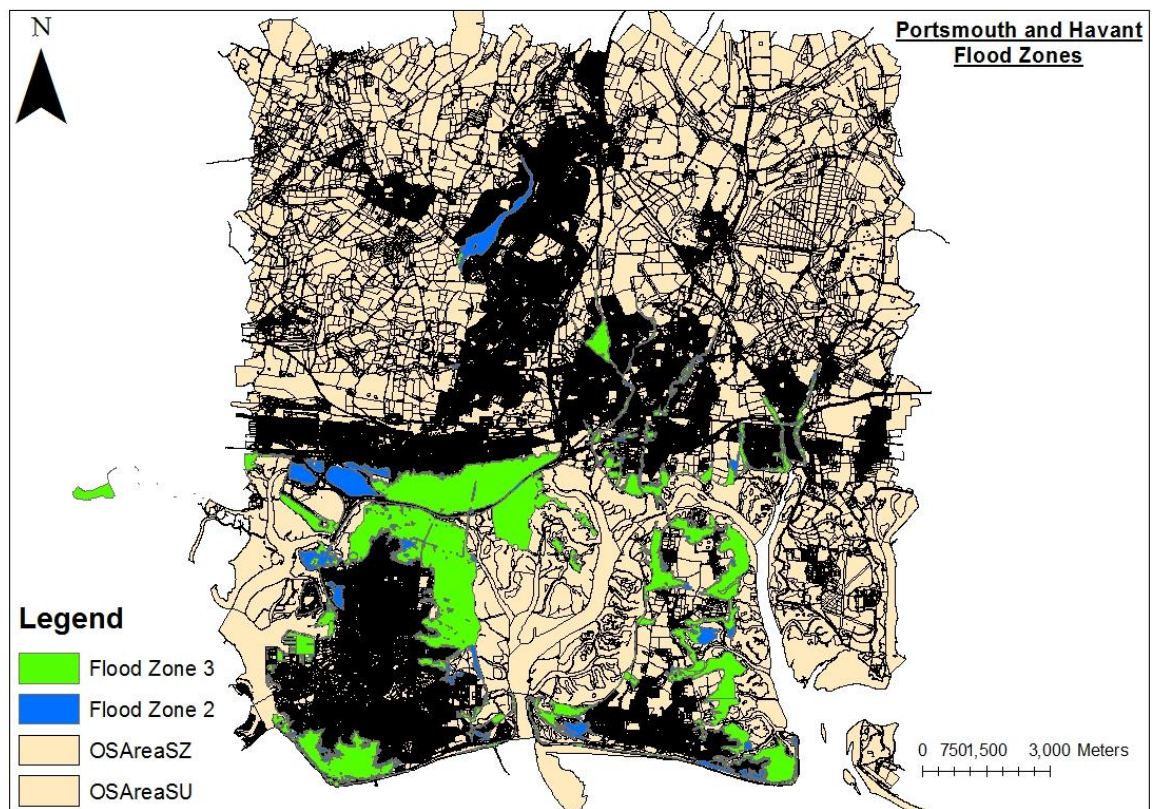
This separation of data to ward level, allowed for Ordnance Survey data to be assessed in detail at a more manageable level. The ward of St Jude (Figure 3.2) was used to display, manipulate and understand the breadth and detail of the Ordnance Survey data (examples of this can be seen in Appendix B, pg 321). Displaying and assessing each of the original 43 layers, allowed the selection from the corresponding attribute table of relevant columns of data for this project (examples of this can be seen in Appendix C, pg 325). The details of what data was chosen and why will be discussed within section 3.2, as those datasets are connected to the measurement of exposure (physical vulnerability).



**Figure 3.2.** Portsmouth Ward Boundaries. St Jude and Hilsea highlighted by red and blue squares (Hampshire County Council, 2010).

Environment Agency (EA) Flood Zone 2 and Flood Zone 3 data were acquired under a Special Non-Commercial Licence and incorporated within ArcGIS to show areas that would be inundated by flood events. EA data was chosen for the hazard analysis as these flood zones are used nationally by local authorities within their Strategic Flood Risk Assessments (SFRAs). Thus, the CoFR results produced from this research could be

compared with local (Atkins, 2007) and national (Lindley et al, 2012) flood vulnerability and risk assessments, which also use these datasets within their analyses (described further in Chapter 4, Part B and Chapter 6). EA Flood Zone 2 represents areas where the chance of flooding in any one year is between 0.1% and 0.5% (i.e. between a 1000 to 1 and a 200 to 1 chance). The outer edge of this zone is the 'Extreme Flood Outline' (EFO). Flood Zone 3 represents areas with the highest probability of flooding, with the chance of flooding in any one year being greater than or equal to 0.5% (i.e. a 200 to 1 chance). The distribution of Flood Zones 2 and 3 around Portsmouth and Havant can be seen in Figure 3.3.



**Figure 3.3.** Portsmouth and Havant geographical areas with added EA Flood Zones 2 & 3.

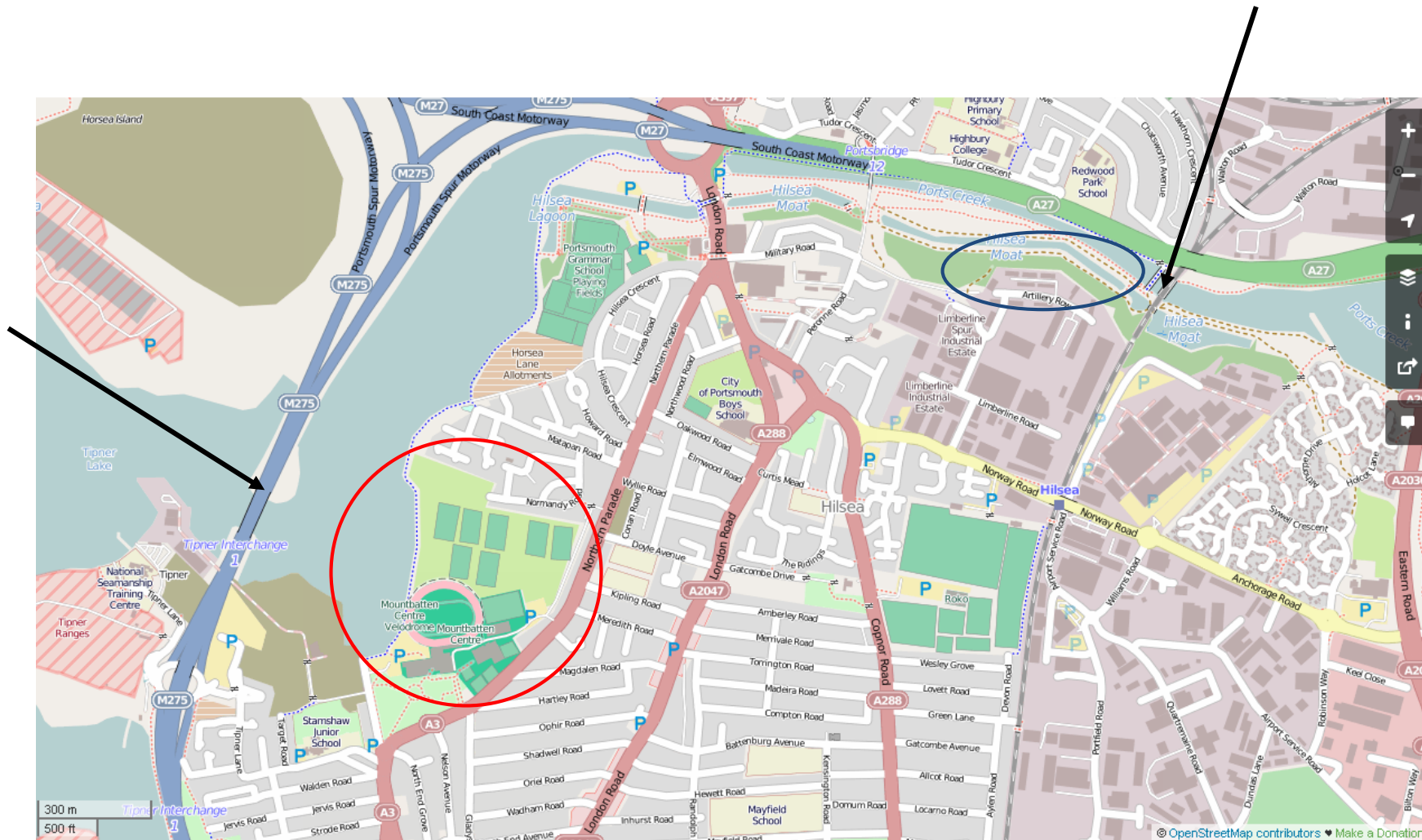
The EA Flood Zone layers 2 and 3 were laid on top of the clipped Portsmouth ward OS data within ArcMap. The flood zones were clipped to ward size, allowing analysis of the potential spatial inundation of those flood zones within the Portsmouth wards.

After this initial flood data analysis, the Ordnance Survey data investigation, the scoping of social data (i.e. where it was held, its form and structure, how it was acquired) and the reviewing of other Coastal Flood Vulnerability studies, further confirmed this project



towards a methodology designed to carry out vulnerability analysis and mapping at a the most detailed level possible with Ordnance Survey, 2011 UK National Census, and Environment Agency data. One ward in Portsmouth was chosen to develop and test the methodology: Hilsea (Figure 3.2). Hilsea was chosen because it is a ward within Flood Cell 4 (flood cells identified by the local SFRA and described in Chapter 1), which has been identified by Portsmouth City Council (2011a) as one of the most critical, due to its high capital costs, potential high risk from inundation of future flooding zones (EAs flood zones 2 and 3), and the potentially high risk to life.

Hilsea is situated in the northwest corner of Portsea Island and is predominantly of low relief. The land cover of this ward is mainly residential, although it has significant industrial/commercial areas, along with substantial open spaces in the form of parks, playing fields and the Hilsea Lines (a scheduled ancient monument). The coastline runs from the Mountbatten Sports Centre on Tipner Lake, to the railway bridge on the south side of Ports Creek (Figure 3.4).



**Figure 3.4.** Hilsea ward with specific areas identified; black arrows represent the start and end points of the Hilsea coastline; red circle represents Alexander Park; Blue oval indicates the Hilsea Lines (OpenStreetMap.com, 2014).

To analyse Coastal Flood Risk for Hilsea ward at neighbourhood (Output Area) level, a methodology framework was outlined (Figure 3.5) and has been broken into four key stages (stage 5 is described in Chapter 5). The risk, hazard, vulnerability model (Figure 2.6) and equation set in Chapter 2, brought together the three main components of vulnerability (physical vulnerability, socio-economic vulnerability and limited resilience) and combined them with hazard to make one risk, hazard, vulnerability framework.

To create a detailed and uniquely visualised Coastal Flood Vulnerability and Risk analysis stemming from this, the four key components were combined into one methodology framework (Figure 3.5). Figure 3.5 contains five key stages of the methodology. Boxes on the left represent factor development for the different CoFR elements, they are coloured dark blue (hazard factors), pale yellow (physical vulnerability factors – day and night), or dark grey (socio-economic vulnerability and limited resilience factors – day and night). Boxes in the middle represent the data used to populate those factors and are either coloured blue (hazard data), green (physical data), or pink (socio-economic data). Boxes on the right represent key processes in the methodology, and are coloured light grey. Boxes 1a-1d are associated with the hazard analysis and represent stage 1 of the methodology, this is recounted in section 3.1. Boxes 2a-2j represent the physical vulnerability analysis and are stage 2 of the methodology, described in section 3.2. Boxes 3a-3f are associated with the socio-economic vulnerability and limited resilience analyses, they represent stage 3 of the methodology and are discussed in section 3.3 and 3.4. Specifically boxes 1d, 2j and 3d represent the data standardisation process and are explained in Chapter 4 Part A. Boxes 4a-4b are stage 4 of the methodology and are associated with the final CoFV and CoFR analysis, described in Chapter 4 Part B. The very light grey box in the bottom left hand corner (box 5a) represents the exploration in visualisation (Chapter 5), that came after the main CoFR analysis and contains no factor development. Boxes 5a-5f are associated with the exploration of visualisation techniques in co-ordination with objective 6 (Chapter 1), described in Chapter 5, and different datasets were required to do that. Yellow boxes represent visual data, and green boxes physical data from Ordnance Survey. This study combines the individual factors of these components in detail into one Coastal Flood Risk methodology that can be applied to different spatial scales for a coastal area.

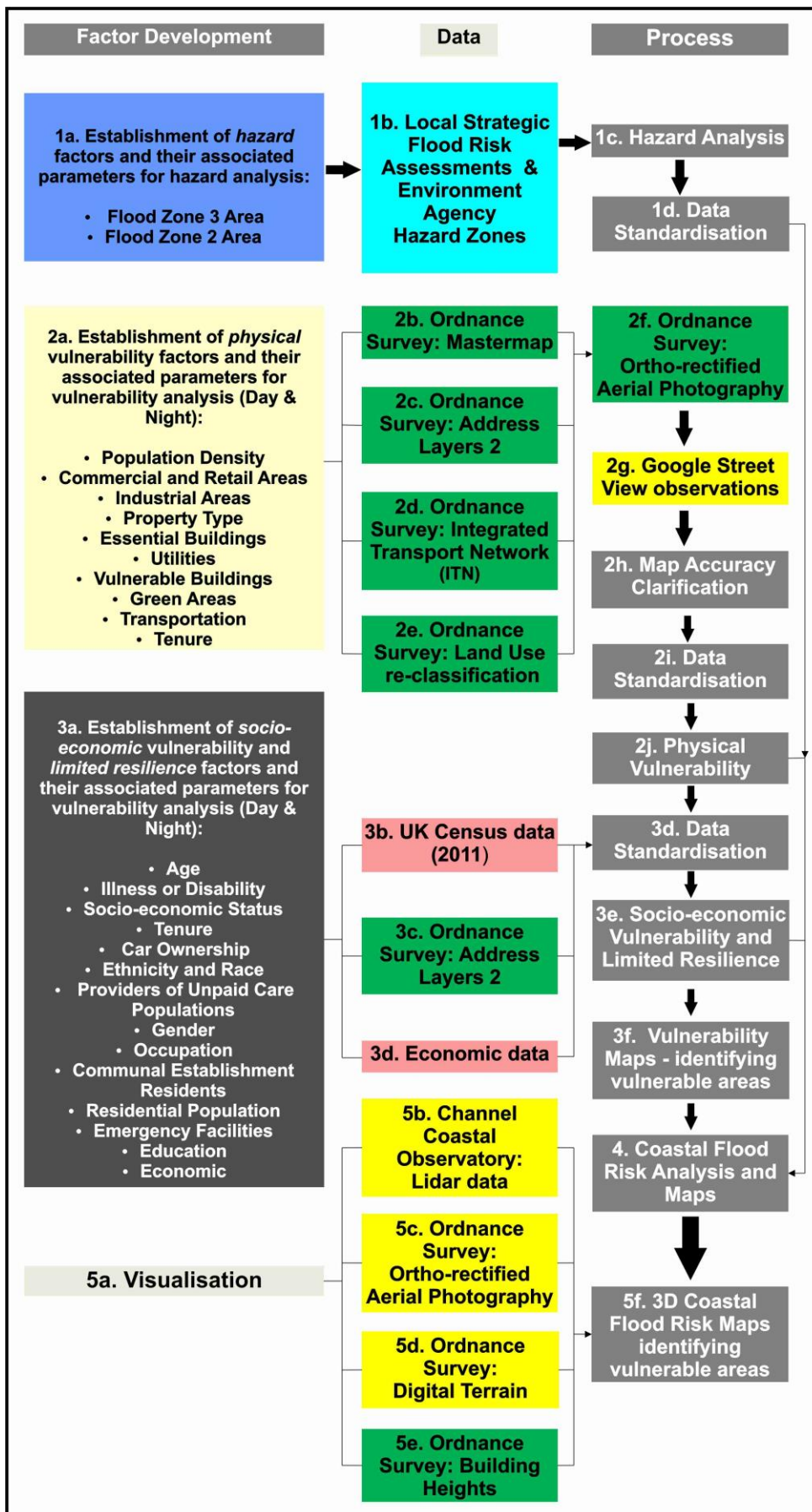


Figure 3.5. Methodology framework

A large amount of geoinformatic datasets are available for the UK, and can be used to represent different aspects and internal characteristics of geographical areas. However, it was understood through identification of previous vulnerability and risk studies, that several different data sources being incorporated into one model requires a standardisation of the data, to ensure uniformity in scales and units (Cutter et al., 2003; Tapsell et al., 2010; Menoni et al., 2012). Therefore, an index approach would be adopted in order to enable all the different vulnerability factors to be combined into their respective Coastal Flood Vulnerability components.

Indexing is one of the most commonly used and simplistic system when assessing flood vulnerability to natural and climate induced coastal processes and hazards (erosion, flooding, sea-level rise etc) (Ramieri et al., 2011). Therefore, hazard and vulnerability indices were created and combined in the equation  $Risk = hazard \times vulnerability$  (identified in Chapter 2), to create a Coastal Flood Risk index. It is a simple numerical basis for ranking sections of coastlines in terms of their potential for impact and change, which can be used by coastal managers to identify those regions most at risk. These results can also be displayed on maps to highlight specific regions assisting the identification of factors that might contribute to the vulnerability of those areas. The first methodological steps, according to Gornitz et al (1991), are to identify the key factors representing significant driving processes influencing the coastal vulnerability. The number and typology of these factors vary according to the focus of the assessor, but there are typically between 5 and 7 factors. The second step is the quantification of these key factors, however this may not always be possible with each of the factors. For this project, quantification of all factors was possible, due to the nature of the initial raw data.

Vulnerability indices have been developed as a quick and consistent method for characterising the relative vulnerability of different areas. The simplest of these, are assessments of the physical vulnerability, the more complex are those that examine aspects of economic and social vulnerability (Balica, 2012a; Balica et al, 2012). Globally, many indices have been created for coastal vulnerability studies, notably by Gorintz (1991), Gornitz and Kanciruk (1989), and Thieler and Hammer-Klose (2000), whose indexes were applied in the United States and modified for Canada and South Africa.

Social data has been identified as essential information for vulnerability analysis and measuring risk, notably by Cutter et al., (2003), Boruff et al., (2005), Abuodha and Woodroffe (2007) and Gornitz (1991). The social vulnerability index (SoVI) uses 42 socio-economic variables, reduced to 11 statistically independent factors, i.e. age, race, ethnicity, education, family structure, social dependence, occupation etc (Balica et al., 2012b). This method has been applied at a coastal county basis, and is a principle component in producing the overall coastal social vulnerability score (CSoVI). It is combined with geomorphology variables (coastal physical aspects), such as dune height, barrier type, beach type, relative sea level change, shoreline erosion and accretion, mean tidal range and mean wave height.

This research proposes to create a Coastal Flood Vulnerability Index and combine it with a hazard index, to produce a Coastal Flood Risk Index for each OA of the Hilsea ward coinciding with the risk, hazard, vulnerability model (Figure 2.6) and equation (equation 2.2) set in chapter 2. In a given flood-risk area (such as Portsmouth) the probability of flooding may be equal for all the population. However, different people and areas are not equally vulnerable to flood events, and some could be potentially worse affected than others.

This project has defined vulnerability in terms where physical vulnerability, social vulnerability and resilience are brought together, rather than measuring only one of these components. This vulnerability analysis combines all attributes of vulnerability to therefore create one vulnerability index. Vulnerability is defined as *'characteristics of an area and the person/groups within it, ability to anticipate, cope with, resist, and recover from the impact of natural hazards'*. According to Environment Agency (2006a) vulnerability can therefore relate to the location of the victim, the likelihood of them receiving and understanding adequate warnings, and their ability to survive the effects of contact with floodwater.

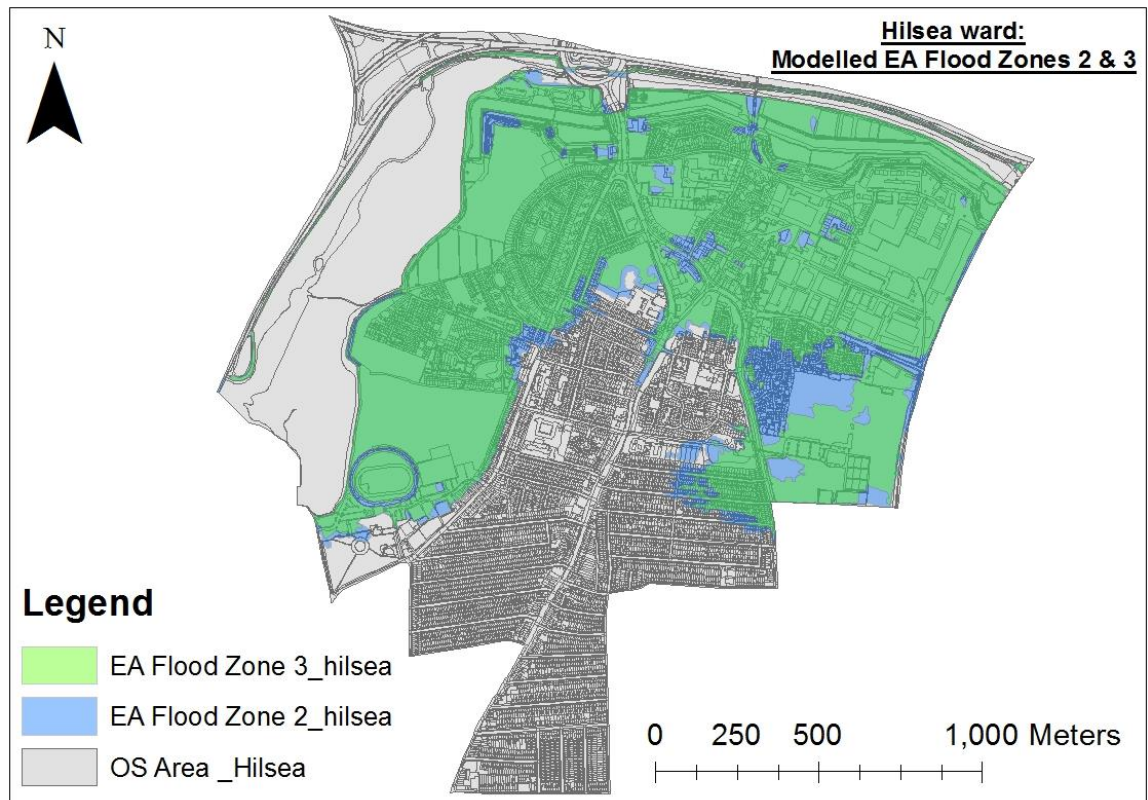
Sections 3.1, 3.2, 3.3 and 3.4 describe the four main stages of the methodology; hazard – coastal flood zones; and the three CoFV components - physical vulnerability (exposure); socio-economic vulnerability (susceptibility); and limited resilience. Firstly, the key factors of that component were identified, which assisted the analysis of overall Coastal Flood

Risk. This was done by identifying factors that have been presented in other studies (Cutter et al, 2003, 2010; Environment Agency, 2006b; Atkins, 2007; Haynes et al, 2007; Kazmierczak & Cavan, 2011) and new factors that would quantify all aspects of risk - with particular emphasis on vulnerability. The factors selected and the related reasoning is presented in each section. Once the factors are chosen, each section describes the data acquired, its assessment and any manipulation that took place to populate each factor. Section 3.1 outlines the hazard factors chosen, the available data, and which datasets were chosen for the hazard index.

### 3.1 Hazard – Coastal Flood Zones

When measuring coastal flood risk, it is essential to know where the potential flood zones could be situated. Whatever is situated in those zones will dictate the vulnerability of those areas. Therefore, the original hazard factors were simply EA Flood Zone 2 Area and EA Flood Zone 3 Area, i.e. what was the potential inundation surface area for each zone in each OA within Hilsea.

The flood zones were added into ArcMap and laid over Hilsea ward (Figure 3.6). The EA flood zones were produced for England and Wales due to the publication of Planning Policy Statement (PPS) 25 for England and TAN 15 for Wales (2009). The other drivers included the EA's constant commitment to improving information of flood risk, plus pressure from the Government to provide Local Planning Authorities with quality-assured flood risk data (Environment Agency, 2011). The flood zones are used as the main constraint map that underpins the Flood Risk Standing Advice (FRSA) within England and Wales.



**Figure 3.6.** EA modelled Flood Zones (2 and 3) over OS Area Hilsea ward (Sources: Environment Agency & OS Mastermap Topography Layer).

The flood zones are divided areas of the natural floodplain, presented in map format. There are three divides (or three zones) and they do not show or take into account any present flood defences. They are referred to as zones 1, 2 and 3 and were developed using a combination of data in a consistent way to create a national product. Modelled data (from S105 studies) was used where available (Portsmouth flood zones acquired, are modelled) and where it fitted specific consistency criteria (required for PPS25), which included; modelled without defences, without allowance for climate change, and excluding blockage or other scenarios. Where available, this new modelled data was supplemented within national generalised modelling. In summary, a modelling process (a 2d hydraulic modelling package, developed by JBA consulting, known as JFLOW (2006)) was applied, which runs the appropriate flood event over the height model and records the maximum extent of the water (Environment Agency, 2006d). The resulting maps show the extent of the predicted flooding.



The national generalised modelling has applied flow and tide models to a Digital Terrain Model (DTM) of England and Wales (Environment Agency, 2011). A 5 m grid DTM was used and created via airborne radar system, as part of the NEXTMap Britain mapping programme (Environment Agency, 2006d). Before the DTM was used, any flood defences that were not removed from the original filtering process, were removed, to ensure an undefended flood model (Environment Agency, 2006d). The flow data is a national dataset (England and Wales) of peak flood estimations, provided by the Centre of Ecology and Hydrology (CEH). This data was derived from the Flood Estimation Handbook (FEH) (Morris et al, 2003), which used automated procedures to extract the data required and then perform a statistical analysis.

The resulting data provided median annual maximum discharge (QMED) values for all the drainage paths within the FEH, every 200 m. The data was ordered and relocated to its watercourse centreline by using JBA's automated routines. Before the model could proceed, the flow data required further work. To ensure JFLOW could identify the correct area required for modelling and the flow direction, cross sections were created for each flow data point (Environment Agency, 2006d). Routines written by JBA automated this procedure, therefore drawing cross sections from the watercourse banks (left to right) to provide direction. JFLOW used national grid references (cross section end points) to determine the model area, and this cut a portion of the DTM to speed up the modelling process. The width of the area was determined from the cross section and a percentage, however the length was normally stretched to 1000 m downstream, but in lowland areas, longer box sizes were required. This all determined the reach of the flood water within the model. The DTM used however, did not contain channel information, as radar signals are reflected off water.

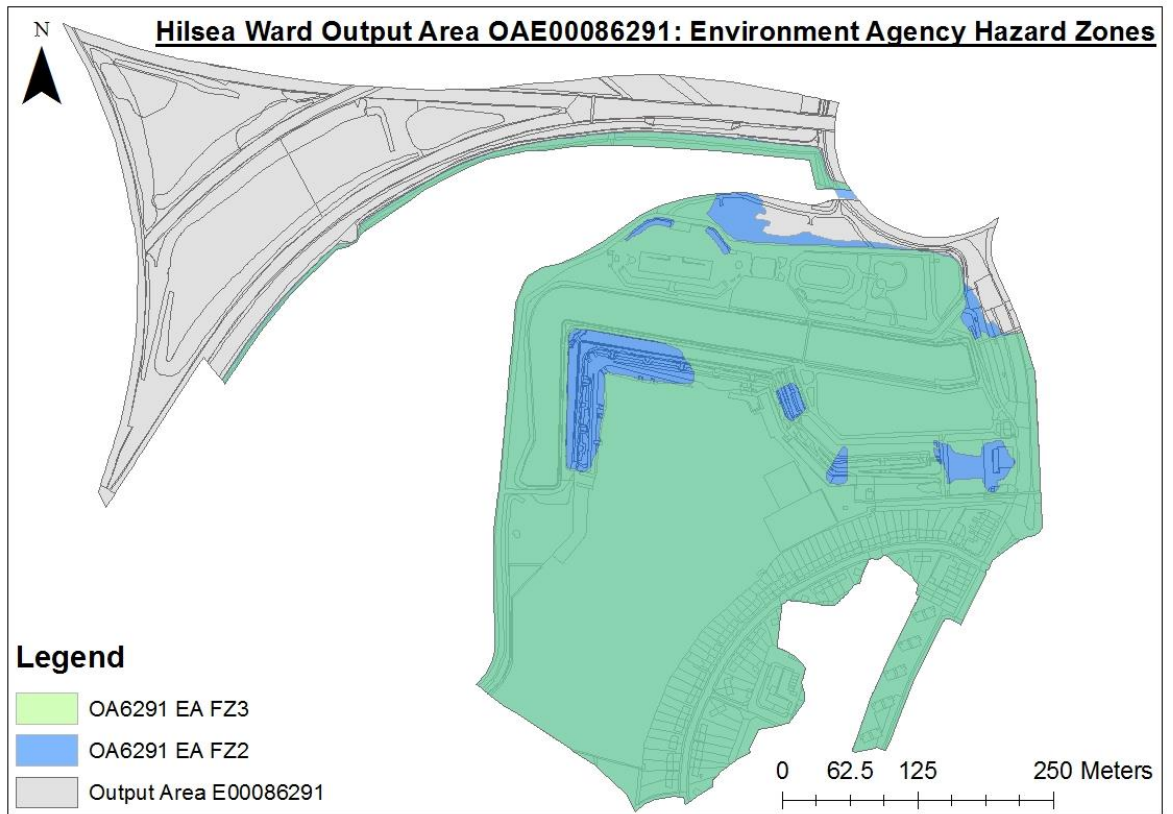
The national modelling was at a large scale, therefore the assumption that flooding would only occur when the hydrograph increased above the level of QMED was adequate for this project. Each flow data point was modelled as an individual flood event and the depth (flood) results were written into the database (Environment Agency, 2006d). The last routine written enabled the results to be extracted and converted into the flood extents. The resulting flood zones are summarised (Environment Agency, 2011):

- Zone 1 – Shows areas with the lowest probability of flooding from the sea and rivers, a less than 0.1% chance in any one year (a 1000 to 1 return period).
- Zone 2 – Between zone 1 and 3 and represents an area with the chance of flooding in any one year between 0.1% and 0.5% coastal (between a 1000 to 1 and a 200 to 1 return period). The outer edge of zone 2 is known as the ‘Extreme Flood Outline’ (EFO).
- Zone 3 – An area where the chance of flooding in any one year is greater than or equal to a 0.5% coastal (200 to 1 return period).

These EA flood zones (2 and 3), were then clipped to each OA boundary (English Output Areas 2011 - acquired via UK Data Service) within Hilsea (43 in total). This hazard data was modelled and gave insight to direction and maximum extension of flow water, however, when presented in ArcGIS, the polygons appear empty of information (see Figure 3.7). To measure the surface area this flood hazard zone would cover within each output area; the geometry was calculated within Arc, adding a value to the shape area in m<sup>2</sup>. For example Output Area E00086291 is prominently situated in both EA flood zones (see Figure 3.8), the surface area these zones would cover were calculated (examples shown in Figure 3.10). However, OA6291 Flood Zone 3 layer provided an extra step, due to 2 polygons represented this zone’s coverage in this neighbourhood. For ease and summarisation, this layer was dissolved, i.e. combining both the polygons into one total shape area (see Figure 3.9). This method was used for all the Output Areas in Hilsea, providing summary figures for the hazard component that could be incorporated into Excel.

	FID	Shape *	UNIQUE_ID	TYPE	SHAPE_AREA	SHAPE_LEN
▶	0	Polygon	0	Tidal Models	0	0

**Figure 3.7.** Attribute table for clipped Hilsea ward EA Flood zone 2.



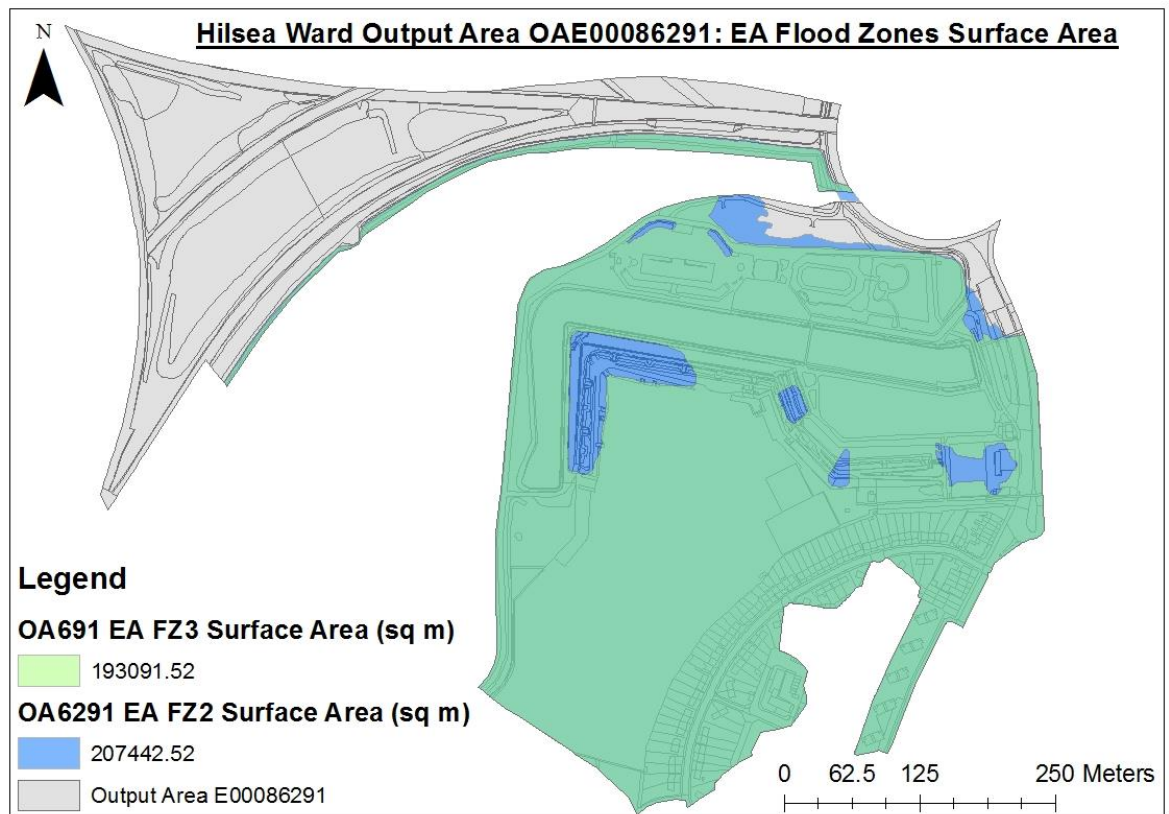
**Figure 3.8.** Output Area E00086291 - OS Area Mastermap data with added EA Flood Zones 2 and 3 (Sources: Environment Agency & OS Mastermap Topography Layer).

OA6291 EA FZ3						
	FID	Shape *	TYPE	UNIQUE_ID	SHAPE_AREA	SHAPE_LEN
	0	Polygon	Tidal Models	0	187792.145256	0
	1	Polygon	Tidal Models	0	5299.381009	0

OA6291 EA FZ3 Dissolve				
	FID	Shape *	TYPE	SHAPE_AREA
▶	0	Polygon	Tidal Models	193091.526266

**Figure 3.9.** Dissolving OA6291 FZ3 polygons and calculating total area (m<sup>2</sup>).



**Figure 3.10.** Output Area E00086291 with calculated coastal flood zones surface areas m<sup>2</sup> (Sources: Environment Agency & OS Mastermap Topography Layer).

The next stage of the analysis utilised new data from the PUSH Project (part of the local SFRA, 2007), which had been used within the North Solent Shoreline Management Plan (NSSMP), to assist LPA's and the Environment Agency in coastal management decisions for the city of Portsmouth. The main goal of the Output Packages from the PUSH project (the flood hazard zones are part of those packages), is to provide information, to guide decisions on location of future development in relation to areas of flood risk, specifically, the Flood Zones (Atkins, 2007). The users involved in spatial allocation of any new development include LPA Planners, LPA/Environment Agency Flood Risk Managers and Environment Agency Development Control Officers. It is important to note that if there is development pressure in Flood Zones 2 and 3, the output packages can assist the application of the Exception Test within this zone. It provides information to assist identification of lowest and highest flood hazard/danger. Lastly, can help guide development to areas with lowest probability of flooding and lowest flood hazard/danger, or, when no other option is available, to areas of medium to high probability and low hazard/danger (Atkins, 2007). The PPS25 recognises there are times where allocations

within Flood Zones 2 and 3 are necessary, due to fulfilling wider sustainability objectives or avoiding social/economic blight of an urban area. It is in these instances, a geographic area may qualify for development if the criteria of the 'Exception Test' can be fulfilled. The flood hazard zones produced for the Solent SFRA were analysed for application to this research.

Flood Zones used within the SFRA, represent the most critical dataset in the application of the PPS25 policies, as they define the areas that fall within each category in terms of the probability of flooding. The SFRA Flood Zones are provided by the Environment Agency. Due to the strategic nature of the SFRA and the large scale of the study area (the Solent), where there are diverse sources of flood risk to consider, no further hydrological modelling was undertaken in an attempt to improve or refine the existing Flood Zones created by the EA.

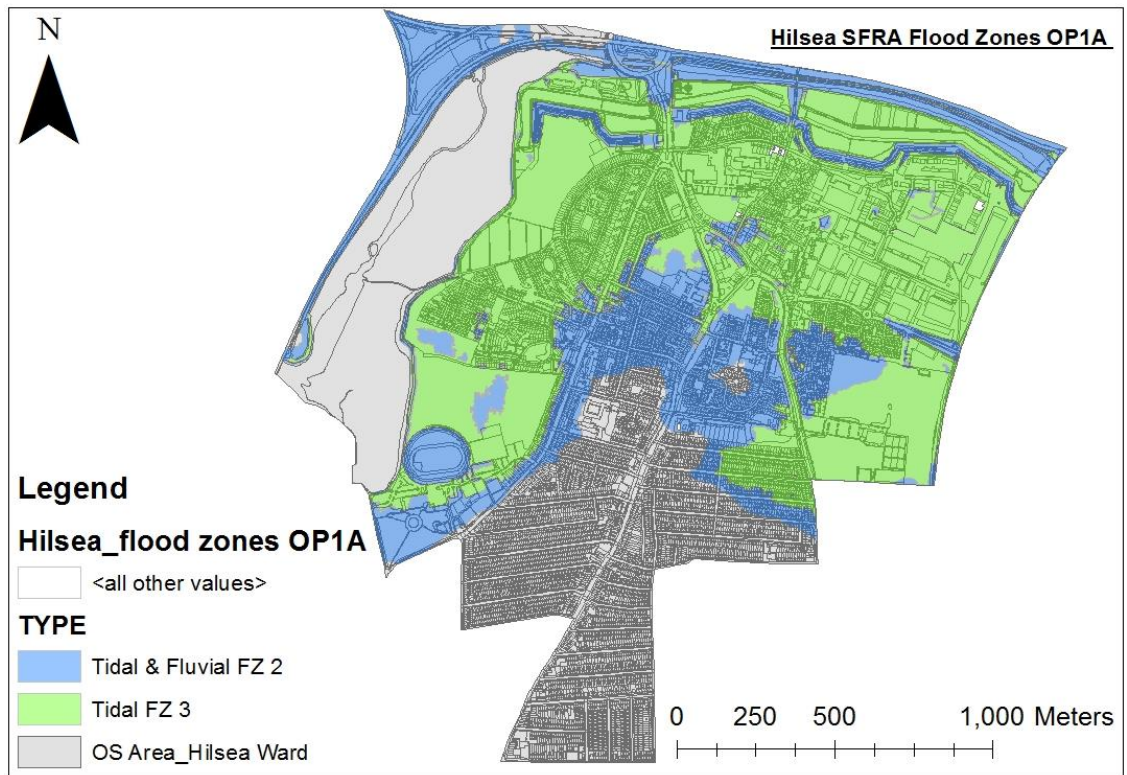
When examined within ArcGIS, the hazard data presented in the 3 Output Packages is in six different layers, not all were applicable for this project, however the following section describes the layers that required further investigation and could be considered to represent the hazard datasets.

### 3.1.1 The Local Strategic Flood Risk Assessments Output Packages

The first flood zones that were analysed further from the SFRA, are from Output Package 1A. Table 1 shows the examples of the Flood Zones in Map Set 1A, and Figure 3.11 shows this layer clipped to the Hilsea ward. Tidal flooding can be seen as the main hazard in Hilsea, covering just below 50% of the ward. The Map Set 1A shows areas within the hazard zones of a flood, of a given probability, without the presence of defences (Atkins, 2007). A 1 in 200 – 1 in 1000 flood (Flood Zone 2) covers a greater percentage of the ward, especially towards the centre and east of the centre. The Output Package 1A flood zones do not hold as much information as the original acquired modelled EA Flood Zones, due to the lack of modelled flood flow represented. They only represent a summarisation of the possible inundation area without extra information considered and were therefore discounted for this research.

Flood Zone	Description (annual probability of flooding)
Flood Zone 1	Low probability of flooding (< 0.1% or 1 in 1000)
Flood Zone 2	Medium probability of flooding - tidal (0.5% or 1 in 200 - 0.1% or 1 in 1000) Medium probability of flooding - fluvial (1% or 1 in 100 - 0.1% or 1 in 1000)
Flood Zone 3a	High probability of flooding - tidal (> 0.5% or 1 in 200)
	High probability of flooding - fluvial (> 1% or 1 in 100)
	High probability of flooding – fluvial and tidal combined where available (> 0.5% or 1 in 200)
Flood Zone 3b	The functional floodplain (> 5% or 1 in 20 where applicable see Appendix B) ( <i>Fluvial Flooding only</i> )

**Table 3.1.** The SFRA Flood Zones (Atkins, 2007).



**Figure 3.11.** SFRA Output Package 1A (OP1A) Flood Zones clipped to Hilsea ward (Sources: PUSH & OS Mastermap Topography Layer).

The Map Set from Output Package 1B offers a breakdown of Flood Zones 2 and 3. Like Map Set 1A, it presents the hazard zones posed by flooding without consideration of the

mitigating effect of existing flood defences (Atkins, 2007). However, within these two Output Package 1B layers, a hazard index is provided within the map. This set is a function of velocity and depth of the flood water, and was estimated using appropriate assumptions and methods identified in the best practice guidance – Defra/Environment Agency Flood and Coastal Defence R&D Document: Flood Risk to People (2006) (please see Figure 3.12) (Atkins, 2007). The index within each Flood Zone (2 and 3) have been estimated based on the flood conditions that define that Zone e.g. within the Flood Zone 2, the index is based on the potential depths the flood water could be during a 1 in 1000 year event. For both Zones the index was estimated using appropriate assumptions regarding potential velocity, based on the distance from the source of the flood (i.e., the coastline; see Table 3.2) (Atkins, 2007). A summary table of the index displayed within the Map Set 1B is presented in Table 3.3, and the corresponding index value is shown in Table 3.4. A summary map of this layer when categorised and clipped to Hilsea is shown in Figures 3.13 and 3.14.

Velocity Coefficient C (V+C) * D Velocity	Depth									
	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
0.00	0.13	0.25	0.38	0.50	0.63	0.75	0.88	1.00	1.13	1.25
0.50	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
1.00	0.38	0.75	1.13	1.50	1.88	2.25	2.63	3.00	3.38	3.75
1.50	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
2.00	0.63	1.25	1.88	2.50	3.13	3.75	4.38	5.00	5.63	6.25
2.50	0.75	1.50	2.25	3.00	3.75	4.50	5.25	6.00	6.75	7.50
3.00	0.88	1.75	2.63	3.50	4.38	5.25	6.13	7.00	7.88	8.75
3.50	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
4.00	1.13	2.25	3.38	4.50	5.63	6.75	7.88	9.00	10.13	11.25
4.50	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00	11.25	12.50
5.00	1.38	2.75	4.13	5.50	6.88	8.25	9.63	11.00	12.38	13.75

	From	To	
Class 1	0.75	1.25	Danger for some
Class 2	1.25	2.50	Danger for most
Class 3	2.50	20.00	Danger for all

**Figure 3.12.** Velocity, depth and flood hazard matrix (Environment Agency, 2006).

Distance from river or coastline (m)	Velocity (m/s)
0	3
50	2
100	1.8
250	1.3
500	1.2
1000	0.2
Edge of the flooded area	0

**Table 3.2.** Velocity estimates based on distance from the coastline or river (Atkins, 2007).

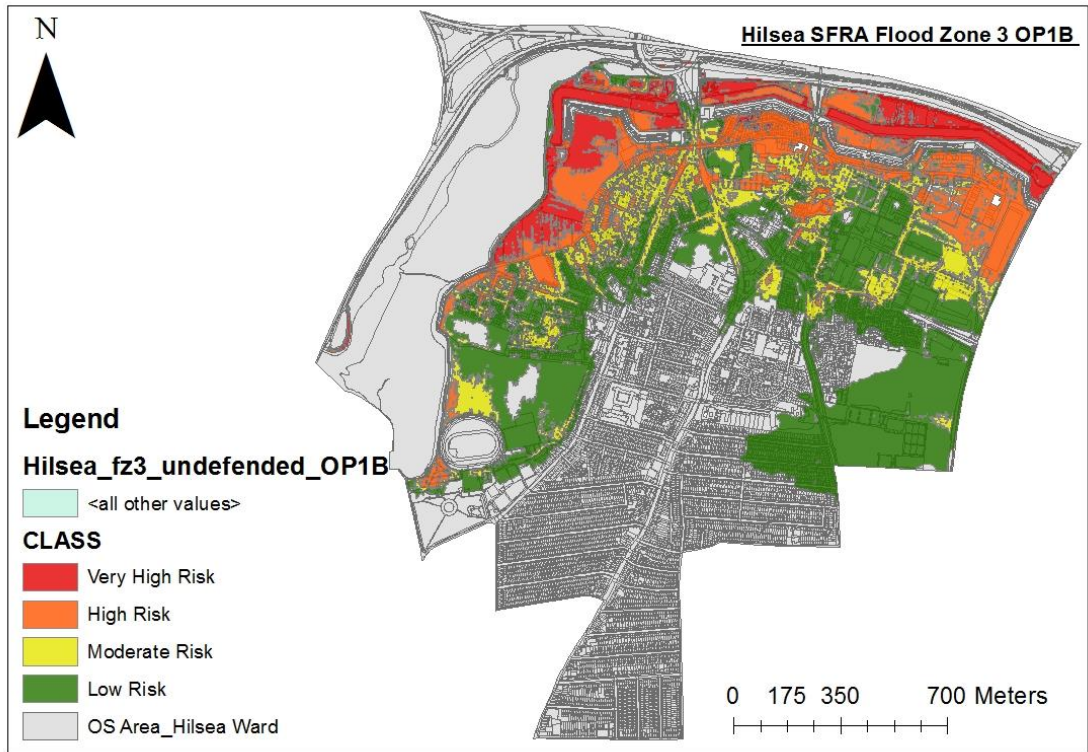
Classification	Description
Low	Caution <i>"Flood zone with shallow flowing water or deep standing water"</i>
Moderate	Dangerous for some (i.e. children) <i>"Danger: Flood Zone with deep or fast flowing water"</i>
High	Dangerous for most people <i>"Danger: Flood zone with deep fast flowing water"</i>
Very High	Dangerous for all <i>"Extreme danger: Flood zone with deep fast flowing water"</i>

**Table 3.3.** Definition of Un defended Flood Hazard Index as displayed within Map Set 1B (Atkins, 2007).

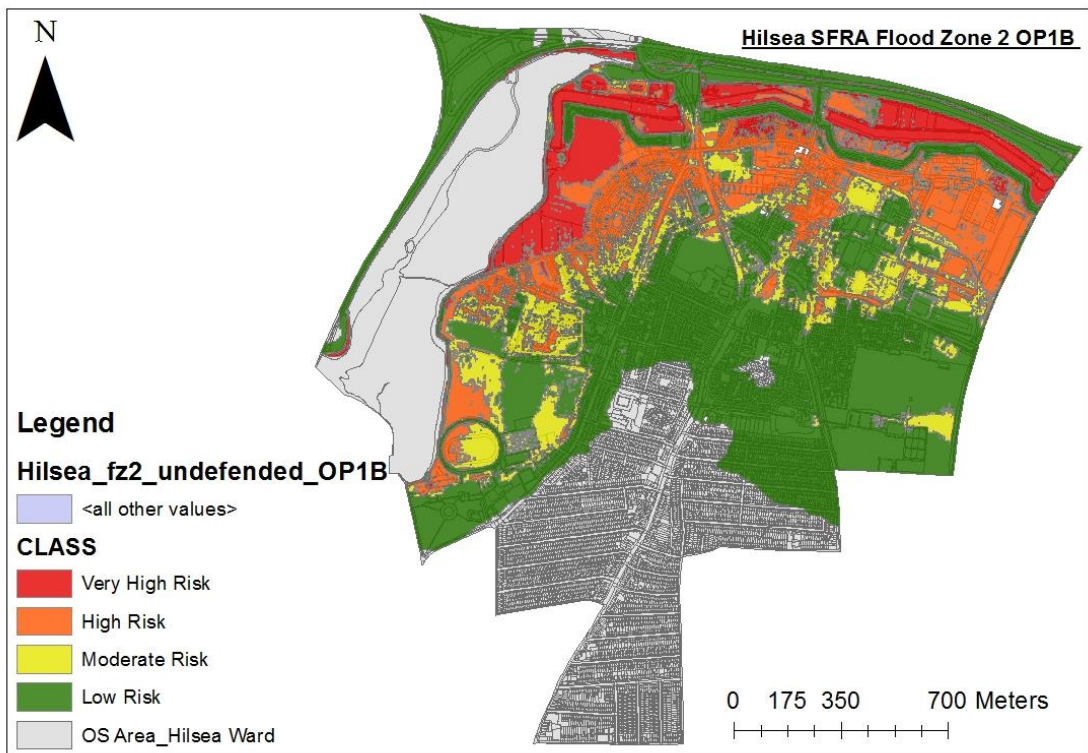
Value of Index	Hazard Classification
<0.75	Low
0.75-1.25	Moderate
1.25-2.5	High
>2.5	Very High

**Table 3.4.** Un defended flood hazard index values (Atkins, 2007).





**Figure 3.13.** SFRA OP1B Flood Zone 3 clipped to Hilsea ward (Sources: PUSH & OS Mastermap Topography Layer).



**Figure 3.14.** SFRA OP1B Flood Zone 2 clipped to Hilsea ward (Sources: PUSH & OS Mastermap Topography Layer).

As a risk tool, the 1B Map Sets provide an extra level of detail in addition to the Flood Zones themselves. The original acquired EA Flood Zones provided (results for Hilsea, seen in Figure 3.6) although modelled to indicate and estimate the flood water pathway, the SFRA's OP1B layers allow identification of areas where a flood of equal probability would have very different consequences for the affected area i.e. the level of risk. The index is relative and contributes to a higher level of assessment of the overall flood risk to different areas (in this case OA's) within the same Flood Zone relative to one another. The original purpose of this OP (1B) was to allow LPAs to use it for allocation of sites for development (Atkins, 2007). This hazard data, unlike the original EA Flood Zones acquired, has not been calculated using modelling or other detailed numerical methods, and was seen as inappropriate for identifying any design parameters which is part of site specific FRAs.

Output Package Map Set 1D is very similar to 1B as it provides information on potential variations of the flood hazard within areas situated in the same Zone. Unlike focussing on depth and velocity as 1B, these layers were defined as 'danger to people from breaching' of flood defences. They are a function of distance from breachable defences and are a function of potential depth of flood water, and estimated using appropriate assumptions and methods again identified within the EA's best practice guide (2006a). This index has been calculated for at any one point, using a predicted depth of water (determined by predicted extreme sea levels) and the perpendicular distance from that point to the nearest line of defence (Table 3.5). These layers can be used to indicate the magnitude of the hazard during a defence breach.

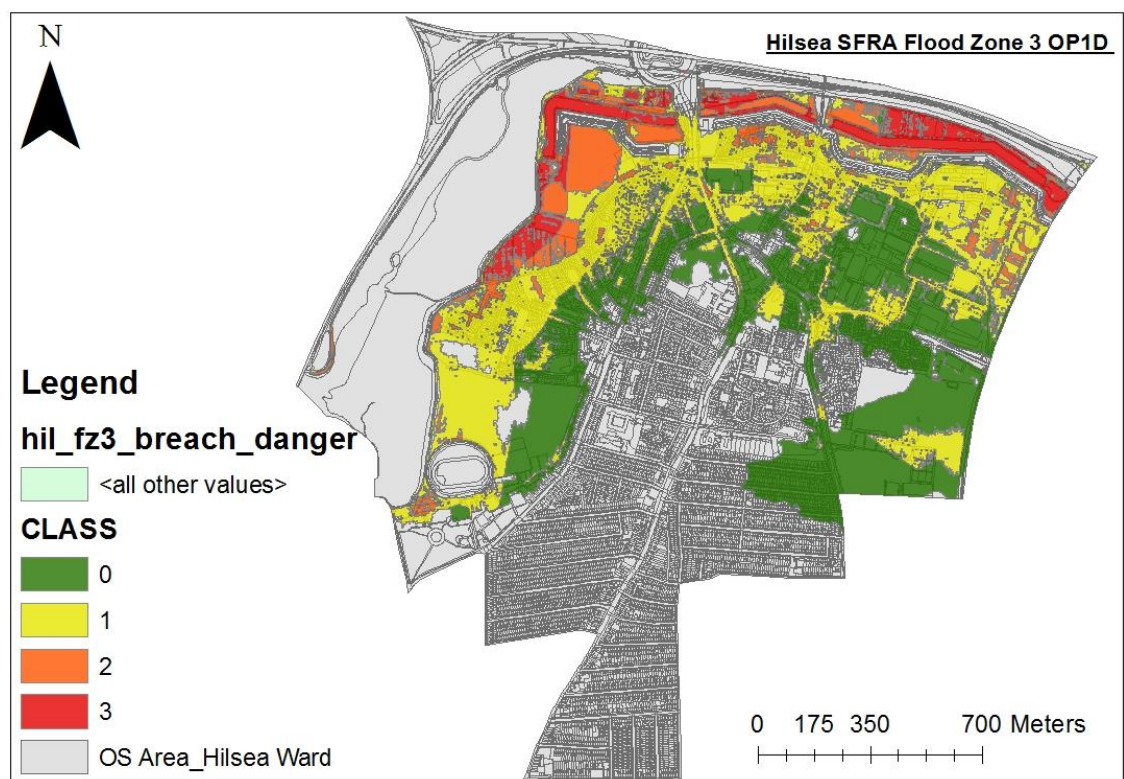
Distance from Breach (m)	Water level above ground level (m)		
	Danger to some	Danger to most	Danger to all
0 -100	0-0.5	0.5-1	1-6
100 - 250	0-1	1-2	2-6
250 - 500	0.5-1	1-2	2-6
500 -1000	0.5-2	2-3	3-6
1000 -1500	1-2	2-4	4-6

**Table 3.5.** Index for assessing danger to people from defence breaching (Atkins, 2007).

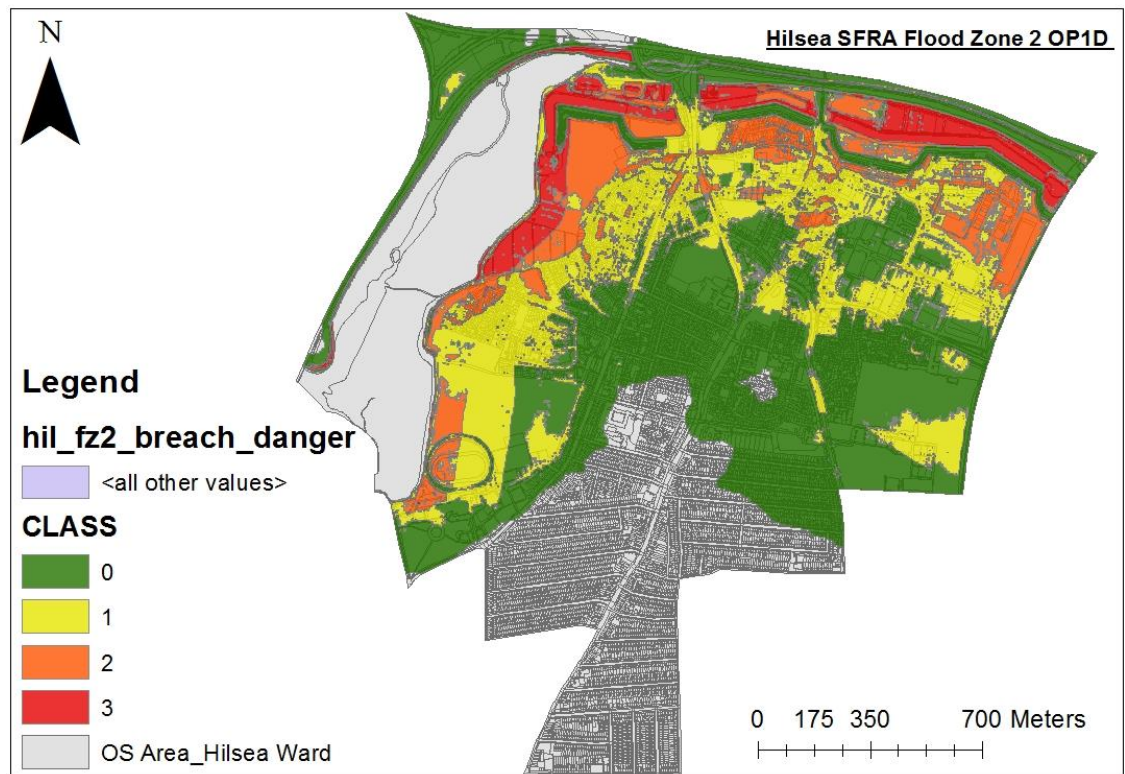
Map Set 1D – is only applicable to areas with coastal defences and subsequent coastal flooding events. Only the potential hazard due to breaching is estimated, this does not include the probability of occurrence or where that would take place. These layers provide

an initial guide and useful identification of where detailed breach assessments may be required.

Map Set 1D can be seen as providing a more relevant representation of the flood hazard, rather than Map Set 1B. However, once the majority of defences have been overwhelmed, 1B becomes the more relevant hazard map i.e. 1B represents the worst case scenario. Like Output Package 1B, 1D produces a higher level of assessment than OP1A and assists identification of specific geographic areas that potentially could have large spatial areas inundated, resulting in a greater level of overall risk. Preliminary results for the layers of OP1D, clipped to Hilsea ward, are shown in Figures 3.15 and 3.16.



**Figure 3.15.** SFRA Output Package 1D Flood Zone 3 clipped to Hilsea ward (Sources: PUSH & OS Mastermap Topography Layer).



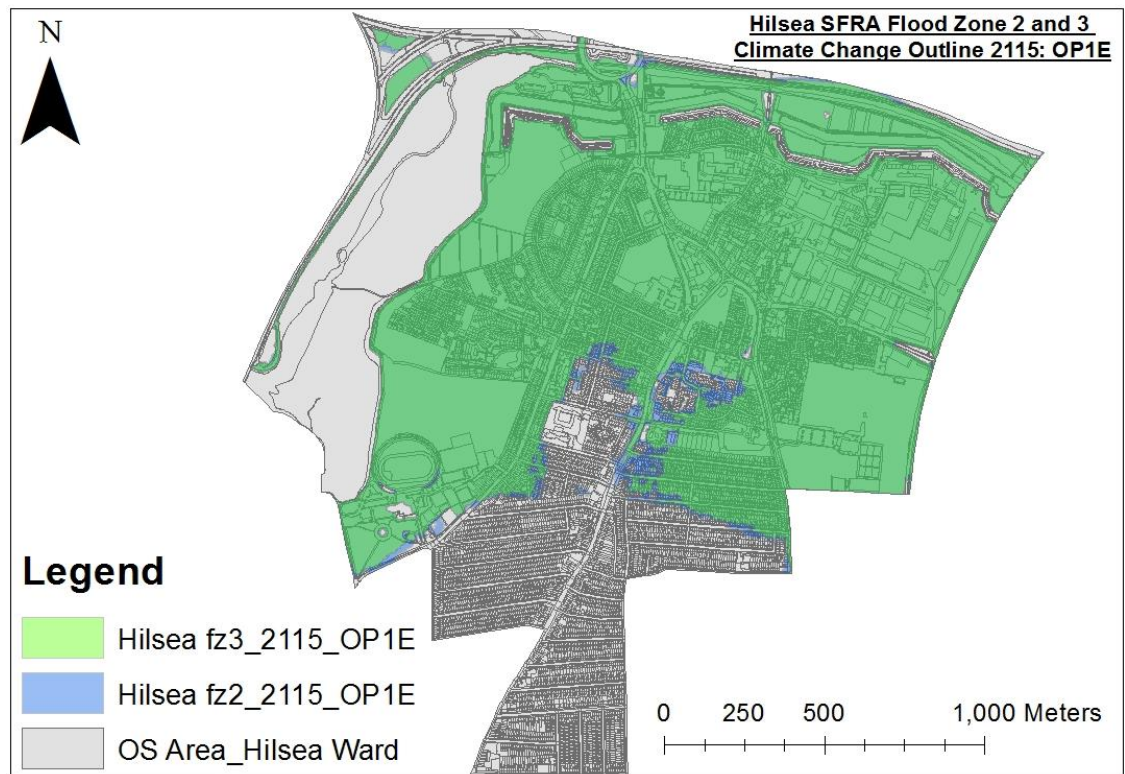
**Figure 3.16.** SFRA Output Package 1D Flood Zone 2 clipped to Hilsea ward (Sources: PUSH & OS Mastermap Topography Layer).

The final hazard dataset from the SFRA data catalogue that had potential for use within this research was OP Map Set 1E. Also known as the Climate Change Flood Outlines. Due to PPS25's practice guide recognising the effects of climate change as important factors when regarding decisions for new development and flood risk, the SFRA produced revised outlines of Flood Zones 2 and 3 for a number of years over the next century, in order to allow considerations of the effect of climate change (Atkins, 2007). The outlines were produced for the years 2025, 2055, 2085 and 2115. This was done to comply with DEFRA guidance on climate change which provided allowances for sea level rise to 2025, 2055, 2085 and 2115. In tidal areas like Portsmouth, EA extreme sea levels were projected inland to the PUSH sub-region (see Appendix D, pgs 308-312) topographic grid, using a methodology defined by the EA. The extreme sea level method was based on the JBA Extreme Sea Levels Report (2004). The 2000 base levels at analysed sites (no interpolation) were backdated to 1990 by removing the 6mm/yr climate change allowance. The now revised 1990 tide levels were interpolated for intermediate sites and the revised DEFRA sea level rise allowances were added to these new interpolated 1990 tide levels which produced a level for each epoch in the DEFRA guidance i.e. 2025, 2055 etc (Atkins,

2007). The EA provided these levels for the Flood Zones 2 and 3 return tides. Atkins (2007) produced the final report for PUSH, as part of the local SFRA, and used this method to generate even more frequent return period level; tables listing the various tide levels for 1 in 1000, 1 in 200, 1 in 100, 1 in 50 and 1 in 20 year events (shown in Appendix D, pgs 308-312). 1 in 1000 and 1 in 200 year tide levels (Flood Zone 2 and 3) were used within all analyses in the SFRA.

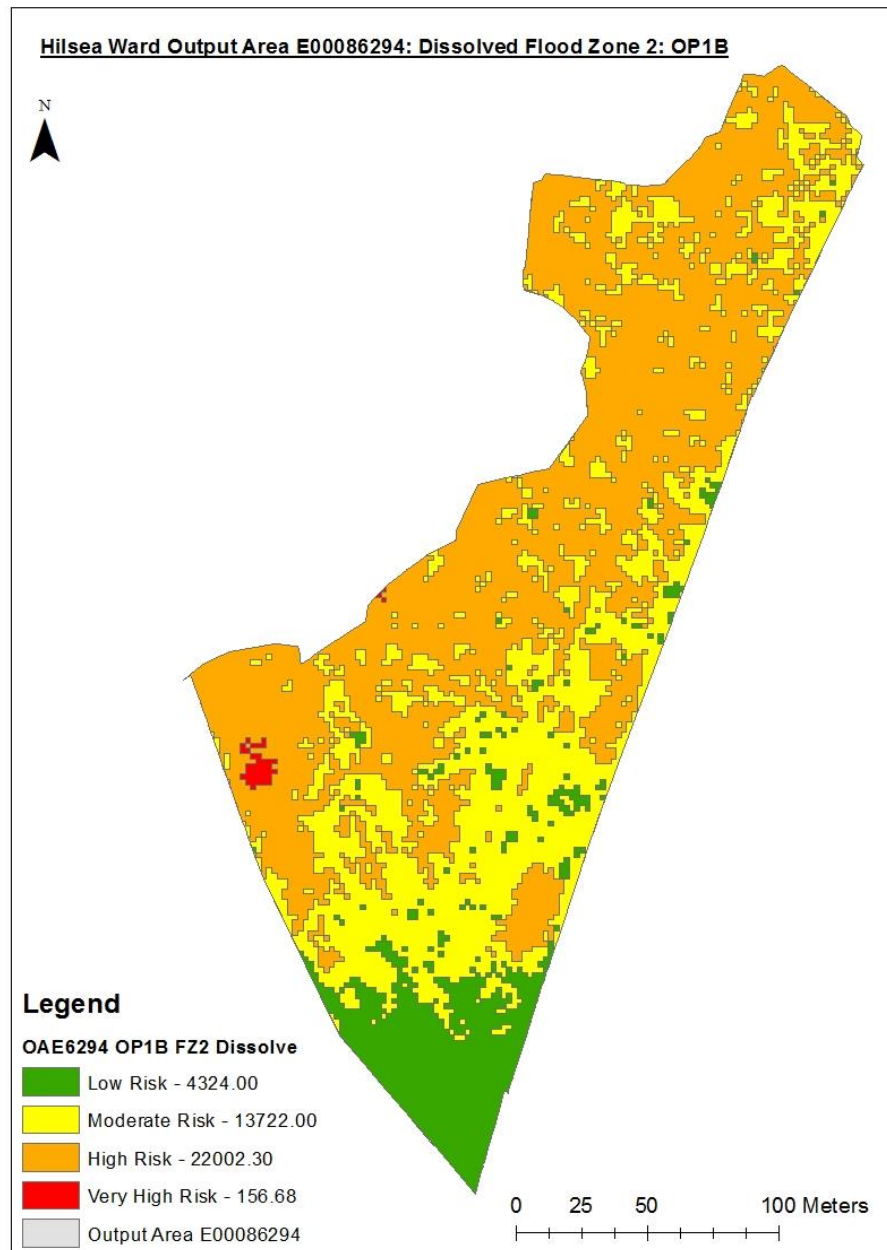
The tidal climate change outlines were generated by applying the extreme water levels, to the PUSH sub region topographic grid. The EA methodology involved a water surface grid, created for this sub region and applied to the extreme water levels to EA sea level polygons. This topographic grid was then subtracted from the water surface grid, this results in a flood depth grid and + ve values represent a flooded area. This flood depth grid was reclassified, producing flooded and non-flooded polygons. This layer was then updated with the area of each individual polygon (Atkins, 2007). However, due to an Environment Agency Flood Mapping policy, polygon areas of less than 200m<sup>2</sup> that were non-flooded, were re-set as flooded. Any flooded polygon area less than 5m<sup>2</sup> was removed.

Map Set 1E can be used to assess if an area that is presently not located within Flood Zones 2 and 3 will likely to be within these zones in the future, due to climate change impacts. All planning decisions are made using the present day predicted Flood Zones; however PPS25 has stated that flood risk needs to be considered throughout the lifetime of a development. The climate change outlines show areas most vulnerable to rising sea levels i.e. indicated as those areas where there is greater variation between each climate change outline. The preliminary results for these hazard layers clipped to Hilsea can be seen in Figure 3.17 and Appendix D (pg 330).



**Figure 3.17.** SFRA Output Package 1E climate change outline 2115 clipped to Hilsea ward (Sources: PUSH & OS Mastermap Topography Layer).

Map Set 1B, ‘Undefended Hazard’, was chosen to analyse the hazard for this research. Although the original EA Flood Zones gave an account of flood water movement, the map layers from Output Package 1B gave example of the hazard posed by the flood water within these zones, the worst case scenario, i.e. when the mitigating effects of flood defences are not considered - which areas would be inundated. These Flood Zones could be separated into low, medium, high and very high hazard, with corresponding depth and velocity measurement ranges of flood water for each hazard level. Within ArcMap it was possible to ‘dissolve’ each hazard level (low, medium, high, or very high) for Flood Zones 2 and 3, and measure their total surface area (m<sup>2</sup>) for each OA. When Output Package 1B was clipped to each OA of Hilsea, it became apparent that more than one hazard level was contained in that OA (Figure 3.18). Dissolving each hazard level within each OA that was within the Flood Zones, gave a clear picture of which hazard level would inundate the most, and what depth and velocity that flood water could be. Figure 3.18 shows that for Flood Zone 2, **OAE00086294** would be inundated by all 4 hazard levels, however the majority of flood water is described by the SFRA as ‘high risk’ (22,002.3 m<sup>2</sup>).



**Figure 3.18.** SFRA Output Package 1B Flood Zone 2 dissolved - clipped to OA6294 within Hilsea (Sources: PUSH & OS Mastermap Topography Layer).

Output Package 1B shows that different hazard levels can be present in one region, and these levels have different flood water attributes such as velocity and depth. Giving a far more detailed analysis of the potential hazard and producing a ‘truer’ indication of coastal flood risk. Based on the findings of the SFRA Flood Hazard Zones assessment, all Output Package 1B Zones were clipped to each OA in Hilsea, and the total surface area (m<sup>2</sup>) each flood hazard zone and hazard level covered was calculated in ArcMap and recorded in Excel (this and the results are discussed in Chapter 4). These results populated the Coastal

Flood Hazard Index for a Flood Zone 3 and 2 event, and were combined with the Coastal Flood Vulnerability Index results creating the Coastal Flood Risk Indexes (CoFRI).

### 3.2 Physical Vulnerability (Exposure)

Pinpointing attributes to vulnerability and the ability to measure them in terms of data, is a challenging task. A great deal of geoinformatic data is available for the UK, and more has recently become obtainable through Open Data Licences. Vulnerability has been defined as a combination of exposure, susceptibility and resilience. This and the next two sections (3.3 and 3.4) describe these terms within the research, what factors were chosen to represent them, the data sets needed to populate these factors, and the methodologies used to acquire that data. Chapter 4 discusses how the resulting factor data sets were combined to create a hazard, vulnerability and risk index along with associated maps for Hilsea. This section covers the process that was involved in understanding and measuring physical vulnerability.

#### 3.2.1 Physical Vulnerability Factors

In recent years, natural hazards in metropolitan areas, such as floods and landslides, have shown that environment-compatible urbanisation has not occurred (Başaran-Uysal et al., 2014). Residential areas with an inadequate physical environment or inappropriate housing, suffer the most in natural disasters (White et al, 2004; Wamsler, 2006). To summarise, there is a close relationship between natural disasters and sustainable urban development (Ayal-Carcedo, 2004; Wisner et al, 2004) and residential areas. To mitigate against hazards such as flooding, the degree of physical vulnerability and overall risk in urbanised areas is of utmost importance to determine (Başaran-Uysal et al., 2014). Current adaptation policy focuses on personal factors such as health and age and environmental factors such as flood prevention; however social factors also need to be addressed including income inequalities, the existence of social networks and social characteristics of neighbourhoods (Lindley et al, 2011; Cardona et al, 2012; Climate Just, 2015).

Vulnerability refers to the propensity of exposed elements including human beings and their assets to suffer adverse effects when impacted by hazard events (Bogardi and Birkmann, 2004; UNISDR, 2004; Birkmann, 2006b; Cardona et al, 2012). Therefore, physical and social characteristics of any community must be analysed in detail (Każmierczak and Cavan, 2011; Lindley et al, 2011; Balica, 2012b; Birkmann et al, 2013;



Climate Just, 2015). How disadvantaged a community will be by climate change depends on the degree of vulnerability to an event such as coastal flooding, and vulnerability is a measurement of characteristics/components of that community. Physical and social vulnerability are matters of how external events convert into internal losses for that community.

Exposure contributes to vulnerability, and within this flood-focused research is defined by physical assets (an inventory of elements) within the community exposed within the flooding 'pathway' to the coastal flooding hazard. The assets which are present at the location where floods can occur, are the assets that are exposed. These assets include buildings, roads, power stations, critical infrastructure, land, dwellings/households, individuals, and their proximity to the coastline etc (Każmierczak and Cavan, 2011; Cardona et al, 2012; Menoni et al, 2012). Exposure is the extent to which humans and their homes are positioned in proximity to the flooding pathway (UNDP/BCPR, 2004; Kaźmierczak and Cavan, 2011). It is a summary of the essential characteristics of the urban environment and the population density within the exposed area, i.e. the predisposition of a community to be disrupted by a coastal flooding event (Birkmann, 2006b; Kaźmierczak and Cavan, 2011; Lindley et al, 2011; Birkmann et al, 2013). These factors can either exacerbate or reduce the hazard's impact and therefore affect the overall risk of that environment (Cardona et al, 2012).

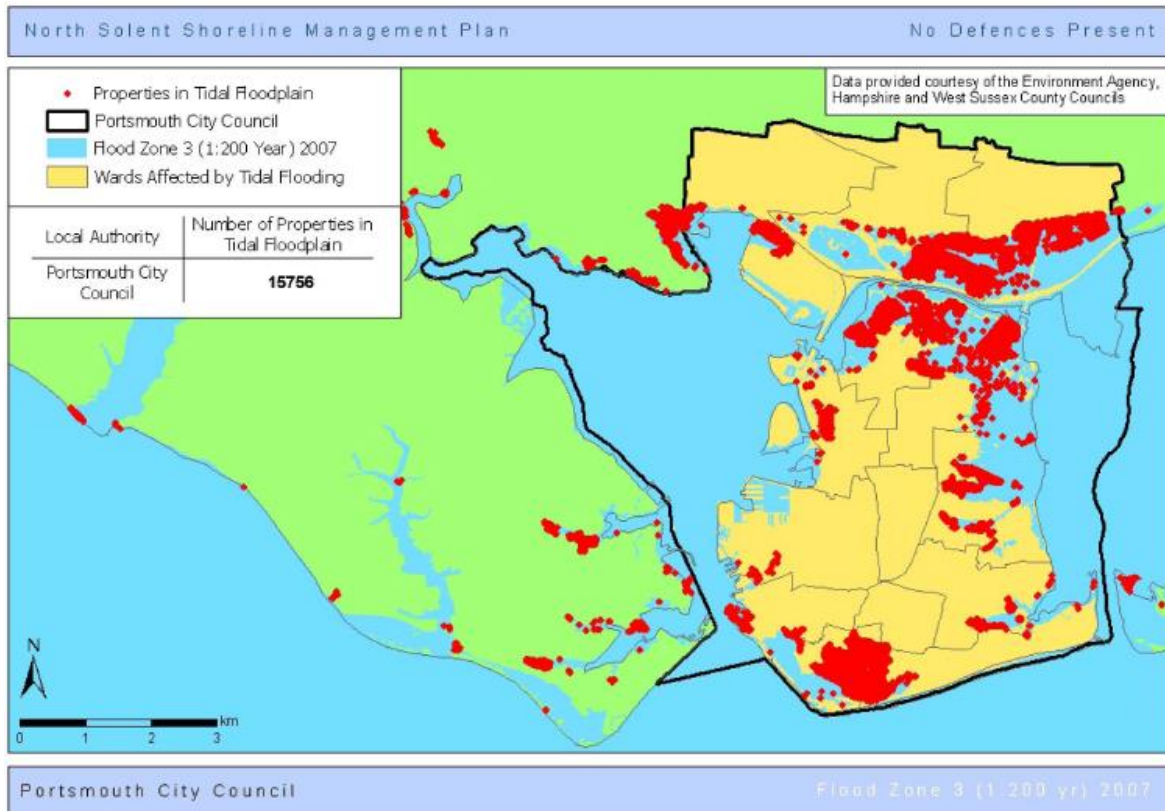
These essential physical characteristics were identified through literature review, observation and evaluation. A set of physical vulnerability factors were then created to guide data selection and manipulation, resulting in a physical vulnerability analysis in the form of a Coastal Flood Physical Vulnerability Index (CoFPVI); aided by remote sensing, image processing and GIS using QGIS and ArcGIS software. The Coastal Flood Physical Vulnerability (CoFPV) factors are listed in Table 6, detailed explanations of the factors are given in Appendix E (pg 335):

<b>Vulnerability Component</b>	<b>Physical Vulnerability Factors</b>
Coastal Flood Physical Vulnerability (CoFPV)	<i>Population Density</i>
	<i>Property Type</i>
	<i>Commercial and Retail Areas</i>
	<i>Industrial Areas</i>
	<i>Transport</i>
	<i>Green Areas</i>
	<i>Essential Buildings</i>
	<i>Utilities</i>
	<i>Tenure</i>
	<i>Vulnerable Buildings</i>

**Table 3.6.** Coastal Flood Physical Vulnerability (CoFPV) factors.

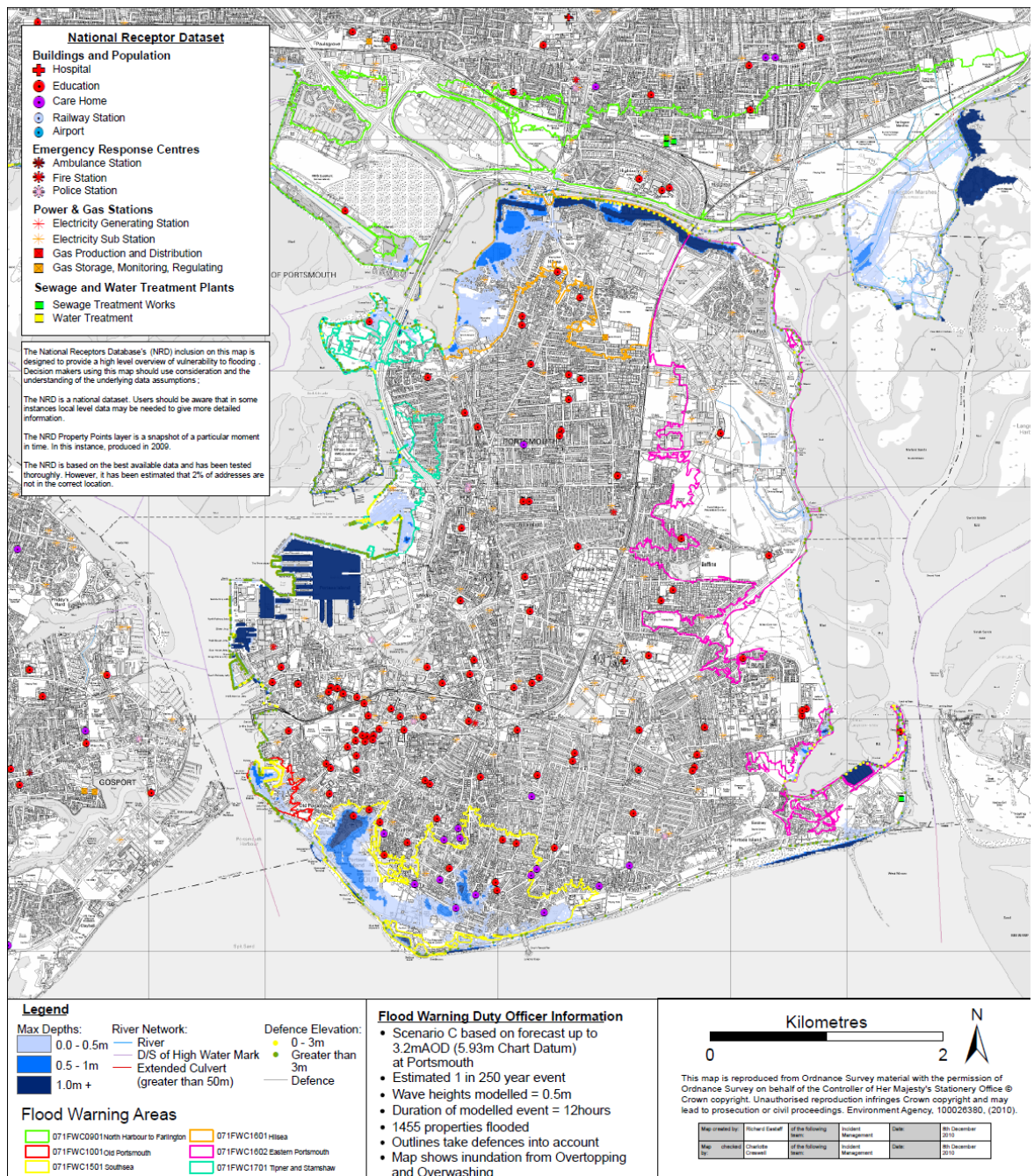
Land use (City of Portland Bureau, 2002; Hart per comms, 2010; Kinley, 2010; Kaźmierczak and Cavan, 2011) and population density are geoinformatic variables that can represent the physical factors that characterise an area’s physical vulnerability. *Population density* was measured by downloading the ‘population density’ spreadsheet from the 2011 UK National Census (last updated 2013) for each Output Area (OA) within Hilsa. The total population density for each OA was collated within MS Excel, ready for final standardisation (described in Chapter 4).

The remaining physical vulnerability factors require data that was not readily available. Previous flood risk assessments that included physical vulnerability components tended to use data that is readily available (Kaźmierczak and Cavan, 2011; Lindley et al, 2011; Balica, 2012a; Climate Just, 2015). Other assessments have identified specific buildings on maps i.e. residential, or commercial (NSSMP, 2010) (see Figure 3.19) or the EA’s National Receptor Dataset (NRD) (2010) (Portsea example see Figure 3.20). The NRD provides an extra level of detail that could assist coastal flood vulnerability analysis by identifying emergency response centres, power and gas stations, sewage and water treatment plants, and buildings. However, this information is not combined into the vulnerability analysis that forms part of local SFRA’s.



Local Authority	Electoral Ward	Number of properties in tidal flood-plain from a 1 in 200 year event		Commercial		Residential	
		2007	2115	2007	2115	2007	2115
Portsmouth City Council	Baffins	1213	3832	60	87	1153	3745
	Central Southsea	10	185	5	35	5	150
	Charles Dickens	140	483	16	70	124	413
	Copnor	1144	1879	219	288	925	1591
	Cosham	2243	2711	74	124	2169	2587
	Drayton and Farlington	1616	1858	176	184	1440	1674
	Eastney and Craneswater	1877	3646	96	170	1781	3476
	Fratton	0	25	0	15	0	10
	Hilsea	2005	2999	207	225	1798	2774
	Milton	154	1120	13	43	141	1077
	Nelson	673	1433	38	82	635	1351
	Paulsgrove	652	894	39	56	613	838
	St Jude	3244	5618	309	486	2935	5132
	St. Thomas	785	1806	88	145	697	1661

**Figure 3.19.** Total number and type of properties per Portsmouth City Council Ward, potentially within tidal floodplain, assuming no defences for 2007 and 2115 (NSSMP, 2010).

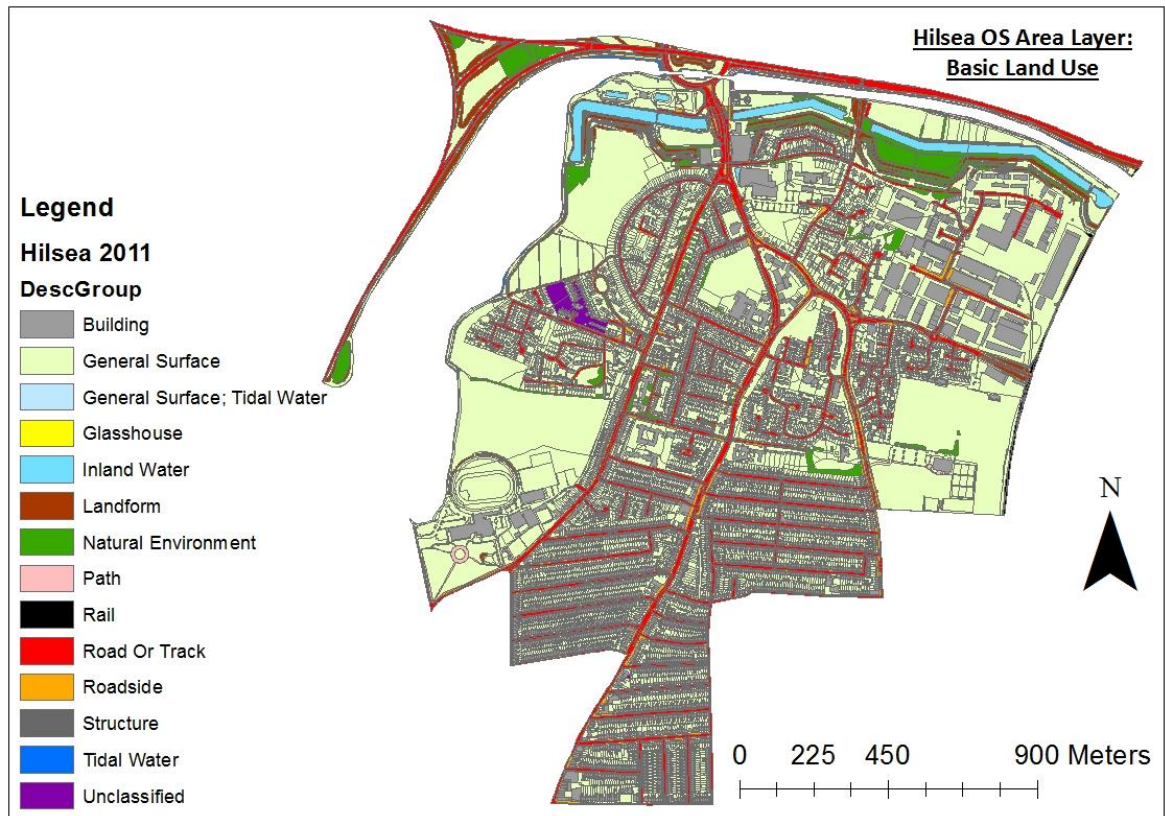


**Figure 3.20.** Portsea Island Flood Inundation Scenario C: NRD (Environment Agency, 2009).

To populate the physical vulnerability factors chosen for this research, certain land use information was needed. Initial investigations of OS's Mastermap, Address Layers, Integrated Transport Network (ITN) and Points of Interest datasets alluded that the data required was present but concealed within many layers. Initial meetings with the OS, along with Kinley's private OS report (2010) highlighted there is currently no generic system for the identification of land use or consensus on how it should be defined within OS.

Currently Mastermap does not contain a separate land use or land cover layer. To understand what relevant land use information OS data held for this research, all the acquired Ordnance Survey Mastermap, Integrated Transport Network (ITN), and Address Layers were clipped to Hilsea ward level within ArcGIS 10 (47 separate layers). Attribute tables for all 47 layers were then analysed for land use information. The selected physical vulnerability factors were populated after a process of elimination and separation of the OS data layers.

Initial OS data analysis that occurred for St Jude's ward, identified the layer OS Area (within the Mastermap layers) as containing land use data. When examining this layer's attribute table, a column described as 'DescGroup' had 'basic' land use and land cover descriptions, e.g. general surface, tidal water, building, natural environment, structure, road, etc (an example of this attribute table with highlighted column, can be seen in Appendix C – pgs 303-307). Therefore, this information was used to classify the shapefile polygons within this layer. The categorised results for Hilsea are shown in Figure 3.21. Other identified OS layers that contained specific data columns that would assist with the land use analysis, were then chosen and processed. These included Address Layer 1, Address Layer 2 (Postal and Non Postal), and Road Link. The same categorisation methodology was applied to these layers and examples of their attribute tables, including the data columns identified, are shown in Appendix C – pg 325).



**Figure 3.21.** Hilsea OS Area categorised to basic land use (Source: OS Mastermap Topography Layer).

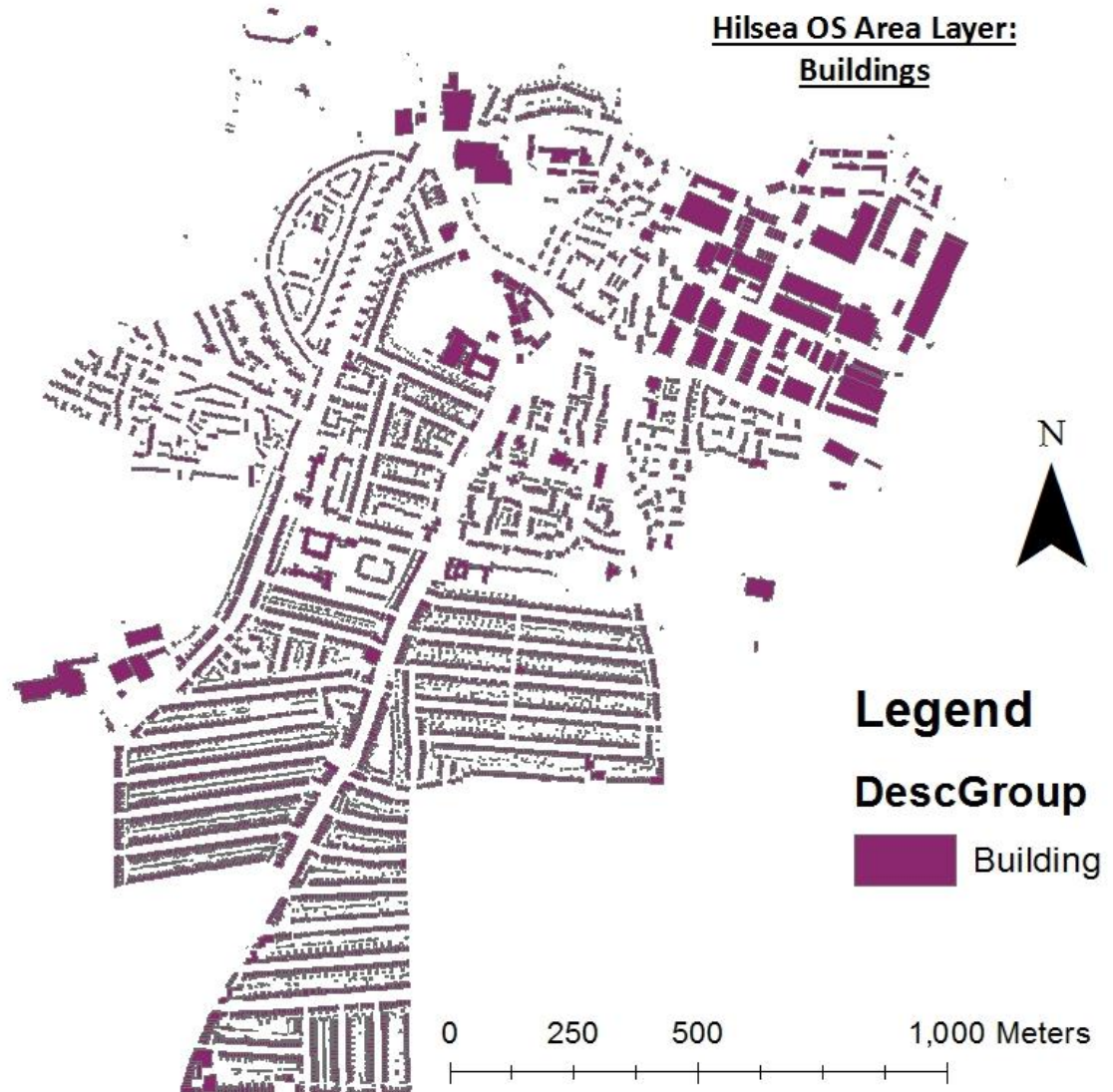
Through the initial investigations of the census and OS's datasets, more detail could be achieved through analysing at ward and 'neighbourhood' scale. Neighbourhood scale risk assessment methodologies present decision makers and planners with 'truer' insights and a resource to help manage cities, communities and individual properties from impacts to climate change such as coastal flooding (Handley and Carter, 2006). The specific land use data found within the different OS layers was required to populate the physical vulnerability factors, however to extract and use this data required separate methodologies. A new land use classification system was established (see Table 3.7) to guide the production of the physical vulnerability themed land use layers, which were needed to extract the necessary land use data that would then populate the physical vulnerability factors. Through investigation of the land use data included within the OS data it was possible to create each new land use class by a process of identification and combination, within ArcGIS 10, using the identified OS layers; OS Area, Address Layers 1 & 2 (Postal and Non Postal), and Road Link. Section 3.2.2 describes the land use methodology.

<b>Land Use Classes</b>	<b>Examples</b>
Residential	<i>Dwellings</i>
Residential Multiple Occupancy	<i>Multiple occupancy</i>
Roads (main roads only)	<i>Motorway, A road, and minor roads</i>
Essential Buildings	<i>Universities, hotels, schools, churches, halls, community centres, social club, shelters, vicarage, club house, hospice, hostel</i>
Emergency Facilities	<i>Hospitals, fire stations, police stations, airports, ports, pier, pontoons, HM coastguard rescue, HM naval base, police services, RN Lifeboats, Territorial Army</i>
Utilities	<i>Electricity generating station, electricity substation, gas production and distribution, gas storage, monitoring and regulating, sewage treatment works, water treatment, pump house, public waste disposal, pumping, reservoir, sewage treatment, waste disposal, telecommunications</i>
Industry	<i>Chemical works, distribution, engineering works, factory, filling station, iron works, packing, printing works, public recycling, recycling, steel works, tyre depot, works, chemical works, chimney, depot, distribution, engine house, fuel depot, industry and business services, joinery, landing stage, mineral and fuel extraction, public waste disposal, tank, waste disposal</i>
Commercial and retail	<i>Art centre, cafe, car dealer, chemist, dental surgeon, restaurant, post office, estate agent, fitness club, general commercial, office, bar, sandwich bar, bingo hall, take away, bowling, building society, financial and professional services, filling station, launderette, insurance broker, public house, hairdresser, garage, hire shop, cash and carry, car wash, chandlery, bank, dancing, sport clubs, road haulier, supermarkets, superstore</i>
Green Spaces	<i>Natural ground, general use</i>
Vulnerable Buildings - Day	<i>Bungalows, schools, nurseries, care homes, mobile homes, day care, chemical works/factories, hospitals, prisons</i>
Vulnerable Buildings - Night	<i>Bungalows, mobile homes, care homes, prisons, hospitals, chemical works/factories, children's homes, student halls of residence, social services homes, hostels, hotels</i>

**Table 3.7.** Portsmouth physical vulnerability themed land use classification, includes classes, examples and reasoning.

### 3.2.2 Land Use Reclassification Methodology

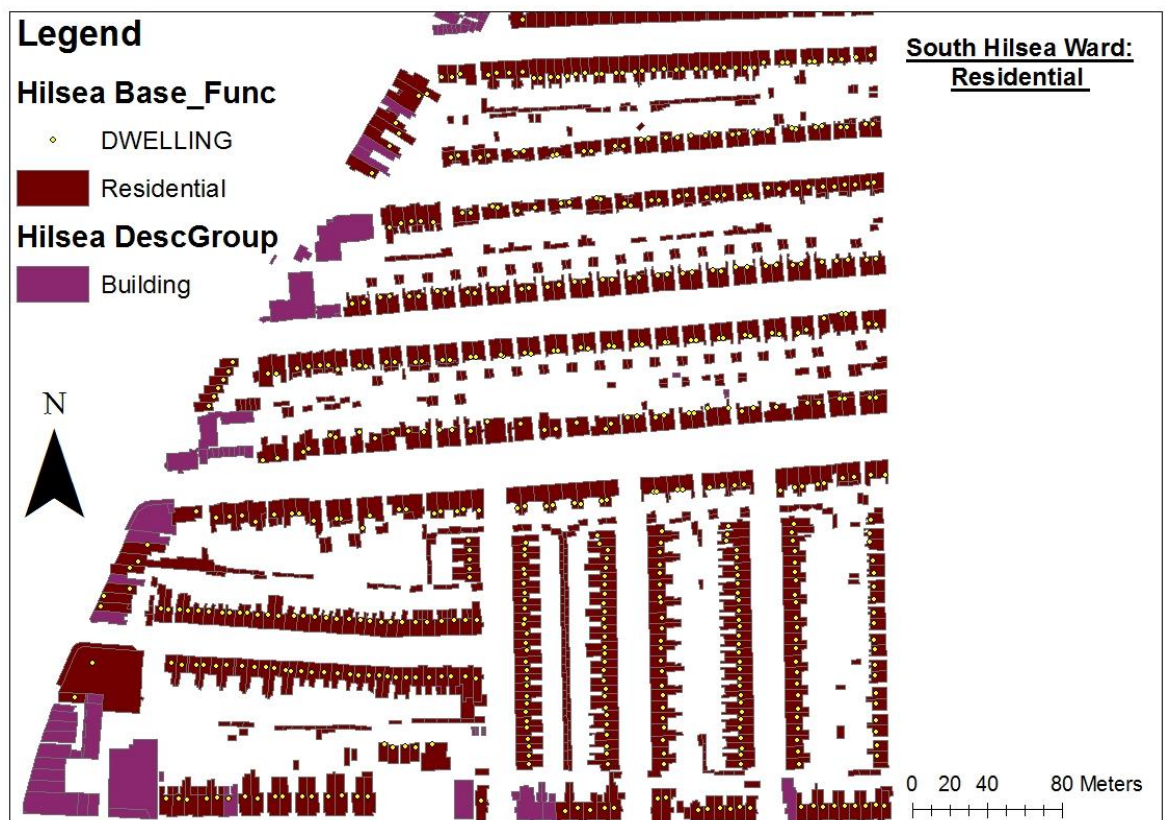
Each new land class was firstly created as a new shapefile layer (polygon) within ArcCatalog, geographically referenced to OSGB 1936, then added (empty) into ArcMap. The first task was identifying all buildings within Hilsea, as the majority of new land classes refer to the identification and re-labelling of building uses. Firstly, the OS Area layer was clipped to the Hilsea ward OS Boundary shapefile (earlier in the methodology, the OS Boundary shapefile was split to create copies of all wards in Portsmouth, an example was shown in the St Jude data trials – Appendix B pg 321), which created a new Hilsea OS Copy and Area Layers. The new Hilsea OS Area layer was categorised to show only buildings and then exported as a separate data layer into the projects data Catalogue. Meaning this new Hilsea Buildings layer could be added into future ArcMap files from this project's ArcCatalog, without having to re-do the initial categorisation process again (see Figure 3.22).



**Figure 3.22.** Hilsea Buildings in ArcMap 10 (Source: OS Mastermap Topography Layer).

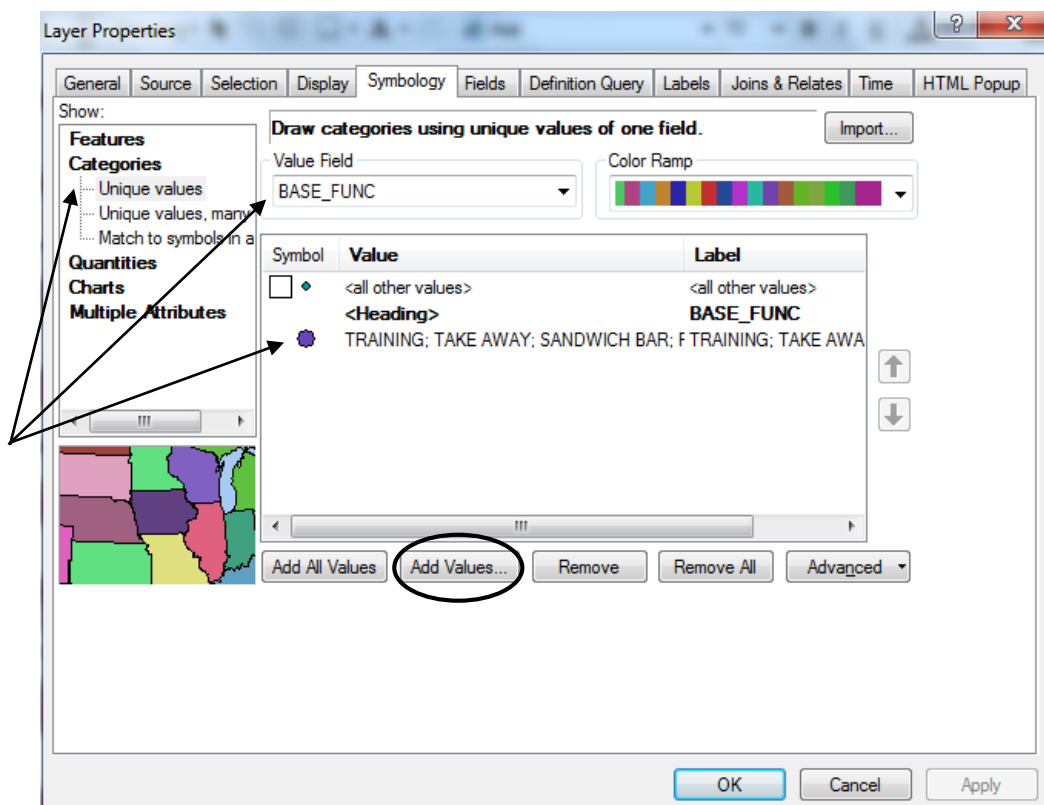


This new buildings layer formed the basis of new land use layers: residential, residential multiple occupancy, commercial and retail, industry, utilities, emergency facilities, essential buildings, and vulnerable buildings. The latter layer evolved at the end of the land reclassification process, as explained in Section 3.2.4. The first layer created was residential. OS Address Layer 2 is a ‘point’ shapefile. The postal layer within Address Layer 2 held address information i.e. if the building was a dwelling, a church, general commercial, address and postcode. Address Layer 2 Postal and Non Postal were used to pinpoint which buildings could be identified as residential. A dwelling category layer was created using the OS Address Layer 2 Postal and Non Postal data and laid over the buildings layer. The new empty residential layer in ArcMap was laid over the top of the OS building layer. It was then edited manually using the dwelling category map that corresponded to the buildings layer. A residential polygon layer (see Figure 3.23) was created.



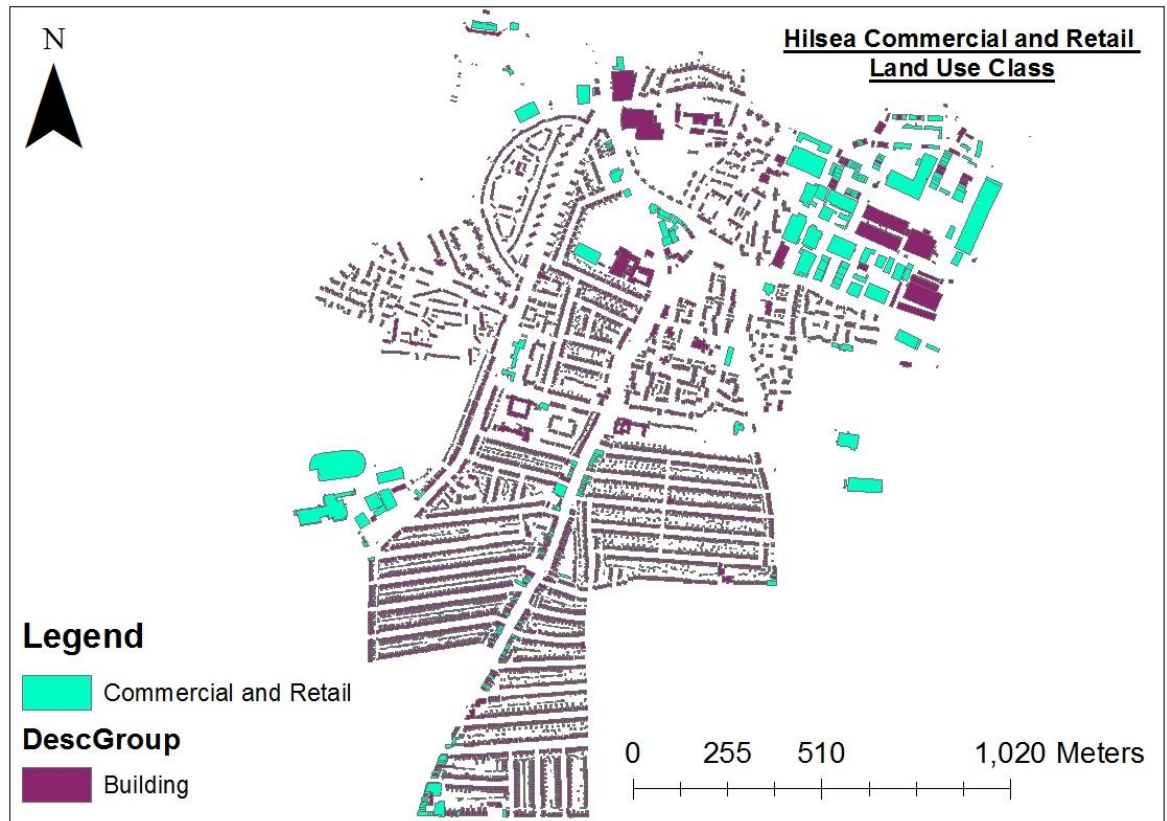
**Figure 3.23.** Zoomed in new residential layer in Hilsea Ward (southern part of the ward) (Sources: OS Mastermap Topography Layer & OS Mastermap Address Layer 2).

The land use classes; Essential Buildings, Emergency Facilities, Utilities, Industry, and Commercial and Retail, were created in the same way using specific parts of the OS Area, and Address Layer 2 datasets. Examples of different types of land use that guided re-classifying buildings are shown in Table 7. Every new empty class layer was added, one at a time, into ArcMap and laid over the clipped to Hilsea, OS Area. This led to an individual folder and ArMap file for each class, assisting data management and re-use of the data. The clipped to Hilsea Postal and Non Postal Address Layer 2 (ADL2) point layers were laid over and categorised according to which class was being created and the examples selected to represent that class (described in Table 7). For example to achieve the commercial and retail class, firstly, after re-examining the attribute table of the ADL2, a column within the layer described as Base Function distinguished the basic use of the building. The symbology properties window of the ADL2 Postal layer was opened, and the Base Function value field was selected, as was the option to categorise by unique value. By de-selecting the option 'all other values' individual values (or land use options) could be added and then grouped together into one point (please see Figure 3.24).



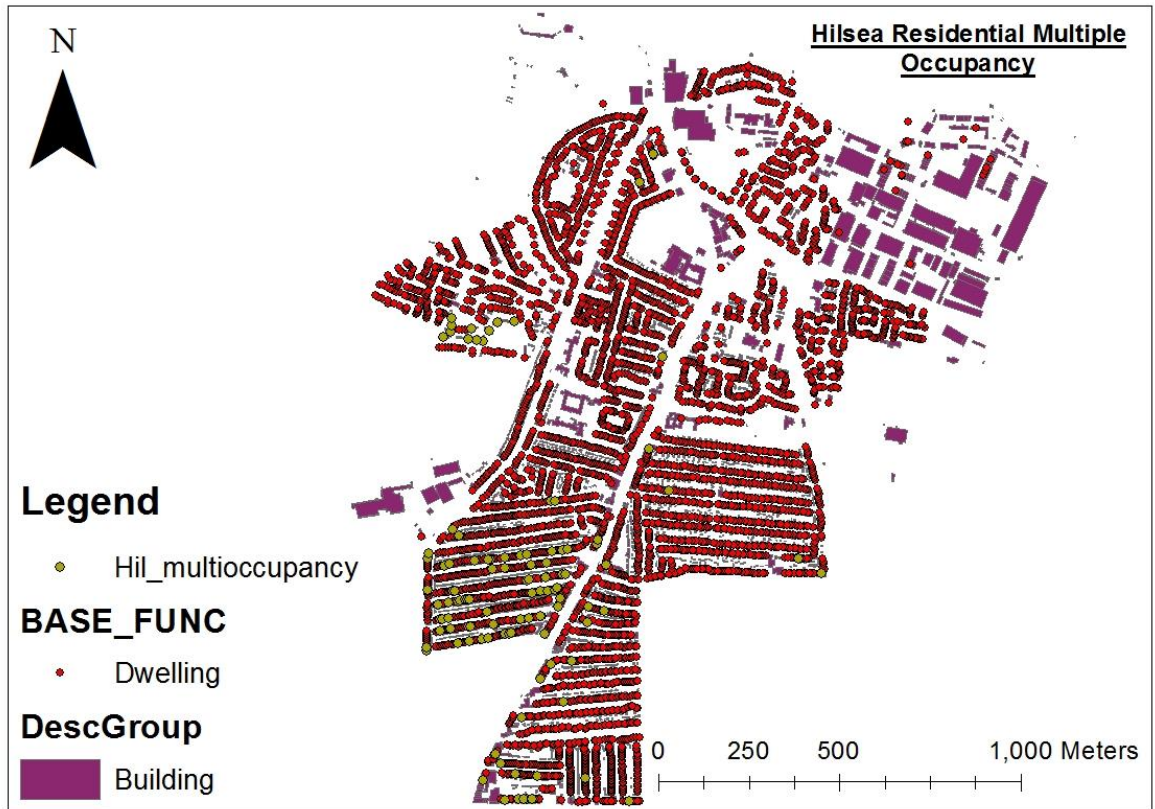
**Figure 3.24.** Grouping all individual land use examples from ADL2 Postal layer to create new Commercial and Retail land use class. All main methodology points highlighted by black arrows and oval.

The resulting point file was re-named commercial and retail and used to pinpoint which buildings within the exported OS Area Buildings layer (Figure 3.22) needed to be re-created as Commercial and Retail buildings, leading to a new Commercial and Retail layer (see Figure 3.25).



**Figure 3.25.** New Commercial and Retail land use class for the ward of Hilsea (Sources: OS Mastermap Topography Layer & OS Mastermap Address Layer 2).

To create the class Residential Multiple Occupancy, a point layer known, as multiple occupancy was used. This is a separate layer within ADL2 and was laid over the categorised dwelling layer that was made for the residential class creation, and Hilsea buildings layer (see Figure 3.26). The empty new land use polygon shapefile Residential Multiple Occupancy was added on top of the Hilsea building layer and the newly identified Residential Multiple Occupancy were created via editing in ArcMap.

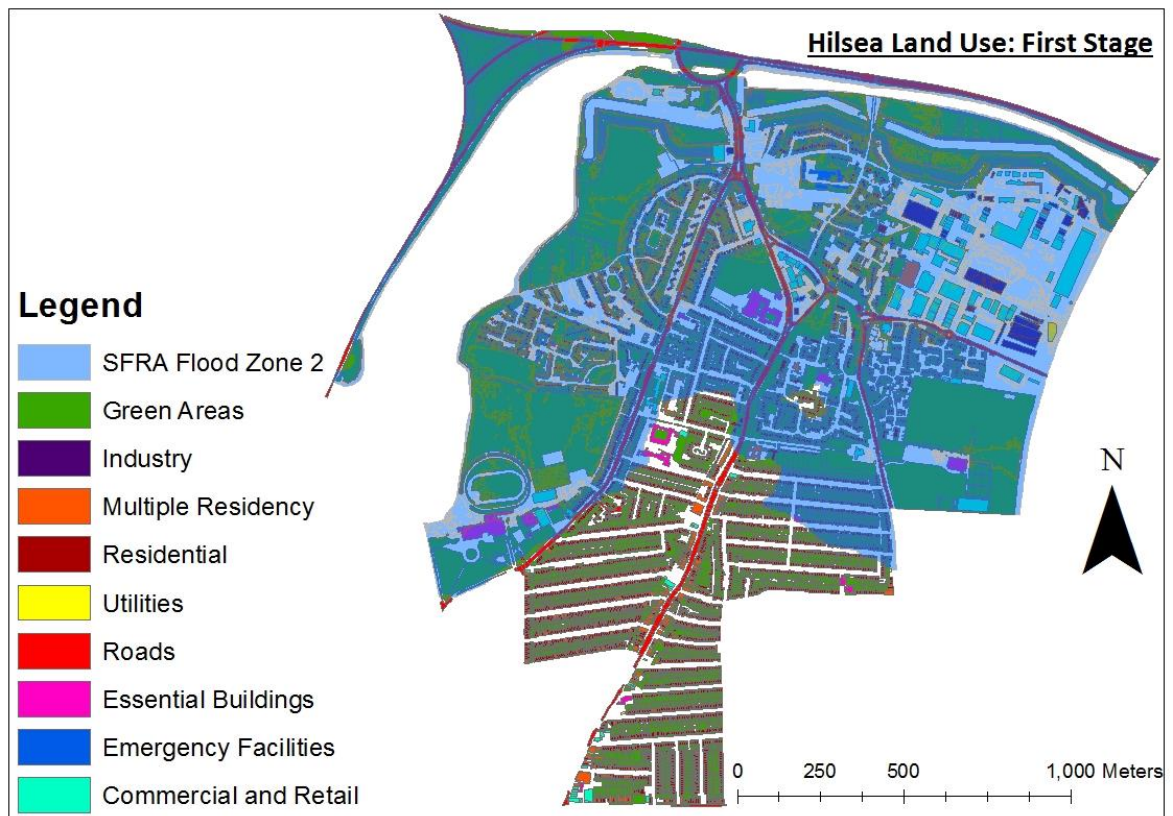


**Figure 3.26.** Hilsea Residential Multiple Occupancy class creation. (Sources: OS Mastermap Topography Layer & OS Mastermap Address Layer 2)

To create the Roads class, the OS layers OS Area and OS Road Link were used. The OS Road Link was added into ArcMap over the categorised to description group, Hilsea OS Area layer. The Road Link layer (a polyline layer) was then clipped to the Hilsea ward and categorised in a similar way to the Commercial and Retail class. The Road Link's attribute table presented a column called description term. This column allowed the road link to be categorised to only present main roads e.g. motorways, A roads, B roads or minor roads. Local streets, private roads (restricted and public access), and alleys were not selected.

Using this categorised road layer, the new empty Roads polygon shapefile was added over the categorised to description group, Hilsea clipped OS Area. One of the main categories within the description group was road or track (shown in Figure 3.21). Specific road polygons within the Hilsea OS Area layer, were now identified, via the categorised Hilsea Road Link layer. The empty Roads class layer could now be edited and created.

The Green Spaces class involved a different method. The empty new Green Spaces polygon shapefile was added into ArcMap and green areas were identified and edited via the OS Area layer categories within the description group known as natural ground and general surface. To certify these were in fact green areas, a geotiff file consisting of merged OS aerial photos, was added as a base layer, the OS Area for Hilsea was added on top and over that the preliminary new Green Spaces layer. The latter two layers' transparency levels were increased, allowing clarification and editing of the Green Spaces layer for the Hilsea ward. The initial resulting hazard orientated 2D new land use class map for the ward of Hilsea can be seen in Figure 3.27.



**Figure 3.27.** 2D Initial Hilsea Land Use Map, including SFRA OP1B Flood Zone 2 (Sources: PUSH, OS Mastermap Topography Layer & OS Mastermap Address Layer 2).

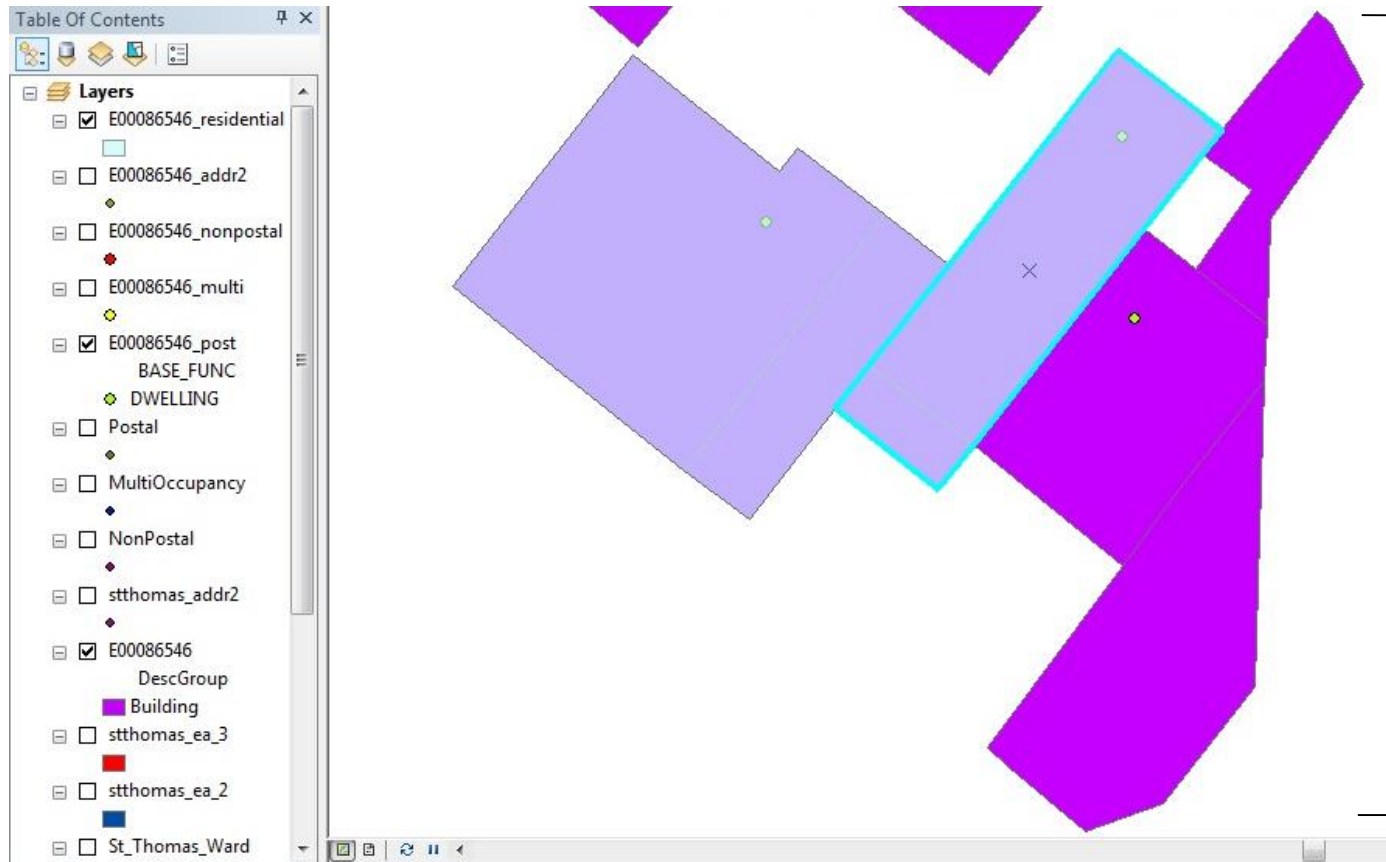
### 3.2.3 Land Use Map Verification

#### *3.2.3.1 Verification Stage 1*

To ensure the new land use layers for Hilsea were accurate and this methodology was applicable; verification was required. When creating the new land use layers within ArcMap, the most prominent issue encountered was that of buildings appearing to be joined in ownership/use. Digitally this was seen by either a line between the polygons or

two separate polygons being very close in one small geographic area. These polygons either seemed to appear 'together' or appear as two polygons of the same land use (Figure 3.28). The main issue was the land use 'point' data provided by ADL2 was only shown within one of the polygons, suggesting that the particular land use there is only for that single polygon. However, many buildings have other smaller buildings attached to them, perhaps not physically, but in use i.e. residential properties and garages or sheds. These buildings are under the same land use class, but have no point data to clarify this. The aerial photos resolved most of these issues as it could be seen clearly that these extra building polygons were part of the main land use dictated by the ADL2 data. Lines shown between polygons (as shown in Figure 3.28), are due to height differences in joined buildings i.e. extensions on houses (Hart, 2013; 2014, pers comm)

The first verification stage involved using the aerial photography provided by Ordnance Survey to justify a building polygons land use that was questioned due to lack of information provided by the OS layers data from Mastermap and ADL2. Or to add any buildings to a land use class. This was due to not seeing the full 'picture' from the initial OS Mastermap data, due to the omission of a separate land use layer within their data.



**Figure 3.28.** Problems encountered when issuing land use to some polygons/buildings that appear to have extensions or extra buildings (identified by black bar), but not established by Address Layer 2 in ArcMap. Here the building marked, has not yet been edited into the new Residential layer as the extra polygons need clarification (Sources: OS Mastermap Topography Layer & OS Mastermap Address Layer 2).

Using ArcMapper, the merged geotiff output of the Portsmouth area was placed beneath all the new land use class layers and the transparency of these layers was increased. Thus one class layer remained selected and the others de-selected, allowing a testing of accuracy, one layer at a time. This process resulted in:

- Joined polygons were both edited to become one land use type;
- Separate polygons that had not yet been classed, but that were in very close proximity to one main identified polygon (via ADL2), were labelled as the same land use, due to land use attachment that could only be seen via aerial photography.

The problems encountered with re-classing the land when using OS data, is something that OS is aware of and striving to change (Hart, 2014, pers comm). The new OS Sites layer attaches all separate polygons that are associated with the main polygon e.g. schools, hospitals; solving the problem when separate polygons in very close proximity to the main labelled polygon, but they are not labelled themselves, therefore giving you the building premises. The OS Sites layer will eventually incorporate dwellings and all polygons associated with them i.e. garages, sheds etc (Hart, 2014, pers comm). An example of the first verification stages results for an OA in Hilsea can be seen in Figure 3.29.

Overall the first clarification stage appeared to be successful, however for the purpose of this research it was necessary to clarify further the land use reclassification methodology, and resolve any final data queries. The second clarification stage involved ‘ground truthing’ the Hilsea ward.





**Figure 3.29.** Clarification stage 1 using Portsmouth geotiff under new land use layers. Here only residential, multiple residency, and green areas needed clarification (Sources: OS Aerial Imagery).

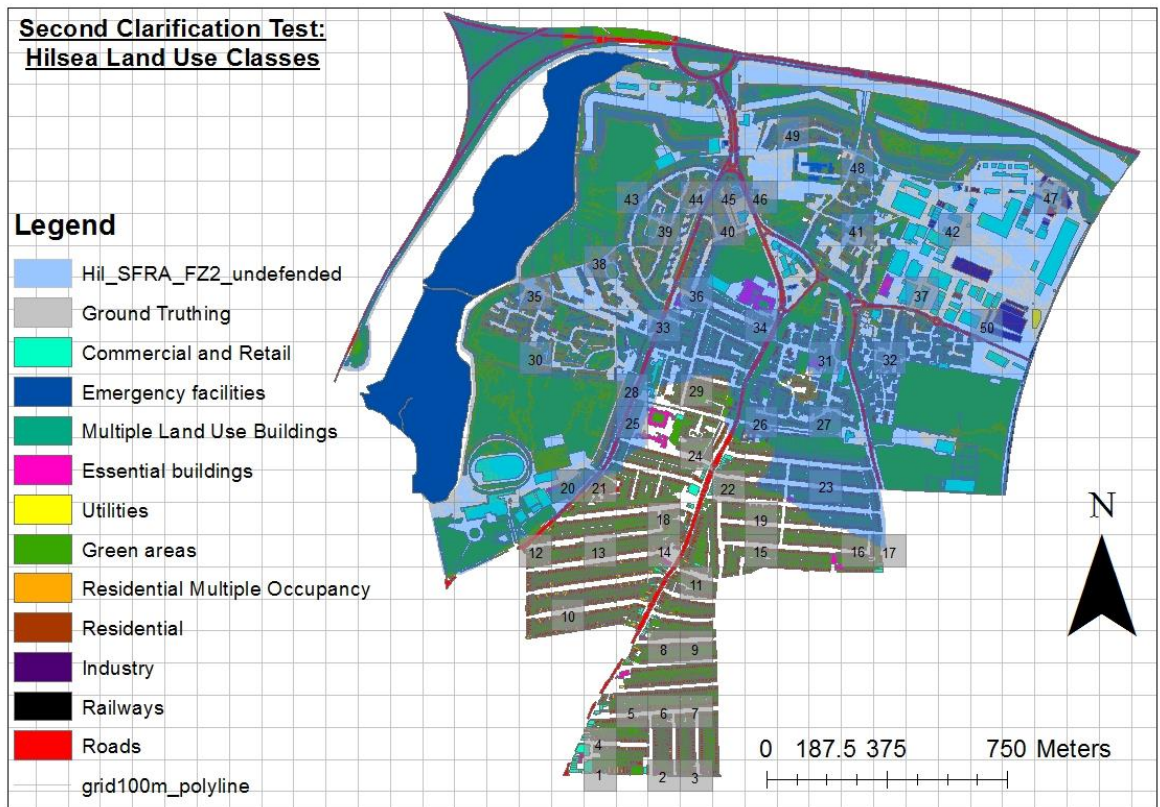
### 3.2.3.2 Verification Stage 2

For the purpose of this research a second verification stage was created to ensure the new land use classification methodology was correct. Google Street View was used to ground truth the Hilsea ward, due to its high usability and smaller time requirement. Fieldwork surveys are time consuming and costly to initiate, whereas Google Street View is quick and user friendly.

This final verification test was created to clarify the accuracy of the land use reclassification methodology, and assist removal of any last inaccuracies within the land use classification system. Examples included:

- Address Layer 2 land use for buildings changing from the initial 'use' due to time
- Identification of buildings that shared a land use e.g. some two storey buildings comprised of both residential and commercial.

A random selection of areas within Hilsea, were identified for the ground-truthing exercise. Within ArcMap, a 100 m British National grid layer was added on top of the new land use map for Hilsea. 50 random 100 m<sup>2</sup> polygon areas were selected and numbered in the Hilsea ward for testing, and can be seen in Figure 3.30. A confusion matrix table was created for each 'test' polygon to allow the calculation (%) and visualisation of the accuracy of the new land use classification methodology. Within these polygons the new land uses (predicted) would be noted against the actual land use by Google Street Map and View.



**Figure 3.30.** Verification test 2: random polygon selection for confusion matrix test (Source: PUSH).

The numbers for each new land class of predicted, actual and total accuracy are presented in Table 3.8. This was done by measuring the number of polygons for each class within each test polygon (via the attribute table). The ground-truthing test polygons were converted into a shapefile, allowing each land use class to be clipped to each test polygon for measurement. An original version of each land use class (i.e. before clarification stage 2 took place) was kept on a separate hard drive and the predicted number of polygons for each class was measured. A copy of this data folder containing all land use class data and layers was made and saved. The land use polygons in each test area were checked, and any mistakes were corrected. This process was done, to ensure that the predicted numbers were counted correctly. Within ArcGIS, once an edit is made to a layer, it is permanent, and this test was specifically done to check the accuracy of the land use reclassification methodology.

<b>Land Use Class</b>	<b>Total Predicted Value</b>	<b>Total Actual Value</b>	<b>Total Percentage Accuracy (%)</b>
Residential	1774	1811	<b>97.9</b>
Residential Multiple Occupancy	40	31	<b>77.5</b>
Commercial and Retail	56	40	<b>71.4</b>
Industry	12	1	<b>8.3</b>
Transport	35	35	<b>100</b>
Utilities	8	7	<b>87.5</b>
Emergency Facilities	Not Present	Not Present	<b>Not Present</b>
Essential Buildings	19	6	<b>31.5</b>
Green Areas	1417	1807	<b>78.4</b>

**Table 3.8.** Clarification stage 2 results for each new land class.

Overall the greatest change error was to the Industry and Essential Building classes' the accuracy for both was less than 50%. However, with regard to the Industry class, these buildings were only present in two of the test areas. Also the OS ADL2 layers used for the classing were unfortunately from 2010. Since 2010 we have had a recession, causing many businesses to close. The same problem was seen with the Essential Buildings, as those that needed alteration were mainly local shops/stores and had been made into residential properties or were now empty buildings i.e. no land use at all. In the north of Hilsea it appears some deprecation has taken place since 2010, as quite a few buildings are now empty or boarded up. This could only be seen via Google Street View. However it appears the main recommendation here is that more regular updates are required for OS ADL2 layers. As it stands, this research would recommend that those two particular classes would need this second clarification test to clarify these layers. The Residential, Transport, Utilities, Commercial and Retail and Green Areas had between high and very high total accuracy results. Some changes were required with Green Areas polygons, these were mostly what appeared in the aerial photos as drive ways, when inspected at street level, there were very small green areas present. Perhaps in the future an average green area size should be stipulated, and once under this area should be ignored. For example, In

Portsmouth there is a very large percentage of terraced housing compacted on small streets, and the green areas present (e.g. front gardens), have very small surface areas. To understand the total accuracy of this methodology, the whole ward would need to be verified via this method. However, this would have been a time consuming endeavour, beyond the time and resources available for this project.

#### 3.2.4 Land Use Reclassification Methodologies Updated

During verification stage 2 further developments were made with the data. Firstly it became apparent that some buildings had been classed as more than one land use. This was initially thought to be due to errors during the land classification; however when analysing the aerial photography and Google Street View, it became apparent that these buildings shared land use. A common land use shared was: commercial or retail business on the ground floor, and residential accommodation on the upper floor/s. It is difficult to determine the nature of these buildings, and this could cause problems during evacuation, i.e. who is within these buildings and how many? This data variable could be used along with residential numbers, to populate the Coastal Flood Physical Vulnerability (CoFPV) factor *Property Type*. Although useful to know, it's affects on vulnerability seemed less significant compared to the other data variables used to measure physical vulnerability.

After verification stage 2 a reassessment of the 'polygon' land use reclassification methodology was made. The main constraint was the time needed to create each new polygon land use shapefile, especially for the Residential layer, mainly due to its size. The second problem was the significance of small buildings i.e. garages and sheds when mapping, as they are attached to the residential building and likely owned by the residents. Meaning they may contain possessions of high economic value e.g. cars inside them, and residential buildings with extra structures such as garages are normally of greater value, than those without. To use these classes to measure CoFPV, originally these land use polygons would be counted (via the attribute table) to measure the amount of that class, i.e. the higher the number of residential building polygons, the higher the vulnerability. Another, possibility was to dissolve all the individual class polygons and calculate the surface area (m<sup>2</sup>), using this figure to measure the land use. Again the higher the value of land use coverage in each Output Area (OA), the higher the vulnerability. However, when re-examining the OS Address Layer 2 data, it became apparent the count of the number of

dwelling addresses in each OA was on average much higher than that of the number of residential building polygons identified. Large buildings that hold many separate dwellings (i.e. flats), were being counted as one building and therefore a true reflection of the residential figure was not being measured. *Property Type* was changed to *Dwellings* and within ArcMap the ADL2 postal and non-postal layers were activated and clipped to each OA. Again only the dwellings group was categorised, and the number of residential addresses were counted and used to populate the new Dwellings factor.

After the residential numbers were calculated in this way; the same practice was used for the classes Commercial & Retail, Industry, Essential Buildings, Emergency Facilities. Like the polygon method the OS Address Layer 2 postal and non-postal layers were categorised depending on the land class being counted and the examples selected to represent that class (described in Table 7). Each number of these classes addresses were counted, as like the residential layer, large buildings can hold many smaller businesses inside; shopping centres are examples of this. Greater numbers of commercial addresses means more businesses and greater revenue.

A further problem was encountered with the Residential Multiple Occupancy land use class. Through local knowledge of the test area it was established some known multiple residency buildings were not being presented in the results. After communication with Ordnance Survey (Hart, 2013, pers comm) it was discovered the Multiple Occupancy point shapefile within ADL2 only pointed to multiple residency buildings that shared one post box. Many shared buildings, specifically large houses that have been converted to flats, have multiple post boxes for each dwelling address.

Further investigation was carried out to identify a method to map these missing buildings. Within ArcMap, clipped OS Area to **OAE0006285** was added and categorised to display only buildings. The **OA6285** polygon Residential Multiple Occupancy layer was added on top and finally the clipped to **OA6285** ADL2 postal layer. The latter layer's attribute table was opened and the permanent addresses were examined. Some addresses had shared house numbers (see Figure 3.31), these were pinpointed by categorisation, and using the identify tool showed this residence to be of multiple occupancy (Figure 3.32). Within **OA6285**, four new residential multiple occupancy buildings were found, that had not been

previously identified (see Figure 3.33). A new empty point land use class shapefile was created within ArcCatalog and mapped via this method. All OA's in Hilsea were checked and mapped in the same way, one at a time. This was a fairly timely exercise, however this class has not been mapped to this extent before, and the final results (see Figure 3.34) for Hilsea showed the amount of buildings missing when using the original ADL2 multiple occupancy layer (Figure 3.26).

When identifying the buildings, progress was quicker when within the addresses descriptions, flats were named Flat 1, 2, 3 etc, all with the same house name. Also flats could be identified by letters being used by the numbers e.g. 40B; however, this was not always a certainty. Examples were found where letters were used with numbers in addresses i.e. 40A, 40B, 40C and were in fact separate houses. To be completely accurate it is suggested that each dwelling address point investigated in more detail. The identifier window shows if there are two or more addresses attached to a building (see the red arrow shown in Figure 3.32), however, each address must be checked to see if both are dwellings and not a mixture of e.g. dwelling and commercial (see black arrow in Figure 3.32) before being mapped. This class was re-named Multiple Residency.

6285_postal			
FID	Shape *	PREM_ADDR	LEGEND
18	Point	92 ORIEL ROAD, PORTSMOUTH, PO2 9EQ	Building existing surveyed sml
19	Point	96 GLADYS AVENUE, PORTSMOUTH, PO2 9BH	Building existing surveyed sml
20	Point	98 GLADYS AVENUE, PORTSMOUTH, PO2 9BH	Building existing surveyed sml
21	Point	100 GLADYS AVENUE, PORTSMOUTH, PO2 9BH	Building existing surveyed sml
22	Point	102 GLADYS AVENUE, PORTSMOUTH, PO2 9BH	Building existing surveyed sml
23	Point	88 ORIEL ROAD, PORTSMOUTH, PO2 9EQ	Building existing surveyed sml
24	Point	86 ORIEL ROAD, PORTSMOUTH, PO2 9EQ	Building existing surveyed sml
25	Point	84 ORIEL ROAD, PORTSMOUTH, PO2 9EQ	Building existing surveyed sml
26	Point	82 ORIEL ROAD, PORTSMOUTH, PO2 9EQ	Building existing surveyed sml
27	Point	80 ORIEL ROAD, PORTSMOUTH, PO2 9EQ	Building existing surveyed sml
28	Point	78 ORIEL ROAD, PORTSMOUTH, PO2 9EQ	Building existing surveyed sml
29	Point	76 ORIEL ROAD, PORTSMOUTH, PO2 9EQ	Building existing surveyed sml
30	Point	74 ORIEL ROAD, PORTSMOUTH, PO2 9EQ	Building existing surveyed sml
31	Point	72 ORIEL ROAD, PORTSMOUTH, PO2 9EQ	Building existing surveyed sml
32	Point	70 ORIEL ROAD, PORTSMOUTH, PO2 9EQ	Building existing surveyed sml
33	Point	68 ORIEL ROAD, PORTSMOUTH, PO2 9EQ	Building existing surveyed sml
34	Point	66 ORIEL ROAD, PORTSMOUTH, PO2 9EQ	Building existing surveyed sml
35	Point	65 SHADWELL ROAD, PORTSMOUTH, PO2 9EH	Building existing surveyed sml
36	Point	63A SHADWELL ROAD, PORTSMOUTH, PO2 9EH	Building existing surveyed sml
37	Point	63 SHADWELL ROAD, PORTSMOUTH, PO2 9EH	Building existing surveyed sml
38	Point	61 SHADWELL ROAD, PORTSMOUTH, PO2 9EH	Building existing surveyed sml
39	Point	59 SHADWELL ROAD, PORTSMOUTH, PO2 9EH	Building existing surveyed sml
40	Point	57 SHADWELL ROAD, PORTSMOUTH, PO2 9EH	Building existing surveyed sml

**Figure 3.31.** Shared House Numbers Highlighted – Suggesting Multiple Residency.

Identify

Identify from: <Top-most layer>

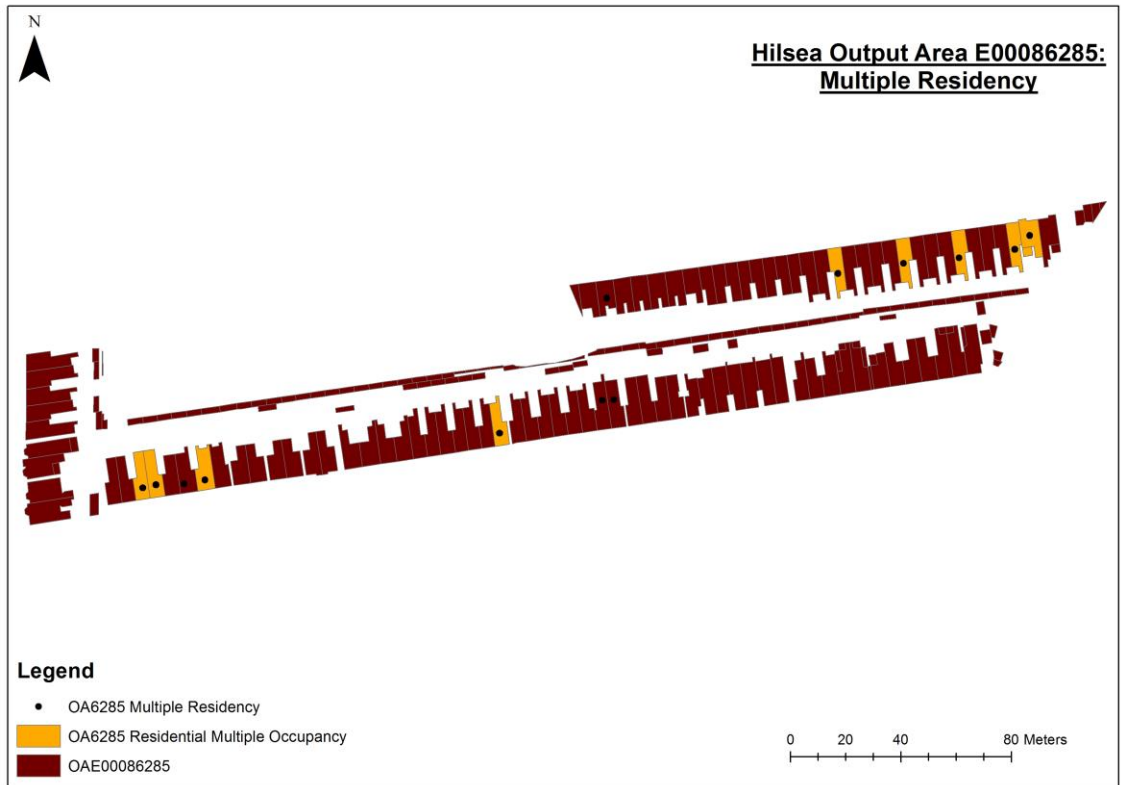
6285\_postal

Location: 465,032.668 102,929.075 Meters

Field	Value
LEGEND	Building existing surveyed sml
TOID	1000002118796562
VERSION	5
VER_DATE	22/11/2007
STR_TYPE	Permanent Building
PHYS_STAT	Existing
PQ_ACCURCY	Surveyed
PCODE_TYPE	Small
M_STATUS	Matched
ORG	
DEPARTMENT	
PQ_BOX	
SB_NAME	
BLD_NAME	63A
BLD_NUMBER	
D_THFARE	
THOROFARE	SHADWELL ROAD
DD_LOCALTY	
D_LOCALITY	
POST_TOWN	PORTSMOUTH
POSTCODE	PO2 9EH
DP_SUFFIX	5D
MO_COUNT	1
NONGEOG	0
P_QUALITY	Final
OSAPR	APJQ8V8W5P851WDGW3
PROC_DATE	05/09/2011
CHUNK_ORIG	SU6302
PA_DATE	15/06/2006
BASE_FUNC	DWELLING
LAND_USE	U071
AD_KEY	23066088
ORG_KEY	
CLASS_CONF	0
PDESCCODE	
SCAT	0
UDPRN	19178300
CT_UARN	210538175
NDR_UARN	
LACODE	1775

**Figure 3.32.** Identifier window for OA6285 Address Layer 2 Postal Dwelling Point - Red arrow points to number of addresses attached to this point; black arrow shows basic function of this building is dwelling.





**Figure 3.33.** Actual Number of Multiple Residency Buildings in OA6285 (Sources: OS Mastermap Topography Layer & Mastermap Address Layer 2).



**Figure 3.34.** Final Map of Multiple Residency Buildings in Hilsea Ward (Sources: OS Mastermap Topography Layer & Mastermap Address Layer 2).

In the polygon methodology the land use class Green Areas, was measured by polygon numbers of this class when clipped to each individual OA in Hilsea. This was changed to dissolving the Hilsea green areas layer and re-clipping the dissolved layer to each Output Area. One at a time these layers were added into ArcMap and the surface area (m<sup>2</sup>) was calculated. This figure was used to measure the amount of green space within each neighbourhood resulting in a more realistic measurement of this land cover (see Figures 3.35 and 3.36).



**Figure 3.35.** Original Polygon Layer of Hilsea Green Areas.



**Figure 3.36.** New Hilsea Green Areas Dissolved for OA Surface Area Calculations.

The roads layer measurements were also altered. Rather than again counting polygons of that class per OA, it was decided to measure the length of main roads available i.e. more roads available equates to more main evacuation routes and therefore decreases vulnerability. The RoadLink layer was clipped to each OA in Hilsea and individually each clipped OA level RoadLink was categorised the same way as before i.e. only showing main roads – Motorways, A Roads, B Roads, and Minor Roads. The attribute table for these clipped polyline layers were opened and the sum of the lengths of each of these main roads available in these neighbourhoods, was made and recorded. Roads changed to *Transport*.

Further development occurred, as communications with local emergency service officers (Spiller, 2013, per comms; Hampshire Fire and Rescue, 2013, pers comm) about the effectiveness of the methodology, led to requests for the identification of particularly vulnerable buildings such as schools, nurseries, care homes and low level buildings i.e. mobile homes or bungalows. The land use class Vulnerable Buildings was created and guided by Table 3.7, where bungalows, mobile homes, nurseries, schools and care homes

were identified by OS Area, OS ADL2, and OS Building Heights. The empty new point shapefile of Vulnerable Buildings was added into ArcMap, above OS Area Buildings, the old Residential class layer and OS Building Heights. ADL2 Postal and Non Postal layers were categorised to only display care homes, nurseries and schools. This pinpointing of certain buildings facilitated the editing and creation of the Vulnerable Buildings class via the editorial suite in ArcMapper.

To pinpoint low level buildings such as bungalows and mobile homes, the new layer OS Buildings Heights was activated, the ADL2 Postal and Non Postal were recategorised to only display dwellings. The OS Building Heights properties window was categorised to only display firstly buildings of heights between 6-7 meters, then 3-4 meters. Through a web search it was found that the average height of a bungalow was 6-7 meters (Amor, 2013) and a mobile home was between 3-4 meters (Butter, 2012). These categorical height maps were used in conjunction with the dwellings points to identify and map these low level vulnerable buildings. To validate the methodology, Google Street View was used, as only a few low level buildings were identified. No errors were detected in the test area.

The creation of this land use class catalysed the development of the factors Vulnerable Buildings Day and Vulnerable Buildings Night. These two factors would be used to distinguish Coastal Flood Physical Vulnerability for day and night-time. The difference being that some vulnerable buildings will not be as such during the night, as they are no longer occupied e.g. schools, nurseries etc (see Table 3.7). It was decided that a day and night time analysis would take place for Coastal Flood Vulnerability and Risk, as floods at different times of day could have very serious repercussions. Floods at night are more dangerous than during the day; the 1953 North Sea storm surge mainly occurred at night, with 307 deaths in the England, 19 in Scotland and 1800 in the Netherlands, (Met Office, 2014). People are unaware of disasters occurring during the night, as most residents would be sleeping. Therefore, people become aware of the situation perhaps when it is 'too late' and it becomes very dangerous, with increased risk to life. Darkness leads to disorientation and inability to observe flood dangers such as flood water (risk of contamination), flooded drains, missing manhole covers, dangerous submerged large/sharp objects, fast moving objects or depth of water (15 cm of water can force people to lose their balance and cars can be swept away by water only 60 cm deep) (Newry, Mourne and Down District

Council, 2016; NOAA, 2016). It is therefore vital to assess CoFV and CoFR at different times of day as this results in a more complete vulnerability and risk assessment. Floods at different times of day result in different levels of impact due to different dangers presented. It is key to pinpoint neighbourhoods where these perils may arise in order to improve our evacuation and mitigation strategies and target where our resources are needed.

The final results maps for each CoFPV factor, for Hilsa at OA level can be viewed in Appendix F (pg 337). The results for each CoFPV factor, populated the Coastal Flood Physical Vulnerability Index for a day and night flood event. This index was later combined into the Coastal Flood Vulnerability Index, along with the Coastal Flood Socio-economic Vulnerability Index and the Coastal Flood Limited Resilience Index, for Hilsa at community level, for different flood magnitudes at different times of day (Chapter 4).

### 3.3 Socio-economic Vulnerability (Susceptibility)

This section reviews concepts of susceptibility, factors that represent it, and datasets that populate these factors.

Coastal vulnerability assessments still focus mainly on climate change aspects, such as sea-level rise, flooding potential and overall risk of flooding. Less attention is paid to other dimensions of climate change, such as the influence of socio-economics, so much so that it is often completely ignored (Nicholls *et al.*, 2008). To better support the development of coastal management policy and planning integrated assessments of climatic change in coastal areas are required, including the significant non-climatic aspects, such as physical (the land), socio-economic and resilience indicators.

As stated in Chapter 2, there is scope to enhance our understanding of vulnerability and to develop methodologies and tools to assess it. Vulnerability analysis involves the identification of conditions that make people and places vulnerable to extreme natural events (Cutter *et al.*, 2003; Cardona *et al.*, 2012; Birkmann *et al.*, 2013). It is an integral part to measuring and analysing risk (Cardona *et al.*, 2012; Birkmann *et al.*, 2013; IPCC, 2014). The risk of a disaster occurs in the interaction zone of the human environment and the physical environment; yet we know very little about the social-economic aspects of

vulnerability (Cutter et al., 2003; Lindley et al, 2011), and there are few examples of thorough social vulnerability assessments included in vulnerability analyses for applied risk management. Socially created vulnerabilities are normally ignored, due to the difficulty in quantifying them. Mostly, social vulnerability is described as individual characteristics such as age, race, income, employment etc (Cutter et al., 2003; Kaźmierczak and Cavan, 2011).

The coast is a constantly changing and dynamic environment, where land, sea and humans interact. Increasing human settlement in coastal areas heightens pressures upon natural processes, which in turn can bring about local issues that can morph into regional problems. Human settlements bring many potentially conflicting social activities upon the coast: urbanisation, leisure, recreation, agriculture, fishing, ports and harbours etc. There needs to be an organised balance and greater understanding between the demand for development and the requirements to defend the coastline.

One of the most important tasks when assessing Coastal Flood Vulnerability is to create a readily understandable link between the theoretical concepts of flood vulnerability and the everyday decision-making or management process, and to then encapsulate this link into a tool that can be easily accessible (Balica et al, 2012). The Defra/EA Flood Risks to People Methodology, although identifying eight socio-economic vulnerability factors/indicators, only takes forward two into the assessment (% of all residents suffering from long-term illness; and % of all residents aged over 75) (HR Wallingford, 2006b). The PUSH SFRA uses four demographic variables to create their Social Flood Vulnerability Index (SFVI): People aged 75 and over; People suffering from a long-term limiting illness; Lone Parent Households; and Financially deprived households (the latter dataset does not exist in the current 2011 census) (Atkins, 2007).

This research identifies vulnerability as a combination of exposure, susceptibility and limited resilience. The concept of *susceptibility* (or sensitivity), was defined in 1977 by Penning-Rowsell and Chatterton as the relative ‘damageability’ of property and materials during floods or other hazardous events. However, the IPCC (2001) argued that susceptibility is the affected system’s degree of incapability to cope with the consequences from climate related stimuli. Balica (2012a) defined susceptibility as relating to a system’s

characteristics, including social conditions. Within the MOVE framework Birkmann et al (2013) identified susceptibility (or fragility) as the predisposition of elements at risk (social and ecological) to suffer harm. Within this research susceptibility is described as socio-economic vulnerability, and is understood as the social and economic elements susceptible within the system, influencing the probabilities of being harmed at times of hazardous events, such as flooding (Cardona, 2001, 2011; Carreno, 2007a; Cardona et al, 2012).

### 3.3.1 Socio-economic Vulnerability

According to Fekete (2010), Cardona et al (2012) and Birkmann et al (2013) there can be no analysis of risk management, resilience and adaptation options without first understanding *vulnerability*. Vulnerability to natural hazards is an indicator of the susceptibility and capacities of any system, physical or social (Tapsell et al, 2010). Socio-economic vulnerability focuses on those demographic and socio-economic factors that increase the impacts of hazard events on populations and communities (Tierney et al, 2001; Heinz Carter, 2002; Cutter et al., 2009). In terms of the assessment and reduction of socio-economic vulnerability, different policy and research communities disaster risk reduction, climate change adaptation, poverty reduction and environmental management have discussed this issue individually (Thomalla et al., 2007).

Cutter et al (2003) believe socio-economic vulnerability is a product of combined social and place inequalities, i.e. the social factors that influence or shape the susceptibility of various groups to harm and that also govern their ability to respond. The ‘place’ factors are characteristics of communities and the built environment around them, e.g. levels of growth rates, urbanisation and economic vitality that contribute to the socio-economic vulnerability of areas. Cutter’s description of socio-economic vulnerability has similarities to Bogardi’s et al (2005) viewpoint regarding vulnerability. In order to improve risk reduction and disaster mitigation, socio-economic vulnerability needs to be identified and assessed in coordination with economic, physical and environmental vulnerability assessments, thereby wholly assessing vulnerability for areas at risk from natural hazards.

*Susceptibility* in this research is equated with socio-economic vulnerability, as both social and economic data were collected and analysed. Economics plays a significant role within flood risk assessments that occur in the UK. Strategic Flood Risk Assessments (SFRA),

take place to assist future development projects in 'at risk' areas; e.g. the first key objective of the PUSH SFRA is to '*consider the impacts of existing and future flood risk and assess the feasibility of delivering 80,000 houses across the PUSH sub-region, and the individual Local Planning Authority (LPA) housing allocations*' (Atkins, 2007). Economics is the main focus within these assessments. It is also an important factor within Lindley et al's (2012) socio-spatial vulnerability index (described further in Chapter 4, Part A). Therefore, it is integral that it is included and highlighted within the vulnerability assessment.

This research examines how we measure socio-economic vulnerability in the context of coastal flood hazards. This study will measure levels of socio-economic vulnerability, rather than identifying socio-economic vulnerability by single characteristics. Data variables from the National UK Census (2011) database, will be used to populate socio-economic vulnerability factors that have been created to measure socio-economic vulnerability. These factors were then standardised, for incorporation into a Coastal Flood Vulnerability Index (CoFVI) that contributed to a Coastal Flood Risk Index (CoFRI) (details of the procedures are given in Chapter 4).

Cutter et al, (2003) noted that research into social and environmental indicators research has been experiencing a renaissance (Kaźmierczak and Cavan, 2011; Lindley et al, 2011; Balica et al, 2012; Birkmann et al, 2013). However despite that there is still no consistent set of metrics used to assess vulnerability to environmental hazards, although there are calls for such an index. The major factors that influence socio-economic vulnerability are (i) a lack of resources, including the information, knowledge and technology; (ii) social capital, which includes social networks and connections; (iii) limited access to political power and representation; and (iv) physically limited individuals (Cutter et al., 2003). There are many variables within the context of these factors and these have been used in past socio-economic vulnerability assessments. The more commonly used variables include age, gender, race, lone parent households, socio-economic status, and special needs populations (Cutter et al, 2003, 2010; Atkins, 2007; Haynes et al, 2008; Kaźmierczak and Cavan, 2011). There are other considerations/variables and the next section discusses the socio-economic vulnerability factors chosen for this research.



### 3.3.2 Coastal Flood Socio-economic Vulnerability Factors

Knowledge of hazards aids the understanding of the ‘physical’ aspects of disasters; however, it may also result in the perception that extreme weather events impact all residents of the affected location the same (Każmierczak and Cavan, 2011). Some people are more susceptible to harm than others, due to their varying capabilities to deal with a hazard. Socio-economic vulnerability to flooding is sometimes understood simply as people’s ability to respond, by physically being able to withstand the flood’s water velocity and depth (DEFRA & EA, 2006; Kaźmierczak and Cavan, 2011). However, human vulnerability has a much broader spectrum than being physically able to withstand flood water e.g. it can encompass the characteristics of people and households within flood zones.

Essential socio-economic characteristics were identified through literature review, observation and evaluation. A set of socio-economic vulnerability factors were created to guide data selection; resulting in a Coastal Flood Socio-economic Vulnerability (CoFSV) analysis in the form of a Coastal Flood Socio-economic Vulnerability Index (CoFSVI). The socio-economic vulnerability factors refer to the pre-event, inherent characteristics or qualities of social systems that create the potential for harm (Cutter et al., 2008). Flooding affects the day-to-day lives of the receptors in the flood water pathway. Along with the destruction of buildings and transport disruption etc, flooding can also lead to fatalities. The social component relates to the presence of human beings and involves the issues related to humans i.e. deficiencies in the mobility of humans due to age, gender, or general disabilities. The economic component is related to the income or other issues that are related to economics, which are predisposed before disaster occurs. Many economic activities in urbanised coastal areas can be affected by coastal flooding, they include – residency; tourism; fisheries; industries; agriculture; availability of potable water etc. All of these variables affect the economic prosperity of an area (Balica, 2012a).

To summarise vulnerability is a function of the exposure (how many and what is at risk), sensitivity (the degree to which people and places can be harmed) and resilience of a system (ability of a system to respond and recover).

Socio-economic variables add an inherent cultural bias to a vulnerability index (McLaughlin and Cooper, 2010). The following Coastal Flood Socio-economic Vulnerability (CoFSV) factors were created (shown in Table 3.9, with detailed reasoning presented in Appendix G – pg 343):

<b>Vulnerability Component</b>	<b>Socio-economic Vulnerability Factors</b>
Coastal Flood Socio-economic Vulnerability (CoFSV)	<i>Age</i>
	<i>Household Structure</i>
	<i>Illness or Disability</i>
	<i>Ethnicity and Race</i>
	<i>Gender</i>
	<i>Occupation</i>
	<i>Economic</i>
	<i>Providers of Unpaid Care</i>
	<i>Communal Establishment Residents</i>
	<i>Home Population (Day)</i>
	<i>Residential Population (Night)</i>

**Table 3.9.** Coastal Flood Socio-economic Vulnerability (CoFSV) Factors.

The data available to populate all the assessed factors were collected from the 2011 UK National Census (January 2013 version), under the Open Government Licence v2.0, which permits re-use of this information free of charge, in any format or medium (<http://neighbourhood.statistics.gov.uk/dissemination/>).

To view the UK Census data associated with the corresponding OA within the Hilsea ward, via the Neighbourhood Statistics website of the Office for National Statistics, the correct OA code must be entered (see Figures 3.37 and 3.38) e.g. E00086281. The page also included a map of the OA, which was checked against the Hilsea OA OS 2011 Boundary map, created originally in ArcMap (created earlier in the project – see Figure 3.39). For ease when adding the final vulnerability index and risk index in ArcMap, they will be attached to the Hilsea OA OS 2011 Boundary map (see Figure 3.39), the OA labels were used to join the results to the correct OA.

Internet Explorer Issues

We are aware that users of Versions 10 and 11 of Internet Explorer browsers are experiencing some issues. We are working on a solution and will update you when it is available.

FIND STATISTICS FOR AN AREA [More about areas](#)

This search allows you to find **detailed statistics** within specific geographic areas.

**1** First enter the name of an area OR full postcode:  
e.g. Clapham Park e.g. N5 1JP

**2** Then select the type of area you need statistics for:

- Local Authority
- Middle Layer Super Output Area
- Lower Layer Super Output Area
- Ward
- Output Area
- Primary Care Organisation
- Health Authority
- Education Authority
- Westminster Parliamentary Constituency
- Parish

[Fewer areas](#) ▲

**3**

Figure 3.37. Neighbourhood Statistics (Office for National Statistics, 2013).

**Area: E00086281 (Output Area) [↗](#)**

**Topics**

[2011 Census: Quick Statistics \(64 datasets\)](#)

Quick Statistics tables generally provide information about a single census topic.

[2011 Census: Key Statistics \(33 datasets\)](#)

Key Statistics tables provide summary figures that cover the full range of results from the Census.

[2001 Census: Census Area Statistics \(59 datasets\)](#)

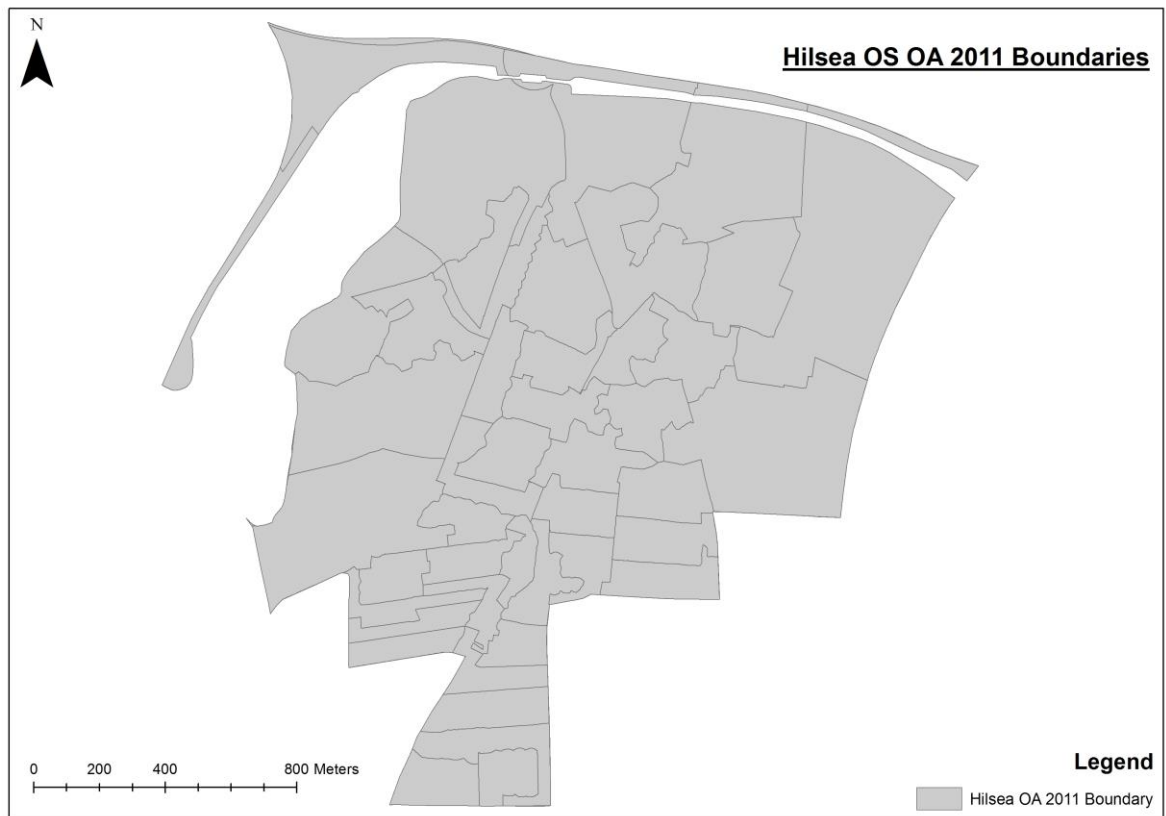
A selection of tables from the Census Area Statistics giving detailed information on specific census variables.

[2001 Census: Key Statistics \(31 datasets\)](#)

Key Statistics cover all main census topics, presented as counts and percentages in a limited number of simple tables.



**Figure 3.38.** OA E00086281 2001 and 2011 Census datasets (Office for National Statistics, 2013).



**Figure 3.39.** Hilsea ward OA OS 2011 Boundary Map (Source: OS Boundary Line).

The following 2011 UK National Census datasets were chosen for the socio-economic analysis (a mixture of quick and key statistics, (Office for National Statistics, 2013):

- Age by single year, 2011 (QS103EW) (updated 30/01/13)
- Country of birth (detailed), 2011 (QS203EW) (updated 30/01/13)
- Proficiency in English, 2011 (QS205EW) (updated 30/01/13)
- Sex, 2011 (QS104EW) (updated 30/01/13)
- Long-term health problem or disability, 2011 (QS303EW) (updated 30/01/13)
- Provision of unpaid care, 2011 (QS301EW) (updated 30/01/13)
- Dwellings, 2011 (QS418EW) (updated 30/01/13)
- Lone parent households with dependent children, 2011 (KS107EW) (updated 30/01/13)
- Industry, 2011 (QS605EW) (updated 30/01/13)
- Occupation (minor groups), 2011 (QS606EW) (updated 30/01/13)
- Hours worked, 2011 (QS604EW) (updated 30/01/13)
- NS-Sec (National Statistics Socio-economic Classification), 2011 (QS607EW) (updated 30/01/13)

- Communal establishment residents, 2011 (KS405EW) (updated 30/01/13)
- Method of travel to work, 2011 (QS701EW) (updated 30/01/13)

Each of the following datasets were downloaded for each OA (43) in Microsoft Excel format (an example is shown in Table 3.10, again for **OA6281**), and catalogued into new CoFSV factor folders, therefore ensuring re-usability and continuing the research's data management practice. For most of the datasets, it was obvious which part would be important to populate each factor. For instance, referring to Table 3.10, the female population was required to populate the gender vulnerability factor. However, some factors required a combination of values from two or more datasets, although this could only occur if the data was measured in the same units. For some of the CoFSV factors created, there were no single datasets to populate them, or there were several datasets that could aid to the analysis of that particular factor. Vulnerability analyses can use *single datasets to represent their vulnerability factors* (Cutter et al., 2003; HR Wallingford, 2006b; Atkins, 2007; Alexander et al., 2011; Kaźmierczak and Cavan, 2011), or *multiple datasets to represent factors of vulnerability* (comprehensive vulnerability assessments) (Vincent, 2004; Balica, 2012a; Balica et al., 2012c).

				<b>E00086281</b>	<b>Portsmouth</b>	<b>South</b>	<b>England</b>
				<b>Output</b>	<b>Unitary</b>	<b>East</b>	<b>Country</b>
				<b>Area</b>	<b>Authority</b>	<b>Region</b>	
<b>All Usual Residents</b>	Count	Persons	Mar-11	354	205056	8634750	53012456
<b>Males</b>	Count	Persons	Mar-11	172	103201	4239298	26069148
<b>Females</b>	Count	Persons	Mar-11	182	101855	4395452	26943308

**Table 3.10.** OAE00086281 Sex, 2011 (QS104EW) (updated 30/01/13) dataset. Crown Copyright (Office for National Statistics, 2013).

Some of the census datasets do not simply contain one or two data variables. Therefore identification of the relevant data value was required and pasted into the final Excel results table, against its appropriate OA OS code, for combination with other relevant data identified, creating a final value for that vulnerability factor. All factor results were collected and added into the CoFSV MS-Excel tables for a day and night-time analysis.

Section 3.2 discussed the formation of the day and night time vulnerability analysis creation after the formation of the factors *Vulnerable Buildings Day* and *Night*. These two factors were used to distinguish a separate *day* and *night* Coastal Flood Physical Vulnerability Index (CoFPVI). The Vulnerable Buildings Day was combined with the other CoFPV factors to form a *Day* CoFPVI, and the Vulnerable Buildings Night was combined with the other factors to form a *night* CoFPVI, i.e. a separate day and night index. Within the Coastal Flood Socio-economic Vulnerability (CoFSV) component the factors Home Population and Residential Population were developed and measured to form a separate *day* and *night-time* CoFSVI (further details area present in Chapter 4).

No economic data to measure the value of areas is present within the UK Census. Economic analysis was provided from estate agent websites notably, [www.rightmove.co.uk](http://www.rightmove.co.uk) and [www.zoopla.co.uk](http://www.zoopla.co.uk). Sold house prices for each post code present in each individual Output Area was collected from 2011-2014, and the mean value was used to represent the economic factor for each OA in the Hilsea ward. The results were added into the CoFSV MS-Excel tables for future standardisation (explained in Chapter 4).

The final results maps for each CoFSV factor, for Hilsea at OA level can be viewed in Appendix H (pg 349). The results for each CoFSV factor, populated the Coastal Flood Socio-economic Vulnerability Index for a day and night flood event. This index was later combined into the Coastal Flood Vulnerability Index, along with the Coastal Flood Physical Vulnerability Index and the Coastal Flood Limited Resilience Index, for Hilsea at local community level, for different flood magnitudes, and at day and night (described in Chapter 4).

### 3.4 Limited Resilience

In 1973, Holling outlined the original concept of resilience as ‘a measure of persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations and state variables’. The most essential feature of ecosystems is that they recover from disturbances. This recovery means that the principal characteristics of a system are restored; however they do not have to be exactly the same as

they were previously (Balica, 2012a). Holling (1973) went on to suggest that another definition of resilience; the capacity of any system to regain its equilibrium after a reaction to a disturbance – is in fact a definition of stability. Holling (1973) therefore introduces the concept resilience as another dynamic within systems, that emphasises systems are not stable and do not return to stable equilibriums. Resilience is the capacity of all systems potentially exposed to hazards, to adapt to any change, by either resisting or modifying itself in order to maintain or achieve an acceptable level of functioning and structure, this includes a society or a community (Balica, 2012a). Resilience has also been described as the capacity to adapt, to adjust to threats and mitigate or avoid harm (Pelling, 2003).

Resilience (a term that has become more prolific in hazard research and Government in recent years), is connected with vulnerability (Lindley et al, 2011; Birkmann et al, 2013; Climate Just, 2015). According to Cutter et al (2009) it speaks of the population, system, or place, to buffer or adapt to changing hazard levels. Within climate change research, resilience is used alongside adaptation, in order to gauge society's response to the threat. Vulnerability is now a term that is widely used within hazard and risk science, particularly in flood risk management. A hazard is the trigger to the disaster, whereas vulnerability determines whether, or in what circumstances, a hazard will result in a disaster (Balica, 2012a). In this research, the vulnerability of a community depends on its physical and socio-economic settings. The different components within this vulnerability analysis, generate the potential impacts which a coastal flood may have and the ability to then cope/overcome these impacts (resilience) (Birkmann et al, 2013).

Resilience in communities, including institutions for collective action, robust governance systems, local education and public understanding are important assets for buffering the effects of natural hazards and promoting social reorganisation (Adger, 2005). Coastal communities with knowledgeable, prepared and responsive institutions are more likely to be able to prevent a continuous coastal flooding cycle transitioning from extreme natural hazard to longer-term social disaster.

Floods are a physical disruption that can threaten social, environmental and economic systems. Flood resilience can be seen as a community or system's ability to either defy or alter itself so that the damage of floods is either mitigated or minimised. Within this



research resilience is analysed in a negative state as ‘limited resilience’, where resilience refers to the capacity of linked systems to absorb recurrent disturbances such as storms or floods, so as to retain or adapt and mitigate or avoid harm, maintaining a significant/acceptable amount of processes, functioning and structure (Adger, 2005; Balica, 2012a). Limited resilience is determined by limitations in terms of access to and mobilisation of the resources of a community or system in responding to a hazard. This includes pre-event risk reduction, in-time coping and the post-event response measures (Birkmann et al., 2013). Limited resilience refers to existing capacities.

### 3.4.1 Limited Resilience Factors

The essential limited resilience characteristics were identified through literature review, observation and evaluation. From this a set of Coastal Flood Limited Resilience (CoFLR) factors were created to guide data selection, resulting in a Coastal Flood Limited Resilience Index (CoFLRI) aided by GIS and remote sensing techniques (QGIS and ArcGIS). The following CoFLR factors were created (see Table 3.11 with detailed reasoning presented in Appendix I – pg 355):

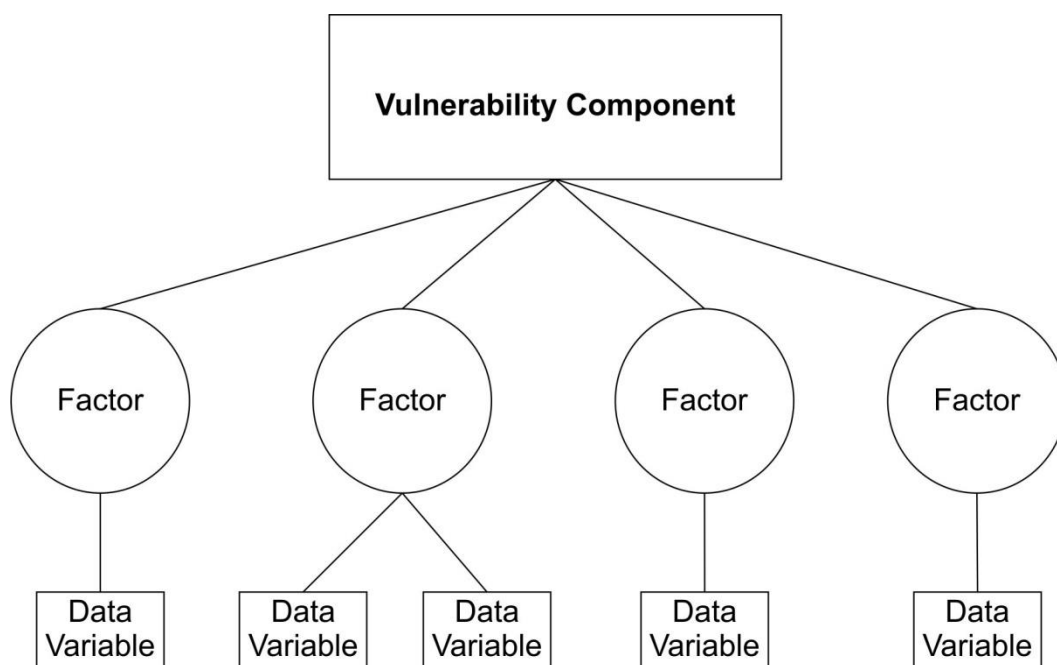
<b>Vulnerability Component</b>	<b>Limited Resilience Factors</b>
Coastal Flood Limited Resilience (CoFLR)	<i>Socio-economic Status</i>
	<i>Education</i>
	<i>Car Ownership</i>
	<i>Emergency Facilities</i>

**Table 3.11.** Coastal Flood Limited Resilience (CoFLRI) Factors.

The following 2011 UK Census Datasets were chosen for the limited resilience analysis:

- Economic Activity, 2011 (QS601EW) (updated 30/01/13)
- Highest level of qualification, 2011 (QS501EW) (updated 30/01/13)
- Adults not in employment and dependent children and persons with long-term health problem or disability for all households, 2011 (KS106EW) (updated 30/01/13)
- NS-SeC, 2011 (QS607EW) (updated 30/01/13)
- Car or van availability, 2011 (QS416EW) (updated 30/01/13)

Firstly there is no separate day and night-time analysis for the CoFLR assessment, as no significant or reflective factor could be established to represent each time zone for this CoFV component. Like the socio-economic vulnerability analysis, each of the following datasets were downloaded for each OA (43) in Microsoft Excel format, and catalogued into CoFLR factor folders. The emergency facilities dataset was created during the land use re-classification stage during the CoFPV assessment (Section 3.2.2). It was decided this was more of a resilience factor than an exposure factor. It is important to note that many of the vulnerability factors fall into more than one vulnerability component (Balica, 2012a), however within this research a factor is only considered for one vulnerability component i.e. physical, socio-economic or limited resilience. An example of the research’s Coastal Flood Vulnerability Component, factor and data variables model is shown in Figure 3.41.



**Figure 3.40.** Example of research’s vulnerability component, factor and data variables model.

The final results maps for each CoFLR factor, for Hilsea at OA level can be viewed in Appendix J (pg 357). The results for each CoFLR factor, populated the Coastal Flood Limited Resilience Index for a Flood Zone 2 or 3 event. This index was later combined into the Coastal Flood Vulnerability Index, along with the Coastal Flood Physical Vulnerability Index and the Coastal Flood Socio-economic Vulnerability Index, for Hilsea at community level (described in Chapter 4).

A summary table (Tables 3.12a, b and c) of all data variables, data sources, vulnerability factors, and vulnerability components is presented below. Chapter 4 will describe the reduction in the complexity of the Coastal Flood Vulnerability Index; the standardisation of the data; the creation of the coastal flood hazard, vulnerability and risk indexes; as well as the results of those indexes when mapped for the Hilsea ward test area.

<b>Coastal Flood Vulnerability Component</b>	<b>Vulnerability Factor</b>	<b>Data Variables</b>	<b>Datasets Used</b>
<b>Coastal Flood Physical Vulnerability</b>	<i>Commercial &amp; Industrial Areas</i>	LU Commercial & Retail	Categorised OS ADL2 Postal and Non Postal
		LU Industry	Categorised OS ADL2 Postal and Non Postal
	<i>Essential Buildings</i>	LU Essential Buildings	Categorised OS ADL2 Postal and Non Postal
	<i>Utilities</i>	LU Utilities	Categorised OS ADL2 Postal and Non Postal
	<i>Vulnerable Buildings</i>	LU Vulnerable Buildings	Categorised OS Building Heights and ADL2 Postal and Non Postal
	<i>Green Areas</i>	LU Green Areas	Dissolved Categorised OS Area
	<i>Transport</i>	LU Transport	Categorised OS RdLink
	<i>Dwellings</i>	LU Residential	Categorised OS ADL2 Postal and Non Postal
	<i>Population Density</i>	2011 UK National Census 'Population density'	Numbers of Persons per Hectare
	<i>Tenure</i>	LU Multiple Residency Buildings	Categorised OS ADL2 Postal and Non Postal & OS ADL2 Multiple Occupancy
		2011 UK National Census 'Tenure households' (Renters)	Number of Households Socially and Privately Rented
2011 UK National Census 'Economic Activity – Full-Time Students'		Number of Persons Full-Time Students Aged 16-74	

**Table 3.12a.** Vulnerability Component CoFPV - Factors and Data Variables Summary

Table (LU – New Re-classified Land Use Layer).

<b>Coastal Flood Vulnerability Component</b>	<b>Vulnerability Factor</b>	<b>Data Variables</b>	<b>Datasets Used</b>
<b>Coastal Flood Socio-economic Vulnerability</b>	<i>Age</i>	2011 UK National Census 'Age by a single year' (Children)	Number of persons between 0-5 years
		2011 UK National Census 'Age by a single year' (Elderly)	Number of persons over $\geq 75$ years
	<i>Household Structure</i>	2011 UK National Census 'Lone parent households with dependent children'	Number Lone Parent Households with Dependent Children Where the Lone Parent is 16-74
	<i>Illness or Disability</i>	2011 UK National Census 'Long-term health problem or disability'	Number of Persons Day-to-Day Activities Limited a Lot and a Little
	<i>Ethnicity &amp; Race</i>	2011 UK National Census 'Proficiency in English'	Number of Persons Cannot Speak English Well or At All
		2011 UK National Census 'Country of Birth'	Number of Persons Born Outside of UK – Not including Ireland, Australia, Canada or USA
	<i>Gender</i>	2011 UK National Census 'Sex' (Female)	Number of Females
	<i>Occupation</i>	2011 UK National Census 'Hours worked' (Part-time workers)	Number of Persons 15 Hours or Less and 16 to 30 Hours Worked
	<i>Economic</i>	Average house prices	Sold residential property prices 2011-2014
	<i>Providers of Unpaid Care</i>	2011 UK National Census 'Providers of unpaid care'	Number of Persons Providing Care (all Hours)
	<i>Communal Establishment Residents</i>	2011 UK National Census 'Communal establishment residents'	Number of Persons in Communal Establishment Residents
	<i>Home Population</i>	2011 UK National Census 'Method of Travel to Work' & 'Age by a single year' (Elderly)	Number of Persons Work Mainly or From Home, Not in Employment, over $\geq 75$ years
	<i>Residential Population</i>	2011 UK National Census 'Population density'	Number of Persons All Usual Residents

**Table 3.12b.** Vulnerability Component CoFSV - Factors and Data Variables Summary  
Table (LU – New Re-classified Land Use Layer).

<b>Coastal Flood Vulnerability Component</b>	<b>Vulnerability Factor</b>	<b>Data Variables</b>	<b>Datasets Used</b>
<b>Coastal Flood Limited Resilience</b>	<i>Socio-economic Status</i>	2011 UK National Census 'Economic activity' (Unemployed)	Number of Persons Unemployed
	<i>Education</i>	2011 UK National Census 'Highest level of qualification'	Number of Persons Either no or low level qualifications (Level 1)
	<i>Car Ownership</i>	2011 UK National Census 'Car or van availability'	Number of Households with No Cars or Vans
	<i>Emergency Facilities</i>	LU Emergency Facilities	Categorised OS ADL2

**Table 3.12c.** Vulnerability Component CoFLRI - Factors and Data Variables Summary Table (LU – New Re-classified Land Use Layer).

## Chapter 4. Indexing, Formation and Compilation

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## Chapter 4. Indexing, Formation and Compilation

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This chapter is split into two parts; Part A and Part B. **Part A** Section 4.1 reviews past vulnerability and risk indices that have influenced the development of the creation of the indexes formulated in this research, including standardisation practices and equations used to assign a numerical value, allowing comparisons of levels of vulnerability and risk. Section 4.2 accounts the extensive process that was undertaken to reduce the complexity of the Coastal Flood Vulnerability Index (CoFVI), in order to reduce multicollinearity and the number of factors. This included the additional analysis of two other wards in Portsmouth (Eastney and St Thomas). A Pearson correlation test was applied and the results are discussed including the final model visualising the Coastal Flood Risk Index (CoFRI) data variables, vulnerability factors, and weights used. Section 4.3 describes the standardisation process assigned to each data variable to produce uniformity. This depended on the variable's functional relationship to each coastal flood vulnerability component i.e. do high numbers of children decrease or increase coastal flood socio-economic vulnerability? **Part B** contains three main sections. Section 4.4 discusses the creation of each index for each Coastal Flood Risk (CoFR) component (CoFHI, CoFPVI, CoFSVI, CoFLRI, and CoFVI); the equations used in order to assign a numerical value to allow comparison of different hazard or vulnerability levels for each neighbourhood (OA) within each ward; the maps produced via ArcMap that visualise these indexes; and discussion of these results. Section 4.5 contains the final CoFRI results and these are then compared with those from the Local Strategic Flood Risk Assessment (LSFRA) and the findings are discussed.

### **Part A - Indices and Reducing the Coastal Flood Vulnerability Index Complexity.**

#### 4.1 The Coastal Flood Hazard, Vulnerability and Risk Indices

There is a need to enhance our understanding of vulnerability and develop methodologies and tools to assess vulnerability (Balica, 2012a; Balica et al, 2012; Birkmann et al, 2013). As stated previously the aim of this research is to develop an effective methodology for the assessment and mapping of flood vulnerability and risk for UK coastal communities. A model and equation (Chapter 2) were developed to assess risk and vulnerability, combining the different components of vulnerability into one model. The methodology framework (chapter 3) created, encapsulate that model, and an index approach was chosen. Previous research has used index based approaches to measure vulnerability, as an index is made of

a set of factors; which can be defined as inherent characteristics which quantitatively estimates the condition of a system i.e. they usually focus on minor, palpable and telling pieces of a system that can give users a sense of the bigger representation (Balica, 2012a; b). Vulnerability encompasses a variety of concepts and elements exposed, susceptible and unable to cope or adapt, to harm. It is therefore vital when assessing Coastal Flood Vulnerability to create understandable links between the theoretical concepts of vulnerability and decision making processes, i.e. encapsulating that link in an accessible tool (Balica, 2012a; Balica et al, 2012).

There are many vulnerability indices: Flood Socio-spatial Vulnerability Index (FVI: Lindley et al, 2011) Social Vulnerability Index (SVI and SoVI: Cutter et al, 2003; Adger, 2006); Social Flood Vulnerability Index (SoVI: Tapsell et al, 2002; HR Wallingford, 2006a; Atkins, 2007; Alexander et al, 2011); Global Risk and Vulnerability Index (GRVI: Peduzzi et al, 2001); Climate Vulnerability Index (CVI: Sullivan and Meigh, 2003); Economic Vulnerability Index (EcVI: Briguglio, 1993; Guillaumont, 2008); Flood Vulnerability Index (FVI: Connor and Hiroki, 2005); Coastal Vulnerability Index (CoVI: Gornitz, 1990; Pethick and Crooks, 2000; Balica et al, 2009; McLaughlin and Cooper, 2010; Dinh et al, 2012). The use of indices within policy tools started in 1920 (Balica et al, 2012). They are numbers based on factors, which measure a quantity relative to a base period.

The first coastal vulnerability index was developed and produced by Gornitz (1990). In this index, the six variables chosen were related in a measurable way that manifests the relative vulnerability of the shore to any physical changes due to sea-level rise (Dinh et al, 2012; Balica, 2012b). McLaughlin and Cooper (2010) created a multi-scale coastal vulnerability index that uses the physical nature of the coast, the magnitude and frequency of the perturbation (forcing factor) and the degree to which such changes impact on human activities or properties (Balica, 2012b). Factors are a statistical concept; they present a form of measurement of a given quantity or state at a certain time, in an indirect manner.

In 2005, Connor and Hiroki created a methodology to calculate a **Flood Vulnerability Index (FVI)** for river basins. Eleven factors were used and divided into four separate components. There were two sub-indices in the index for computation; a human index



which corresponds to the social element; and the material index which represents the economic element (Balica, 2012b). Of the possible 40 factors identified, only 11 were verified. The methodology was tested on river basins in Japan, due to high accessibility of information. The data from Japan was used to perform a multi-linear regression analysis in order to calculate the weights of each factor to each element i.e. human or material. There was also an important step of standardisation included in this methodology i.e. the factors were converted into non-dimensional units by interpolating the maximum and minimum of the series of the data obtained. The resulting FVI values oscillate between 0 and 1; 1 representing high flood vulnerability and 0 low vulnerability to floods (Connor and Hiroki, 2005; Balica, 2012b). This method was tested on river basins in the Philippines; however some indicators were changed or added due to lack of information. The equation used for this FVI was (Equation 4.1):

*Equation 4.1*

$$FVI = \frac{w_c C + w_h H + w_s S}{w_m M}$$

C = Climate Component; H = Hydro-geological Component; S = Socio-economic Component; M = Counter measures Component; w = weights of each Component

Balica (2009; 2012a), revised this methodology to compute FVI for river basins, by basing the factors that were aimed at assessing the conditions which induce flood damage at various spatial scales i.e. river basin, sub-catchment and urban area (Balica, 2012b). This factor based methodology initially considered 71 factors, but only 40 were computed; this was mainly due to either difficulty of obtaining the required data, low relevance in flood vulnerability or redundancy of definitions. After applying derivative and correlation methods and a significant indicator survey, the number of factors was reduced to 28. All of the factors were standardised between predefine minimum and maximum value to create dimensionless factors (Connor and Hiroki, 2005). **The Integrated Flood Vulnerability Index (IFVI)** created by Balica (2009) was based on four components – social, economic, ecological and physical. The factors within each component were weighted, and a matrix was used to rate the components of this method. The vulnerability was then computed and the total IFVI was simply a summation of the components social, ecological and economic (Balica, 2012b).

The local SFRA (2007), contains a **Social Flood Vulnerability assessment (SFVI)**, and is used to identify communities that are more vulnerable to the adverse health and social effects associated with floods. It was created by the Flood Hazard Research Centre (FHRC) at Middlesex University, and is a composite index based on four demographic variables, populated by the 2001 UK National Census (Atkins, 2007):

- People aged 75 and over
- People suffering from a long-term limiting illness
- Lone parent households
- Financially deprived households

This index was further developed by Alexander et al (2011) in order to produce a GIS based flood risk assessment tool, to support flood incident management at local scale. The factors unemployment, overcrowding, non-car ownership and non-home ownership were added to the index to analyse social vulnerability.

The **Climate Vulnerability Index (CVI)**, by Sullivan and Meigh (2003), used climate factors to help establish if the climate was changing. It is a holistic methodology for assessing water resources, and the index ranges from 0 to 100, with the total being produced as a weighted mean of six major components (also scored between 0-100). The methodology was based on the Water Poverty Index (Sullivan et al, 2002) and used Equation 4.2. Every component has sub-components, and these are joint using a composite index structure:

*Equation 4.2*

$$CVI = \frac{(w_r R + w_a A + w_c C + w_u U + w_e E + w_g G)}{w_r + w_a + w_c + w_u + w_e + w_g}$$

Where *CVI* – Climate Vulnerability Index; *R* – Resource component; *A* – Access component; *C* – Capacity component; *U* – Use component; *E* – Environment component; *G* – Geospatial component; *w<sub>r</sub>*, *w<sub>a</sub>*, *w<sub>c</sub>*, *w<sub>u</sub>*, *w<sub>e</sub>*, *w<sub>g</sub>* – weights of the factors.

The national **Flood Socio-spatial Vulnerability Index** by Lindley et al (2011) refers to mapped social vulnerability with respect to flooding. The factors used incorporate personal, social and environmental data, which help explain uneven impacts on people and

communities that come together in particular neighbourhoods. The maps of this index show the results of equally weighted combined neighbourhood scores for factors within five dimensions of socio-spatial vulnerability: sensitivity, enhanced exposure, (in)ability to prepare, (in)ability to respond and (in)ability to recover. This index occurs at Middle Super Output Area (MSOA) level and uses only 2011 UK National Census data. This vulnerability index is combined with a potential river and coastal flooding exposure index, both are equally weighted and produce the **River and Coastal Flood Disadvantage Index**. This accounts for both the likelihood of coming into contact with a flood and the severity of negative impacts to health and well-being. Again this index occurs at MSOA level.

The UK flooding events of late 2013 and early 2014 remind us of the marked increase in frequency, intensity and economic effects of flood events in the UK. The first step in any factor based assessment is to select the factors. The objective of developing flood factors, is to provide decision makers with tools for assessing and analysing flood events. Factors through an index can be a guide to a holistic understanding of the current states of a system, indicating areas that need the most attention with the often limited budgets that are available for flood management (Balica, 2012b). The factors used within this research, and the data variables used to populate them are described within chapter 3. This includes their suitability, definition (or theoretical structure) and their availability. The factors have been deduced through theoretical research (Tapsell et al, 2002; Cutter et al., 2003; HR Wallingford, 2006a; Atkins, 2007; Haynes et al., 2008; Kaźmierczak and Cavan, 2011; Lindley et al, 2011; Balica et al, 2012; Birkmann et al, 2013; Climate Just, 2015) where links have been derived from a theoretical framework, with proxies chosen based on those links (Balica, 2012a; 2012c; Damm, 2010). The final Coastal Flood Vulnerability Index (CoFVI) methodology is described in Part B of this chapter as well as the Coastal Flood Hazard Index (CoFHI), the Coastal Flood Physical Vulnerability Index (CoFPVI), the Coastal Socio-economic Vulnerability Index (CoFSVI), and the Coastal Flood Limited Resilience Index (CoFLRI) methodologies. The final stage involves the Coastal Flood Hazard Index (CoFHI) and CoFVI combined (see Equation 4.3) to create the final Coastal Flood Risk Index (CoFRI).

*Equation 4.3*

$$\text{CoFRI} = \{\text{CoFHI} * \text{CoFVI} (\text{CoFPVI} + \text{CoFSVI} + \text{CoFLRI})\}$$

CoFRI = Coastal Flood Risk Index; CoFHI = Coastal Flood Hazard Index; CoFVI = Coastal Flood Vulnerability Index; CoFPVI = Coastal Flood Physical Vulnerability Index; CoFSVI = Coastal Socio-economic Vulnerability Index; CoFLRI = Coastal Flood Limited Resilience Index

The creation of the coastal flood hazard, vulnerability and risk indices for this research have been influenced by elements of many of the different natural hazard indices methodologies, especially Connor and Hiroki (2005), Balica's (2009; 2012a) Lindley et al's (2011) and Balica et al's (2012) FVI methodologies; Sullivan et al's (2003) The Water Poverty Index (WPI); Sullivan and Meigh's (2003) Climate Variability Index (CVI); Briguglio's (2004) Composite Vulnerability Index for Small Island States (CVISIS); and Gornitz's (1990) Coastal Vulnerability Index (CVI). Indexes assist decision-making in coastal flood risk management, by allowing emergency planners to gain insights into the most vulnerable and at-risk areas.

The CoFVI & CoFRI can be used to communicate this complicated and multidisciplinary area in a relatively straightforward way. The CoFVI and CoFRI integrate large numbers of factors and present an overview of coastal flood vulnerability and risk at the most detailed level possible for the UK. The indexes produce a numeric value for both coastal flood vulnerability and risk. Indexes like these can be used as a quantitative approach for communicating these issues to the many stakeholders involved within the coast; improving education and helping to raise awareness (Balica, 2012b). This will result in increasing the capacity of managers to implement adaptation measures and increase local community resilience.

The CoFRI provides a holistic view of coastal flooding, helping managers to determine areas subject to high levels of danger, allowing them to select mitigating actions and pinpoint where their resources would be best. The resulting CoFVI and CoFRI maps can be used as a measure for prioritising adaptation (Balica, 2012b) and as an educational tool. 3-D visualisations help to clarify things that were not obvious in 2-D maps (see Chapter 5).

Even when there are large volumes of data, patterns can be quickly spotted when visualised correctly. They convey information in a universal manner and broach all levels of coastal stakeholders (including the general public) and assist with the sharing of ideas in a simple display.

The collated data from the methodology framework stages 1-4 (described in Chapter 3 and summarised in Figure 3.1); were collected and entered into MS-EXCEL 2007 in the form of a regular matrix. The columns represented the factors data variables and the rows represented the different OA's present in Hilsea (shown by their individual OA code e.g. E00086287): an example can be seen in Table 13. To maximise future re-usability and interchange ability, data was separated into its particular hazard section or vulnerability components.

The first step of the indexing, involved screening all datasets for either singularity or multi-co linearity. These data characteristics can cause significant problems when analysing large volumes of data. Large datasets can cause difficulties finding unique data contributions of the variables to the factors being determined, simply due to their size and the impracticality of the task. This data screening ensures that data which is either perfectly or very highly correlated, are isolated from the model before indexing takes place. A revision of all data variables for all vulnerability factors took place, and is described in the next section.

<b>Output Area (OA) Label</b>	<b>Age: Elderly: Age by single year, 2011 (QS103EW)</b>	<b>Age: Children: Age by single year, 2011 (QS103EW)</b>	<b>Household Structure: Lone parent households with dependent children, 2011 (KS107EW)</b>	<b>Illness and Disability: Long-term health problem or disability, 2011 (QS303EW)</b>	<b>Ethnicity and Race: Proficiency in English, 2011 (QS205EW)</b>	<b>Ethnicity and Race: Country of birth (detailed), 2011 (QS203EW)</b>	<b>Gender: Sex, 2011 (QS104EW)</b>	<b>Occupation: Hours worked, 2011 (QS604EW)</b>
E00086307	36	11	5	52	40	14	133	40
E00086279	14	27	11	72	41	8	177	44
E00086288	30	24	5	62	32	6	161	54
E00086289	28	22	7	57	18	0	172	49
E00086290	37	35	6	76	23	6	198	52
E00086283	11	22	6	49	34	7	127	53
E00086287	11	28	8	36	30	4	143	55
E00086316	28	13	5	49	16	3	146	48
E00086282	9	22	12	70	35	2	186	58
E00086285	11	16	3	50	31	2	152	47
E00086284	6	27	8	42	28	2	117	27
E00086286	13	23	12	32	21	4	140	49
E00086281	27	32	10	42	26	4	182	51
E00086318	4	12	8	32	40	4	95	23

**Table 4.1.** Exert from raw CoFSVI Flood Zone 2 & 3: Day entered in MS-Excel 2007.

#### 4.2 Reducing the Number of Factors

Currently a total of 31 data variables are used for the current CoFRI methodology; 29 of which are used for the CoFVI. The CoFVI data variables represent identified factors that have been split into the three identified components of Coastal Flood Vulnerability; Coastal Flood Physical Vulnerability (CoFPV), Coastal Flood Socio-economic Vulnerability (CoFSV), and Coastal Flood Limited Resilience (CoFLR). All the data variables used to populate each vulnerability component's factors provide valuable information regarding the identification of the potential of coastal flood vulnerability.

It is important to note that a single factor cannot assess the CoFVI or its potential for further development. For a complete picture of a multidisciplinary problem, several factors such as the ones used in this research need to be quantified. This research has mainly concentrated on how factors are populated via UK data, and if more can be done than simply using current available data. This project has identified new factors that can be quantified; leading to finding, using and creating data that has not been used previously in other UK vulnerability assessments, via new methodologies (described in the previous chapter). The aim of this research was to concentrate on creating a new methodology to analyse, use, and combine data that can represent coastal flood vulnerability into one framework, particularly combining physical and socio-economic datasets (described in Chapter 3, section 3.2 onwards). However, when creating indexes that use many factors, some could have either very little impact on the results or perhaps too much. This problem is described as multicollinearity, and is something that needs to be avoided as it can lead to over-counting or bias, resulting in an unreliable model. Multicollinearity increases the standard errors of the coefficients. Increased standard errors mean that coefficients for some independent variables would be close to zero; i.e. making some variables statistically insignificant when they are actually significant. If multicollinearity is removed the coefficients might be significant. Although vulnerability is complicated, and has many possible factors that can increase or decrease the issue, sometimes too many factors fail to make things clearer.

For this methodology to be sustainable, the most significant vulnerability factors needed to be identified. This involved firstly re-analysing each data variables' relevance, to check whether all the variables chosen portrayed the reality of coastal flood vulnerability

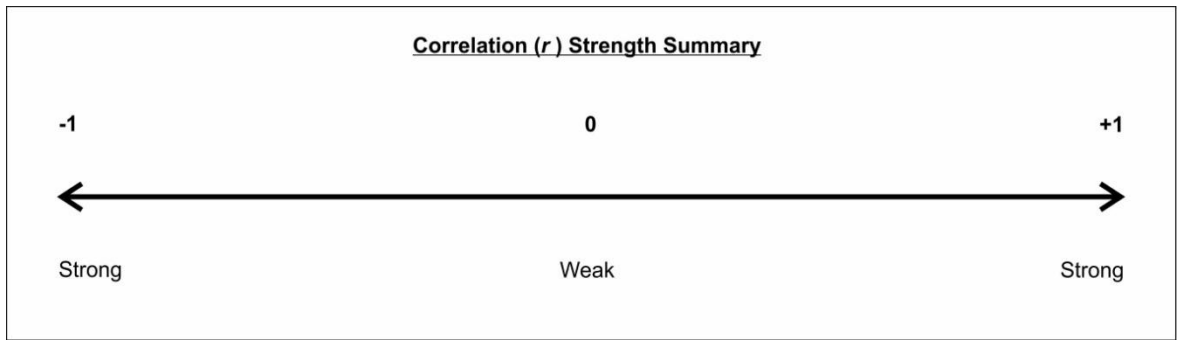
(Każmierczak and Cavan, 2011; Balica, 2012b). The CoFSV factor *Ethnicity and Race* is populated by two variables; Proficiency in English and Country of Birth: the latter is an unnecessary extra variable, because Proficiency in English provided the data needed to populate that factor: not being able to communicate or understand instructions during an emergency increases vulnerability. The final variable removed was from the CoFPV factor *Tenure*: number of students. This variable was not seen as an important contributor to vulnerability compared to the other *Tenure* variables (renters and multiple residency buildings).

To further improve the Coastal Flood Vulnerability Analysis and to further reduce the number of factors, multicollinearity needed to be analysed. A Pearson's Correlation test was used to compare the CoFV component's factors against one another. Correlation is a useful and common statistical method and is preferred over a Principal Component Analysis (PCA) (Jolliffe, 2002; Damm, 2010; Balica, 2012b). A correlation is a single number that describes the degree of a relationship between two data variables, also sometimes referred to as bi-variate correlation and is notated as  $r$ , with a value between -1 and +1. *Direction* and *strength* are the two primary attributes from correlation. *Direction* is indicated by the sign (+ve or -ve) of  $r$ , i.e. positive correlations (0.....+1) emerge when two variables move in the same direction, and negative correlations (-1.....0) emerge when the two variables are moving in different directions. *Strength* is indicated by a numeric value. A correlation, where the  $r$  is close to zero is seen as weaker than those nearer to +1 or -1 (see Figure 4.1) (Knapp, 2014). Therefore, if two factors have a strong positive correlation (i.e. >0.75) then this suggests they are too similar in type and could cause multicollinearity, affecting the overall CoFVI results. The Pearson correlation is computed as (Equation 4.4 (Balica, 2012b)):

*Equation 4.4*

$$r = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{(n-1)S_x S_y}$$





**Figure 4.1.** Correlation Strength Summary (Knapp, 2014).

Another way to reduce the number of factors is by understanding their relationship or value to a dependent or criterion variable. This was used for the FVI on river basins in Japan (Connor and Hiroki, 2005) in order to remove factors but also to calculate weights of each factor to the human and material FVI component; by basing each multiple regression on number of casualties and material losses of past flood events ( $y$  or intercept value), the factors reflected the actual vulnerability to floods of each river basin (Balica et al, 2012). This analysis was pursued in detail as an option for reducing the number of factors and factor weight calculation. The general multiple regression model (see Equation 4.5) is written where  $y$  is the dependent variable and  $x_1, \dots, x_k$  are independent variables, therefore providing a prediction of  $y$  from the form where  $\beta_0 + \beta_1 x_1 + \dots + \beta_k x_k$  is the deterministic portion of the model and  $\varepsilon$  is the random error. We then further assume that for any given values of the  $x_i$ ,  $\varepsilon$  is normally and independently distributed with a mean of zero.

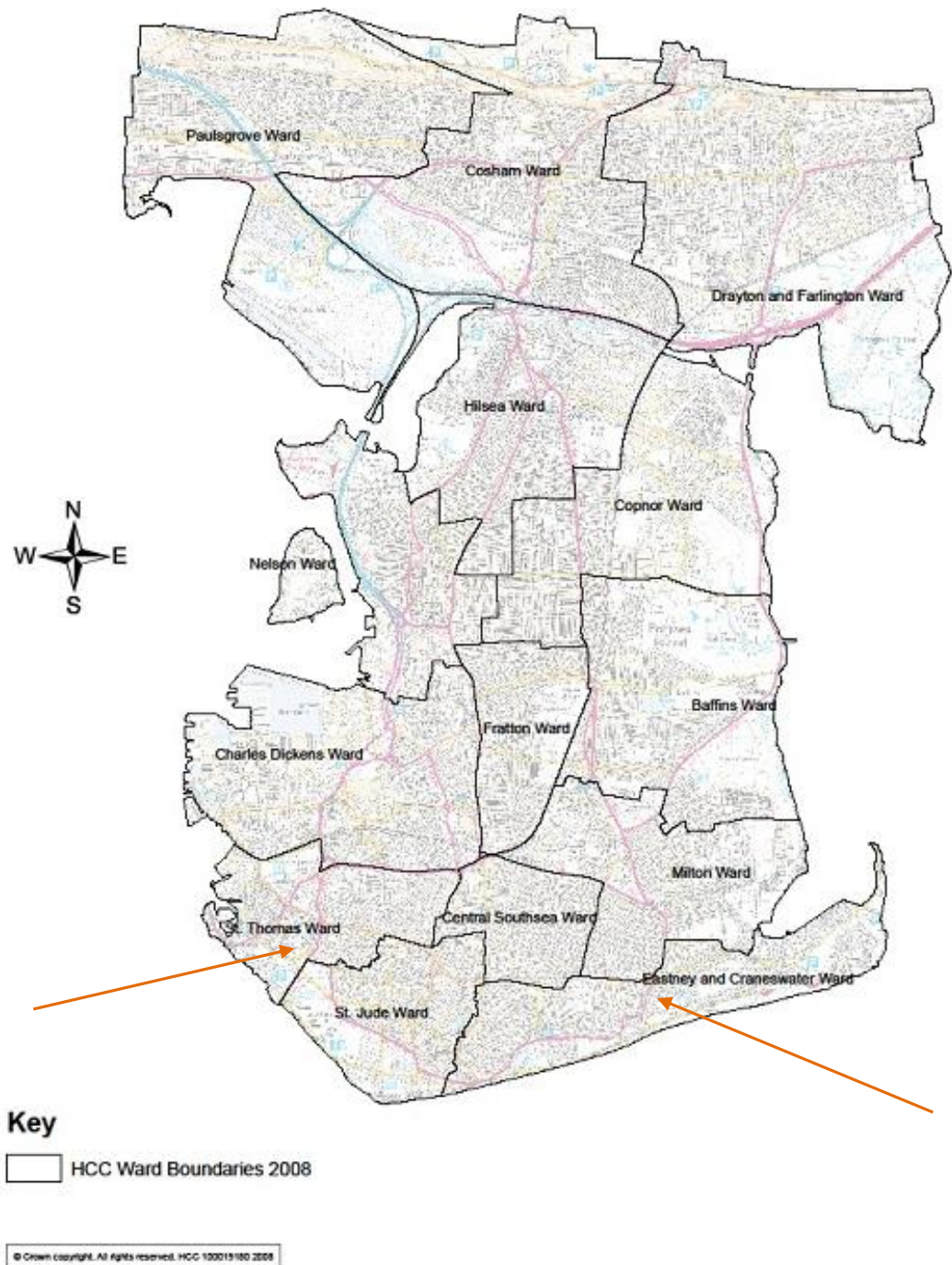
Equation 4.5

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_k x_k + \varepsilon$$

Unfortunately, no data comparable to that used by Connor and Hiroki (2005) to populate the dependent value ( $y$ ) exists for Portsmouth, as these indexes have been created to better understand and measure levels of ‘possible’ coastal flood risk. This type of analysis would be appropriate for the CoFVI if a suitable intercept value was possessed, i.e. a regression analysis is there to assist your understanding of your equation/predictions or the ‘why’ of relationships. However, to accomplish this, another independent dataset would be needed, i.e. you cannot use it to understand what factors have the most affect on the end CoFVI

value, as that CoFVI value is a result of those factors. Therefore a Pearson correlation analysis was carried out.

In order to compute the Pearson correlation between the CoFV data variables, two other wards from Portsmouth were added to the analysis; Eastney & St Thomas (see Figure 4.2), with the goal of having more case studies for improved correlation results (Balica, 2012b). The addition of two extra wards gave a further 99 OAs to be analysed.



**Figure 4.2.** City of Portsmouth ward boundaries. Highlighted new test areas Eastney & Craneswater and St Thomas.

#### 4.2.1 Correlation Results and Discussion

All correlation results for the three wards are presented in Tables 4.2-4.5, they have been separated into their CoFV components (CoFPVI etc), but during the analysis, all variables were correlated together, including the *night* variables i.e. Residential Population and

	Utilities	Green Areas	Dwellings	Renters	Multiple Residency	Essential	Commercial	Industry	Vulnerable Buildings Day	Transport	Population Density	Vulnerable Buildings Night
Utilities	1											
Green Areas	0.593927	1										
Dwellings	0.158287	0.038581	1									
Renters	0.155113	0.003983	0.388932	1								
Multiple Residency	0.093652	0.013909	0.202395	0.539689	1							
Essential	0.235547	0.29985	0.175717	0.213118	0.033001	1						
Commercial	0.328109	0.101204	0.09196	0.105939	0.124922	0.21186	1					
Industry	0.662911	0.280311	0.004862	-0.00424	0.057599	-0.01923	0.465684	1				
Vulnerable Day	0.209447	0.220874	0.262919	0.085677	0.181318	0.096882	0.000685	0.088762	1			
Transport	0.376217	0.682181	0.050061	-0.06614	-0.03812	0.225481	0.12444	0.273239	0.092529	1		
Population Density	-0.15428	-0.21513	0.018337	0.31762	-0.09465	-0.06797	-0.0961	-0.08253	-0.07671	-0.2163	1	
Vulnerable Night	0.208693	0.22241	0.268153	0.094433	0.189599	0.085103	0.003633	0.091982	0.9972	0.093616	-0.07166	1

**Table 4.2.** Correlation results – physical vulnerability data variables for Hilsea, St Thomas and Eastney wards. Numbers shown in red symbolise strong correlation.

	Illness	Children	Elderly	Providers of Unpaid Care	Part-timers	Lone Parents	Proficiency in English	House Prices	Communal	Residential Population	Home Population	Gender
Illness	1											
Children	0.40315	1										
Elderly	0.544803	-0.24876	1									
Providers of Unpaid Care	0.40334	0.110271	0.268334	1								
Part-timers	0.057464	0.197571	-0.19395	0.285087	1							
Lone Parents	0.248609	0.652606	-0.33076	0.028155	0.147732	1						
Proficiency in English	0.272493	0.415374	-0.18144	-0.0929	0.074807	0.272275	1					
House Prices	-0.10454	-0.24795	0.211618	0.129054	-0.23741	-0.37684	-0.26958	1				
Communal	0.062669	-0.07488	0.073309	-0.11864	0.258461	-0.11068	-0.03966	-0.00763	1			
Residential Population	0.288427	0.610577	-0.17866	0.234272	0.751417	0.371659	0.239931	-0.21041	0.3631	1		
Home Population	0.197821	0.023363	0.102908	-0.01856	0.500192	-0.02527	0.261234	-0.10909	0.624268	0.591821	1	
Gender	0.421934	0.694958	-0.07763	0.308839	0.66968	0.482102	0.198384	-0.22124	0.285539	0.948016	0.460053	1

**Table 4.3.** Correlation Results - Socio-economic vulnerability data variables for Hilsea, St Thomas and Eastney wards. Numbers shown in red symbolise strong correlation.

	<b>Illness</b>	<b>Children</b>	<b>Elderly</b>	<b>Providers of Unpaid Care</b>	<b>Lone Parents</b>	<b>Proficiency in English</b>	<b>House Prices</b>	<b>Communal</b>	<b>Residential Population</b>	<b>Home Population</b>
<b>Illness</b>	1									
<b>Children</b>	0.40315	1								
<b>Elderly</b>	0.544803	-0.24876	1							
<b>Providers of Unpaid Care</b>	0.40334	0.110271	0.268334	1						
<b>Lone Parents</b>	0.248609	0.652606	-0.33076	0.028155	1					
<b>Proficiency in English</b>	0.272493	0.415374	-0.18144	-0.0929	0.272275	1				
<b>House Prices</b>	-0.10454	-0.24795	0.211618	0.129054	-0.37684	-0.26958	1			
<b>Communal</b>	0.062669	-0.07488	0.073309	-0.11864	-0.11068	-0.03966	-0.00763	1		
<b>Residential Population</b>	0.288427	0.610577	-0.17866	0.234272	0.371659	0.239931	-0.21041	0.3631	1	
<b>Home Population</b>	0.197821	0.023363	0.102908	-0.01856	-0.02527	0.261234	-0.10909	0.624268	0.591821	1

**Table 4.4.** Correlation Results - Socio-economic vulnerability data variables, minus factors: gender and part-time workers for Hilsea, St Thomas and Eastney wards.

	Car availability	Education	Socio-economic status	Emergency Facilities
Car availability	1			
Education	0.30677	1		
Socio-economic status	0.510607	0.537831	1	
Emergency facilities	-0.15481	0.048014	-0.036848	1

**Table 4.5.** Correlation Results - limited resilience data variables for Hulsea, St Thomas and Eastney wards.

Vulnerable Buildings Night. The results of the strongest correlations between the variables are given below.

The strongest positive associations were between the variables Gender and Residential Population ( $r = 0.94$ ); and Vulnerable Buildings Day and Vulnerable Buildings Night ( $r = 0.99$ ). The latter was to be expected and therefore as both factors are used separately in either the *day* or *night* analysis and never together, this correlation was ignored. However, the extremely strong positive correlation between Gender and Residential Population could not be. A scatter plot was created to display the variables relationship to one another (see Appendix K – pg 359), and the variables were very positively correlated; it is understandable and expected that these results would correlate so highly, as both are population datasets. However, Residential Population is the essential data variable when differentiating from the *day* and *night* analyses'. The Gender variable also has strong positive correlation results with the variables Children  $r = 0.69$  and Part-time Workers  $r = 0.66$ . As Residential Population contains the female population, it was felt that the Gender variable should be removed and Residential Population kept. It also might be seen in western society that gender is no longer a measurement of vulnerable criteria, traditional roles of women in the UK today are low as many work and are successful.

The other notable correlated variables was that of Residential Population and Part-time Workers  $r = 0.75$ . Again a scatter plot was created (Appendix K – pg 359) to investigate the relationship further. The scatter plot displayed a positive relationship between the two variables, however this 'could' be causality as again both variables are population datasets, and a fair number of the these wards population are engaged in part-time employment. From correlation one cannot state for certain that 'correlation implies causation', the

reverse of this sentiment is stated in many statistical works (Chen & Popovich, 2002; Wright, 2002). Statistics such as correlation or other advanced statistics provide us mainly with clues regarding what the plausible relationships might be (Chen & Popovich, 2002). However, the scatter plot displayed a strong positive relationship (stronger than others) and as both these variables are in the same CoFV component, to avoid risk of bias within the CoFPVI, the Part-time workers variable was removed as again the Residential Population variable was essential to the *night*-time analysis; leading to the removal of the Coastal Flood Socio-economic Vulnerability factor, *Occupation* from the CoFVI. The new correlation results for the CoFSV component without the Gender and Part-time Workers variables can be seen in Figure 4.5.

Green Areas and Transport also showed a higher positive correlation  $r = 0.68$ . These variables are in the same Coastal Flood Vulnerability component (CoFPV) therefore a scatter plot was created (Appendix K – pg 359) however, it appears a large cluster of OA's share the results of zero for both variables, therefore giving a positive relationship, this is minor compared to those mentioned previously, the result is also less than the recommended +0.7 value (Simon, 2005; Balica, 2012b).

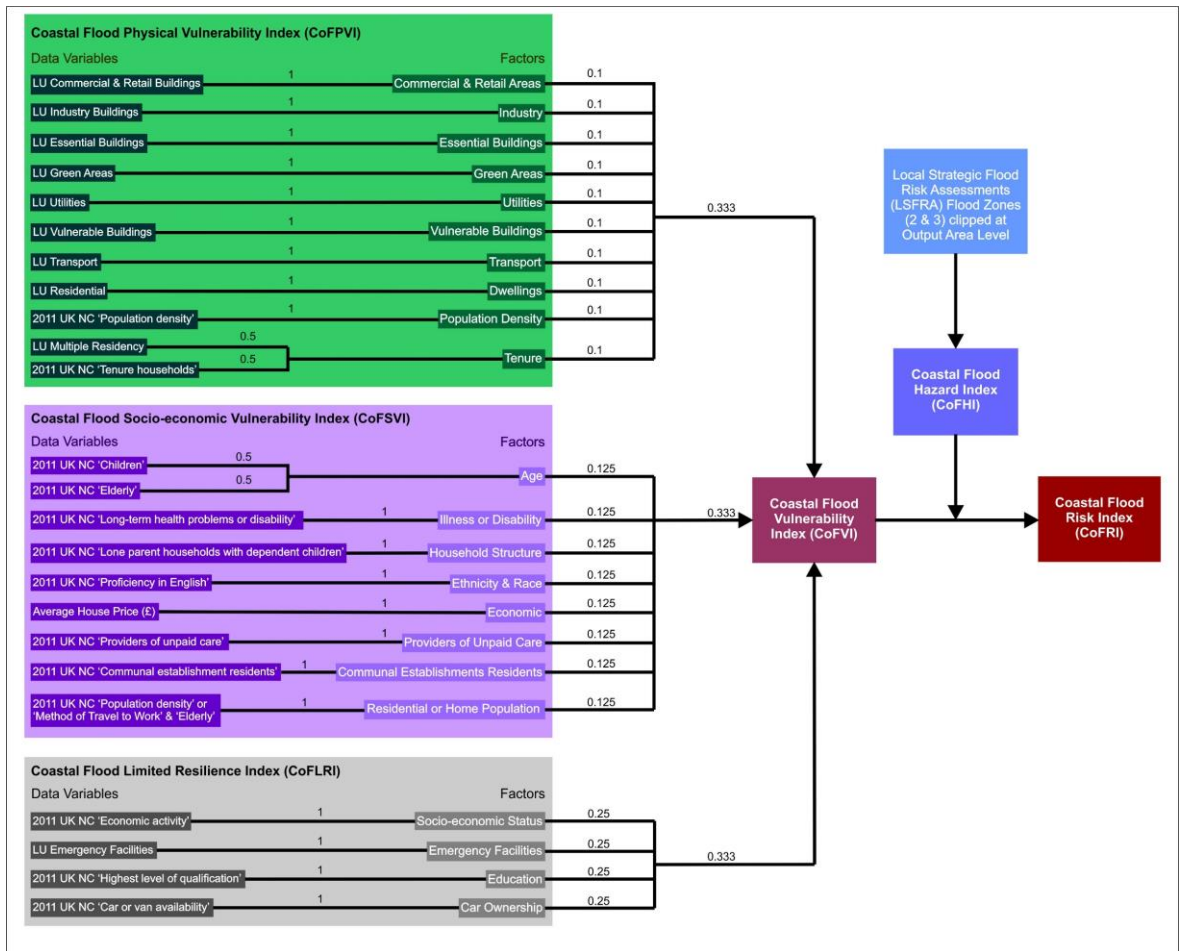
Within the Limited Resilience component all correlation results were very low, only the variables Unemployment and Low Education Levels were more positively correlated  $r = 0.53$  (see scatter plot in Appendix K – pg 359). This could be causality, as it is understandable to suggest that those with low or no levels of education could also be unemployed. Both of these variables are vital indicators of an areas limited resilience, and the  $r$  value is under the +0.7 threshold.

Correlation should not always be taken as an exact result i.e. immediate removal of data variables due to high  $r$  scores. Correlation is a statistical tool that helps guide our attention to trends between datasets; positive, negative or weak. Sometimes causality can be the reason for positive trends, but in examples such as Residential Population, Gender, and Part-time Workers, the datasets are too similar and are likely to cause multicollinearity altering the CoFVI results. The final computed data variables and factors chosen for the Coastal Flood Vulnerability and Risk Indexes have been displayed in Figure 4.3. This figure visualises the final established model of the CoFVI and CoFRI data variables,



vulnerability factors and their added weights. All data variables, the factors they populate and the vulnerability component index to which they are situated are displayed in three coloured boxes to the left of the model. The CoFPVI component is coloured bright green, the CoFSVI component lilac, and the CoFLRI component pale grey. All data variables used to populate each CoFVI component factor are situated on the left in their associated box. Black lines within each CoFVI component box connect each data variable to their corresponding factor; their weights are numbered above the lines. Further black lines are attached to each CoFVI component's factors and move outside each CoFVI component's box, again each factor's weight within their associated CoFVI component are numbered above the line. All factor lines for each CoFVI component merge into one weighted line that are combined together into the burgundy coloured box that represents the creation of the CoFVI. The blue boxes represent the hazard analysis that forms the CoFHI. These results are combined with those of the CoFVI and form the CoFRI (represented by the red coloured box). This model is assigned to measure CoFVI and CoFRI for each OA for each ward and correlate to the risk, hazard, vulnerability model (Figure 2.6) and equation (equation 2.2) set in Chapter 2.

The final computed data variables were placed back into their Coastal Flood Vulnerability components and used to create a CoFVI and CoFRI for the wards of Hilsea, Eastney and St Thomas (**Part B**). The interactions between the different factors for each CoFV component will result in an understanding of what influences coastal flood vulnerability, and makes a system vulnerable.



**Figure 4.3.** Final model of CoFRI and CoFVI data variables and vulnerability factors, with added weights.

### 4.3 Hazard and Vulnerability Data Standardisation

The final 27 data variables need to be standardised to be incorporated into the CoFVI. Standardising data ensures there is uniformity in scales and units. In general, classical proportional normalisation/standardisation is used, which keeps the relative data ratios in the standardised values of the hazard and vulnerability factors as they were, before standardisation (Balica et al, 2013), i.e. factors keep their relative proportions, but are dimensionless. Before standardisation took place, the data variables functional relationship with vulnerability was established i.e. does the variable contribute negatively or positively to the overall vulnerability (UNDP, 2006). Tables 4.6, 4.7 and 4.8 summarises the functional relationships of the CoFVI data variables and factors that have been used to create the CoFHI and CoFVI for the Hilsea, Eastney and St Thomas wards. A negative contribution decreases the hazard or vulnerability, and is displayed as a downward arrow. An upward arrow marks a positive contribution, therefore increasing the hazard or vulnerability. Understanding the variables functional relationship to the overall hazard or vulnerability assisted the standardisation process. This is described in more detail in the following paragraphs.

Once the data variables functional relationship to vulnerability was known, a standardisation equation needed to be computed in order to standardise each variable, for each OA, for each ward. Connor and Hiroki's (2005) FVI, Briguglio's (2003; 2004) CVISIS and the HDI (UNDP, 2006) used Equation 4.6a/b to normalise the different factors identified and created, and involves using a predefined minimum and maximum:

*Equation 4.6a – Positive Contribution*

$$V = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

Where  $V$  = Data Variable;  $X_i$  = Factor value

*Equation 4.6b – Negative Contribution*

$$V = 1 - \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

Where  $V$  = Data Variable;  $X_i$  = Factor value

Index	Component Index	Factor	Data Variable	Functional Relationships	Assumptions
<b>Coastal Flood Hazard Index (CoFHI)</b>	NA	<i>Strategic Flood Risk Assessment Undefended Flood Hazard Zones – 2 and 3 (OPIB)</i>	Output Package 1B Flood Zone 3	↑	From caution to dangerous to all
			Output Package 1B Flood Zone 2	↑	From caution to dangerous to all
<b>Coastal Flood Vulnerability Index (CoFVI)</b>	<i>Coastal Flood Physical Vulnerability Index (CoFPVI)</i>	<i>Commercial &amp; Industrial Areas</i>	LU Commercial & Retail	↑	Commercial and retail buildings increase vulnerability
			LU Industry	↑	Industry buildings increase vulnerability
		<i>Essential Buildings</i>	LU Essential Buildings	↓	Essential buildings decrease vulnerability
		<i>Utilities</i>	LU Utilities	↑	Higher amounts of utilities will increase vulnerability
		<i>Vulnerable Buildings</i>	LU Vulnerable Buildings	↑	Vulnerable buildings increase vulnerability
		<i>Green Areas</i>	LU Green Areas	↓	Green spaces reduce vulnerability
		<i>Transport</i>	LU Transport	↓	Higher amount of transportation routes decreases vulnerability
		<i>Dwellings</i>	LU Residential	↑	More residential addresses increases vulnerability
		<i>Population Density</i>	Population Density	↑	Large population densities increase vulnerability
		<i>Tenure</i>	LU Multiple Residency	↑	Higher amount of multiple residency buildings increases vulnerability, due to more people requiring evacuation
			Tenure - Households	↑	Higher amount of renters increases vulnerability due to not owning property

**Table 4.6.** Functional relationships of data variables and factors for CoFHI and CoFPVI.

NA - Not Applicable.

Index	Component Index	Factor	Data Variable	Functional Relationships	Assumptions
Coastal Flood Vulnerability Index (CoFVI)	Coastal Flood Socio-economic Vulnerability Index (CoFSVI)	Age	Children 5 years & under	↑	Children are vulnerable
			Elderly	↑	Elderly are vulnerable
		Household Structure	Lone Parent Households with Dependent Children	↑	Large amounts of lone parent households with dependent children are more vulnerable
		Illness or Disability	Long-Term Health Problem or Disability	↑	Those with long term health and disability problems are more vulnerable
		Ethnicity & Race	Proficiency In English	↑	Those whose proficiency in English is low are vulnerable
		Residential Population	All Usual Residents	↑	Larger populations increases vulnerability
		Economic	Average House Prices (£)	↑	Higher economics increases vulnerability
		Providers of Unpaid Care	Provision of Unpaid Care	↑	Large numbers of providers of unpaid care increase vulnerability due to accountability
		Communal Establishment Residents	Communal Establishment Residents	↑	Those in communal establishments are harder to account for and therefore more vulnerable
		Home Population	Work mainly at home, not in employment and elderly	↑	Larger home populations increases vulnerability

**Table 4.7.** Functional relationships of data variables and factors for CoFSVI.

Index	Component Index	Factor	Data Variable	Functional Relationships	Assumptions
Coastal Flood Vulnerability Index (CoFVI)	Coastal Flood Limited Resilience Index (CoFLRI)	<i>Socio-economic Status</i>	Unemployed	↑	Those who are unemployed are more vulnerable
		<i>Education</i>	Highest Level of Qualification	↑	Higher numbers with lack of qualifications increase vulnerability
		<i>Emergency Facilities</i>	LU Emergency Facilities	↓	Higher numbers of emergency facilities buildings decrease vulnerability
		<i>Car Ownership</i>	No Cars or Vans in Household	↑	Higher numbers of households with no car or van ownership increases vulnerability

**Table 4.8.** Functional relationships of data variables and factors for CoFLRI.

Equations 4.6a and 4.6b were used to standardise all factor data variables for the CoFV indexes in this research. The resulting values oscillate between 0 and 1; 1 representing high vulnerability and 0 low vulnerability (Briguglio, 2003; 2004; Connor and Hiroki, 2005; Balica, 2012b). Within MS-Excel 2007, standardised data columns for each factor were added alongside each variable. When more than one data variable was used to represent a factor, another total standardised factor column was added (please see Table 4.9). All factors had equal weighting, as do all variables, therefore e.g. CoFSVI uses the factor *Age* in the analysis, this factor is represented by two data variables; children ( $\geq 5$ ) and elderly ( $\leq 75$ ) (*Age* by single year, 2011 (QS103EW) from the UK National Census (2011)). Both variables have equal importance, therefore to calculate the value for the *Age* factor, Equation 4.7 was applied (used by Sullivan and Meigh's (2003) CVI):

*Equation 4.7*

$$Age\_S = \frac{(w_{Age\_E}Age\_E\_S + w_{Age\_C}Age\_C\_S)}{(w_{Age\_E} + w_{Age\_C})}$$

Where *Age\_S* – Age Standardised; *Age\_E\_S* – Age elderly standardised; *Age\_C\_S* – Age children standardised;  $w_{Age\_E}$ ,  $w_{Age\_C}$  – *weight of variables*.

Label	Age_E	Age_E_S	Age_C	Age_C_S	Age_S	HS	HS_S	ID	ID_S	Eth_Prof	Eth_Prof_S
<b>E00086307</b>	36	0.421687	11	0.053763	<b>0.237725</b>	5	<b>0.051282</b>	52	<b>0.3125</b>	14	<b>1</b>
<b>E00086279</b>	14	0.156627	27	0.225806	<b>0.191216</b>	11	<b>0.205128</b>	72	<b>0.625</b>	8	<b>0.571429</b>
<b>E00086288</b>	30	0.349398	24	0.193548	<b>0.271473</b>	5	<b>0.051282</b>	62	<b>0.46875</b>	6	<b>0.428571</b>
<b>E00086289</b>	28	0.325301	22	0.172043	<b>0.248672</b>	7	<b>0.102564</b>	57	<b>0.390625</b>	0	<b>0</b>
<b>E00086290</b>	37	0.433735	35	0.311828	<b>0.372781</b>	6	<b>0.076923</b>	76	<b>0.6875</b>	6	<b>0.428571</b>
<b>E00086283</b>	11	0.120482	22	0.172043	<b>0.146262</b>	6	<b>0.076923</b>	49	<b>0.265625</b>	7	<b>0.5</b>
<b>E00086287</b>	11	0.120482	28	0.236559	<b>0.178521</b>	8	<b>0.128205</b>	36	<b>0.0625</b>	4	<b>0.285714</b>
<b>E00086316</b>	28	0.325301	13	0.075269	<b>0.200285</b>	5	<b>0.051282</b>	49	<b>0.265625</b>	3	<b>0.214286</b>
<b>E00086282</b>	9	0.096386	22	0.172043	<b>0.134214</b>	12	<b>0.230769</b>	70	<b>0.59375</b>	2	<b>0.142857</b>
<b>E00086285</b>	11	0.120482	16	0.107527	<b>0.114004</b>	3	<b>0</b>	50	<b>0.28125</b>	2	<b>0.142857</b>
<b>E00086284</b>	6	0.060241	27	0.225806	<b>0.143024</b>	8	<b>0.128205</b>	42	<b>0.15625</b>	2	<b>0.142857</b>
<b>E00086286</b>	13	0.144578	23	0.182796	<b>0.163687</b>	12	<b>0.230769</b>	32	<b>0</b>	4	<b>0.285714</b>
<b>E00086281</b>	27	0.313253	32	0.27957	<b>0.296411</b>	10	<b>0.179487</b>	42	<b>0.15625</b>	4	<b>0.285714</b>
<b>E00086318</b>	4	0.036145	12	0.064516	<b>0.05033</b>	8	<b>0.128205</b>	32	<b>0</b>	4	<b>0.285714</b>

**Table 4.9.** Exert from raw CoFSVI Flood Zone 2 & 3: Day entered in MS-Excel 2007. Bold figures represent final standardised total for appropriate CoFSVI factor, as some have more than one data variable representing them i.e. Age\_S represents final standardised values for the CoFSVI factor Age.

This step was repeated for any other factors that had more than one variable representing them, including *Tenure*, which is within the CoFPVI.

Standardisation does present problems when large ranges in the data are present, i.e. anomalous results. As this research resulted in analysing Eastney, Hilsea and St Thomas; a choice of whether to standardise each variable using predefined maximums and minimums from all 3 wards or on an individual ward basis, was made (equation 4.6a/b can be used for either option). Therefore, for the vulnerability factor *Community Establishment Residents* from the CoFSVI component, from the Hilsea ward, of the 43 OA's present, there is a range of the  $X_{min} = 0$  and the  $X_{max} = 34$ . However, when standardising to all three wards there is a range from 0-326, but with a larger number of OA's with *Communal Establishment Residents* figures in the lower range of between 0-39. This one very large result skews the standardisation and presents low vulnerability figures for many OA's for this particular factor. This was not an isolated incident; another example was for the factor *Population Density* from the CoFPVI component. Within the St Thomas ward there are now 10 new OA's since 2001, this is due to the development of Gunwharf Quays, an affluent retail area. There are now many high rise apartments with large populations living inside them. Therefore, one OA in St Thomas has a population density of 2766.7 persons per hectare, whereas within the Hilsea and Eastney ward the maximum values were 147.8 and 280.8 persons per hectare. Again when standardising to all three wards, one value such as this gives very small vulnerability scores to all other OA's for this particular factor.

As the aim of this research was to understand and measure coastal flood vulnerability at the most detailed level possible, and not to compare coastal flood vulnerability and risk levels for the city of Portsmouth (the two extra wards were added to assist the correlation analysis and reduce the number of vulnerability factors). The wards will therefore be analysed on an individual basis, pinpointing at the lowest level possible, those areas that are most vulnerable and at the greatest risk. Therefore, the maximum and minimum for each data variable was taken on an individual ward basis. To view all raw data variables, their standardised results, in their allocated spreadsheets, in their correct CoFV components, please see cd-rom (back of thesis), provided at the back of the thesis.



## **Part B - Coastal Flood Vulnerability and Risk Analysis**

### **4.4 The Coastal Flood Vulnerability Index (CoFVI)**

One of the objectives of this research was the determination and quantification of all the coastal flood hazard and vulnerability factors. Therefore, the results were produced when no judgement was made on the relative importance of different factors i.e. equal weights were applied to each factor. The equations used in this analysis link the values of all the factors to their CoFV components (physical, socio-economic and limited resilience) and finally to Coastal Flood Risk (CoFR), with equal weighting. A similar approach was used by Balica (2013) for the Flood Vulnerability Index (FVI), Lindley et al's (2011) Flood Socio-spatial Vulnerability Index and River and Coastal Flood Disadvantage Index, Peduzzi et al (2001), Briguglio (2004) for GRAVITY, and Rygel et al (2006) for the Economic Vulnerability Index.

#### **4.4.1 The Coastal Flood Hazard Index (CoFHI)**

To create the Coastal Flood Hazard Index, the hazard zone data was populated with data from the local SFRA, described as Output Package 1B 'Undefended Hazard' (Chapter 3, Section 3.1). Firstly these flood layers were clipped to each Output Area (OA) within Hilsea, Eastney and Craneswatwer and St Thomas, and dissolved to show the total potential inundation area of Flood Zones 2 (FZ2) and 3 (FZ3). Secondly the surface area of each OA in each ward was calculated and entered into Excel. At the final stages of the project, the CoFHI indexes were combined with the Coastal Flood Vulnerability Index (CoFVI), resulting in a coastal flood risk value for each OA in all three wards, for Flood Zones 2 and 3, at day and night. As all OA's have different geographical areas, a ratio of the inundation area against the surface are for each OA was calculated using Equation 4.8. This standardisation was done to enable a fair comparison of the flood hazard between each OA. This method resulted in a standardisation of the CoFH figures ranging from 0-1; where 1 means complete surface area coverage by the flood zone and 0 represents no surface area coverage by the flood zone. Each ward now has a CoFHI for Flood Zone 2 and Flood Zone 3, at OA level. The CoFHI results for each OA within each ward for each Flood Zone are displayed in Figures 4.4, 4.5 and 4.6.

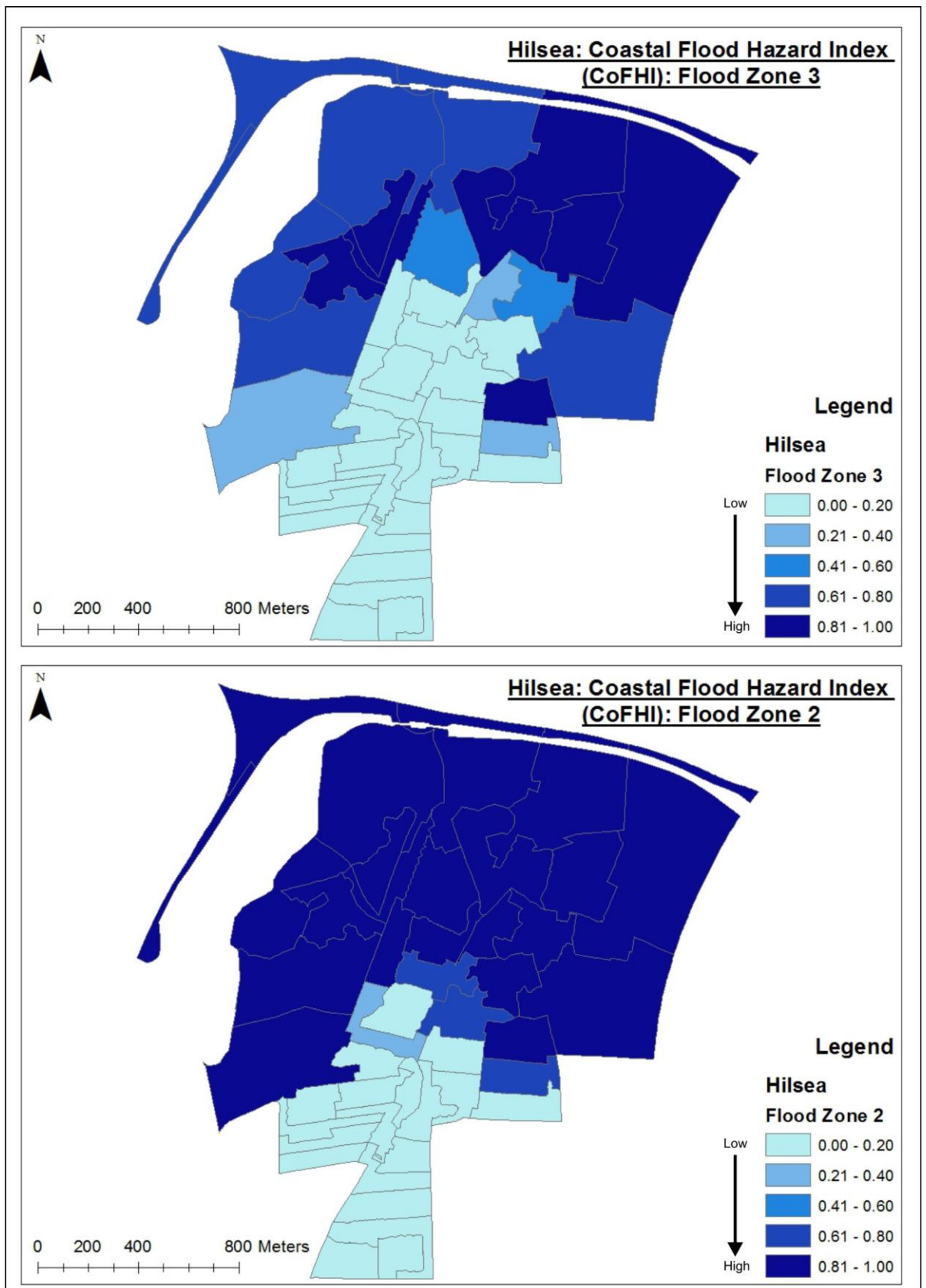
Equation 4.8

$$V = \frac{X_iFS}{X_iS}$$

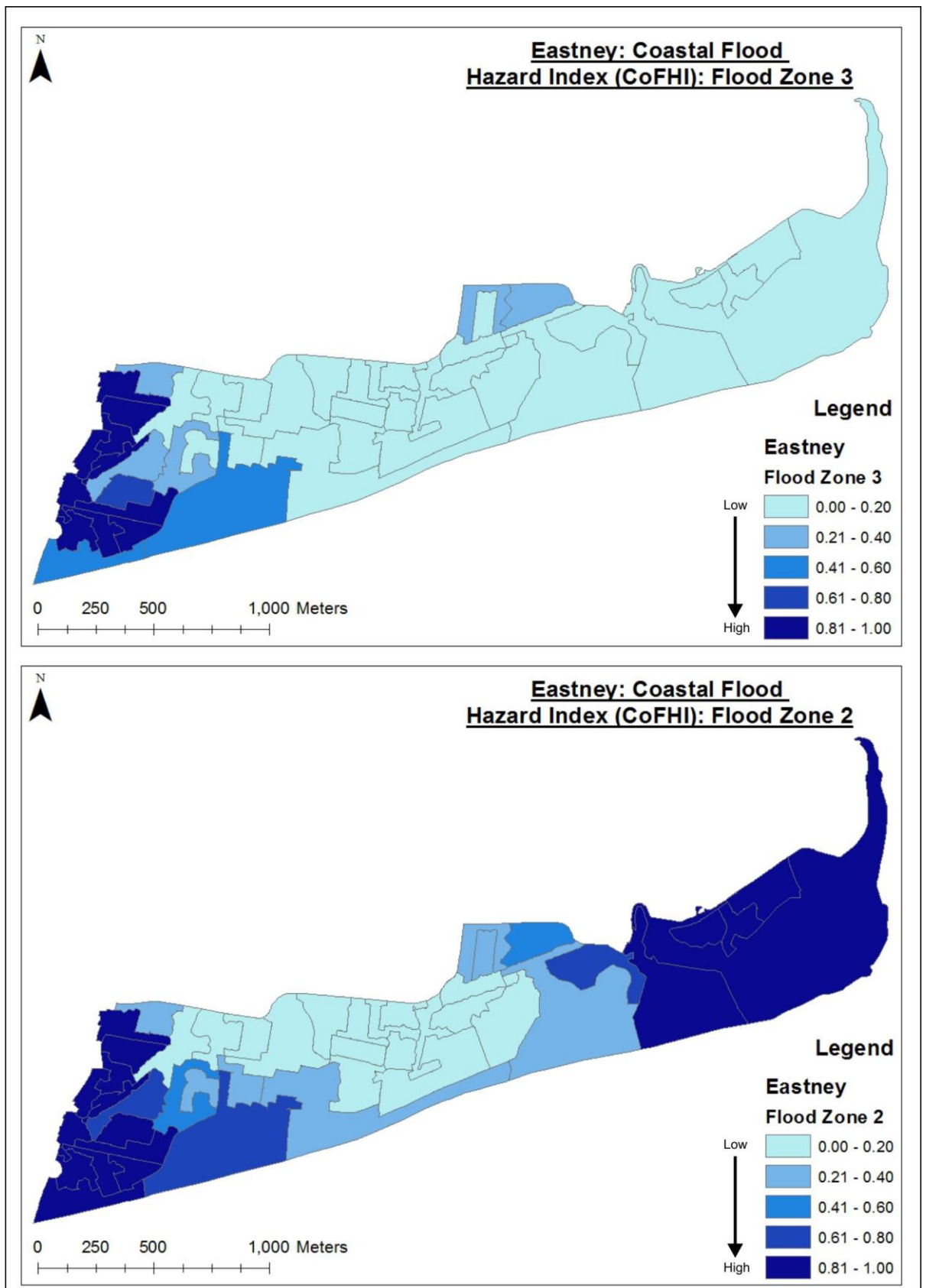
Where  $V$  = Data Variable;  $X_iFS$  = Output Area Total Flood Surface Area;  $X_iS$  = Output Area Total Surface Area.

For Flood Zone 3 (FZ3), the **Hilsea** ward will be substantially inundated. Many OAs at the north of the ward would be almost entirely covered by flood water. To the south of the ward the potential inundation levels are much lower, many with no or minimal flood coverage at all (see Figure 4.4). The south of the ward moves further inland to Portsea Island and away from the coastline, which is why flood water would not be present for a flood of this level. For a Flood Zone 2 (FZ2), many (>50%) of the OAs within Hilsea would be completely covered by flood water. The northern end and middle of the ward would be severely inundated, while the southern part would still have little to no flood water coverage.

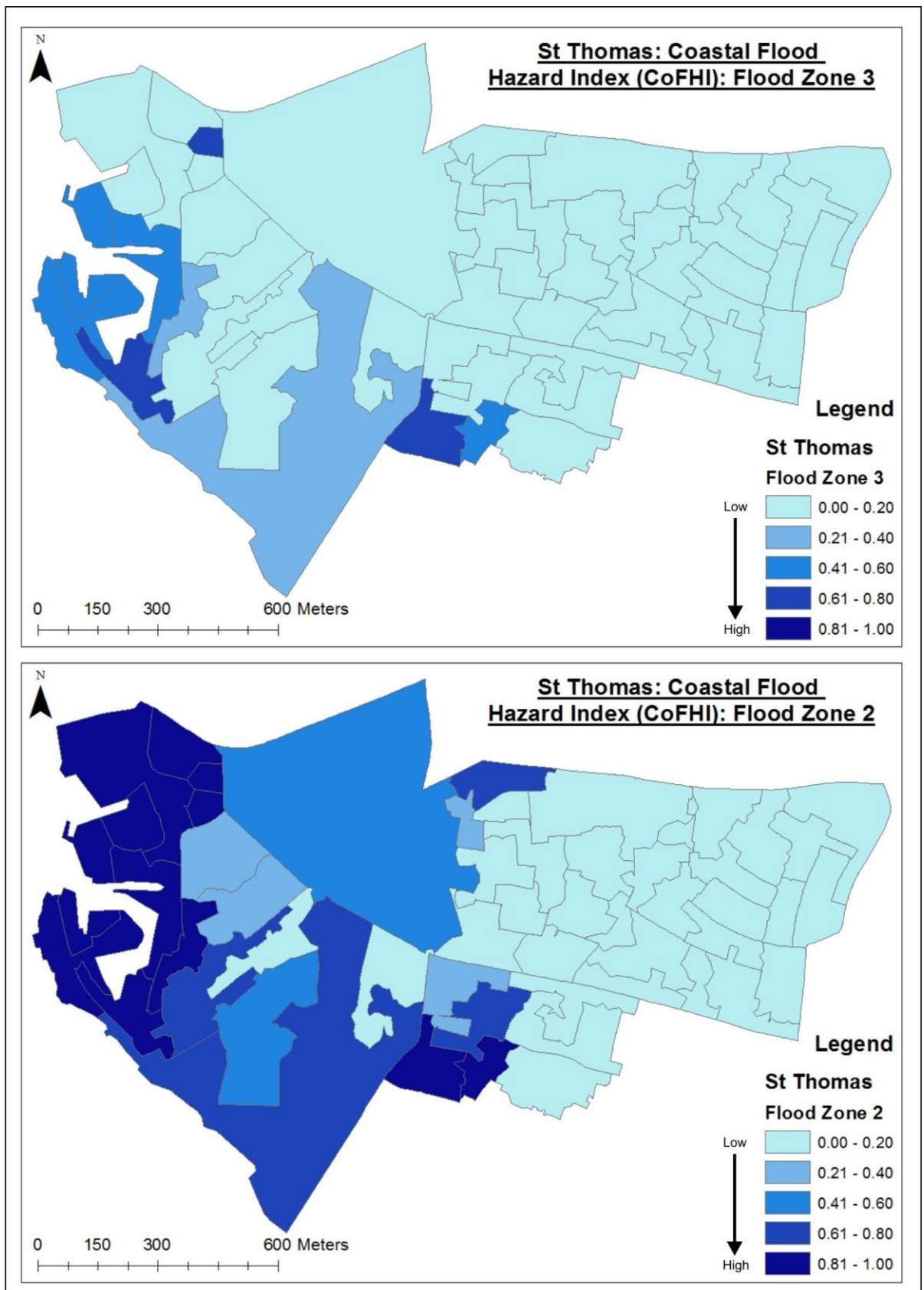
There is a substantial difference between the numbers of amounts of OAs affected by a FZ3 compared to a FZ2. However, although a higher proportion of OAs are affected by a FZ2, specifically in the middle of the ward, the ratio of the type of flood water is predominantly described as *Low* level flood water (explained in detail in Chapter 3). Although this would still cause disruption and damage it is not as severe as the life threatening levels of *High* and *Very High* flood levels, which could have flood water depths of up to 2.5m and flood velocity of between  $1 \text{ ms}^{-1}$  and  $5 \text{ ms}^{-1}$ . These flood levels would be concentrated on the northern fringe of the ward. However, this part of the ward contains a critical arterial thoroughfare (A3), that connects Portsea Island to important routes, and the mainland (only three exit routes are available off Portsea, this is one of them) (see Figure 4.7). This main road has high usage, low lying and surrounded (to the west and east) by tidal water. This is a main evacuation route for Hilsea and Portsea, that could be severely inundated by deep, fast flowing water, that could cause severe damage and loss of life.



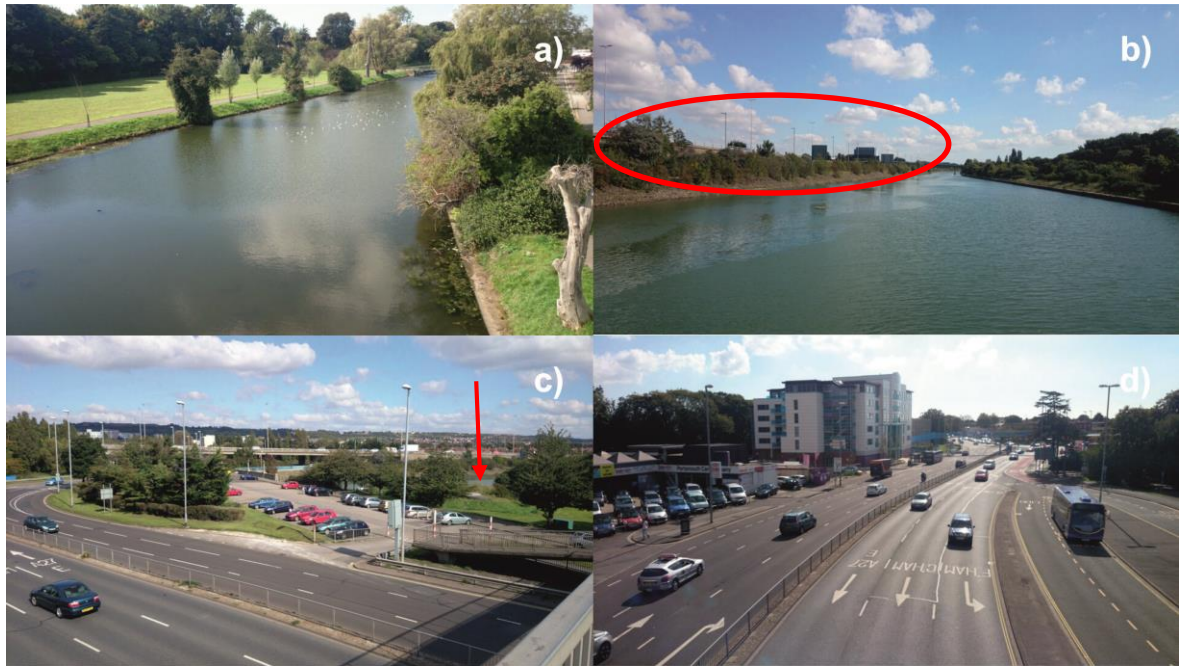
**Figure 4.4.** CoFHI FZ3 & FZ2 for Hilsea ward at OA level (1 means complete surface area coverage by the flood zone and 0 represents no surface area coverage by the flood zone).



**Figure 4.5.** CoFHI FZ3 & FZ2 for Eastney ward at OA level (1 means complete surface area coverage by the flood zone and 0 represents no surface area coverage by the flood zone).



**Figure 4.6.** CoFHI FZ3 and FZ2 St Thomas ward at OA level (1 means complete surface area coverage by the flood zone and 0 represents no surface area coverage by the flood zone).



**Figure 4.7.** A3 road and tidal water in Hilsea ward – image **A** shows tidal water on the north western fringe of Hilsea ward; image **B** presents tidal water on the north eastern fringe of Hilsea ward. The red oval identifies the M27; image **C** shows the main large exit point and roundabout on the A3 on the northern fringe of Hilsea. The red arrow highlights the close proximity of the tidal water that is shown in image **B**; **D** presents the A3 heading south into Hilsea.

The **Eastney and Craneswater ward** would not be severely affected by a FZ3 event (Figure 4.5). Most of the ward would have very little to no coverage of flood water. The OAs most affected are at the west end of the ward, however, this area is the most developed with some prominent commercial and residential properties very close to the seafront and a smaller beach area to protect these buildings (beach width here is smaller compared to the eastern end of the ward – see Figure 4.8). In December 2013, January and February 2014 this area was continually flooded by the storms (see Figure 4.9) and the coastal road (Esplanade) was closed for several weeks due to large amounts of overtopping, large volumes of sand, gravel, debris and concrete slabs dislodged from the seafront promenade and deposited on the road at high tide. It was too dangerous for pedestrians to walk along and inaccessible for vehicles.



**Figure 4.8.** Eastney beach - image **A** is situated at the western end of the ward, where the beach width is smaller compared to image **B** which shows the beach at the eastern end of the ward, where the beach width is substantially much greater.

For a FZ2, Eastney has more OAs that would be completely inundated, the east end of the ward would be seriously more affected compared to a FZ3 event. Despite a wider beach surface area here, compared to the width in front of the Esplanade that was flooded in 2014 (presented in Figures 4.8 & 4.9), the beach reduces in width at the most easterly point of the ward, giving little protection against severe storm waves. Inundation by a FZ2 is most severe at the eastern and western margins of the ward, whereas the middle of the ward has very little flooding. This again is mainly due to the width of the beach on this length of coastline. Eastwards from the new commercial building, the ‘Coffee Cup’, the beach width significantly increases and the gradient from the shoreline to the promenade becomes very steep in places; hence providing ample protection for suburban areas behind it, by naturally dispersing storm waves and their energy.

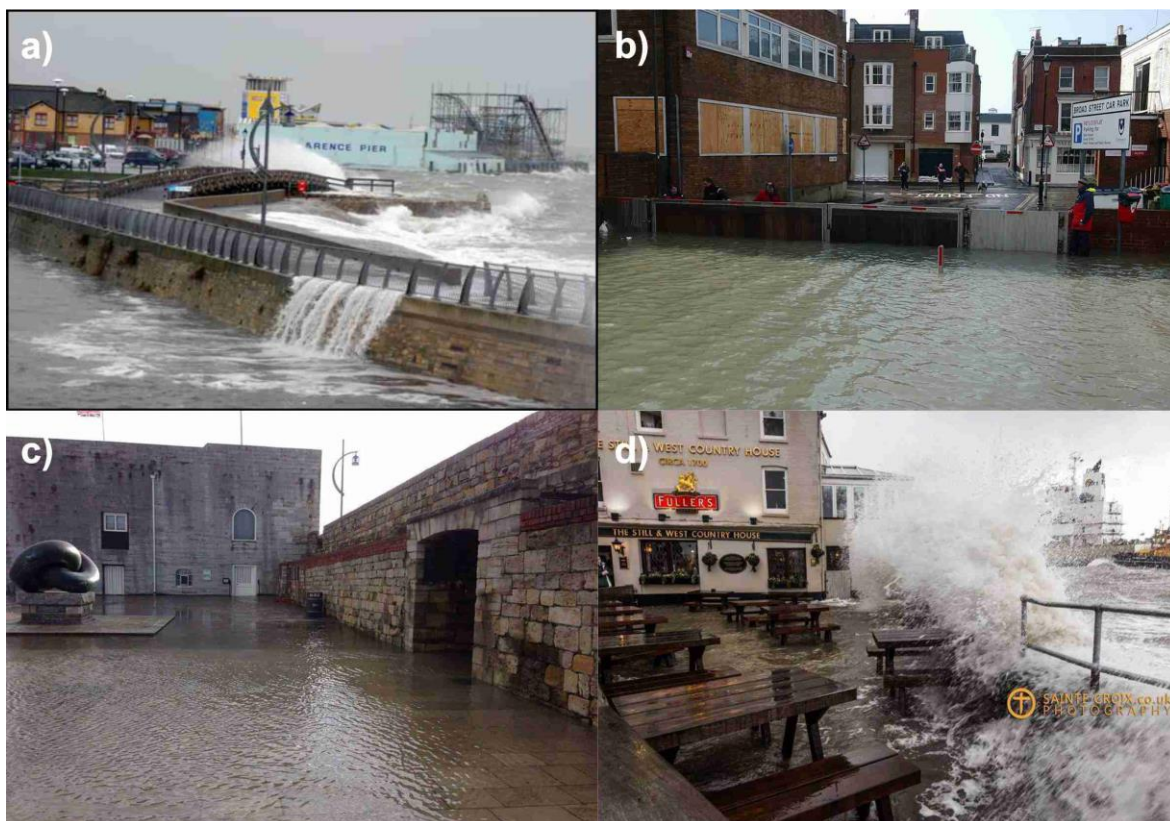


**Figure 4.9.** Flooding image examples of ‘The Esplanade’ road in the Eastney and Craneswater ward during the January and February 2014 storms. **A-D** show flood water on the road, image D also includes the cricket ground and commercial business that was also inundated. Images **E & F** show the damage after the flood water had dispersed. A large amount of clean up and repair was required (3-4 weeks) before this main road was accessible again.

**St Thomas ward** is situated on the west side of Portsea Island, and has OAs on its eastern side that would have no FZ3 flood water inundation (Figure 4.6). There are some areas to the south and south west of the ward that would be inundated, but no OA has more than 80% coverage (although this is still very high). During a FZ3 flood three OA’s in particular



would be severely inundated, including a lone OA in the north west of the ward. However, there are high amounts of commercial and retail buildings and prime real estate in these areas, including the Isle of Wight car ferry port, and many historical assets. It is also a very crowded area (building wise) and the beach present on the shoreline is relatively narrow. In 2013/14 the storms flooded some of these neighbourhoods, as illustrated in Figure 4.10.



**Figure 4.10.** Flooding image examples in St Thomas ward during the January and February 2014 storms. Image **A** shows flood water severely overtopping defences around Clarence Pier and the walkway near the old site of Portsmouth Cathedral. Images **B-D** show the area in Old Portsmouth known as Spice Island. **B** - the new flood gates; **C** – the Square tower and **D** – Still and West Inn (LoveSouthsea, 2014; ESCP, 2015).

A FZ2 event would severely inundate the western part of the ward, including 12 OA's with between 80-100% coverage. There would be a dramatic difference to the flooding levels in this ward compared to a FZ3 event. Again however, the eastern side would not be affected.

#### 4.4.2 The Coastal Flood Physical Vulnerability Index (CoFPVI)

To create the equal weighted Coastal Flood Physical Vulnerability Index (CoFPVI) involved a mixture of Ordnance Survey and UK National Census 2011 data (Chapter 3 Section 3.2). The new land use classification system created for this project, supplied the majority of the data variables for the analysis of this particular vulnerability component. The 2011 UK National Census data variables used are listed in section 3.2.

For the *day-time* and *night-time* analysis, 10 CoFPV factors were used. The difference being a *Vulnerable Buildings Day* factor used in the day analysis and a *Vulnerable Buildings Night* factor for the night analysis; where certain buildings that would be vulnerable during the day, were not at night-time (no longer being occupied at night i.e. schools, nurseries etc). Each data variable representing each Coastal Flood Physical Vulnerability factor was entered into MS-Excel where the data was first standardised using Equation 4.6a or 4.6b (depending on the variables relationship to vulnerability – see Table 4.6); and where necessary for some variables, the  $X_{min}$  was set as 0. Like the hazard index, this was done as the number zero is significant when measuring vulnerability; i.e. if an area does not contain a building that is required to be measured for this analysis it must be stated. The factor *Tenure* used more than one variable, therefore, Equation 4.7 was applied to the variables standardised values, creating a final standardised value for the factor.

Within this assessment all factors for each CoFV component (CoFPV, CoFSV & CoFLR) were weighted equally, however, the equation used (Sullivan and Meigh's (2003) CVI) presents a platform for different weights to be assigned. The resulting indexes value ranges between 0 and 1; 0 representing very low vulnerability and 1 very high vulnerability. To create the CoFPVI values for day and night, Equations 4.9a and 4.9b were applied (used by Sullivan and Meigh's (2003) CVI). All CoFPVI results for day and night analyses for all 3 wards at OA level were added into ArcMap 10.0, where they were joined to an OA level (2011) OS Boundary polygon shapefile for each ward (acquired via OS OpenData). The Coastal Flood Physical Vulnerability levels are displayed at 5 intervals (Damm, 2010; Lindley et al, 2011) between 0 and 1; 0.00-0.20 – **very low vulnerability**; 0.21-0.40 – **low vulnerability**; 0.41-0.60 – **moderate vulnerability**; 0.61-0.80 – **high vulnerability**; and 0.81-1.00 – **very high vulnerability**. All results for the CoFPVI for each ward can be seen in Figures 4.11, 4.12, and 4.13.

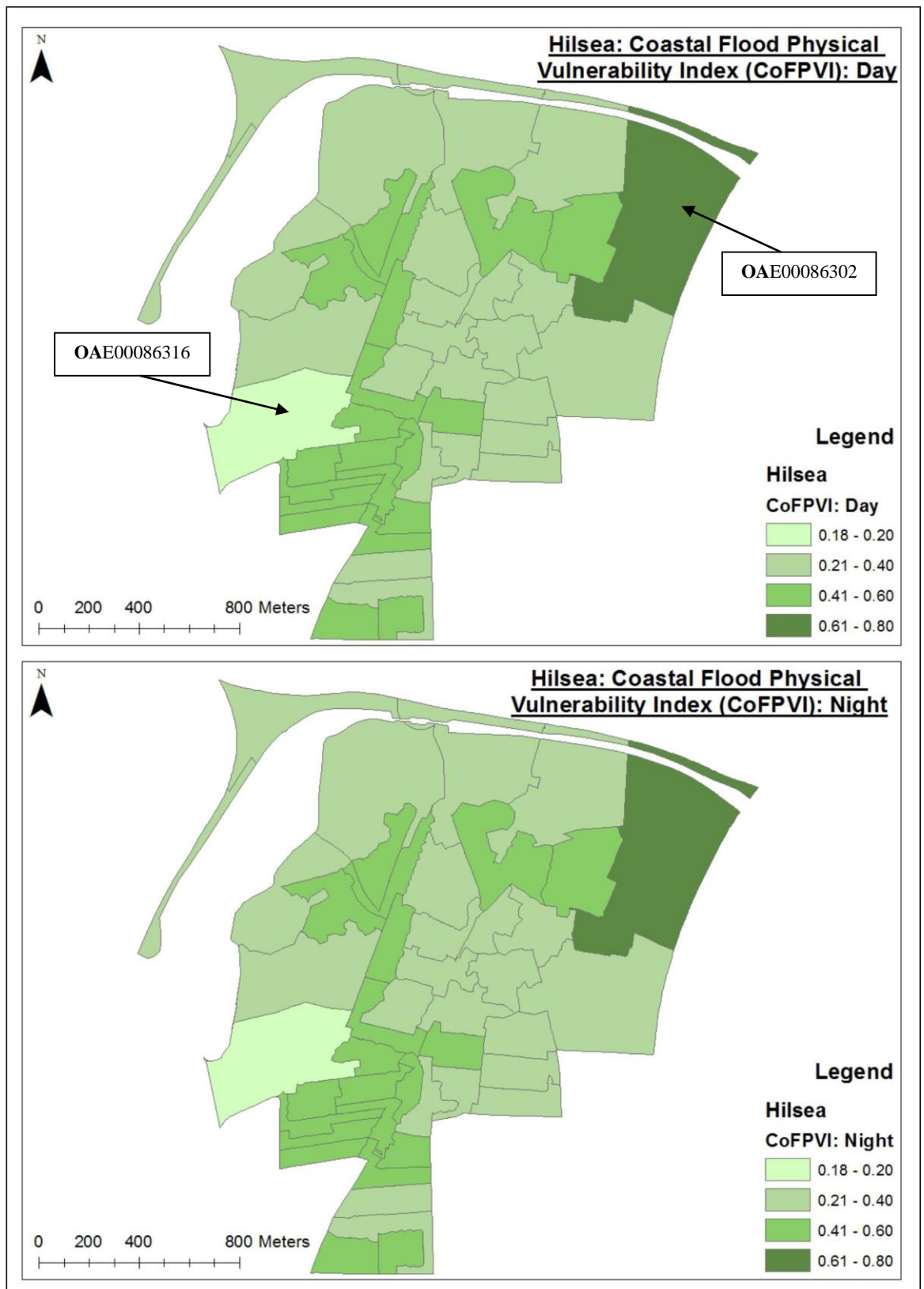
Equation 4.9a - Day

$$\text{Day CoFPVI} = \frac{(w_c C_S + w_i I_S + w_{eb} EB_S + w_u U_S + w_{vbd} VBD_S + w_g G_S + w_t T_S + w_d D_S + w_p P_S + w_{ten} Ten_S)}{(w_c + w_i + w_{eb} + w_u + w_{vbd} + w_g + w_t + w_d + w_p + w_{ten})}$$

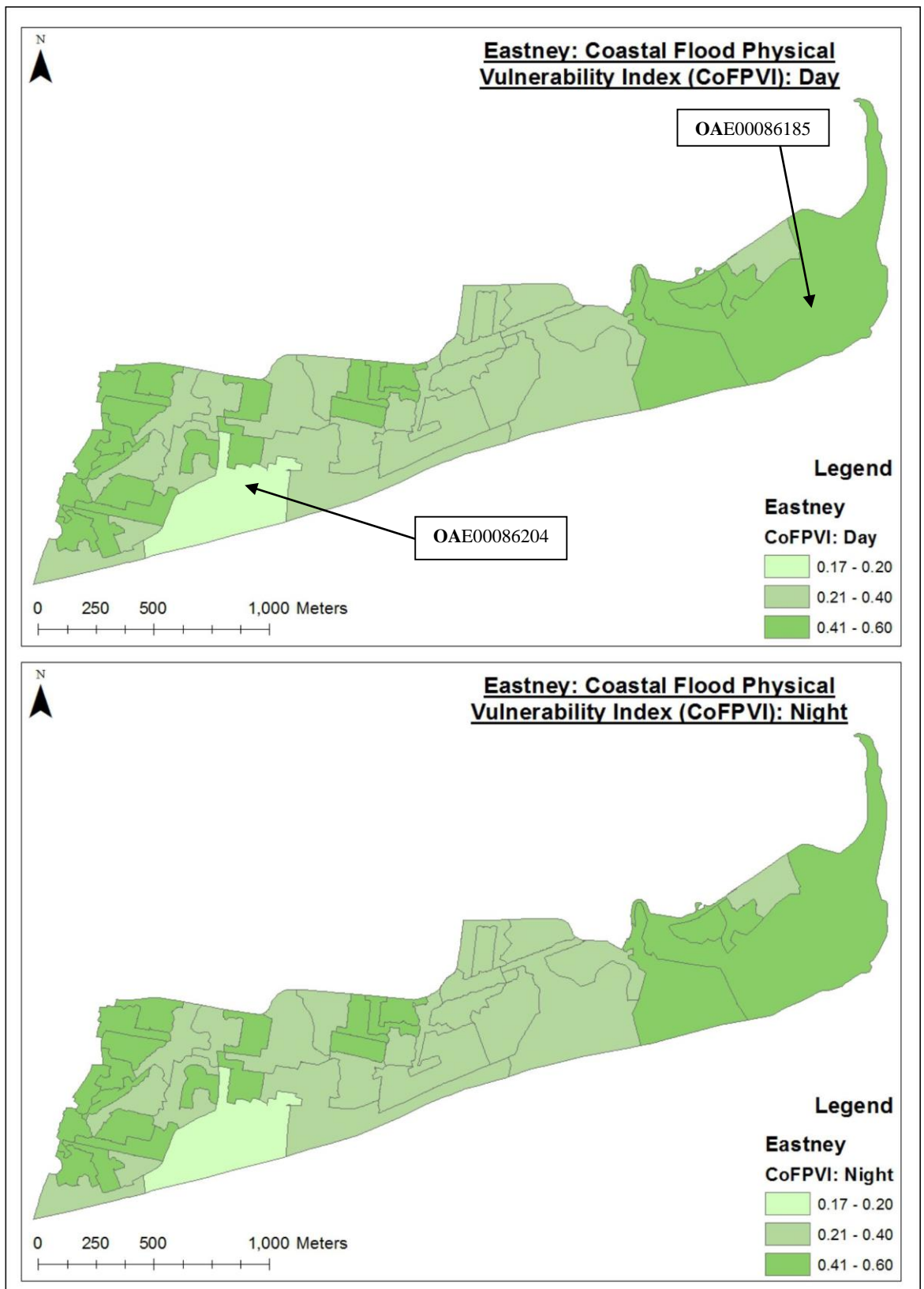
Equation 4.9b - Night

$$\text{Night CoFPVI} = \frac{(w_c C_S + w_i I_S + w_{eb} EB_S + w_u U_S + w_{vbn} VBN_S + w_g G_S + w_t T_S + w_d D_S + w_p P_S + w_{ten} Ten_S)}{(w_c + w_i + w_{eb} + w_u + w_{vbn} + w_g + w_t + w_d + w_p + w_{ten})}$$

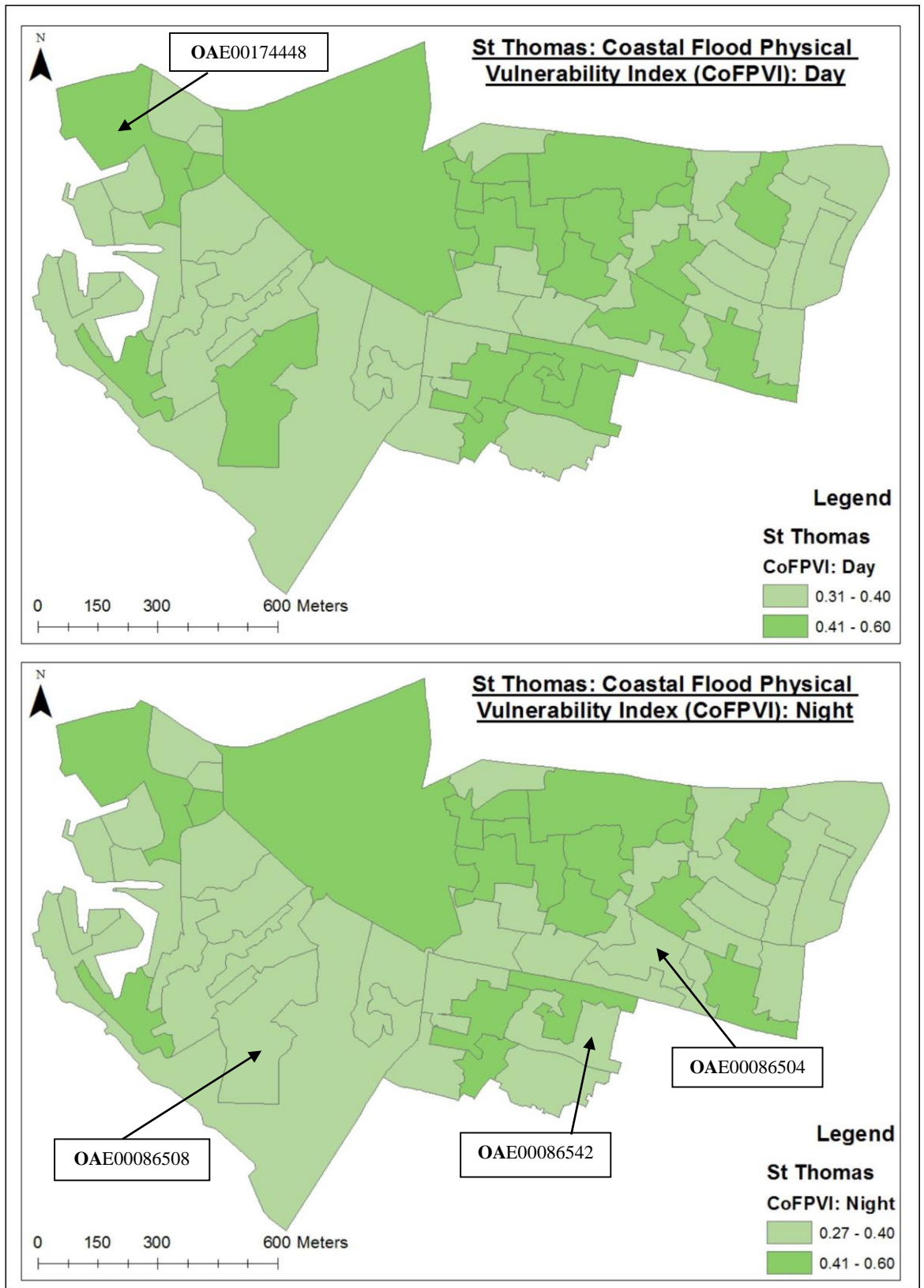
Where CoFPVI – Coastal Flood Physical Vulnerability Index; C\_S – Commercial & Retail Areas standardised; I\_S – Industry standardised; EB\_S – Essential Buildings standardised; U\_S – Utilities standardised; VBD\_S – Vulnerable Buildings Day standardised; G\_S – Green Areas standardised; T\_S – Transport standardised; D\_S – Dwellings standardised; P\_S – Population Density standardised; Ten\_S – Tenure standardised; VBN\_S – Vulnerable Building Night standardised;  $w_c, w_i, w_{eb}, w_u, w_{vbd}, w_g, w_t, w_d, w_p, w_{ten}, w_{vbn}$  – weights of factors.



**Figure 4.11.** CoFPVI for Hilsea ward at OA level – Day & Night. Physical vulnerability ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting vulnerability levels.



**Figure 4.12.** CoFPVI for Eastney ward at OA level – Day & Night. Physical vulnerability ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting vulnerability levels.



**Figure 4.13.** CoFPVI for St Thomas ward at OA level – Day & Night. Physical vulnerability ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting vulnerability levels.

Notably for the **Hilsea ward**, there is one particular OA that is physically more vulnerable (**OAE00086302** – see Figure 4.11) for both day and night analyses, and one that is the least physically vulnerable (**OAE00086316**). This is due to the former **OA** (6302) being a highly commercial and industrial area, having the highest numbers of commercial and industrial buildings in the ward, and the most utilities as well. It also has no essential buildings present and generally high levels ( $> 0.5$ ) for most of the other data variables. The latter **OA** (6316) has generally low levels of vulnerability for each variable ( $< 0.3$ ), apart from small amounts of green spaces and low levels of transport routes available in the area.

Overall, the Hilsea ward neighbourhoods (OA's) have low to moderate physical vulnerability levels (0.2-0.6), with 21 OAs showing moderate to high levels of physical vulnerability. There is little to no difference between the day and night-time analyses. The differences are so small i.e. 0.01 to 0.05, they do not transpire via ArcMap and are not visible in the mapped results. The differences are due to change in status of 'Vulnerable Buildings' i.e. for some OA's that have vulnerable buildings, the numbers of these buildings reduce during the night (i.e. schools, nurseries etc), due to no longer being occupied, therefore altering the overall physical vulnerability results. Overall there are more OA's with low CoFPV scores (0.2-0.4), than with moderate scores (0.4-0.6). The latter are dominantly on the western part of the ward, whereas the former appear to be on the outskirts and centralised. Overall Hilsea has low to moderate physical vulnerability.

For the **Eastney ward**, the OAs with the highest CoFPV levels (moderate physical vulnerability) are at either ends of the ward, while the OAs in the middle and close to the coastline have low physical vulnerability between 0.2-0.4 (see Figure 4.12). This is due to a lack of variety in the physical 'make up' of the land in these OAs, they are very suburban and contain almost exclusively residential properties with large green spaces and long main roads surrounding them. This results in a lower CoFPV result. There are some Multiple Residential properties in the area, but compared to other OAs within the ward these are small numbers. **OAE00086204** has the lowest physical vulnerability result. This is due to low vulnerability levels for almost all of the physical vulnerability data variables, except for Green Areas, which has a high vulnerability level (0.69). There are low amounts of renters in the area, very few utilities, low amounts of multiple residency buildings, moderate amount of residential properties, very high amount of essential buildings, no

vulnerable buildings or industrial buildings, high amounts of transport links available, very small population density and some commercial and retail properties.

Overall out of the 45 OAs in this ward, 22 have moderate physical vulnerability. Again like Hilsea, there is very little to no difference between the day and night analysis CoFPV levels. Whatever difference is present (can be seen on Excel spreadsheets), is too small to be seen visually when 5 vulnerability levels are applied to map these results. Eastney has low to moderate physical vulnerability.

Less than 50% of the **St Thomas ward** OA's have moderate physical vulnerability levels for the day analysis, the rest have low levels. Most of the OA's that are moderately vulnerable are clustered together to the north of the ward. There are also 2 OA's that have moderate physical vulnerability situated on the north-west point of the ward, which is where the Gunwarf shopping area is situated. **OAE00174448** has 123 commercial and retail addresses situated in this neighbourhood, and this is the highest amount for the whole ward (see Figure 4.13). These neighbourhoods have none or very little green areas, no essential buildings, moderate amounts of residential buildings, and little to no main transport links available all of these contribute to higher physical vulnerability. However, the neighbourhoods are balanced to moderate levels, due to moderate to low amounts of renters, low multiple residency buildings, low population densities, no industry buildings, no utility buildings and apart from **OA4448** there are only some commercial and retail buildings in the other OA's. For the night analysis three OA's (**OAE00086508**, **OAE00086504** & **OAE00086542**) physical vulnerability levels decrease from moderate to low. This is again due to vulnerable buildings no longer being designated as 'vulnerable', as it is evening.

#### 4.4.3 The Coastal Flood Socio-economic Vulnerability Index (CoFSVI)

To create the equally weighted Coastal Flood Socio-economic Vulnerability Index (CoFSVI) involved a mixture of UK National Census 2011 (majority) and estate agents (Rightmove & Zoopla) data (Chapter 3, Section 3.3).

For the day and night analysis eight coastal flood socio-economic vulnerability factors were used. The difference being, during the night, Residential Population was measured,



due to human sleep patterns this is when the residential population should be at its maximum. This is an important feature as night-time floods can result in death due to humans being unaware of the flood hazard (Met Office, 2014). During the day, the majority of the residential population should not be at home: theoretically most adults would be at work and the children would be at school. There are no datasets within the census that tell us exactly how many people stay within their home during the day. However, within the Method of Travel to Work (QS701EW) dataset, there are figures that represent those that work mainly at or from home, and those not in employment, however these counts are only for persons between 16 and 74 years. Nevertheless, there is a high probability that the elderly ( $\geq 75$  years) will be situated in their homes during the day as well, and these numbers have been measured for the *Age* factor. Therefore, these datasets were combined to give an indication of a home population figure. Although, people tend to leave their houses during the day for shopping, commuting or other leisure activities, and children have not been considered here ( $\leq 16$  years), as it is assumed they would be at school or nursery (during term time); this is the best measurement possible for this factor with the data available. The Home Population was measured for each OA in each ward and applied within each wards CoFSVI. This factor and the Residential Population factor distinguished the difference between the day and night analyses.

Like the CoFPVI, each data variable representing each coastal flood socio-economic vulnerability factor was entered into MS-Excel. The data was first standardised using equation 4.6a/b (depending on the variables relationship to vulnerability – see Table 4.7), and where necessary for some variables, the  $X_{\min}$  was set as 0, as the number zero is significant when measuring vulnerability. The factor *Age* used more than one variable, therefore, Equation 4.7 was applied to the variables standardised values, creating a final standardised value for the *Age* factor. To create the CoFSVI values for day and night, equations 4.10a and 4.10b were applied (used by Sullivan and Meigh's (2003) CVI), and again the factors were weighted equally. The resulting index value ranges between 0 and 1; 0 representing very low vulnerability and 1 very high vulnerability. The same process of joining these results to ward polygons and displayed in ArcMap 10 was followed, and again vulnerability levels are displayed at 5 intervals (Damm, 2010; Lindley et al, 2011). All results for both CoFSVI day and night analyses for all wards at OA level can be seen in Figures 4.14, 4.15 and 4.16.

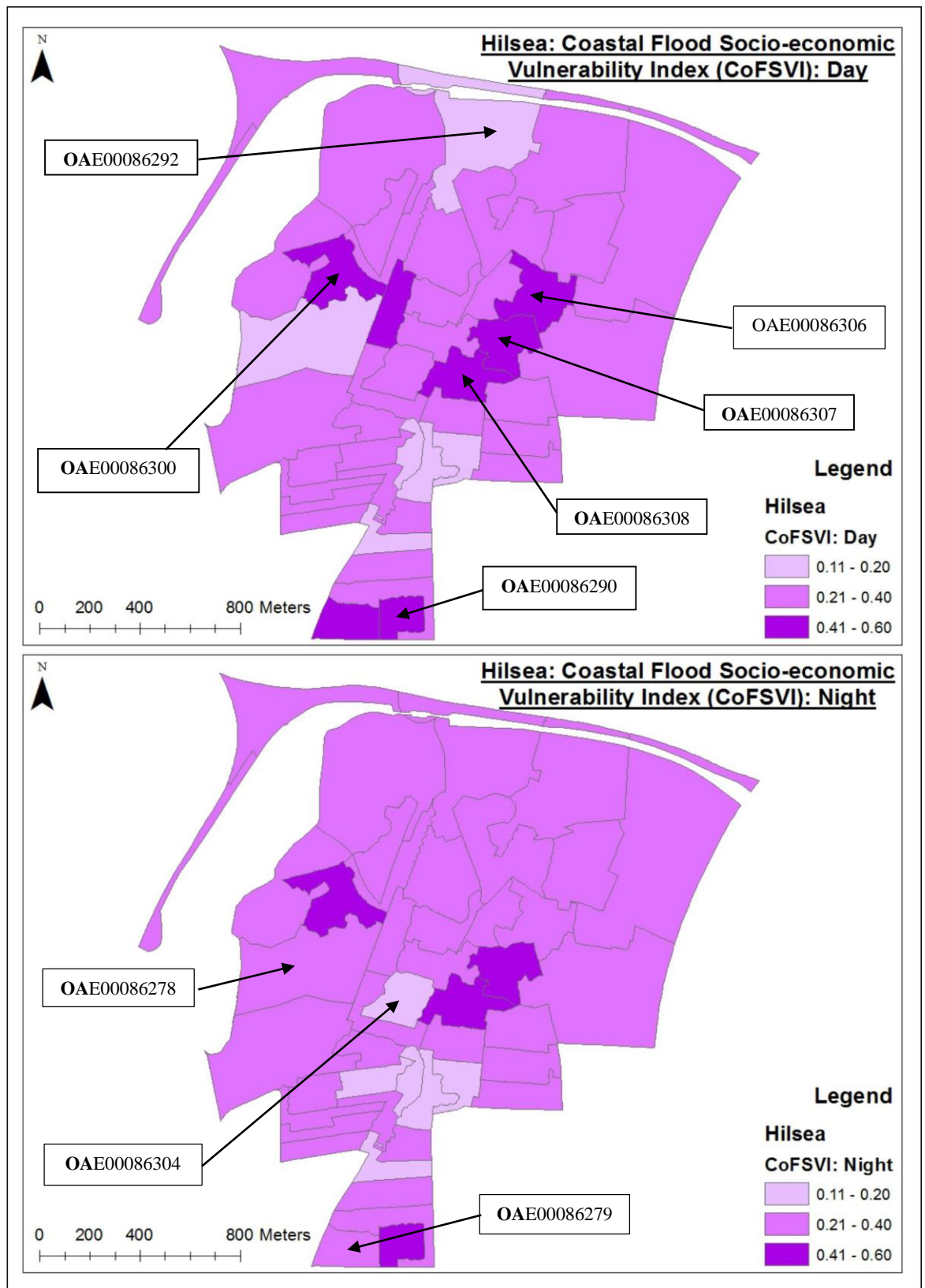
Equation 4.10a - Day

$$\text{Day CoFSVI} = \frac{(w_a A_S + w_{hs} HS_S + w_{id} ID_S + w_e E_S + w_{eco} Eco_S + w_{pupc} Pupc_S + w_{cr} CR_S + w_{hp} HP_S)}{(w_a + w_{hs} + w_{id} + w_e + w_{eco} + w_{pupc} + w_{cr} + w_{hp})}$$

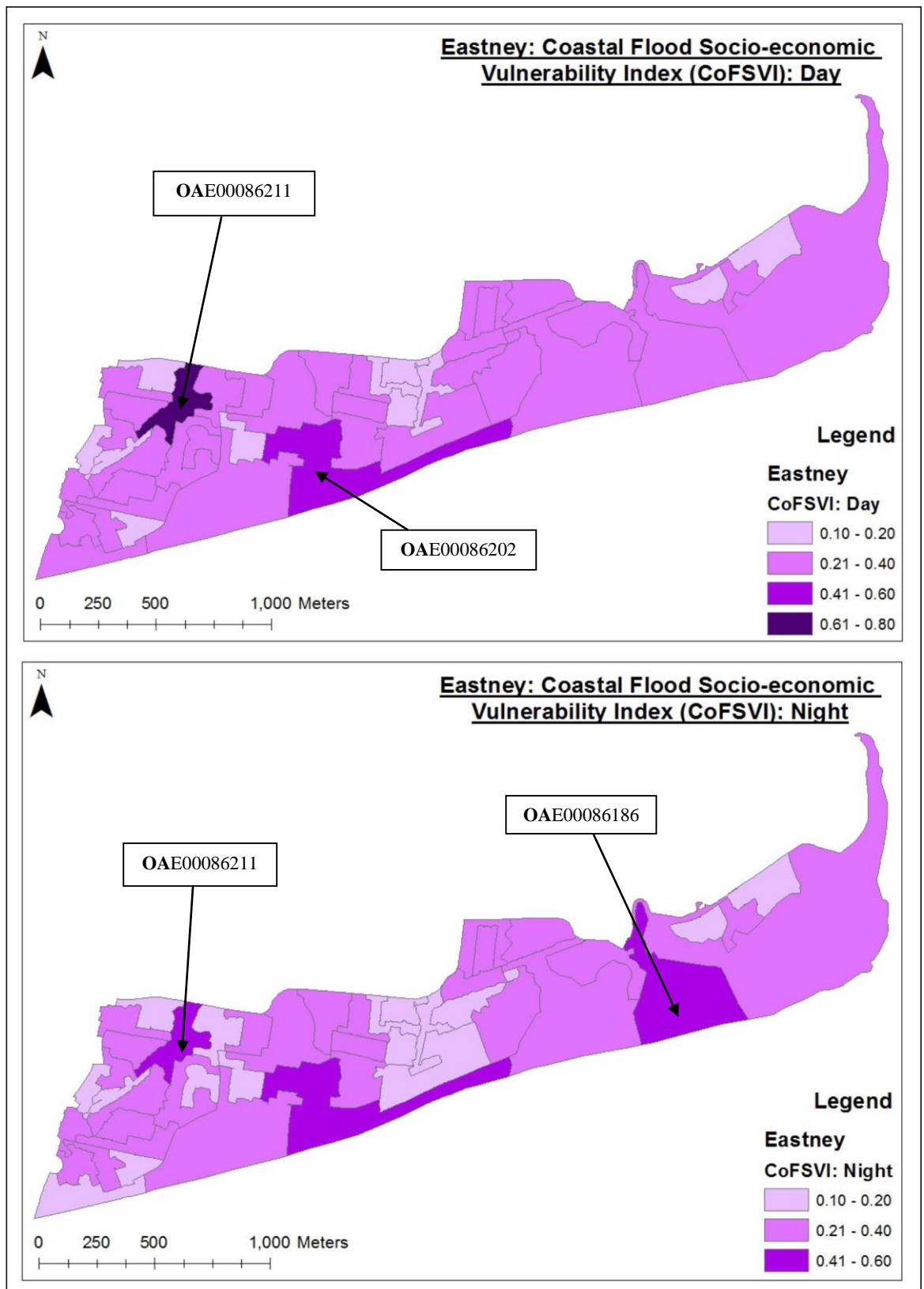
Equation 4.10b – Night

$$\text{Night CoFSVI} = \frac{(w_a A_S + w_{hs} HS_S + w_{id} ID_S + w_e E_S + w_{eco} Eco_S + w_{pupc} Pupc_S + w_{cr} CR_S + w_r R_S)}{(w_a + w_{hs} + w_{id} + w_e + w_{eco} + w_{pupc} + w_{cr} + w_r)}$$

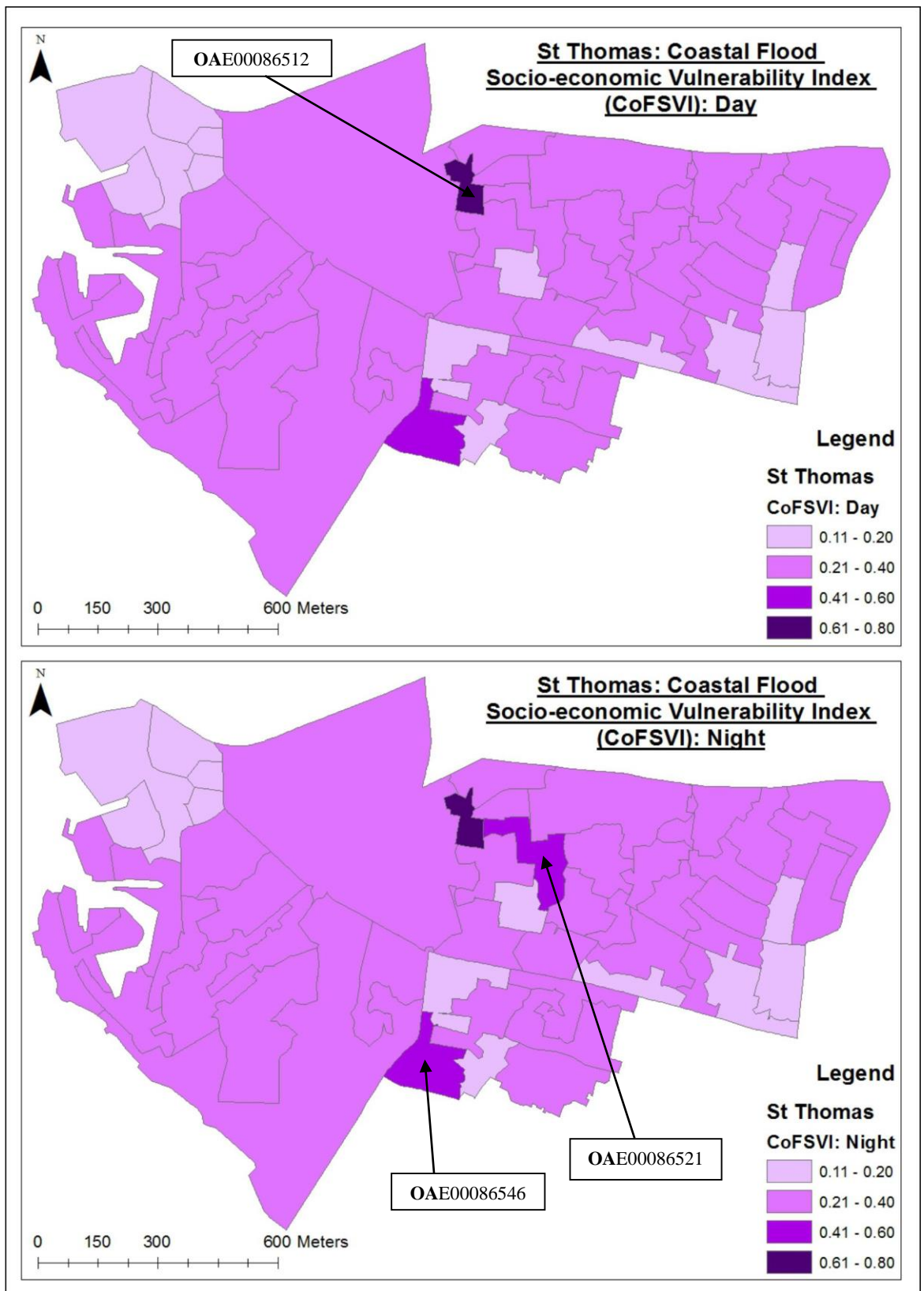
Where *CoFSVI* – Coastal Flood Socio-economic Vulnerability Index; *A<sub>S</sub>* – Age standardised; *HS<sub>S</sub>* – Household Structure standardised; *ID<sub>S</sub>* – Illness and Disability standardised; *E<sub>S</sub>* – Ethnicity and Race standardised; *Eco<sub>S</sub>* – Economics standardised; *Pupc<sub>S</sub>* – Providers of Unpaid Care standardised; *CR<sub>S</sub>* – Communal Establishment Residents standardised; *R<sub>S</sub>* – Residential Population standardised; *HP<sub>S</sub>* – Home Population standardised; *w<sub>a</sub>*, *w<sub>hs</sub>*, *w<sub>id</sub>*, *w<sub>e</sub>*, *w<sub>eco</sub>*, *w<sub>pupc</sub>*, *w<sub>cr</sub>*, *w<sub>hp</sub>*, *w<sub>r</sub>* – weights of factors.



**Figure 4.14.** CoFSVI for Hilsea ward at OA level – Day & Night. Socio-economic vulnerability ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting vulnerability levels.



**Figure 4.15.** CoFSVI for Eastney ward at OA level – Day & Night. Socio-economic vulnerability ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting vulnerability levels.



**Figure 4.16.** CoFSVI for St Thomas ward at OA level – Day & Night. Socio-economic vulnerability ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting vulnerability levels.

Overall for the day and night analysis the **Hilsea ward** has low socio-economic vulnerability. For the day analysis 6 OA's have very low socio-economic vulnerability and two OA's in particular have moderate socio-economic vulnerability (**OAE00086290** & **OAE00086300** – see Figure 4.14). **OA 6300** is due to having the highest counts of children, and single parents with dependent children in the ward. **OA 6290** has high counts of people with serious illnesses or disabilities, home population and communal care residents. It also has moderate counts of providers of unpaid care, economic value and people who do not speak English as their first language.

A night analysis decreases the number of OA's with a moderate socio-economic vulnerability level from seven to four. **OAE00086307** has the highest amount of providers of unpaid care and people with a lack of proficiency in English in the ward. It has a moderate amount of elderly and economic value. **OAE00086308** has a high amount of elderly, economic value and people with serious illnesses or disability; it also has the highest amount of communal establishment residents in the ward. However it has a low night population. **OAE00086304** has moderate economic value but low numbers of elderly, people who are seriously ill or disabled, providers of unpaid care, and critically a low residential population at night compared to a moderate home population during the day. **OAE00086279** has a high numbers of people who are seriously ill or disabled, moderate economic value and numbers of providers of unpaid care, but a low residential population count and numbers of elderly and children. Finally, **OAE00086278** socio-economic vulnerability level has increased from very low to low at night time. It has the lowest numbers of people who are seriously ill or disabled and providers of unpaid care in the ward, low numbers of elderly. However, it has a high residential population level, and high numbers of children. Overall within the ward residential populations at night are not as high as home populations during the day, therefore fewer areas are susceptible, compared to the day analysis.

For the day analysis, **Eastney** has overall low socio-economic vulnerability, with one particular neighbourhood that has high socio-economic vulnerability (**OA6211**). Eleven OA's have very low CoFSV values and one has moderate socio-economic vulnerability (**OAE00086202** – see Figure 4.15). **OA6211** has high levels due to the highest counts in the ward of the elderly, people with serious illness or disability, day population and

communal establishment residents. **OA6202** is the most expensive neighbourhood with average house prices just under £500,000, and high numbers of people providing unpaid care.

Again, for the night time analysis the overall socio-economic vulnerability for the ward decreases. Sixteen OA's have very low levels of socio-economic vulnerability and 1 OA has progressed from low to moderate, while OA's 6202 and 6211 now have moderate socio-economic vulnerability; this is due to moderate and high (respectively) night population levels. **OA6211** has decreased in CoFSV levels due to a high night population, unlike its day population, which was the highest in the ward. However, **OA6211** still has the highest CoFSV score for the ward at 0.58.

**St Thomas ward** predominantly has low socio-economic vulnerability during the day, with the exception of neighbourhood, **OAE00086512** (Figure 4.16), has high socio-economic vulnerability: the highest numbers of people with serious illness or disability, children, providers of unpaid care, single parent families with dependent children, and people for whom English is not their first language. However, it has a very low elderly population, low economic value and no communal care residents; hence a high CoFSV value (0.62).

For the night analysis very little changes except **OAE00086521** goes from low to moderate CoFSV, and **OA6546** and **OA6512** stay at the same level they were for the day analysis. **OA6546** has moderate CoFSV due to having the highest resident population count in the ward. It is also has the highest communal establishment resident count in the ward and **OA6521** has high counts of providers of unpaid care, resident population and single parents with dependent families. Overall the ward has low socio-economic vulnerability.

#### 4.4.4 The Coastal Flood Limited Resilience Index (CoFLRI)

To create the equal weighted Coastal Flood Limited Resilience Index (CoFLRI) involved a mixture of and UK National Census 2011 and Ordnance Survey data (Chapter 3 section 3.3). The new land use classification system created for this project, supplied one of the data variables for the analysis of this coastal flood vulnerability component.

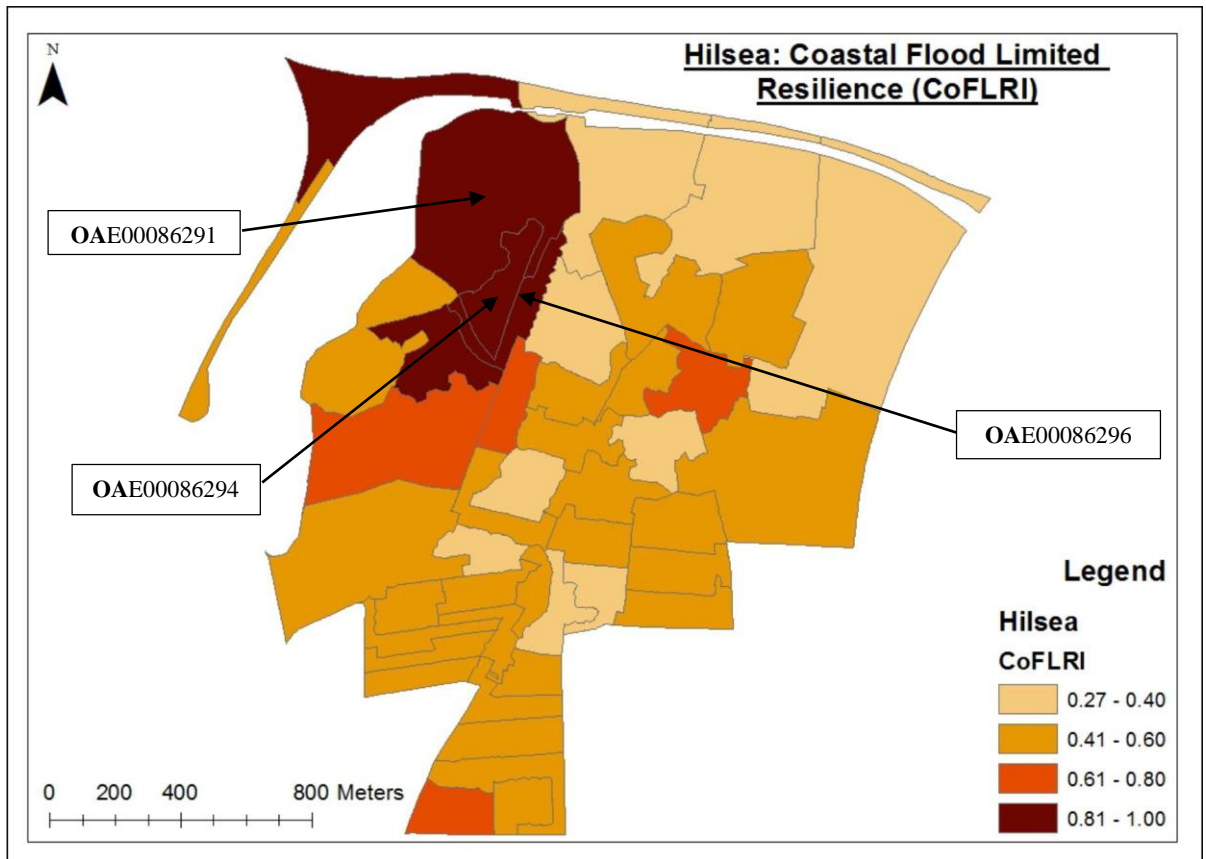
For this analysis, four coastal flood limited resilience factors were used. There is no separate day and night analysis for this vulnerability component. Each data variable representing each CoFLR factor was entered into MS-Excel. The data was first standardised using equation 4.6a/b (depending on the variables relationship to vulnerability – see Table 4.8) and where necessary for some variables, the  $X_{min}$  was set as 0. No factors in this component used more than one variable. To create the CoFLRI values, Equation 4.11 was applied (used by Sullivan and Meigh’s (2003) CVI), and again the factors were weighted equally. The resulting index value ranges between 0 and 1; 0 representing very low limited resilience and 1 very high limited resilience. The CoFLRI of each ward was joined to OA level ward polygons and displayed in ArcMap 10. Limited resilience levels are displayed at 5 intervals (Damm, 2010; Lindley et al, 2011). All CoFLRI results are shown in Figures 4.17-4.19.

*Equation 4.11 – Day and Night*

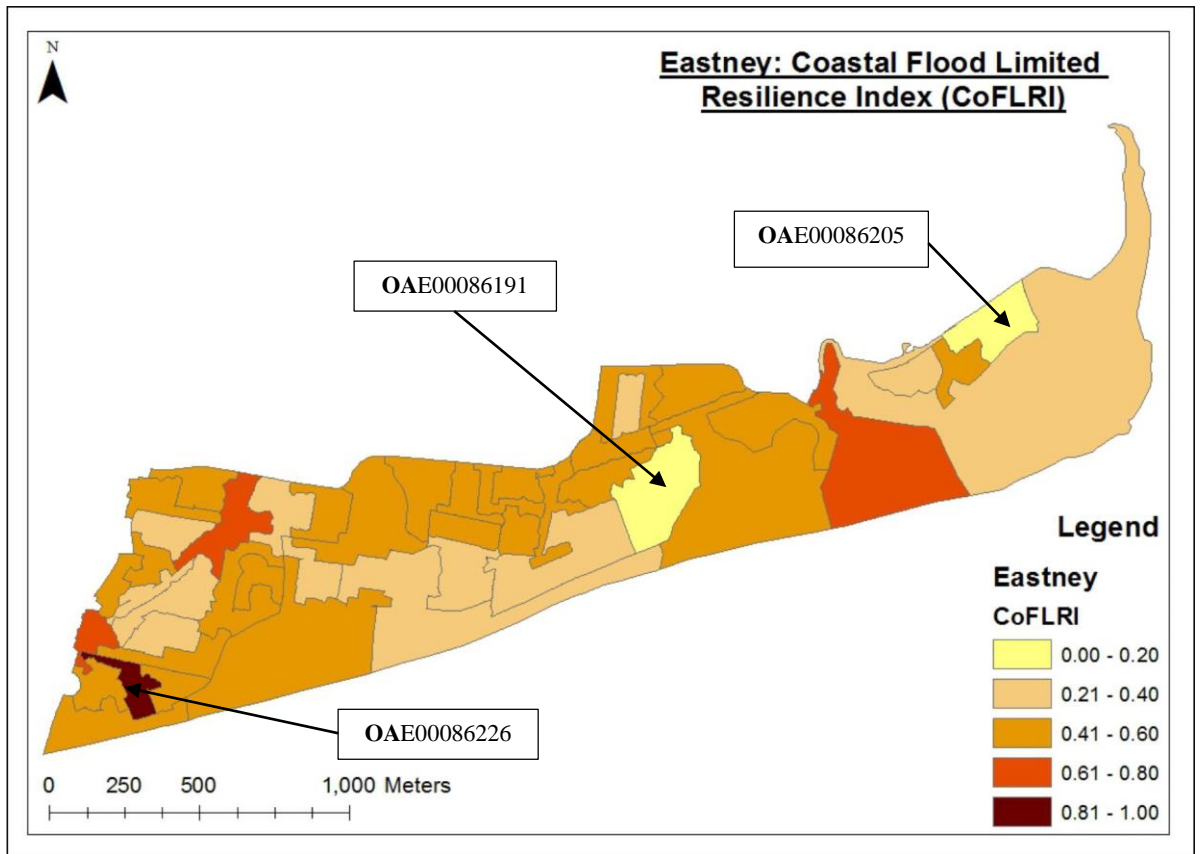
$$CoFLRI = \frac{(w_{soc}Soc\_S + w_{edu}Edu\_S + w_{em}Em\_S + w_cC\_S)}{w_{soc} + w_{edu} + w_{em} + w_c}$$

Where *CoFLRI* – Coastal Flood Limited Resilience Index; *Soc\_S* – Socio-economic Status standardised; *Edu\_S* – Education standardised; *Em\_S* – Emergency Facilities standardised; *C\_S* – Car Availability standardised;  $w_{soc}$ ,  $w_{edu}$ ,  $w_{em}$ ,  $w_c$  – weights of factors.

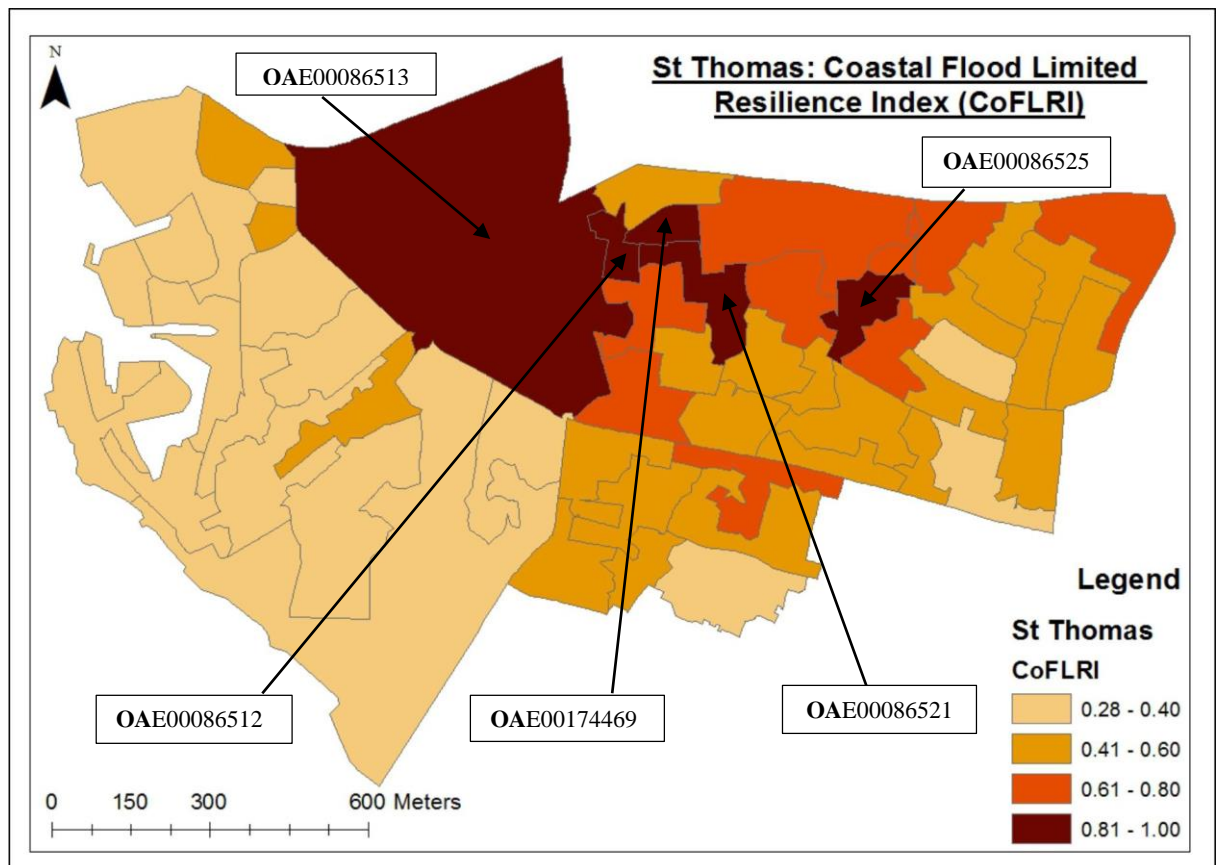




**Figure 4.17.** CoFLRI for Hilsea ward at OA level. Limited resilience ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting limited resilience levels.



**Figure 4.18.** CoFLRI for Eastney ward at OA level. Limited resilience ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting limited resilience levels.



**Figure 4.19.** CoFLRI for St Thomas ward at OA level. Limited resilience ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting limited resilience levels.

**Hilsea** has predominantly moderate limited resilience. Four OA's have high limited resilience and another four have very high limited resilience (**OAE00086291**, **OAE00086296**, **OAE00086294** and **OAE00086300** - see Figure 4.17). **OA6291** has no emergency facilities and very high counts of unemployed people or those with little or no education. **OA6296** also has no emergency facilities and high levels of unemployment and lack of education. It has the highest number of households with no car availability in the ward and has the highest level of overall limited resilience in Hilsea (0.83). **OA6294** has the highest levels of lack of education and unemployment in the Hilsea ward, no emergency facilities, but a low level of households with no car/s available. Lastly **OA6300** has a very high level of unemployment and high numbers of houses with no cars available and high lack of education levels. OA's with higher resilience are concentrated in the north east of the ward.

The majority of OA's in **Eastney and Craneswater** have moderate limited resilience. Three OA's have high limited resilience and one (**OAE00086226**) has very high limited resilience – 0.84. It has the highest amount of unemployed and numbers of households with no car availability in the ward. It also has no emergency facilities present. There are two OA's (**OAE00086191** and **OAE00086205** - see Figure 4.18) that have very low limited resilience levels, due to an emergency facility available, very low numbers of unemployed and households with no car availability in **OA6191**. **OA6205** again has an emergency facility located in the area, very low numbers of households with no car availability and the lowest levels of unemployed and lack of education in the ward. This neighbourhood has the highest level of resilience in the ward.

The western part of **St Thomas** has low levels of limited resilience. The eastern side contains many OA's that have either moderate or high limited resilience. There are five OA's (see Figure 4.19) with very high limited resilience and they are concentrated mostly in the northern part of the ward (**OAE00086513**, **OAE00086512**, **OAE00174469**, **OAE00086525**, and **OAE00086521**). No emergency facilities are present in these five neighbourhoods. **OA's** 4469, 6521, and 6525 have very high unemployment levels; the latter OA has the highest numbers in the ward. All OA's have high numbers of lack of education; 4469 has the highest count in the ward. **OA's** 6512 and 6513 have very high numbers of households with no car availability; the latter OA has the highest number in the St Thomas ward. The neighbourhood 6525 is the least resilient within the ward – 0.89.

#### 4.4.5 Coastal Flood Vulnerability Index (CoFVI)

To create the equally weighted Coastal Flood Vulnerability Index (CoFVI) for the three wards, involved the combination of the Day CoFPVI, Day CoFSVI and CoFLRI in equations 4.12a (based on Sullivan and Meigh's (2003) CVI equation and the developed risk, hazard, vulnerability equation set in this research – equation 2.2, Chapter 2) for the day analysis. Night CoFPVI, Night CoFSVI and CoFLRI in equation 4.12b (based on Sullivan and Meigh's (2003) CVI equation and the developed risk, hazard, vulnerability equation set in this research – equation 2.2, Chapter 2) for the night analysis. Both within MS-Excel. The resulting index value ranges between 0 and 1; 0 representing very low vulnerability and 1 very high vulnerability. The CoFVI of each ward was joined to OA level ward polygons and displayed in ArcMap 10. Vulnerability levels are at 5 intervals

intervals (Damm, 2010; Lindley et al, 2011) between 0 and 1; 0.0-0.2 – **very low vulnerability**; 0.21-0.4 – **low vulnerability**; 0.41-0.6 – **moderate vulnerability**; 0.61-0.8 – **high vulnerability**; and 0.81-1.0 – **very high vulnerability**. However, for display purposes the CoFVI results are displayed between 0.15 – 0.65, in order to show distinction of vulnerability between neighbourhoods for each ward. All CoFVI results are shown in Figures 4.20, 4.21 and 4.22.

*Equation 4.12a – Day*

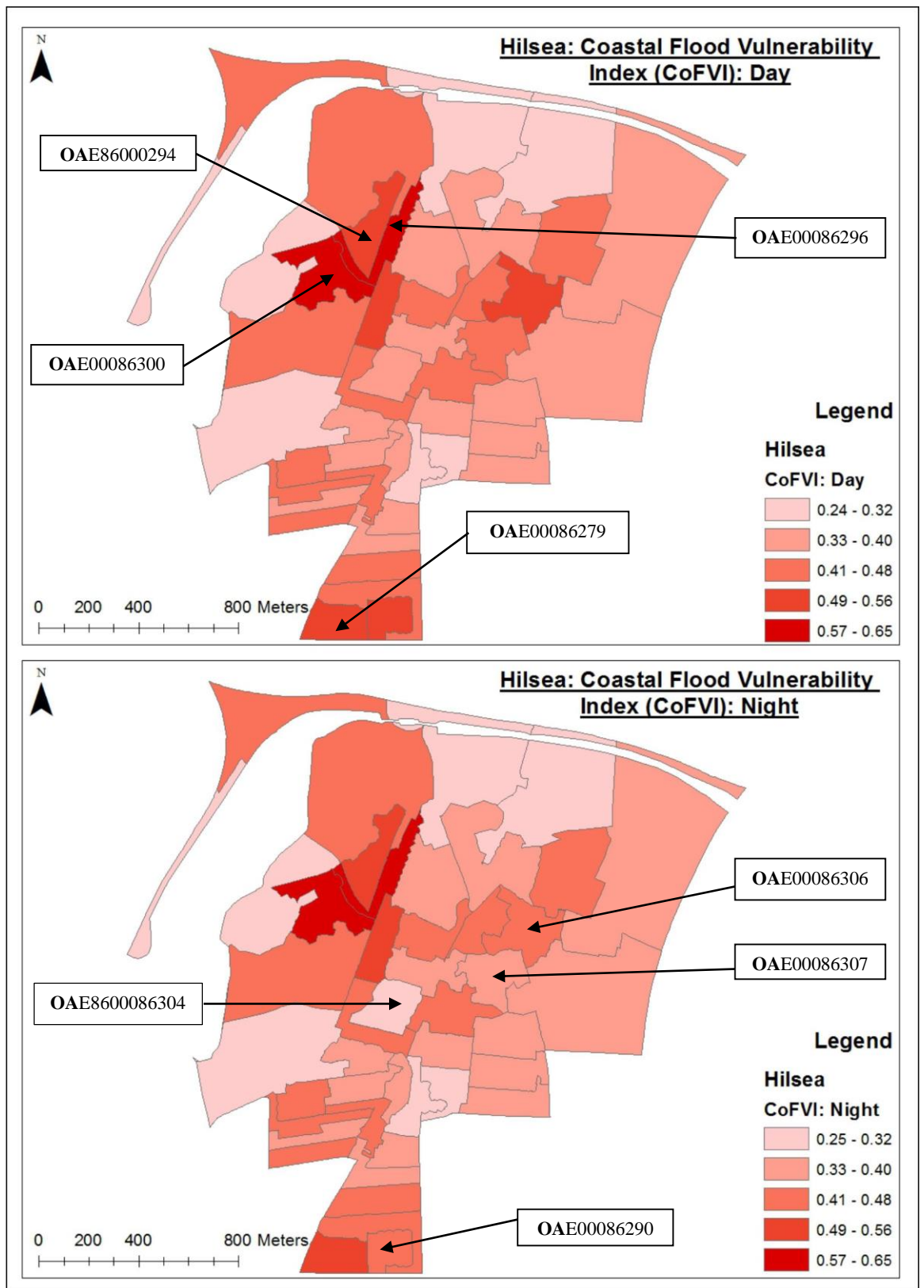
$$\text{Day CoFVI} = \frac{w_{cofpvid}CoFPVid + w_{cofsvid}CoFSVid + w_{coflri}CoFLRI}{w_{cofpvid} + w_{cofsvid} + w_{coflri}}$$

Where *Day CoFVI* – Coastal Flood Vulnerability Index Day; *CoFPVid* – Coastal Flood Physical Vulnerability Index Day; *CoFSVid* – Coastal Flood Socio-economic Vulnerability Index Day; *CoFLRI* – Coastal Flood Limited Resilience Index;  $w_{cofpvid}$ ,  $w_{cofsvid}$ ,  $w_{coflri}$  – weights of vulnerability components.

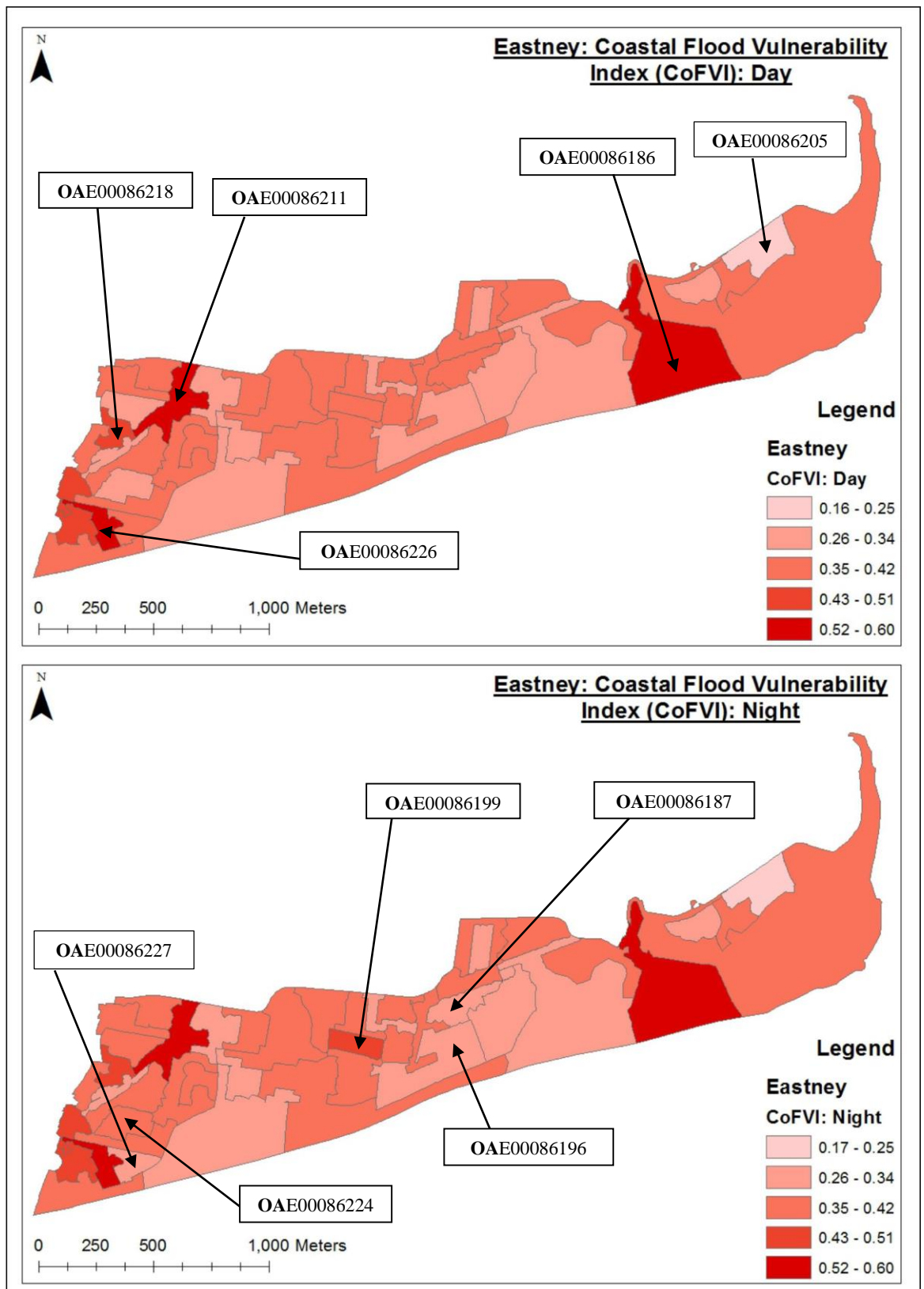
*Equation 4.12b – Night*

$$\text{Night CoFVI} = \frac{w_{cofpvin}CoFPVIN + w_{cofsvin}CoFSVIN + w_{coflri}CoFLRI}{w_{cofpvin} + w_{cofsvin} + w_{coflri}}$$

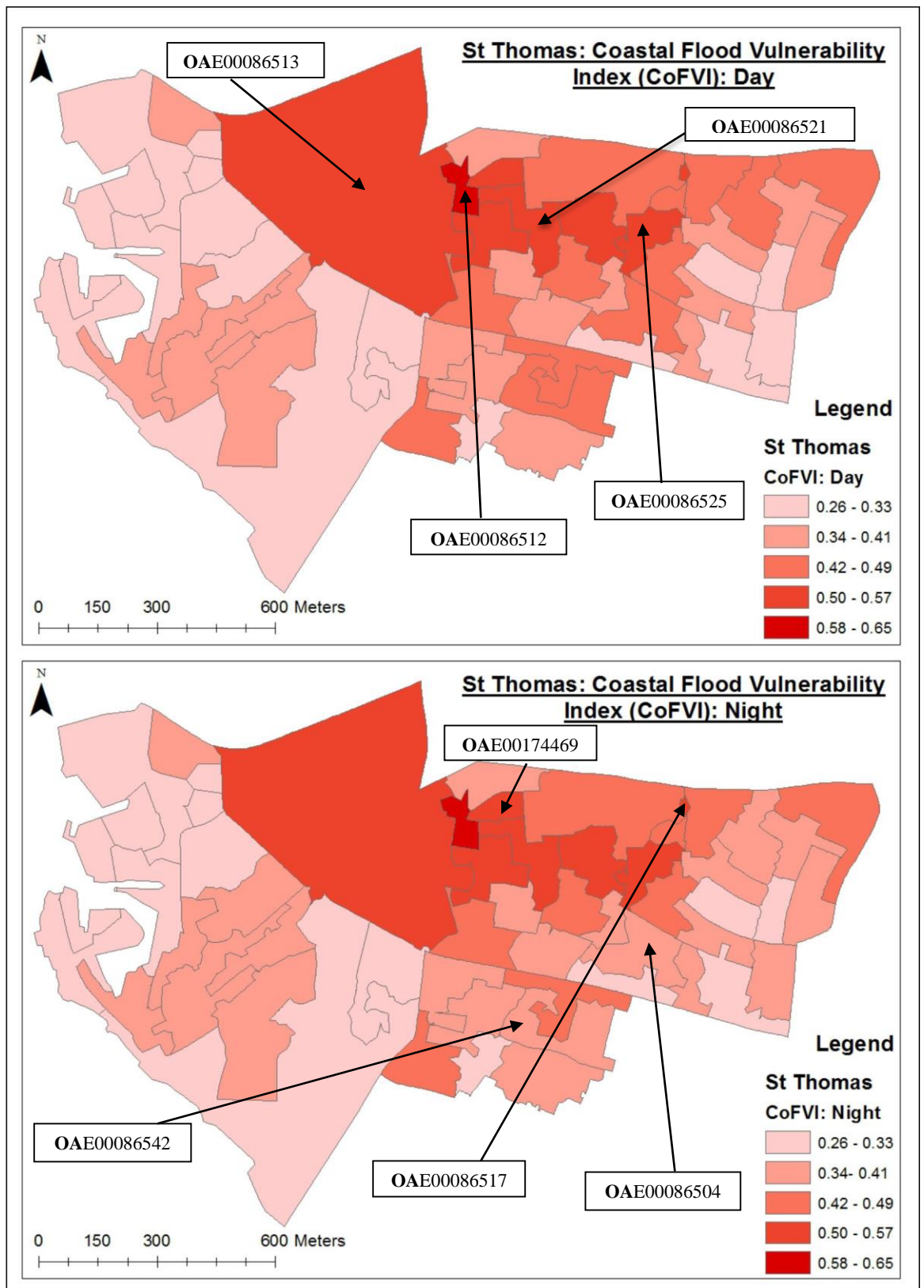
Where *Night CoFVI* – Coastal Flood Vulnerability Index Night; *CoFPVIN* – Coastal Flood Physical Vulnerability Index Night; *CoFSVIN* – Coastal Flood Socio-economic Vulnerability Index Night; *CoFLRI* – Coastal Flood Limited Resilience Index;  $w_{cofpvin}$ ,  $w_{cofsvin}$ ,  $w_{coflri}$  – weights of vulnerability components.



**Figure 4.20.** CoFVI for Hilsea ward at OA level – Day & Night. Vulnerability ranges: **0.00-0.20** – very low; **0.21-0.40** – low; **0.41-0.60** – moderate; **0.61-0.80** – high; and **0.81-1.00** – very high. Arrows highlight certain Output Areas due to resulting vulnerability levels.



**Figure 4.21.** CoFVI for Eastney ward at OA level – Day & Night. Vulnerability ranges: **0.00-0.20** – very low; **0.21-0.40** – low; **0.41-0.60** – moderate; **0.61-0.80** – high; and **0.81-1.00** – very high. Arrows highlight certain Output Areas due to resulting vulnerability levels.



**Figure 4.22.** CoFVI for St Thomas ward at OA level – Day & Night. Vulnerability ranges: **0.00-0.20** – very low; **0.21-0.40** – low; **0.41-0.60** – moderate; **0.61-0.80** – high; and **0.81-1.00** – very high. Arrows highlight certain Output Areas due to resulting vulnerability levels.



For the **Hilsea** ward day analysis (Figure 4.20) the majority of Output Areas (OA) have low or moderate Coastal Flood Vulnerability (CoFV) levels (between 0.33-0.60), and are mostly situated to the east of the ward. Six OA's particularly have low CoFV and these are mostly situated to the south of the ward, with two on the coastline to the north of the ward. The neighbourhoods **OAE00086300** and **OAE00086296** have very high moderate CoFV levels overall within the ward, at 0.59 and 0.58; these are situated adjacent to each other at the north end of the ward, and very close to the coastline. These levels are due to very high limited resilience, and moderate physical and socio-economic vulnerability. **OA6300** has the highest amount of children, lone parents with dependent children, dwelling addresses, renters, very high unemployed numbers, high day population, very little green space and transport links, and no essential buildings. **OA6296** has very little green space and transport links; very high numbers of renters and multiple residency buildings; high unemployed numbers and the highest number within the ward of households with no car availability. Output areas **OAE00086300**, **OAE00086296** and **OAE00086294** also have the highest CoFV levels within the ward.

The night analysis presents change for the Hilsea CoFVI results; now **OA 6300** has high CoFV at 0.61, whereas **OA 6296** still has moderate CoFV. The former neighbourhood has the highest night population within the ward, therefore increasing the night vulnerability level, resulting in **OA6300** having the highest overall vulnerability level in Hilsea for both day and night. **OA6296** compared to other neighbourhoods in the ward has a very low night population, hence decreasing its overall CoFV level. Another OA that has decreased in vulnerability from day to night is **OA6307**; this is due to a moderate day population but a low night population within this ward, hence why the difference is <0.1. With the new day and night populations, there are differences in vulnerability for all OA's from a day to a night analysis, however most are very small i.e. 0.02-0.05.

For the day and night analysis the majority of the **Eastney** ward (Figure 4.21) has between low to moderate CoFV. The three neighbourhoods **OAE00086211**, **OAE00086226** and **OAE00086186** have the highest vulnerability levels; 0.55, 0.56 and 0.51. **OA6226** has very high limited resilience but low socio-economic vulnerability due to no emergency facilities, and the highest numbers of households with no cars and unemployment numbers; very high numbers of dwellings, renters and multiple residency buildings; but very low

numbers of children, elderly and house values within the ward. Whereas **OA6211** has high socio-economic vulnerability and limited resilience due to the highest numbers of elderly, people with serious illnesses or disabilities, communal establishment residents, day population and numbers with no or little education. Lastly **OA6186** has moderate physical and socio-economic vulnerability, but high limited resilience because of high numbers of people with no or little education and no emergency facilities; high numbers of providers of unpaid care and lone parents with many dependent children, but low levels economically and proficiency in English.

**OAE00086205** has very low coastal flood vulnerability for both day and night analysis. The neighbourhoods **OA6187** and **OA6227** decrease in coastal flood vulnerability for the night analysis, but only very slightly – 0.01. However, **OA6199** coastal flood vulnerability level increases at night. This is due to a moderate home population during the day but the highest residential population in the ward at night time. Overall CoFV levels change only slightly from day to night time.

Apart from seven Output Areas that are mostly adjacent or very near to one another; **St Thomas** has low to moderate coastal flood vulnerability (Figure 4.22). One neighbourhood has the highest Coastal Flood Vulnerability level for both the day and night analyses – **OAE00086512** (0.61 – day; and 0.64 – night). This is due to having the highest numbers of children, the sick or disabled, providers of unpaid care, lone parents with dependent children, those who cannot speak English; very low amount of green space, no main transport links, very high night population, renters and very high numbers of those with no education or households with car availability. The 3 neighbourhoods with high moderate CoFV are **OAE00086521**, **OAE00086525** and **OAE00174469**. These have mixtures of very high numbers of uneducated, unemployed and multiple residency buildings; high numbers of providers of unpaid care, night populations, households with no cars, lone parents with dependent children; no main transport links in the areas or essential buildings; all these factors increase vulnerability, however, these areas also have low numbers of children and elderly and population density, low to very low economic values and no vulnerable buildings that balance the overall CoFV to a moderate level. Both **OA6504** and **OA6542** CoFV levels lower from day to night. However, the drop in levels is more considerable for **OA6504**, this is due to the lack of vulnerable buildings that are no longer

vulnerable at night time, hence lowering the areas vulnerability for a night time flood. The low vulnerability neighbourhoods are clustered in the western part of the ward, while the more vulnerable are in the north.

#### 4.5 The Coastal Flood Risk Index (CoFRI)

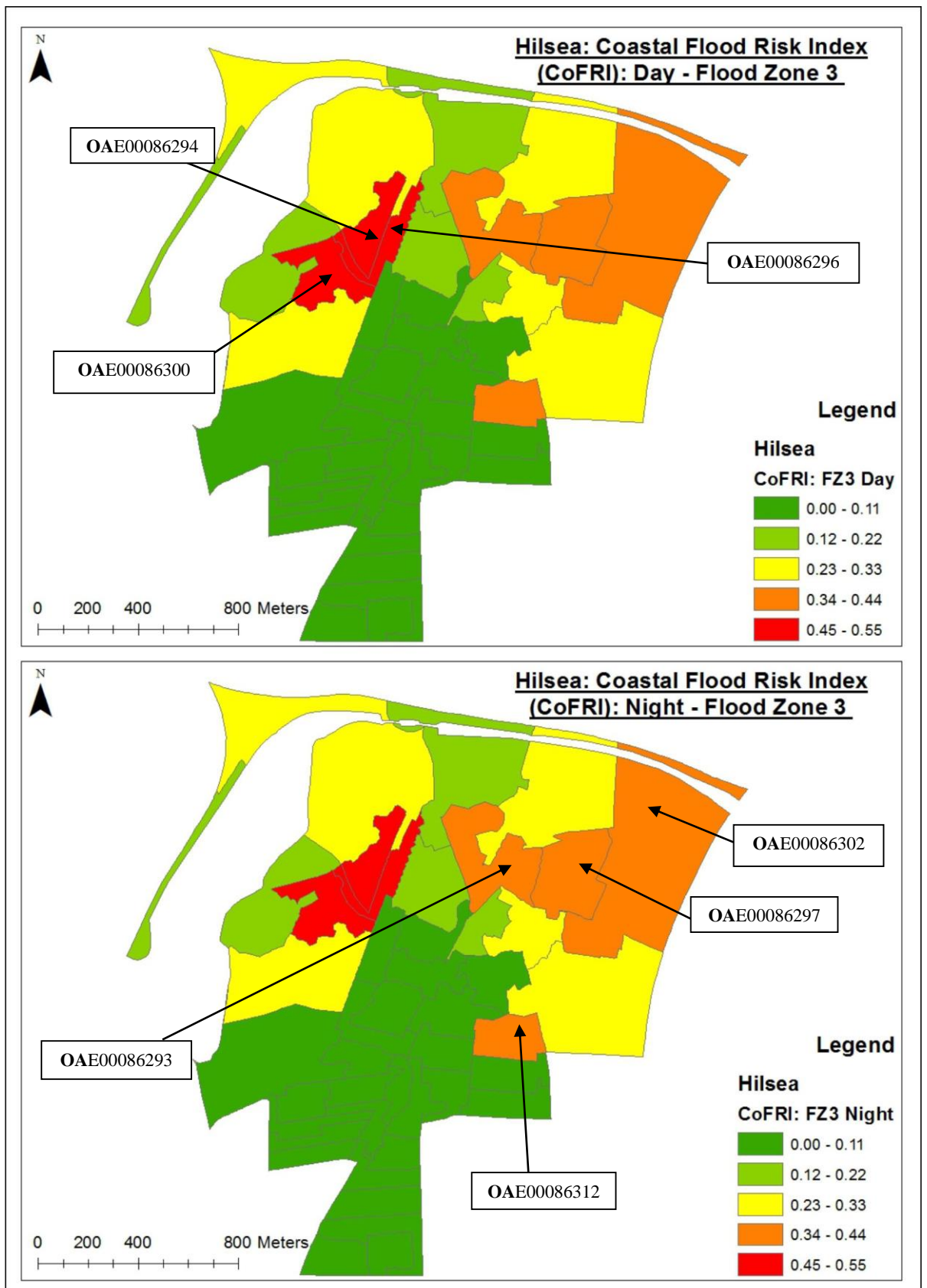
The last stage of the analysis involved creating the equally weighted Coastal Flood Risk Index (CoFRI). This involved combining the *Day* and *Night* CoFVI results with the *Flood Zone 3 (FZ3)* and *Flood Zone 2 (FZ2)* CoFHI results in Equation 4.13 (based on the original risk, hazard vulnerability equation – equation 2.1, Chapter 2). This resulted in four different CoFRI for each ward – Day CoFRI (FZ3); Night CoFRI (FZ3); Day CoFRI (FZ2); and Night CoFRI (FZ2).

*Equation 4.13*

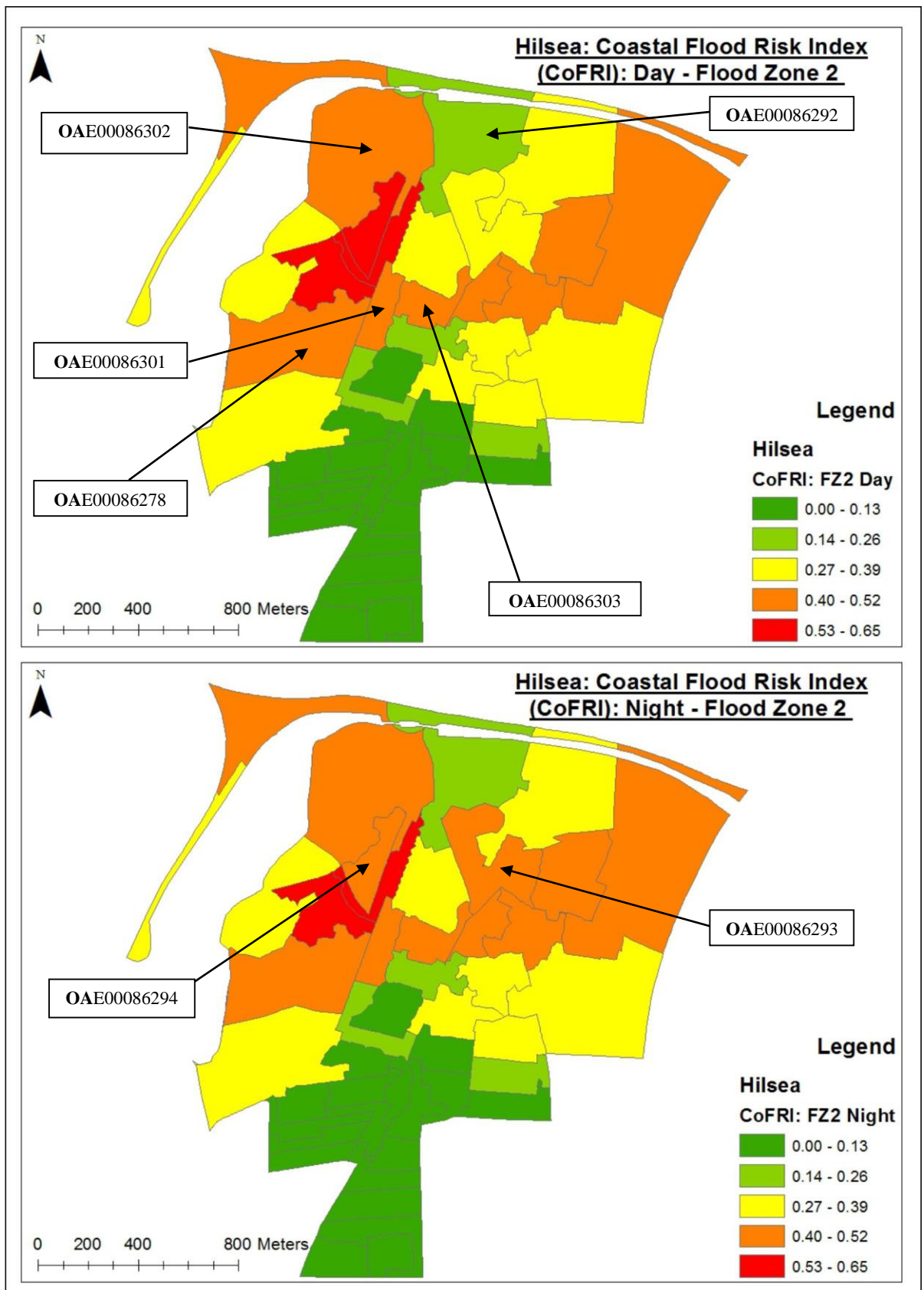
$$\text{Coastal Flood Risk (CoFRI)} = \text{CoFHI} * \text{CoFVI}$$

Where *CoFRI* – Coastal Flood Risk Index; *CoFHI* – Coastal Flood Hazard Index; *CoFVI* – Coastal Flood Vulnerability Index.

Risk levels are at 5 intervals (Damm, 2010; Lindley et al, 2011) between 0 and 1; 0.0-0.2 – **very low risk**; 0.21-0.4 – **low risk**; 0.41-0.6 – **moderate risk**; 0.61-0.8 – **high risk**; and 0.81-1.0 – **very high risk**. All CoFRI results for Hilsea are presented in Figures 4.23 and 4.24; for Eastney Figures 4.25 and 4.26; lastly for St Thomas, Figures 4.27 and 4.28.



**Figure 4.23.** CoFRI for Hilsea ward at OA level – FZ3 Day & Night. Risk ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting risk levels.



**Figure 4.24.** CoFRI for Hilsea ward at OA level – FZ2 Day & Night. Risk ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting risk levels.

For a Flood Zone 3 (FZ3) event during the day and night, the ward of **Hilsea** has three OA's that are most at risk – **OAE00086294**, **OAE00086296** and **OAE00086300** (Figure 4.23). These three neighbourhoods have been dominant at displaying high levels of vulnerability for all three of the vulnerability component analyses (CoFPV, CoFSV & CoFLR). A combination of highly moderate CoFVI results and very high flood zone coverage (predominantly containing flood water described as dangerous for some (Atkins, 2007) – deep or fast flowing) of these areas; **OA's** 6294, 6296 & 6300 have highly moderate Coastal Flood Risk compared to the other neighbourhoods in this ward.

The risk levels for the centre and southern end of the ward are very low, and for some OA's it is zero, due to no flood water coverage predicted in these areas. Northwards from the centre of the ward, all OA's surrounded by the coastline are at risk. To the north eastern end, there are seven neighbourhoods adjacent to one another that have low to moderate risk; four of these in particular – **OA's** 6297, 6302, 6312, and 6293. **OA** 6297 has the highest CoFRI of these four at 0.42, due to a very high flood zone coverage (0.98) and moderate CoFV (0.43). For a FZ3 event, there is very little to no difference between the day and night time analysis results, and what differences are present are not visible via ArcMap.

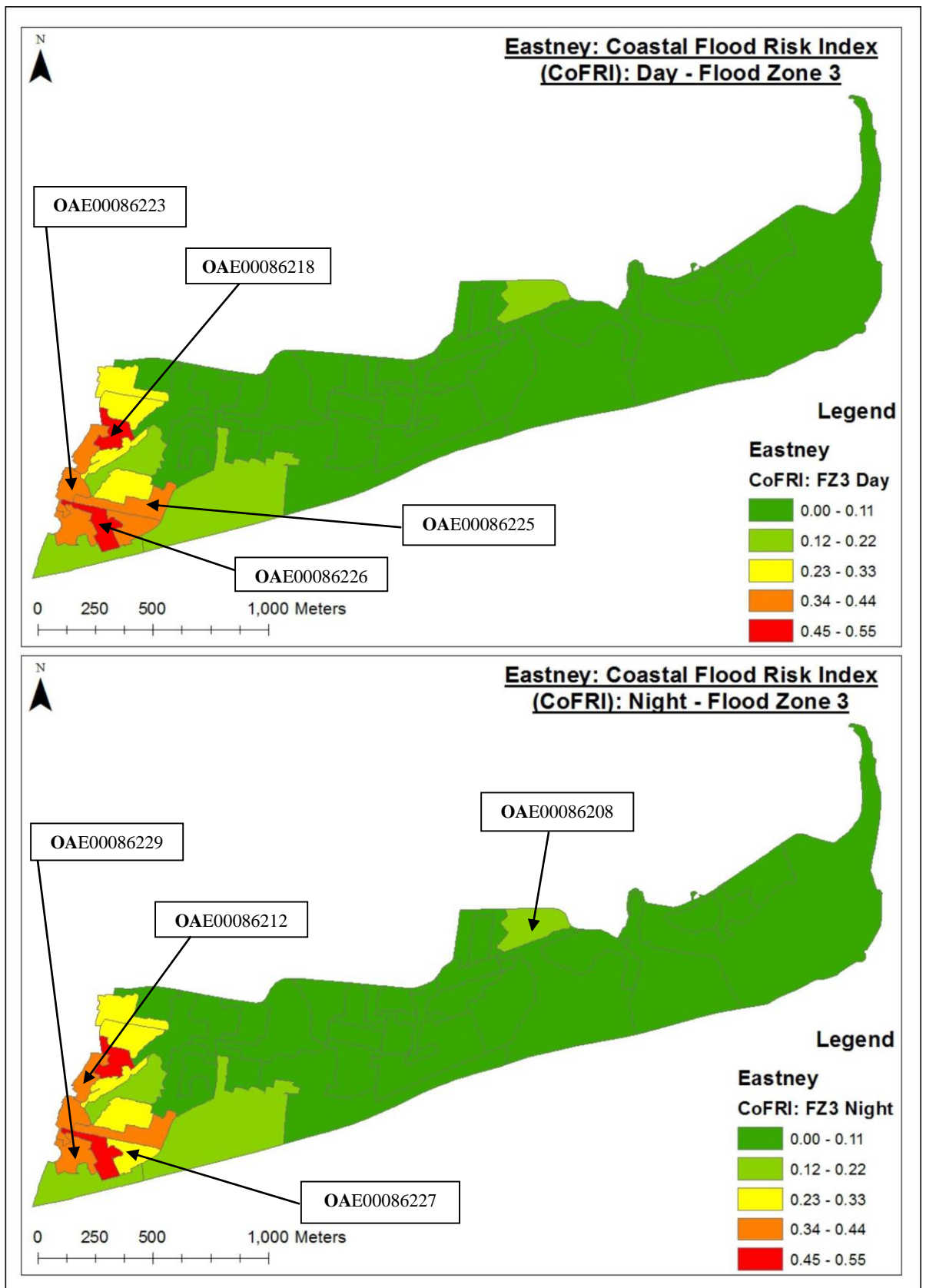
For a Flood Zone 2 (FZ2) event, many more OA's have risk levels compared to a FZ3 event: 20 OA's had no risk level for a FZ3 event, whereas this was reduced to 15 for a FZ2 event. This is due to more flood water inundating areas, and spreading further into the ward, affecting more OA's in the centre and further south compared to a FZ3. No OA within the FZ3 event had a CoFR level higher than 0.55 (moderate risk), whereas for a night FZ2 event, **OAE00086300** reaches 0.61 (high risk). The southern end of the ward has still very low or no risk as the flood water would simply not travel this far. This part of the ward is certainly the safest with regard to coastal flooding, which is advantageous as some of the neighbourhoods' at the most southern end all had moderate vulnerability levels.

Again the three **OA's** 6300, 6296, and 6294 have the highest coastal flood risk levels within the ward for a FZ2 event (flood depths predominantly 0.25-1.25 m with velocities between 0.5-2.5 ms<sup>-1</sup> – meaning dangerous for most people, but especially children and the elderly (Atkins, 2007)). However, **OA** 6294 is displayed as orange in the night analysis

rather than red as in the day analysis. The actual change in level is only 0.01, due to a low night population, but high day population, and therefore not that significant, however, due to the category ranges in the ArcMap settings, the result appears more so.

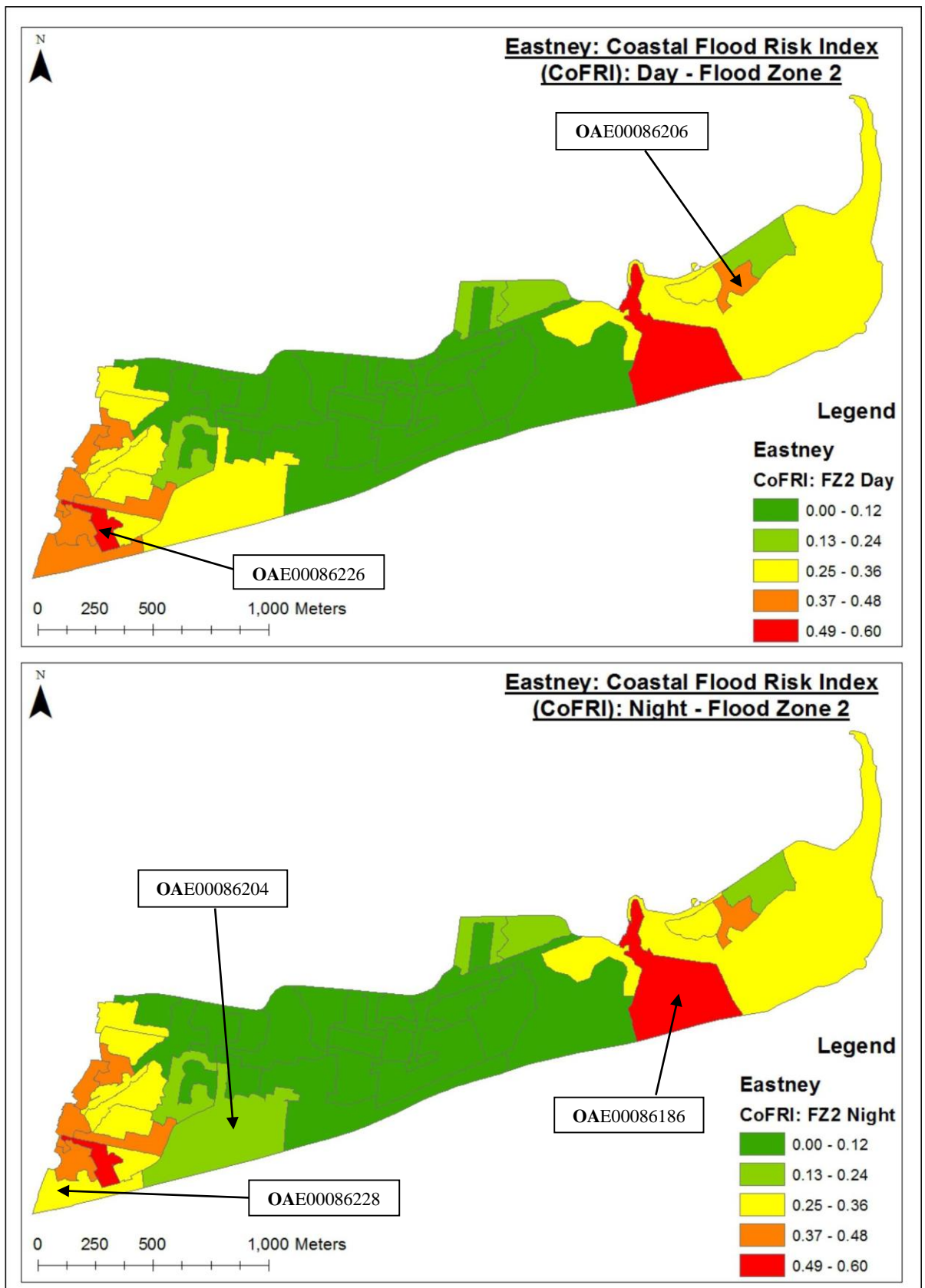
The eastern and western coastline OA's of the ward range from low to moderate CoFR levels, with three OA's showing high moderate or high CoFR. **OA**E00086292 is situated on the northern coastline of the ward, and although almost would have full coverage by flood water (specifically from a FZ2 event), the risk levels are low, due to low CoFV levels (0.25). These low levels are due to many very low levels for the individual vulnerability factors including children, elderly, sick, lone parents, non-English speakers, communal community residents, households without cars, multiple residency buildings, renters, commercial and industrial buildings. Overall there is an obvious increase in the ward's Coastal Flood Risk levels for the magnitude of a FZ2 event, and this is demonstrated in Figure 4.24.

The **Eastney** ward has very little to no Coastal Flood Risk, apart from the western end of the ward for a day or night, Flood Zone 3 event (see Figure 4.25). However, this area is very compact with residents, basement level residency, some commercial buildings and very little green areas. The beach is also narrower in width at this point (South Parade Pier) and continues to be (eastwards) until the Coffee Cup, the only commercial property on the eastern end of the beach (described in Section 4.4). **OA**E00086218 and **OA**E00086226 overall have the highest CoFR levels for the ward at 0.44 and 0.53 (flood water in **OA**6226 will be predominantly be very dangerous with depths ranging from 0.75-2.5 m at a speed of 1-5 ms<sup>-1</sup>). This is due to moderate CoFV levels combined with very high, almost total flood water coverage of the area (0.99 for **OA**6218). These areas where CoFR levels are at their most prominent for a flood of this magnitude, unfortunately dip below sea level, hence why flood water would prominently cover these areas. There are many renters and multiple residency buildings packed into this popular area. Economically these areas fluctuate compared to the rest of the ward. Areas such as Craneswater Park, around Whitwell Road, and near Canoe Lake have very high house prices, some exceeding £1 million; whereas areas prominently in the flood zone such as **OA**6218 and **OA**6223 have some of the lowest. It is fortunate that despite large amounts of potential flood water



**Figure 4.25.** CoFRI for Eastney ward at OA level – FZ3 Day & Night. Risk ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting risk levels.



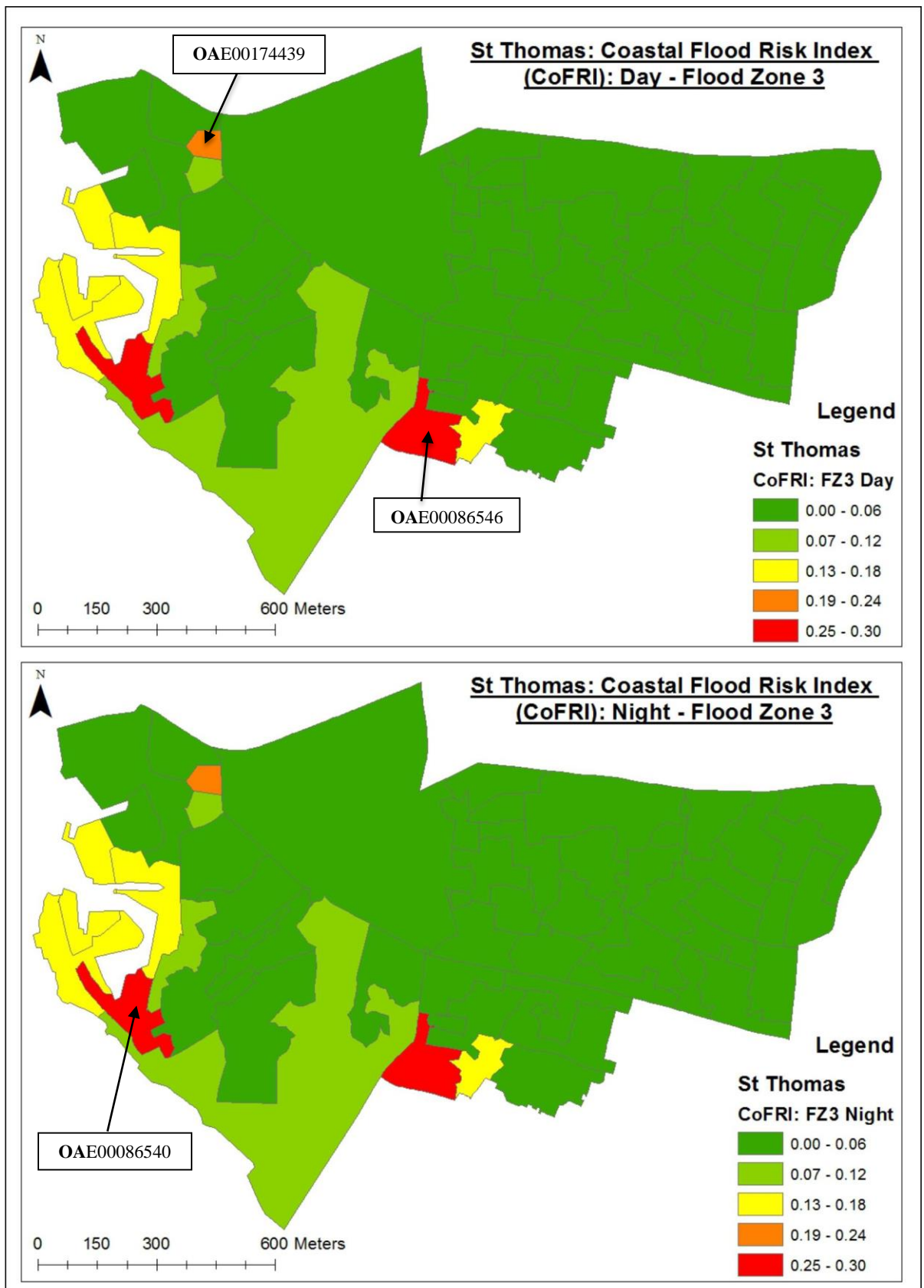


**Figure 4.26.** CoFRI for Eastney ward at OA level – FZ2 Day & Night. Risk ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting risk levels.

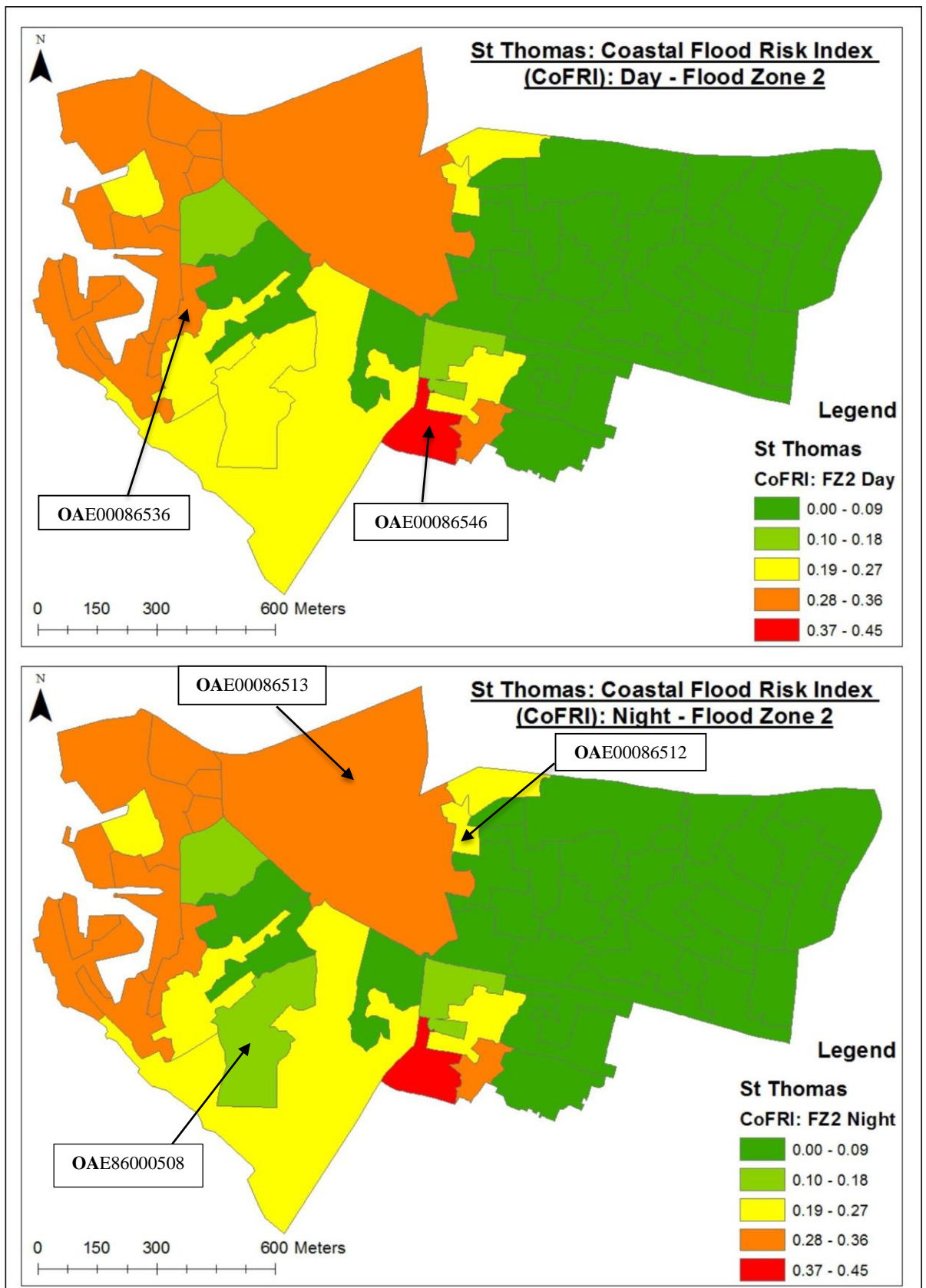
coverage, these neighbourhoods have only moderate physical vulnerability due to these highlighted points, therefore lowering overall risk levels.

A Flood Zone 2 event changes the risk levels within the ward substantially. The east end of Eastney would also be affected. Now 6 new OA's would have CoFR levels ranging from low to high moderate. In a FZ3 event, none of these neighbourhoods were affected, but due to the magnitude of a FZ2 event, flood water would inundate many more areas (see Figure 4.26). In this part of the ward, **OAE00086186** is the most seriously affected, and has an overall Coastal Flood Risk level of 0.48 (flood water depths ranging from 0.25-2.5 m at speeds between 0-5 ms<sup>-1</sup>. Resulting in potentially extremely dangerous conditions). This neighbourhood has very high and high numbers of providers of unpaid care, lone parents with dependent children, lack of education, residential properties, multiple residency buildings, and the highest amount of vulnerable buildings in the ward (47). The latter is due to a permanent mobile home residential park that is right on the waterfront. Coupled with high inundation coverage (0.93), this area has substantial risk for a flood of this level. Again **OA6226** has the highest CoFR level within the ward at 0.56. Overall there are more OA's at risk from a FZ2 event compared to a FZ3. There is also very little difference between a day and night time flood. From Figure 4.26 it appears that two OA's have decreased in risk level for a night flood (**OAE00086228** & **OAE00086204**), however this is by a very small amount (0.01), this is due to moderate day populations but low night populations.

**St Thomas** is smaller in area compared to the other two wards, yet it has the most OA's within a ward at 54. Nine of these were not present in the 2001 census and have been created due to new development in the area; prominently due to Gunwarf's creation. For a FZ3 event, St Thomas has very few areas at risk. The maximum CoFR level is only 0.28, for **OAE00086546**, however the flood water would predominantly be classed as dangerous to most with depths ranging from 0.5-1.5 m at speeds between 1-2.5 ms<sup>-1</sup> i.e. deep fast flowing water. No neighbourhood within St Thomas will be completely inundated by Flood Zone 3 water, the highest CoFHI level is 0.74, which affects **OAE00086540**, yet still a significant amount of inundation.



**Figure 4.27.** CoFRI for St Thomas ward at OA level – FZ3 Day & Night. Risk ranges: **0.00-0.20** – very low; **0.21-0.40** – low; **0.41-0.60** – moderate; **0.61-0.80** – high; and **0.81-1.00** – very high. Arrows highlight certain Output Areas due to resulting risk levels.



**Figure 4.28.** CoFRI for St Thomas ward at OA level – FZ2 Day & Night. Risk ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Arrows highlight certain Output Areas due to resulting risk levels.

Apart from **OAE00174439**, all other neighbourhoods with significant risk levels are concentrated at either the central southern or south western parts of the ward. These only count for 7 OA's out of a possible 56, i.e. a FZ3 event would not have much effect to St Thomas. However, the three areas to the south west are situated in the oldest and some of the most affluent areas in Portsmouth. **OA6540** is the second most expensive OA in the ward, but other than that the other socio-economic vulnerability levels range from very low to low. Despite having over two thirds of the area covered by flood water, **OA4439** has low overall vulnerability levels, due to the lowest numbers in the ward of both day and night populations, lone parents with dependent children, lack of education, utilities, green areas, multiple residency buildings, vulnerable buildings, commercial, industry and those that are sick or disabled; very few children, elderly, renters and unemployed. However, it does have a very high population density and economic level; and a moderate amount of residential properties. Unlike **OA6546**, that has the highest amount of communal establishment residents, night and day populations, small amount of green areas; moderate levels of residential properties, renters, multiple residency buildings, essential buildings, car availability, and lack of education. Overall there is little to no difference between a day and night time flood for a FZ3 event.

For Flood Zone 2, like the other wards, the amount of OA's with CoFR levels increases significantly. Almost the entire western part of the ward has between low to high low risk levels, **OAE00086536** with the highest at 0.34 (flood water would predominantly be shallow with depths ranging from 0.25-1.25 m at speeds between 0-1  $\text{ms}^{-1}$ ). Overall again **OA6546** has the highest CoFR level of 0.42 (moderate risk). Fortunately the flood coverage over **OA6512** is low (0.25) as it has the highest vulnerability value within the ward (0.64), resulting in a low CoFR level. No neighbourhood within St Thomas has CoFR levels above moderate, but 24 OA's now have risk levels unlike only 16 areas for FZ3.

For Flood Zone 2 (Figure 4.28) areas around Old Portsmouth and Gunwharf would be at risk, and apart from some suburban areas in Eastney, are two of those most affluent areas on Portsea Island. Gunwharf has a very large number of commercial and retail buildings, and the area brings in large amounts of visitors throughout the year. It also contains large multiple residency buildings, and also offers large amounts of employment and leisure; it is the most popular area in Portsmouth for dining and entertainment mainly due to the

amount it has to offer the public. Old Portsmouth is also a very popular place for people to live and visit as it is aesthetically pleasing; the buildings are very tightly compacted together in some parts, especially near the sea front, meaning a flood could lead to difficulties with regards to evacuation.

There is again like Eastney and Hilsea, small differences between a day and night flood. Here two OA's (OA6513 and OA6508) increase to higher low CoFR. Again this is only a 0.01 increase and due to higher night populations compared to day populations in the areas.

Further CoFR trials were taken by combining CoFV results with particular inundation coverage of the individual flood water levels present within the SFRA Output Package 1B Flood Zones. The resulting CoFRI maps for the Hilsea ward and further explanation are presented in Appendix L (pg 361).

#### *4.5.1 Comparisons with Local SFRA Results*

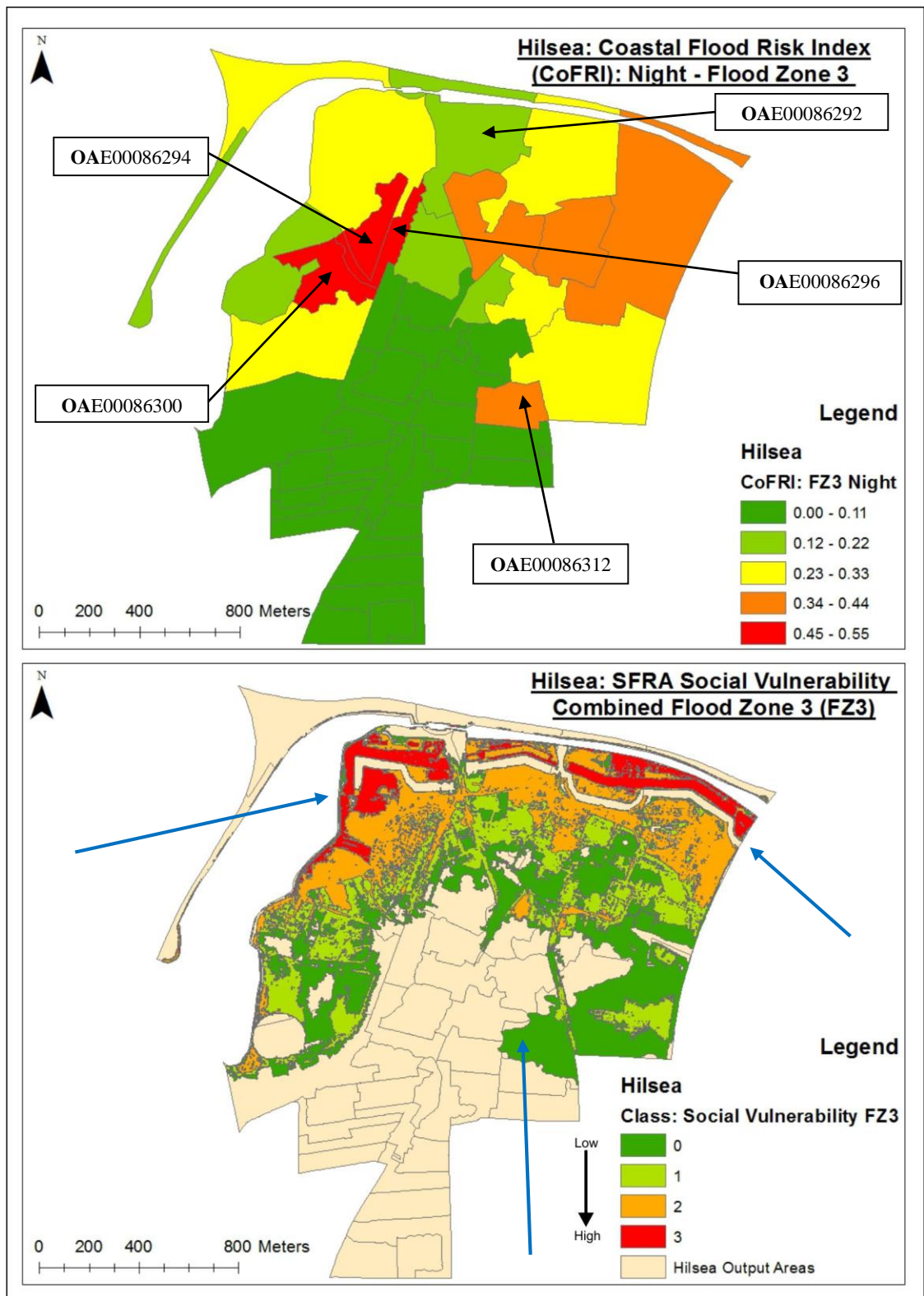
This methodology has used the most relevant factors available to measure the three components of Coastal Flood Vulnerability, aiding our understanding of the different components of vulnerability within three Portsmouth wards. This resulted in a set of coastal flood indices for physical vulnerability (CoFPVI), socio-economic vulnerability (CoFSVI), limited resilience (CoFLRI), overall vulnerability (CoFVI) and overall risk (CoFRI) for each ward at two different flood magnitudes, and for day-time or night-time. The literature review revealed many different types of UK vulnerability assessments (e.g. HR Wallingford, 2006b; Haynes et al, 2008; Alexander et al, 2011; Kaźmierczak and Cavan, 2011), but none of them examined Portsmouth in detail. The only exception was from the Local SFRA, with a report by Atkins (2007) and results available as shapefiles held within different Output Packages.

To assess the viability of the methodology presented in this thesis, Figures 4.29 to 4.36 shows the CoFRI results from this research, for night-time floods at different magnitudes (FZ3 & FZ2); against a comparable set of local SFRA's Coastal Flood Risk maps. The SFRA's 'risk' layer in the figures, is a combination of their Social Flood Vulnerability Index (SFVI), which contains four factors and is populated with 2001 UK National Census data (people aged 75 and over; people suffering from long-term illnesses; single-parent

households; and financially deprived households) and the undefended flood zones (2 and 3) (Output Package 1B), presented as single index. The undefended flood hazard rating (low to very high – Table 2.4) combined with the vulnerability rating (very low to very high) to produce a single index (0 (low) – 3 (very high)), highlighting the areas within FZ3 and FZ2 where both undefended flood hazard and social vulnerability are high, rather than areas where the hazard is high (Atkins, 2007), i.e. a risk indicator. The OS 2011 Output Area Boundary line was placed underneath the SFRA layer in ArcMap as a base map to enable comparison of results with this research's CoFRI results.

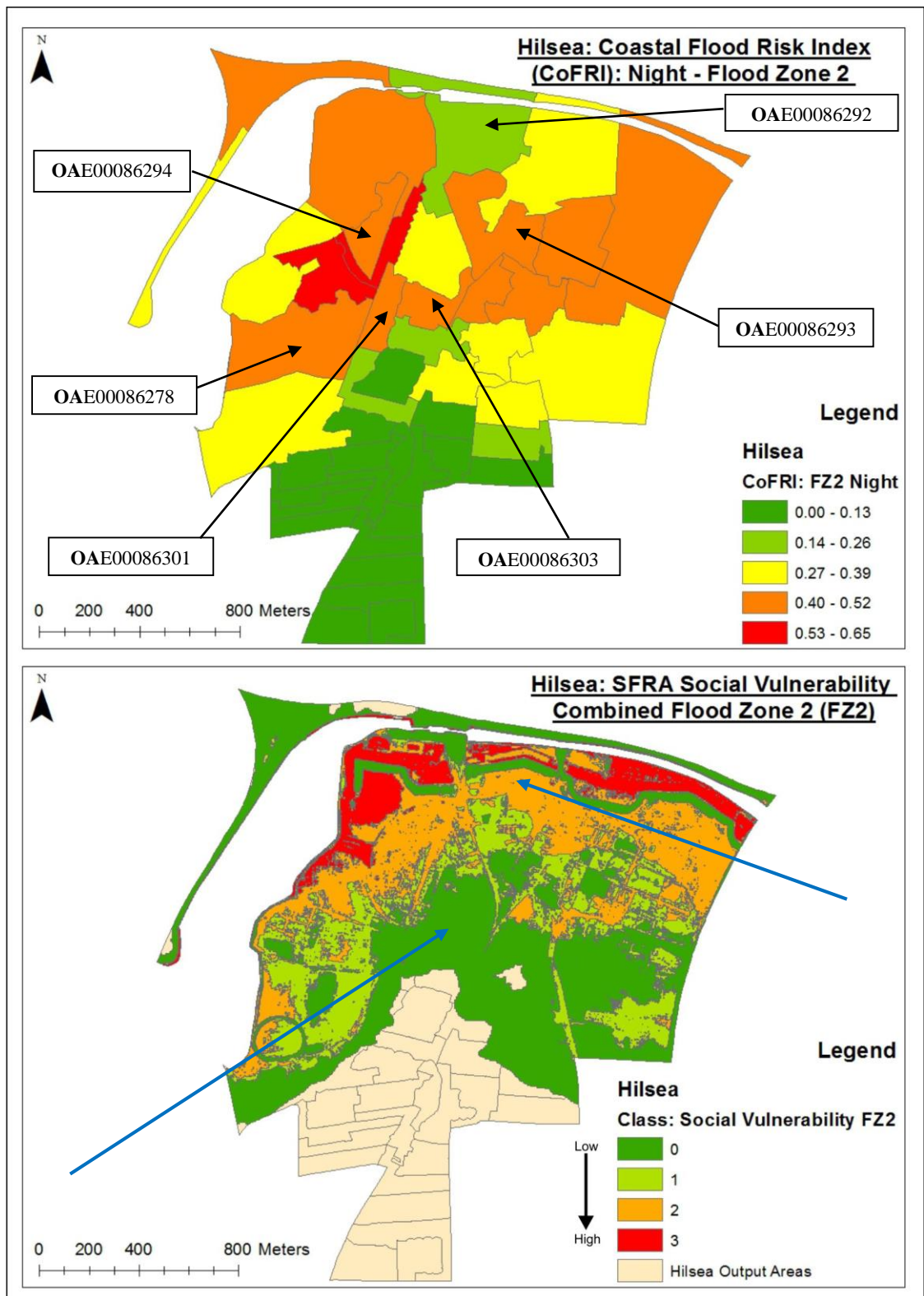
Figures 4.29 and 4.30 present the results for **Hilsea**. For a Flood Zone 3 event (Figure 4.29) both maps show the same areas in Hilsea to be at risk, this is understandable as both indexes are using the same flood zone outline to highlight at risk areas, therefore the risk spatial coverage will be exactly the same. However, whereas the SFRA results pinpoint areas to the northern coastline of the ward to have the highest risk levels, this research indicates three neighbourhoods to the north-west of the ward and a further four areas to the north-east to have moderate to high CoFR (see Figure 4.29). **OAE00086294**, **OAE00086296** and **OAE00086300** were dominant at displaying high levels of vulnerability for all three of the vulnerability component analyses (CoFPV, CoFSV & CoFLR). A combination of moderately high CoFVI results and very high flood zone coverage of these areas, resulted in moderate to high CoFR levels. **OAE00086312** is also a neighbourhood identified within this research with moderate CoFR levels, but is not picked up within the SFRA assessment. This is due to the limited number of vulnerability factors used within the SFRA assessment and only focussing on social factors. **OA6312** was analysed as having higher physical vulnerability and limited resilience levels compared to its socio-economic vulnerability. Hence, resulting in moderate CoFV and (due to almost complete flood water coverage of that area), moderate CoFR. Although the flood water predicted to inundate this area is described as 'Low Hazard Flood Level' (see Figure 3.13) i.e. shallower water with slower velocity, the vulnerability levels have not been accounted for, leading the SFRA results to not highlighting an area of potential concern.

For a Flood Zone 2 event, both results indicate more areas to be affected and have higher overall CoFR levels. Again however, due to only assessing a limited number of vulnerability factors and a specific component, some OA's at risk are missed. For example



**Figure 4.29.** Comparison between this research’s CoFRI results for Flood Zone 3 event in Hilsea and local SFRA equivalent. Risk ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Black arrows highlight certain Output Areas due to resulting risk levels. Blue arrows highlight certain areas due to social vulnerability levels.



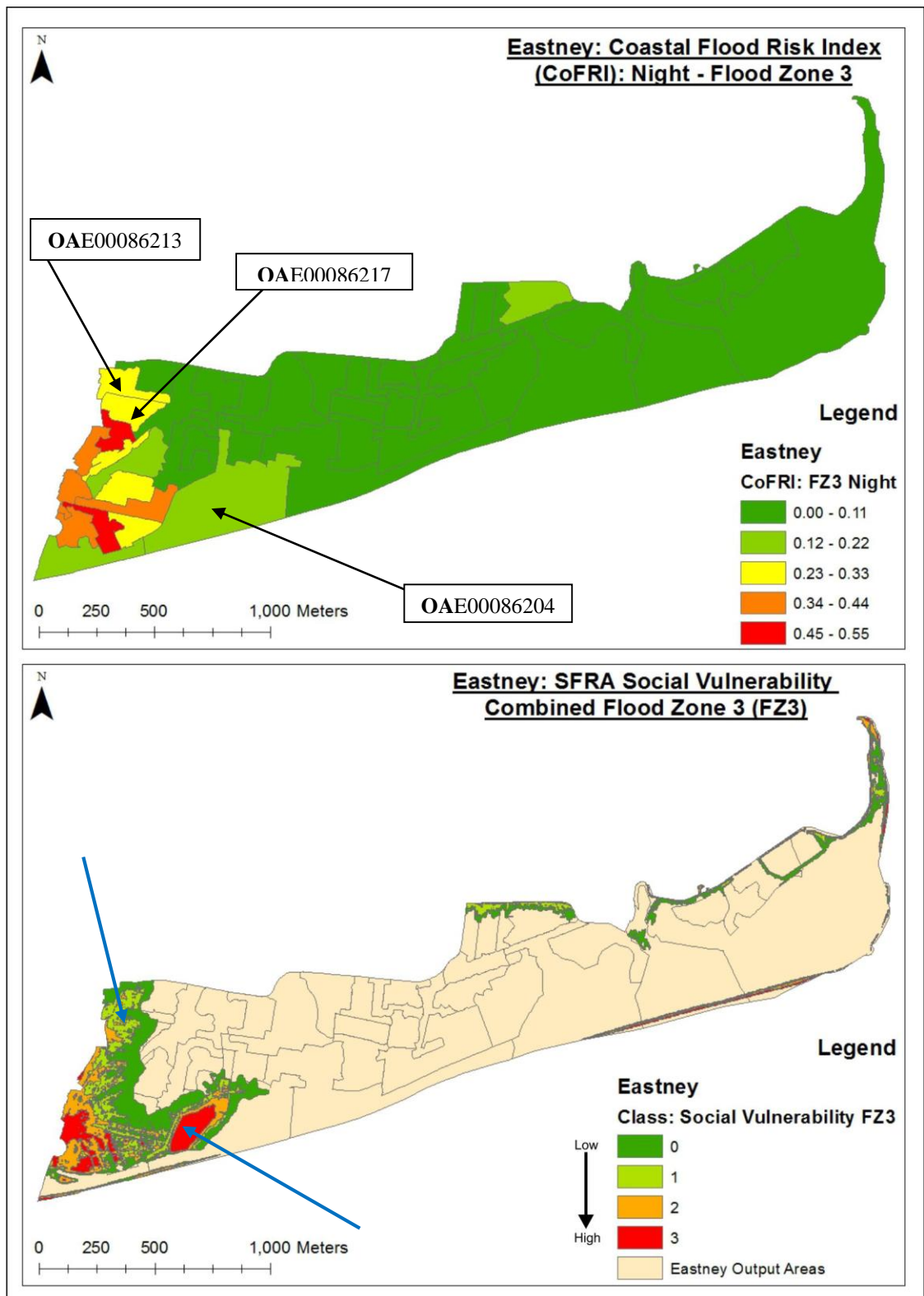


**Figure 4.30.** Comparison between this research’s CoFRI results for Flood Zone 2 event in Hilsea and local SFRA equivalent. Risk ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Black arrows highlight certain Output Areas due to resulting risk levels. Blue arrows highlight certain areas due to social vulnerability levels.

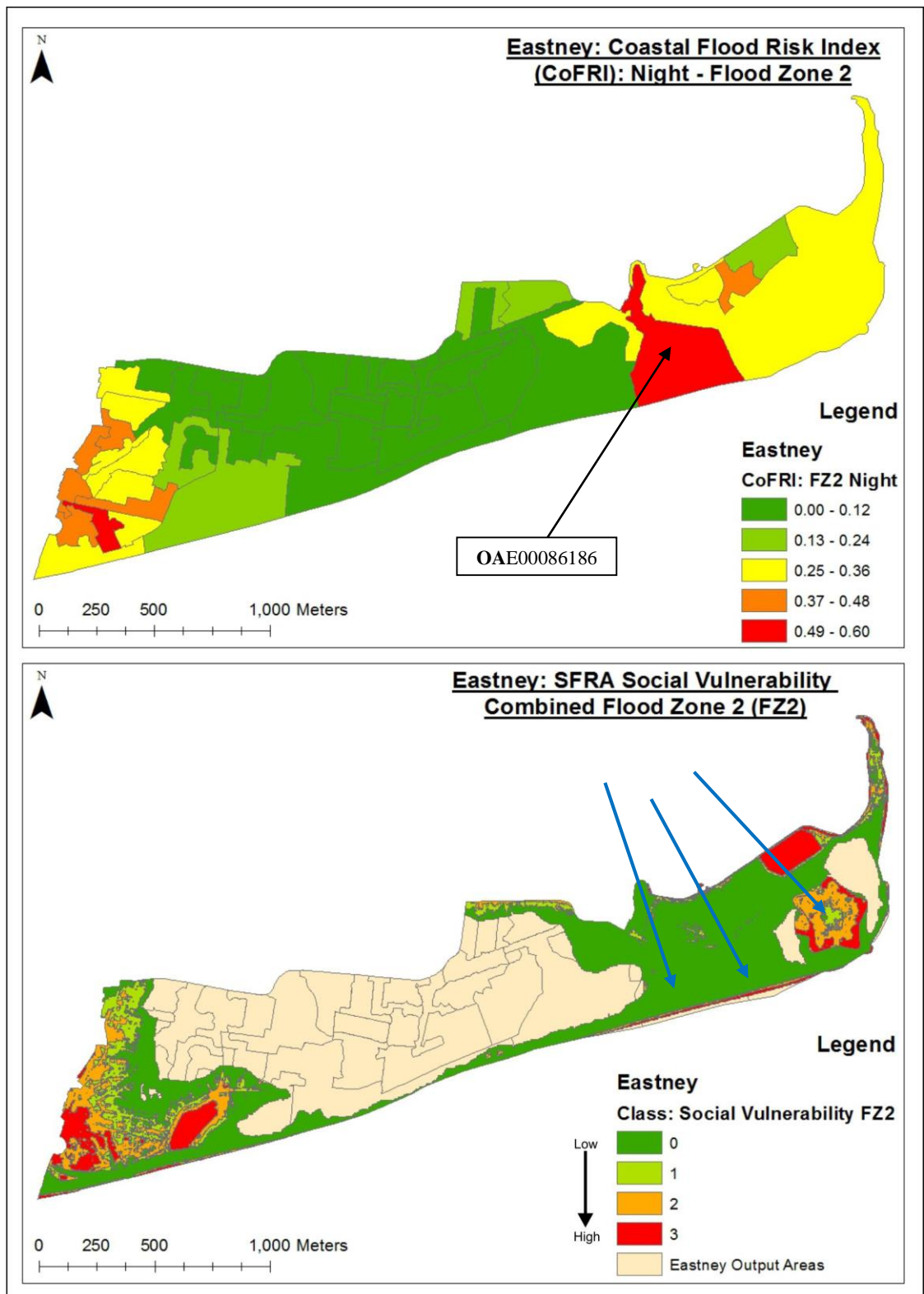
**OAE00086301** and **OAE00086303** are shown with low risk levels, but this research identifies these neighbourhoods to have moderate CoFR (see Figure 4.30). This is due to moderate to high CoFPV and CoFLR levels. The SFRA identifies **OAE00086292** as an area with high to very high risk, whereas this research describes it as low CoFR with a level of 0.25, although almost would have full coverage by flood water (specifically from a FZ2 event), the risk levels are low, due to low CoFV levels (0.25). These low levels are due to many very low levels for the individual vulnerability factors including children, elderly, sick, lone parents, non-English speakers, communal community residents, households without cars, multiple residency buildings, renters, commercial and industrial buildings.

For the ward of **Eastney**, and a Flood Zone 3 event, both sets of results agree that Eastney would have very little to no Coastal Flood Risk, apart from the western end of the ward. The main difference being **OAE00086213** and **OAE00086217** are not identified within the SFRA as having particularly significant flood risk, whereas this research identifies them to have low CoFR (identified in figure 4.31), due to moderate Coastal Flood Physical Vulnerability and Coastal Flood Limited Resilience. **OAE00086204** is described within this research as having very low CoFR, this is due to low CoFV, including a very low CoFPV level due to high coverage of green areas, little utilities, large amounts of main transport routes, very low population density, and low numbers of renters and multiple residency buildings. The SFRA otherwise identified as part of this neighbourhood to have very high risk (see Figure 4.31). Again this is due to a small vulnerability analysis, resulting in a slightly misleading map and deflecting the true vulnerable and at risk areas within this ward.

For a Flood Zone 2 event, more areas are identified at risk by both indexes, the risk levels within the ward change substantially. The east end of Eastney would also be affected, which both results acknowledge (see Figure 4.32). However, this research identifies, in this part of the ward, **OAE00086186** would be the most seriously affected, and has an overall Coastal Flood Risk level of 0.48. This neighbourhood has very high and high numbers of providers of unpaid care, lone parents with dependent children, lack of education, residential properties, multiple residency buildings, and the highest amount of vulnerable buildings in the ward (47). The latter is due to a permanent mobile home residential park



**Figure 4.31.** Comparison between this research’s CoFRI results for Flood Zone 3 event in Eastney and local SFRA equivalent. Risk ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Black arrows highlight certain Output Areas due to resulting risk levels. Blue arrows highlight certain areas due to social vulnerability levels.



**Figure 4.32.** Comparison between this research’s CoFRI results for Flood Zone 2 event in Eastney and local SFRA equivalent. Risk ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Black arrows highlight certain Output Areas due to resulting risk levels. Blue arrows highlight certain areas due to social vulnerability levels.

that is right on the waterfront. Coupled with high inundation coverage (0.93), this area has substantial risk for a flood of this level. The SFRA identify a star shape (see Figure 4.32) as the most at risk within this part of the ward, however this is Fort Cumberland, a disused and derelict MoD property, which has already seen substantial damage (see Figure 4.33). To the west of this structure is a leisure park containing many mobile homes (vulnerable structures to floods due to height and material), and another permanent mobile home residential area further on, that is located on the shoreline (see Figure 4.34). The SFRA results are missing crucial vulnerability factors and not pinpointing these extremely vulnerable areas. Areas such as these are critical during a disaster.

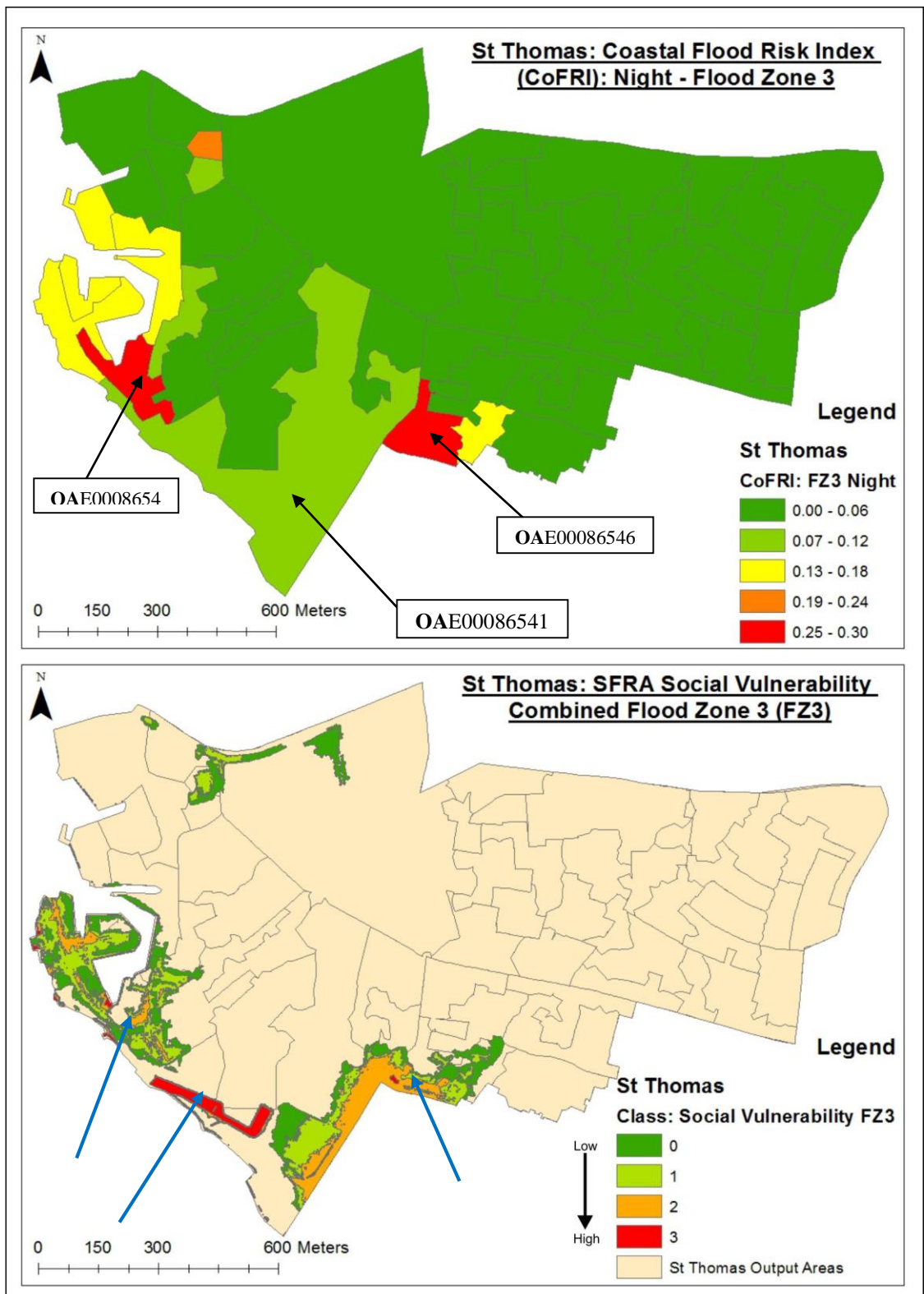


**Figure 4.33.** Shoreline outskirts of Fort Cumberland.

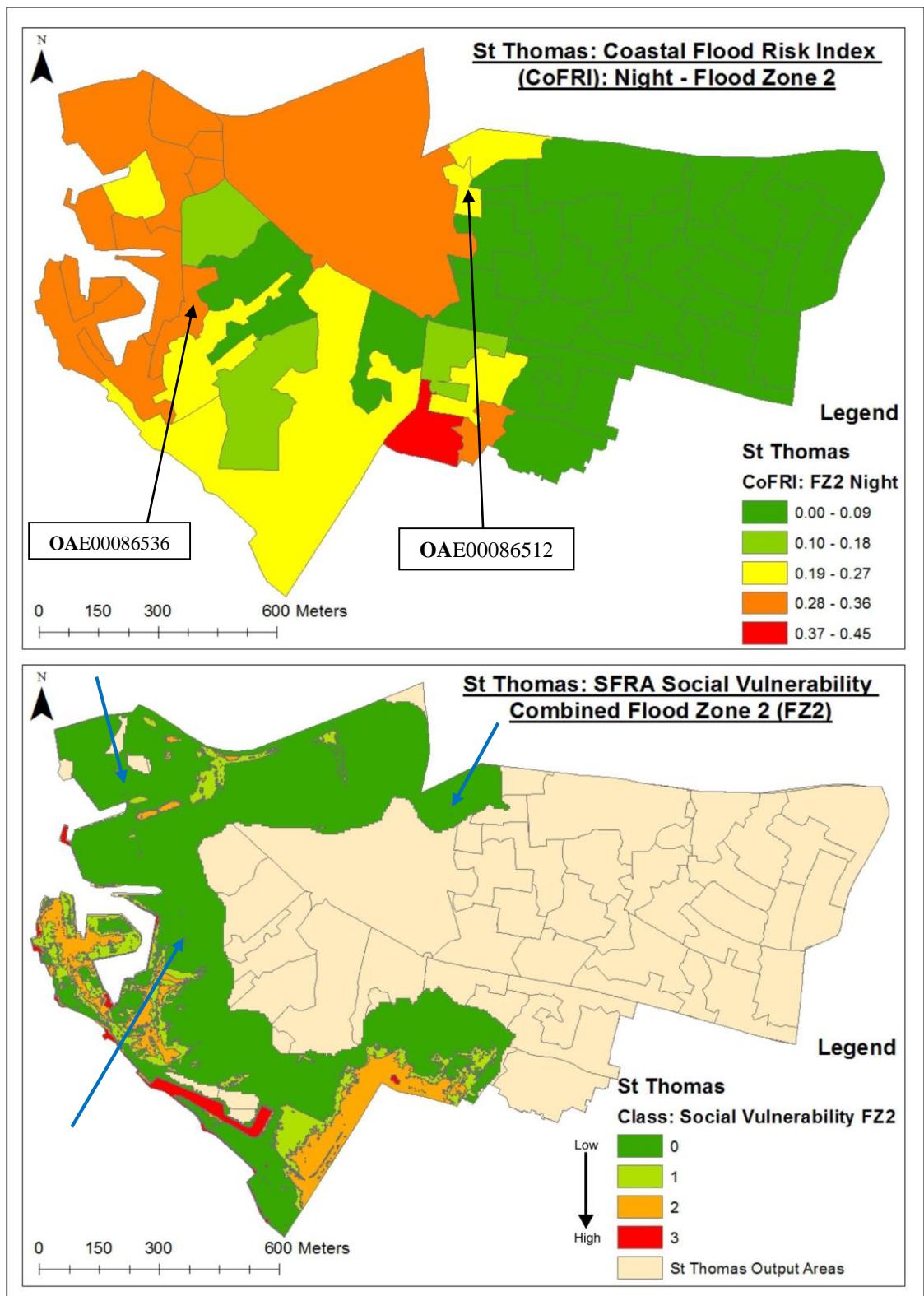


**Figure 4.34.** Permanent Mobile Home Residence in Eastney, containing 47 *Vulnerable Buildings*.

The **St Thomas** ward would have very few areas at risk during a Flood Zone 3 event, and both results show this. This research identified the maximum CoFR level to be 0.29, for **OAE00086546**. No neighbourhood within St Thomas will be completely inundated by Flood Zone 3 water, the highest CoFHI level is 0.74, which affects **OAE00086540** (see Figure 4.35). These neighbourhoods are also identified by the SFRA to be areas within the ward that cause concern, however, this research finds their CoFR levels to be the most significant in the ward, unlike the SFRA which highlights an area within **OAE00086541**. However, **OA6541** is measured as having overall low CoFV and especially low (compared to the rest of the ward) Coastal Flood Limited Resilience, i.e. it is more resilient than many of the other neighbourhoods. Again through analysing a greater variety of vulnerability factors, a clearer window into the communities' reality is given. Within St Thomas, a Flood Zone 2 event (Figure 4.36), causes more neighbourhoods to have greater CoFR levels. However, although this can be seen via the SFRA results, this research identifies many more neighbourhoods to have more substantial risk than just low, one is identified as having moderate CoFR. This area (**OAE00086536**) is not identified to the same extent within the SFRA index and map. **OA6536** is identified in this research due to its moderate Coastal Flood Physical Vulnerability and high low Coastal Flood Limited Resilience. Due to a thorough CoFV analysis, this research also identifies **OAE00086512** as an area that has CoFR, as it has the highest CoFV level within the ward at 0.65. Even though the flood



**Figure 4.35.** Comparison between this research’s CoFRI results for Flood Zone 3 event in St Thomas and local SFRA equivalent. Risk ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Black arrows highlight certain Output Areas due to resulting risk levels. Blue arrows highlight certain areas due to social vulnerability levels.



**Figure 4.36.** Comparison between this research’s CoFRI results for Flood Zone 2 event in St Thomas and local SFRA equivalent. Risk ranges: **0.00-0.20** – *very low*; **0.21-0.40** – *low*; **0.41-0.60** – *moderate*; **0.61-0.80** – *high*; and **0.81-1.00** – *very high*. Black arrows highlight certain Output Areas due to resulting risk levels. Blue arrows highlight certain areas due to social vulnerability levels.



water would be shallower and slower, the community is the most vulnerable here. The SFRA map identifies this neighbourhood as a low risk area.

#### 4.5.2 Summary

In summary, this methodology presents very different results for all three wards for Coastal Flood Risk when flood events of different magnitudes take place. As expected, many more neighbourhoods are at risk when a Flood Zone 2 (0.1-0.5% tidal flooding event) takes place, due to the sheer increase in flood water that would inundate these areas. However, the flood zones used do not take into account any coastal defences that are already in place; these flood zones present us with ‘worst case scenarios’, i.e. these defences have been overcome or breached. In reality the flood extents would perhaps not be as severe as these maps suggest. Nevertheless, there are many stretches of flood defences around Portsea island that are coming to the end of their life spans i.e. they would not be up to the task of withstanding a flood event of FZ2’s magnitude and power.

This methodology also provides results that show few, if any, major differences between the risks from day or night flood events. Insights have been provided into neighbourhood-scale variations in vulnerability: some OAs have large day populations compared to the rest of the ward, due to people working from home or not working at all (mothers, retired etc); yet the night populations are small when compared to other OAs in the ward. This large difference in one factor has led to some OAs in all three wards having higher CoFR levels in daytime than during the night. However, the overall average difference is only between 0.01-0.05, as it is only one factor out of many. The population figures given for the day will probably fluctuate as people tend to leave their houses for errands, social meetings etc. However, these figures at least give indications of the possible populations present in these areas if a flood occurred. Despite the results presented in this chapter, a night flood will always present greater risk; due to the simple fact that people are less aware of its occurrences and extents at night, and darkness can lead to confusion. Portsmouth is a large city and therefore has high amounts of street lighting, but if this was to occur to in a more rural coastal setting (e.g. Great Yarmouth or Hayling Island), darkness would definitely be a factor. This is where weighted indexes have advantages, which is a topic of recommended future research.

The CoFVI produced within this research aims to simplify a number of complex and interacting parameters, represented by many different and diverse data types, into a form that can be readily understood, visualised and incorporated into the coastal flood risk analysis that can then be used within coastal management, as a tool to manage risk and reduce vulnerability at local scales. The results produced here pinpoint vulnerable and high-risk areas, at neighbourhood levels of detail, in a clear and concise way. The combination of flood levels and the Coastal Flood Vulnerability results, showcase the potential this methodology has for pinpointing the most dangerous and life threatening areas at the most detailed level possible with UK Census data. Discussion of these results, the methodologies and future research are presented in Chapter 6.

**Portsmouth Coastal Flood Vulnerability and Risk: Assessment and Mapping of  
Impacts at Microscale**

Sarah E. Percival

**VOLUME II**

**Chapter 5. Communication and Dissemination of Hazard, Vulnerability and Risk**

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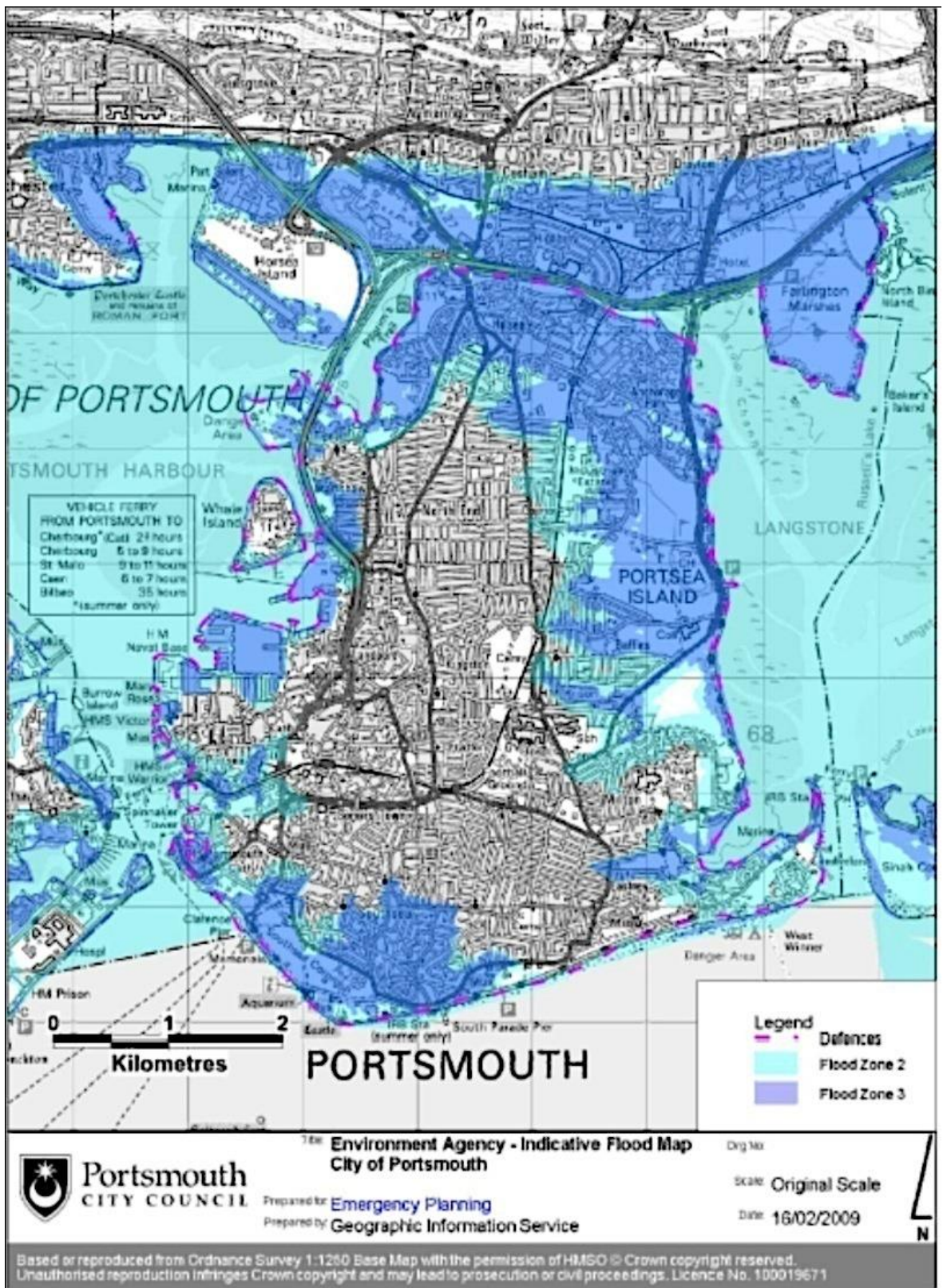
## Chapter 5. Communication and Dissemination of Hazard, Vulnerability and Risk

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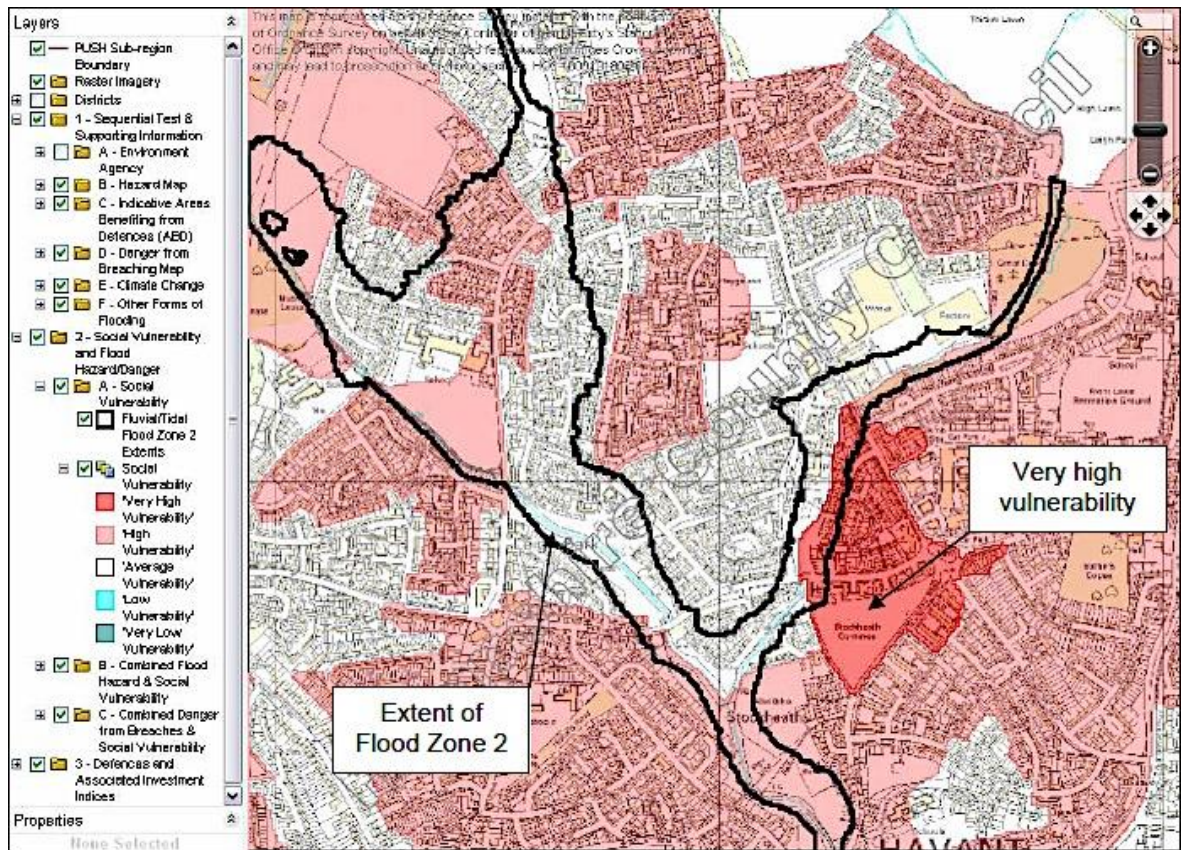
An objective of this research was to explore new visualisation techniques to maximise 3D mapping potential for Coastal Flood Vulnerability and Risk assessment, communication and dissemination. This chapter explores previous visualisation techniques of flood hazard, vulnerability and risk, particularly in the form of mapping. The chapter discusses why visualisation is vital to communication and dissemination especially of flooding (section 5.1) and the trials that occurred during this research to explore 3D flood mapping in three stages (section 5.2). Section 5.3 summarises the findings.

Mapping is a cornerstone to any risk-based approach for flood management in the UK. Risk maps illustrate the spatial relationships between hazard, vulnerability and risk. Effective map visualisation can convey a large amount of data for one geographic area, into a simplified informative image. Flood map visualisation can be used to educate, demonstrate and assist flood hazard science.

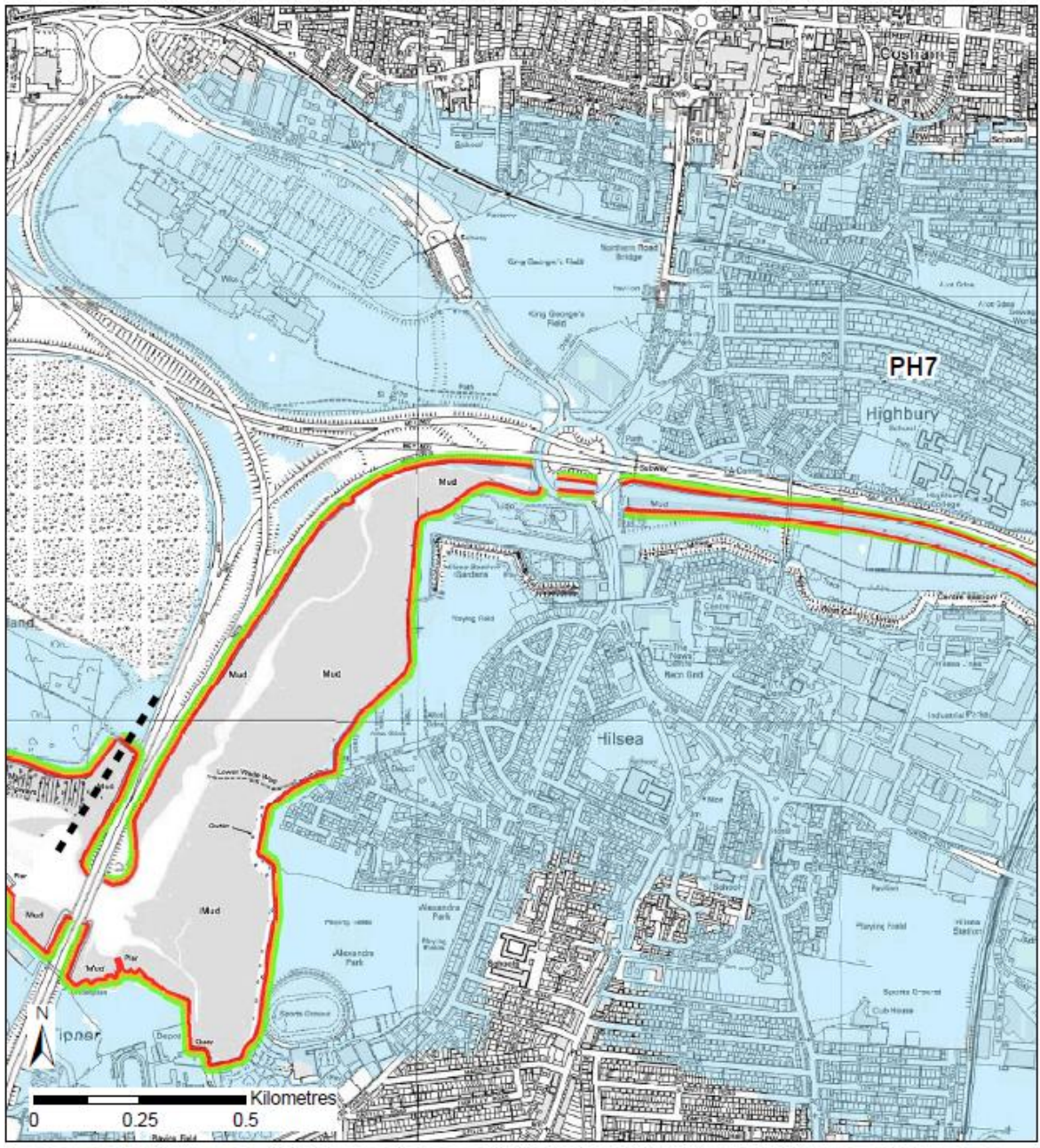
During the initial stages of this project, existing coastal flood vulnerability and risk analyses in the Solent were examined. There was evidence (Portsmouth City Council, Environment Agency, local SFRA) that the resulting visualisation (mainly in the form of coastal flood hazard or flood risk maps), had scope for improvement (Figures 1.4, pg 34; 3.20, pg 93; and 5.1-5.3). There was an opportunity for different techniques to be tried and tested, resulting in improved visualisation to assist understanding of Coastal Flood Vulnerability and Risk. This chapter describes why visualisation is important, the different techniques used and the final 3D visualisation options produced.



**Figure 5.1.** Environment Agency – Indicative Flood Map City of Portsmouth (Portsmouth City Council, 2011a).



**Figure 5.2.** Map example of PUSH OP2A – Social Vulnerability Index added over Flood Zone 2 Outline (Atkins, 2007).



	Unit Boundary
	Complex coastal processes
	Indicative erosion zone up to 2025
	Indicative erosion zone up to 2055
	Indicative erosion zone up to 2105
2115 Indicative Floodplain (1 in 200 year) provided from PUSH	

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**Figure 5.3.** No active intervention flood hazard map for Flood Zone 3 in 2115 for Hilsea (NSSMP, 2010).

## 5.1 Visualisation

The main task of the map is presentation of spatial information, where different types of cartographic presentations serve as a communication tool between the cartographer and the user. It is only a successful map when the user understands and recognises the map's content (Petrovič and Mašera, 2005). Meyer et al (2012) stated maps have three main uses; general orientation, recognition of particular presented objects, or displaying map measurements. These all require adequate experience and knowledge, but some maps are easier to understand than others. Flood hazard, vulnerability and/or risk maps are increasingly regarded as important for mitigating the impacts of natural hazards (Meyer et al., 2012). They not only provide essential information for the public, but are also important tools for the planning authorities and the insurance industry (EC, 2004; Meyer et al., 2012). Maps may therefore be used to raise the awareness of flooding, by highlighting the communities and individuals at risk. They also influence planning processes at local and regional level (Haynes et al., 2007; Hagemeyer-Klose and Wagner, 2009; Meyer et al., 2012).

Biologically our visual system is extremely well developed for visual analysis. Our eyes take in huge amounts of data, it is estimated that the transmission speed of the optic nerve is as quick as 9Mb/sec (Koch et al, 2006). Our brains rapidly process information detecting edges, recognising shapes and matching patterns. It is the latter that is key to the benefits of visual representation. The most critical information from data is represented in patterns, 'connecting the dots', answering questions and understanding situations; recognising trends, gaps and outliers (Petrovič and Mašera, 2005). These visual presentations can very quickly disseminate large amounts of information and help advancements in understanding. However, there are also limits to our visual perceptions, notably we cannot discriminate between more than fifteen distinct colour types, which is an important consideration when preparing colour-coded legends and keys (Koch et al, 2006).

The visualisation of flood data can take many forms. Visualisation through flood mapping is the most effective tool in flood risk management (Wicks et al., 2014). The UK Pitt Review (2008) identified the importance and provision of information before and during a flood event, as well as the need for the Met Office, Environment Agency (EA), and the emergency managers (strategic/'gold' and tactical/'silver' commands) to use modern GIS



mapping technologies to visualise flooding. The Pitt Review (2008) and Exercise Watermark (2011) recommend that the EA should develop and bring flood visualisation tools forward by working with its partners to meet the needs of flood risk managers, emergency planners and responders, i.e. improving flood visualisation and pre-prepared emergency flood maps (Wicks et al., 2014).

Flood maps have to be prepared for low-medium-high probability flood events, under the European Union (EU) floods directive, for areas considered through preliminary flood risk assessment to be subject to significant flood risk (Meyer et al., 2012; Wicks et al., 2014). These maps include flood hazard maps - normally showing extents and sometimes depths and velocities; and flood risk maps – sometimes showing number of residents affected or economic activity affected. More so, a base geographical map, which can be an aerial photograph or an OS map with an inundation level, some critical infrastructure identified or highlighted risk zones (Example shown in Figure 3.20).

Most flood maps are divided into hazard maps or risk maps. Hazard maps show information on the spatial extent and/or depth of inundation for flood events of different probabilities (Figure 5.3 is an example of a hazard map). Risk maps show the consequences of these possible flood events, measured in terms of annual average damage or consequences (Meyer et al., 2012). The majority of vulnerability and risk science is not something that the everyday public are expected to understand; therefore producing maps to assist communication of flood risk findings is a necessary task. However, can we develop better recommendations for flood vulnerability and risk map creation i.e. by incorporating local knowledge, users-specific needs and vitally improve the visualisation in order to produce user-friendly and understandable flood vulnerability and risk maps. Climate change is predicted to have significant impact on coastal flood risk, increasing the number of properties and areas affected and damaged. Land use and development control, coastal management, flood incident management and public awareness of flood risks will need crucial attention. This is not only because of predicted increases in risk but also higher levels of vulnerability, due to the current financial climate and high levels of uncertainty of flood events. Flood visualisation forms an integral part of these functions (Wicks et al., 2014). The following sections describe the visualisation trials that occurred

over the projects lifetime to see if it was possible to improve coastal flood vulnerability and risk map visualisation to meet end user needs and communicate findings clearly.

## 5.2 Initial Trials: Three-dimensional (3D) Implementation

Multimedia cartography has been propelled rapidly forward due to technological advances for the capture, manipulation and presentation of geographical data, with the majority of maps being developed digitally (Pegg, 2013). Due to these developments, the quality and accuracy of today's data capture, data storage, data manipulation capabilities and advances in software; have enabled cartographers to digitally create spatially detailed and high resolution three-dimensional (3D) maps and visualisations. Available digital terrain and elevation models enable a cartographer to present geographical data in 3D space, allowing modelling of not only x and y locations but also the z height, creating a 3D landscape (Pegg, 2013). These aesthetically pleasing and often dynamic and interactive map products are expected to eventually dominate the visual landscape of mapping (Pegg, 2013).

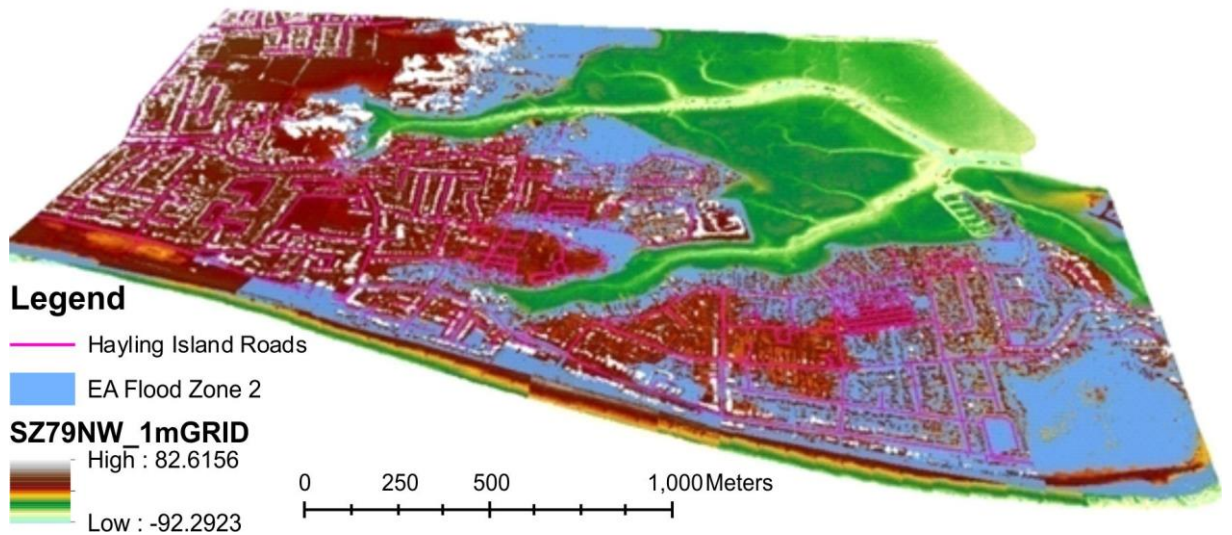
3D maps can be made in different ways, each creating a different representation of the landscape. There are photorealistic 3D maps, where a map of the landscape is created to match the exact landscape i.e. overlaying ortho-rectified photography over a 3D model such as a Digital Terrain Model (DTM), they are also described as a simple map (Pegg, 2013). The other is described as 'symbolistic' (Pegg, 2013), where maps are generalised and symbols are created to show certain object locations or present information.

### 5.2.1 3D Visualisation Stage 1 – OS and Channel Coastal Observatory (CCO) Data

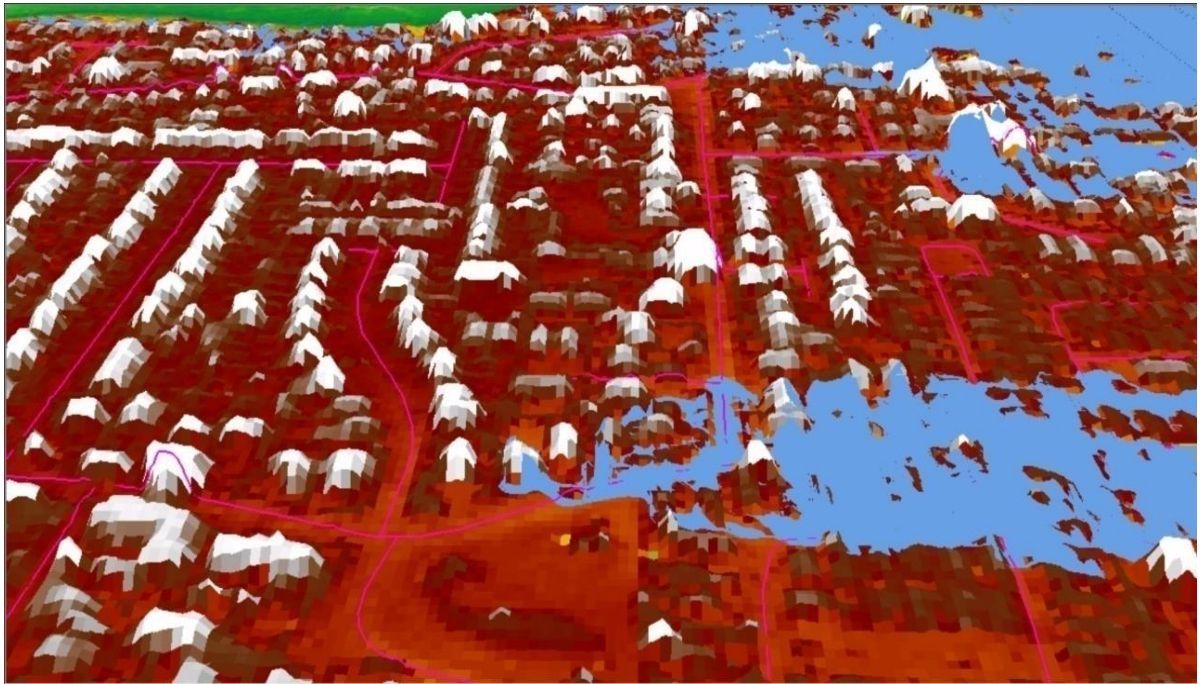
During initial research of existing coastal flood vulnerability analysis in the Solent, there was evidence (Atkins, 2007; Davies, 2010, pers comm; NSSMP, 2010; Portsmouth City Council, 2011a; Southampton City Council, 2011; Hart, 2012, pers comm), that resulting visualisation of those analyses (mainly in the form of coastal flood hazard maps) had scope for different techniques to be tried and tested, demonstrating the potential of visualisation when communicating coastal flood vulnerability and risk to the different stakeholders that populate and manage these coastal areas at risk.

Different visualisations techniques and experiments have taken place during the project's timeline, concentrating on the creation of 3D coastal flood vulnerability and risk maps. The

first examples of 3D flood hazard maps were created with the assistance of OS at the very beginning of the project. The initial visualisation trials occurred at the point where areas on Hayling Island were being considered as one of the test areas for the main research methodology. Using an OS Digital Surface Model (DSM) of Hayling Island, clipped OS Mastermap Area and Road Link and the original acquired modelled EA Flood Zone 2; a 3D coastal flood hazard map was created in ArcScene, using the base heights from the DSM (see Figures 5.4 and 5.5).



**Figure 5.4.** Initial 3D imagery of Hayling Island in ArcScene using new visualisation techniques for coastal flood vulnerability. This section is of the south east of Hayling Island and has added base heights. The data shown includes; Ordnance Survey Digital Surface Model; Ordnance Survey Mastermap Area and Road Link; and Environment Agency (EA) Flood Hazard Zone 2 (Sources: Environment Agency, OS Mastermap Topography Layer & OS Derived DSM).



**Figure 5.5.** Area of east Hayling Island in greater detail (white blocks represent buildings, brown represents land and blue shading represents flood zone).

These initial visualisation techniques gave some detail and a better understanding of:

- which areas would be inundated
- if large amounts of urbanisation were present
- where possible evacuation routes were situated.

This large file size of the Hayling DSM tiles caused ArcScene to freeze and crash due to its data size. For further visualisation trials to take place, smaller DSMs were acquired. Following a meeting with the Eastern Solent Coastal Group Partnership (ESCP), it was decided that Portsmouth would be the area that the project's methodology would be tested on, pinpointing the need for new elevation data to be acquired, for further visualisation trials to occur.

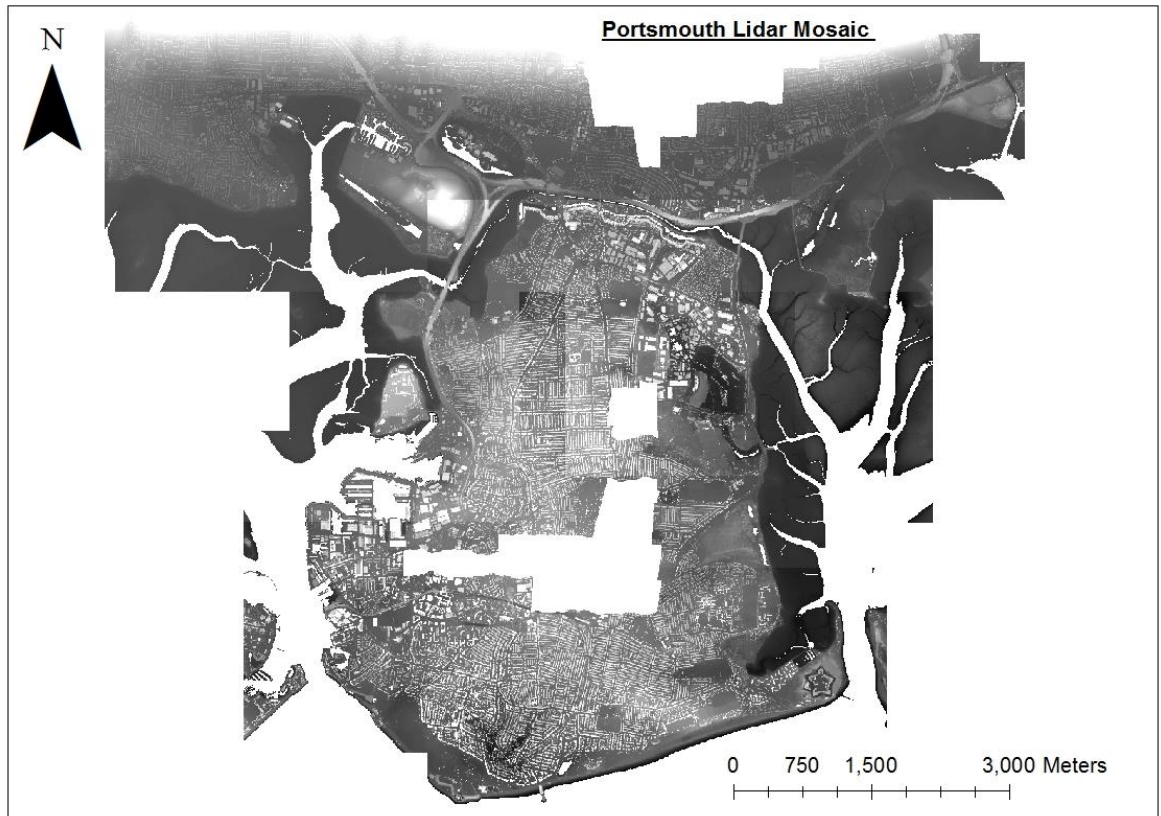
The next step took the 3D visualisation further and produced 3D hazard aerial maps in the shape of electoral wards. The Channel Coastal Observatory (CCO) website ([www.channelcoast.org](http://www.channelcoast.org)); a hub for the national network of regional coastal monitoring programmes of England, held the data needed for further visual trials. This network collects coastal monitoring data in a co-ordinated and systematic manner to serve the needs of coastal engineering and management over six regional programmes (CCO, 2015). The

CCO website contains a data selection map (Figure 5.6), allowing the user to draw (guided by grid squares) a polygon of an area chosen for data selection. All lidar data for Portsmouth was downloaded from CCO, converted from ASCII to raster in ArcMap, and all tiles were mosaiced (see Figure 5.7). When downloading the data from CCO, a data limit was present (500 mb). Therefore batches were downloaded at a time, and due to Portsmouth's size this was significant. Also, the CCO's website does not record your previous selected areas, therefore to ensure repetition did not occur, areas (500 m<sup>2</sup> grid squares presented as file names in geo-referenced OS codes e.g. SU6603ne\_20071208lidaru.asc) were manually documented on a copied version of the CCO selection map at grid square level, resulting in highlighting and manually labelling what had been downloaded systematically.

The next stage was to acquire the CCO's aerial photography. However, even though the CCO website is a large source of free aerial and spatial data of the UK coastline, there are gaps within the data – both lidar and aerial photography. For Portsmouth the lidar gaps can be seen in Figure 5.7. Due to many missing photographs within the Portsmouth dataset (there were only complete sets before 2005); OS aerial photographs were requested instead. Recently though the CCO has added more aerial photographs for Portsmouth from 2013. However, the aerial photographs from OS (although older) required little mosaicing to form one aerial image, whereas the CCO data would have taken longer in time to prepare for visualisation trials, due to the way it had to be acquired e.g. a data limit is added for each data download, meaning small amounts have to be downloaded at a time. This did not coincide with the time constraints of the project. The CCO was the only free source of lidar imagery that could be found, therefore it was used, despite the gaps found in central Portsmouth.



**Figure 5.6.** Channel Coastal Observatory (CCO) data viewer and selection map.

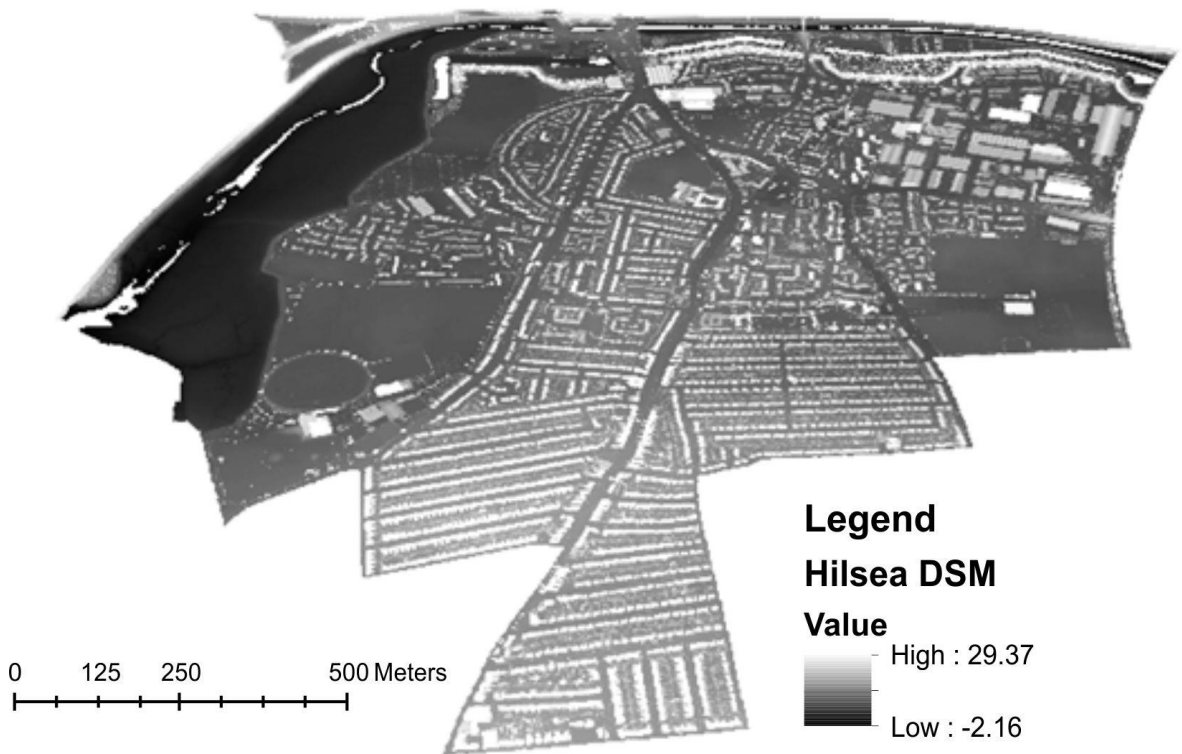


**Figure 5.7.** Mosaiced lidar (mix of 2007 and 2008) of Portsmouth. White empty spaces present gaps in the data (CCO, 2011).

The aerial photography from OS was received in the format of a number of tiles of different areas of Portsmouth (via OS geographical coding), in the form of Enhanced Compression Wavelet (ECW). These photographs needed to be merged together into one image of Portsmouth, as OS coded grid square areas do not match to electoral wards boundaries. ArcMap does have the ability to mosaic aerial images, but it takes time and it requires manual selection of each image. Quantum GIS has a great advantage over ArcMap, as large batches of images/vector files can be transformed or merged fairly quickly. However, ECW images are not supported by Quantum GIS 1.7.4 (QGIS), when merging is required. Nevertheless, once all ortho-rectified images from OS were organised in one folder, a batch transfer from ECW to geotiff could take place within QGIS. Once converted, these geotiff images were merged into one geotiff image of Portsmouth again via QGIS batch mode. The final merged Portsmouth geotiff image was then ready to be added into ArcScene (the resulting image can be seen in Appendix M – pg 365)

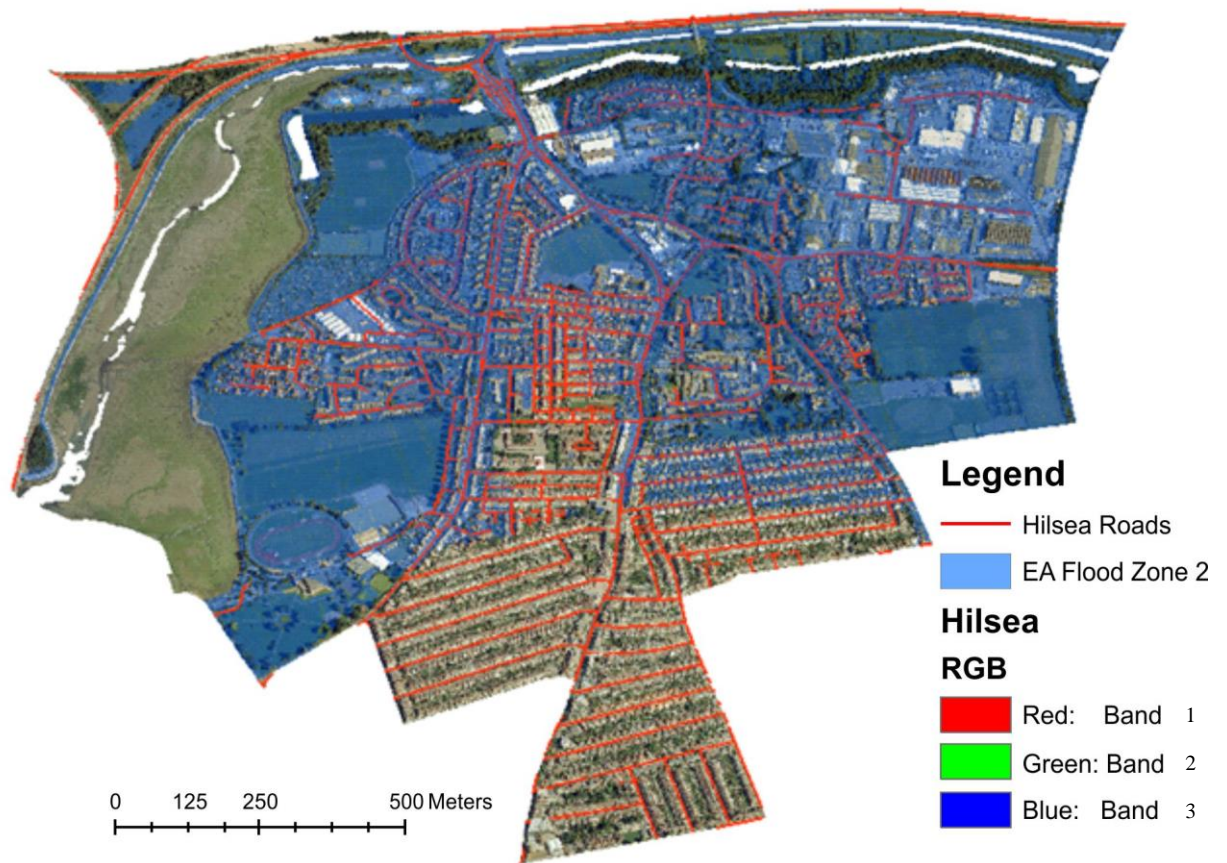
### 5.2.2 3D Visualisation Stage 2 – 3D Coastal Flood Hazard Maps

The lidar data from CCO was merged in ArcMap and extracted by mask to the clipped Hilsea ward OS Area layer, thus creating a DSM of Hilsea, a scale appropriate for this study (see Figure 5.8). This new DSM was added into ArcScene, along with the geotiff aerial image of Portsmouth. The aerial image was made three dimensional by adding base heights via the DSM. This creates a simple 3D image, to make it into a 3D hazard map, the EA clipped Flood Zone 2 (1 in 200 to 1000 year chance) was added (with added transparency) as was the clipped to Hilsea OS Mastermap Road Link to again show the levels of inundation and evacuation routes (see Figure 5.9). Both the flood zone layer and the road link layer were given base heights in order to float over the aerial image, otherwise they would not be visible.



**Figure 5.8.** Extracted by Mosaic DSM of Hilsea ward (Source: CCO).





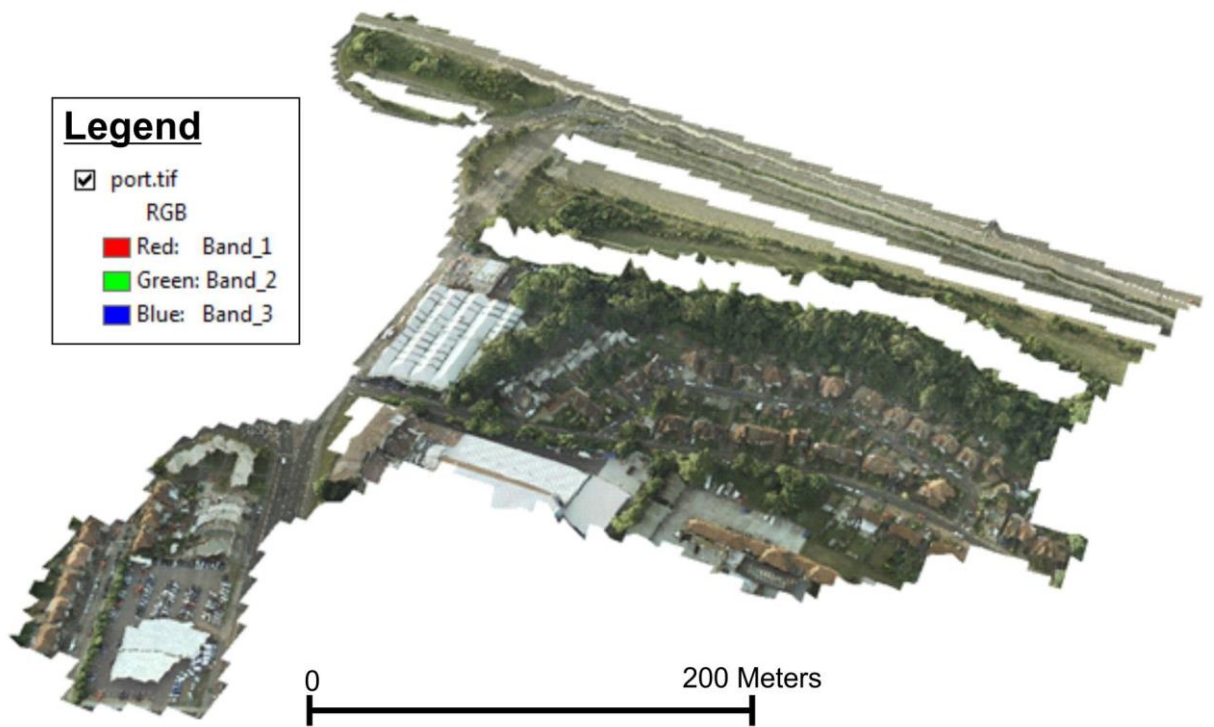
**Figure 5.9.** Hazard 3D map of Hilsea ward; containing ortho-rectified aerial photo (OS), clipped Flood Zone 2 layer (blue shading) with added transparency and ITN (red lines) (Sources: Environment Agency, OS Mastermap Topography Layer & OS Aerial Imagery).

These 3D hazard maps, although simple were a vast improvement on the original trials, due to the greater detail presented by the aerial image; houses, buildings, fields, gardens, trees, sports grounds etc. The maps are easier to understand and disseminating a large amount of information/data for this geographic area, into a simplified compelling image. Figure 5.10 shows the 3D Hilsea Hazard map in greater detail (zoomed in) and the level of detail that can be acquired via this visualisation stage. However, the goal was to create unique and detailed coastal flood vulnerability and risk maps. From the original trials, 3D visualisation has limitations due to software and the size of data being used. This was another reason to examine visualisation at neighbourhood level; resulting in further resolving software issues and aiding understanding.

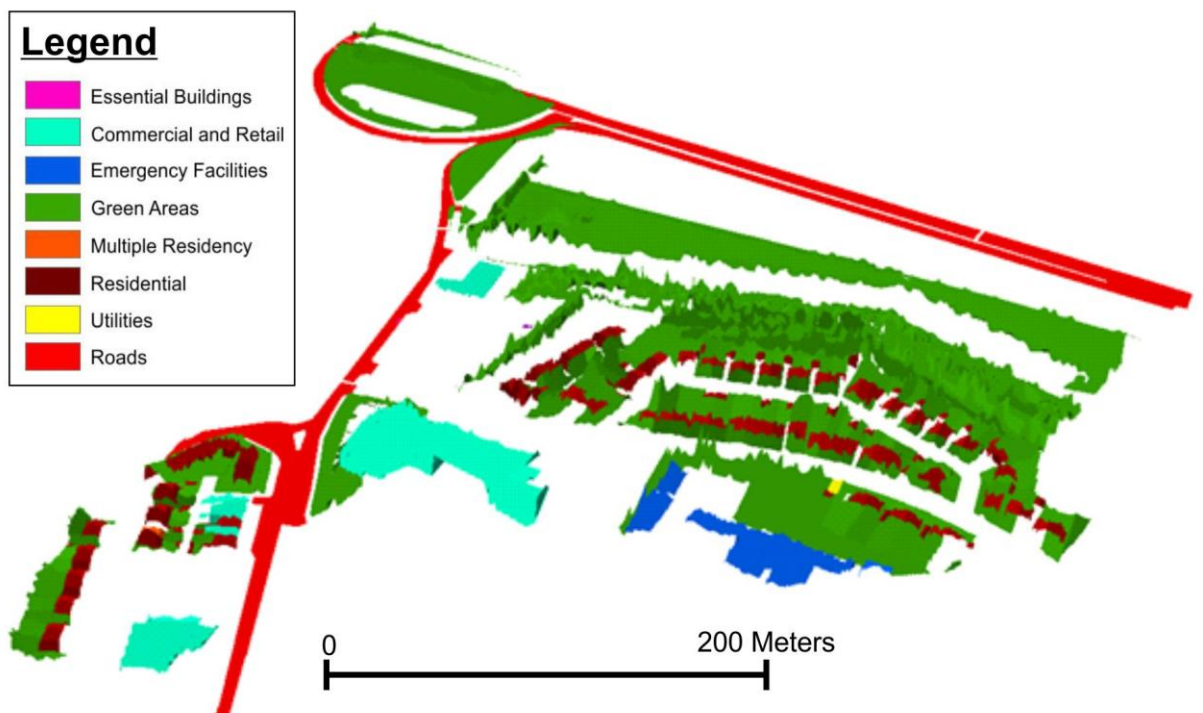


**Figure 5.10.** Zoomed in area of Hilsea aerial 3D hazard map; containing ortho-rectified aerial photo (OS), clipped Flood Zone 2 layer (blue shading) with added transparency and ITN (red lines) (Sources: Environment Agency, OS Mastermap Topography Layer & OS Aerial Imagery).

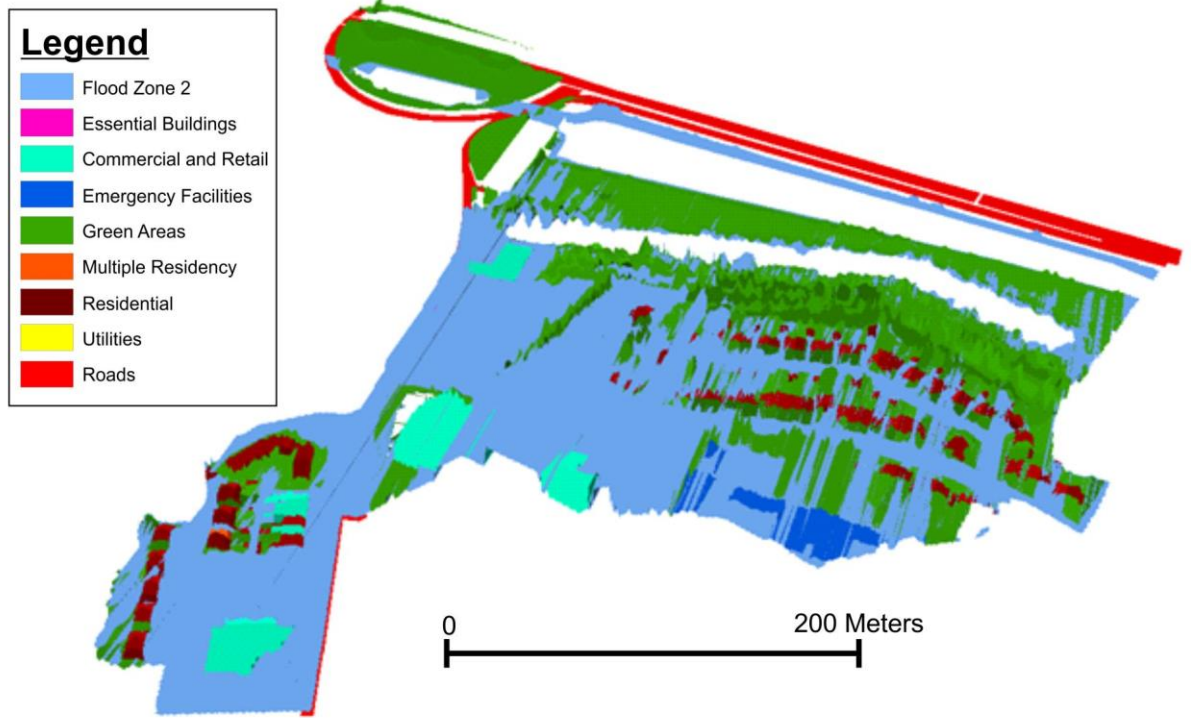
Firstly the neighbourhood **OAE00086292** from the Hislea ward was chosen to trial this particular stage. The Hislea DSM was extracted by mask to **OA6292** in ArcMap and all the re-classified land use polygons for Hislea (originally created for the Coastal Flood Physical Vulnerability analysis), were added into ArcMap, and clipped to **OA6292** for visualisation purposes. The Flood Zone 2 (FZ2) layer was also clipped to this OA. In ArcScene the **OA6292** DSM was added and the Portsmouth aerial added over the top. Again the aerial geotiff was given the DSM's base heights and rendered to the highest quality (see Figure 5.11a). These layers were de-selected and the land use layer polygons were added and given height in the same way (Figure 5.11b). The clipped **OA6292** Flood Zone 2 layer was then added (on top of all the other layers in the ArcScene Table of Contents) (Figure 5.11c). Lastly, the FZ2 layer was given a high percentage of transparency, and the aerial image was selected once more. Thus allowing the user to not only see the level of inundation but also what areas would be in danger. The land use layers gave the user ability to understand what type of structures are present and what that could imply (Figure 5.11d). Another example of the techniques applied at this stage can be seen for the Hislea ward in Appendix M (pg 365). Originally during the land use re-classification (part of the Coastal Flood Physical Vulnerability analysis) the polygons of each land use class were drawn and measured. This methodology was replaced by a simpler and more applicable strategy, but the resulting land use polygon shapefiles were kept. Using the mosaiced Lidar elevation data of Hislea from the CCO a 3-D view of Hislea land use with added Flood Zone (2) is presented.



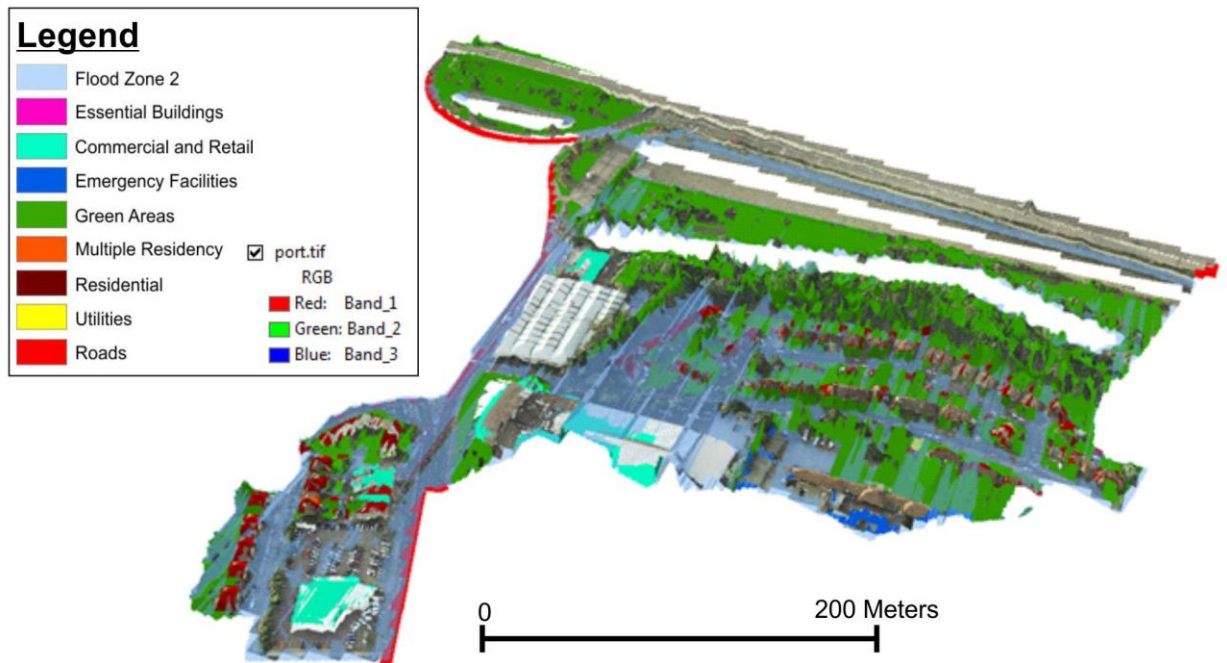
**Figure 5.11a.** Aerial view of Hilsea ward neighbourhood OAE00086292 (Source: OS Aerial Imagery).



**Figure 5.11b.** 3D land use map of Hilsea ward neighbourhood OAE00086292.



**Figure 5.11c.** 3D flood hazard map of Hilsea ward neighbourhood OAE00086292 with land use and FZ2 (Source: Environment Agency).



**Figure 5.11d.** 3D flood hazard map of Hilsea ward neighbourhood OAE00086292 with land use, aerial view and FZ2 (Sources: Environment Agency & OS Aerial Imagery).

The next stage was adding vulnerability and risk levels in maps at this detail. Vulnerability and risk cannot be presented in colour grading system due to the fact only a single neighbourhood is being looked at, also if a colour zone polygon was placed as a layer in the map, it would distract from the hazard layer and have little meaning to the on-lookers. Simply showing where the flood zone would be present in an area, is a very effective way of communicating a hazard's potential and what would be affected. However, vulnerability and risk are much more complicated. In Chapter 4 the Coastal Flood Vulnerability and Coastal Flood Risk results are mapped due to the fact a comparison is being made of all the neighbourhoods in that ward. Unfortunately this scheme cannot be reapplied here, therefore at this geographic level; text stating the Coastal Flood Vulnerability and Coastal Flood Risk results was seen as the best option.

### 5.2.3 3D Visualisation Stage 3 – Ordnance Survey Data

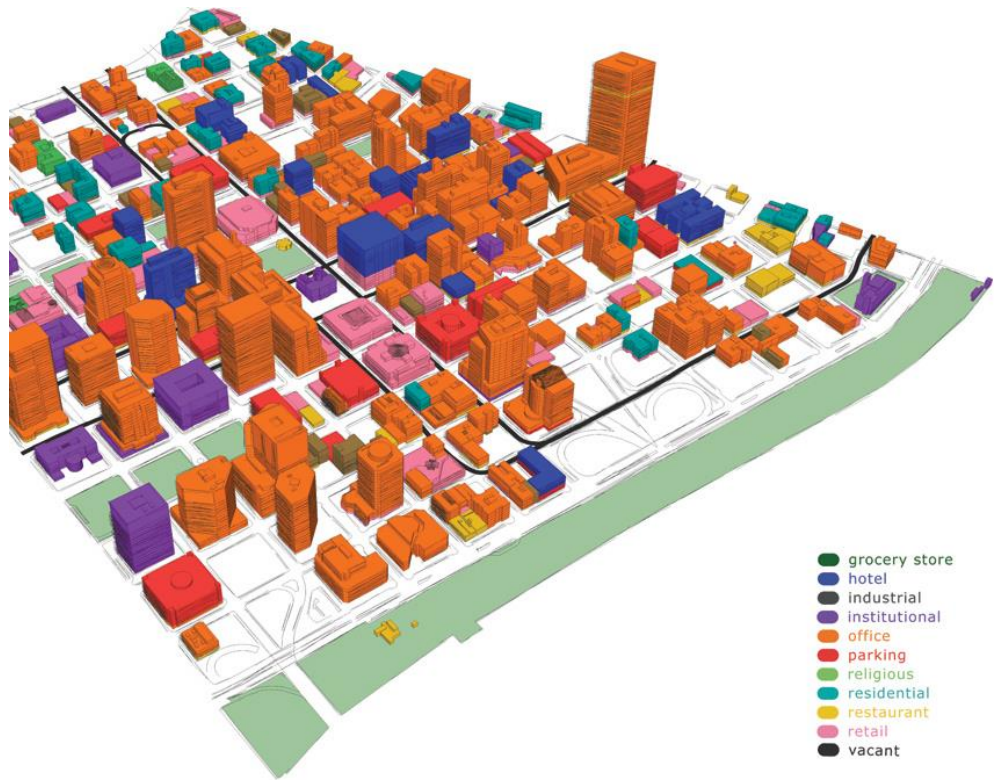
The final figures from visualisation stage 2 (Figures 5.11a-d) showed progression within the visualisation trials; greater detail was achieved; the ability to present maps at the appropriate boundary levels (i.e. wards and Output Areas); create 3D imagery; and to identify/map vulnerable land use. However, these are still examples of hazard maps rather than vulnerability and risk maps, which was the main aim of this section of the research. It was discussed in the previous section the dilemma of adding vulnerability and risk information. The vulnerable land use layers add coastal flood vulnerability information, but they still do not disseminate the overall Coastal Flood Vulnerability of the neighbourhood. The previous visualisation examples (as can be seen in Figures 5.11a-d) - the imagery; although better than stage one examples (Figures 5.4 & 5.5), was still slightly unclear and blurry. It is especially difficult to establish the height and size of the vulnerable land use being identified (Hampshire Fire and Rescue, 2013, pers comm).

The data from CCO and the stage two 3D visualisation trials improved Coastal Flood Hazard maps; especially at ward level (Figure 5.9). The Hilsea ward 3D aerial with added flood zone and main transport links map, is a more accessible map for delegators and the general public compared to examples produced by grey literature i.e. the flood hazard map presented in Figure 5.3 for the North Solent Shoreline Management Plan (NSSMP) (2010) (Hart, 2012, pers comm). Figure 5.3 was actually labelled as a flood risk map in the NSSMP, yet it presents no quantification of risk. To present risk maps for natural hazard

events, a visual identification of risk levels needs to be applied. As previously discussed in Section 5.3.2, risk levels are difficult to apply in 3D maps; therefore text will be added to state both overall Coastal Flood Vulnerability and Risk levels.

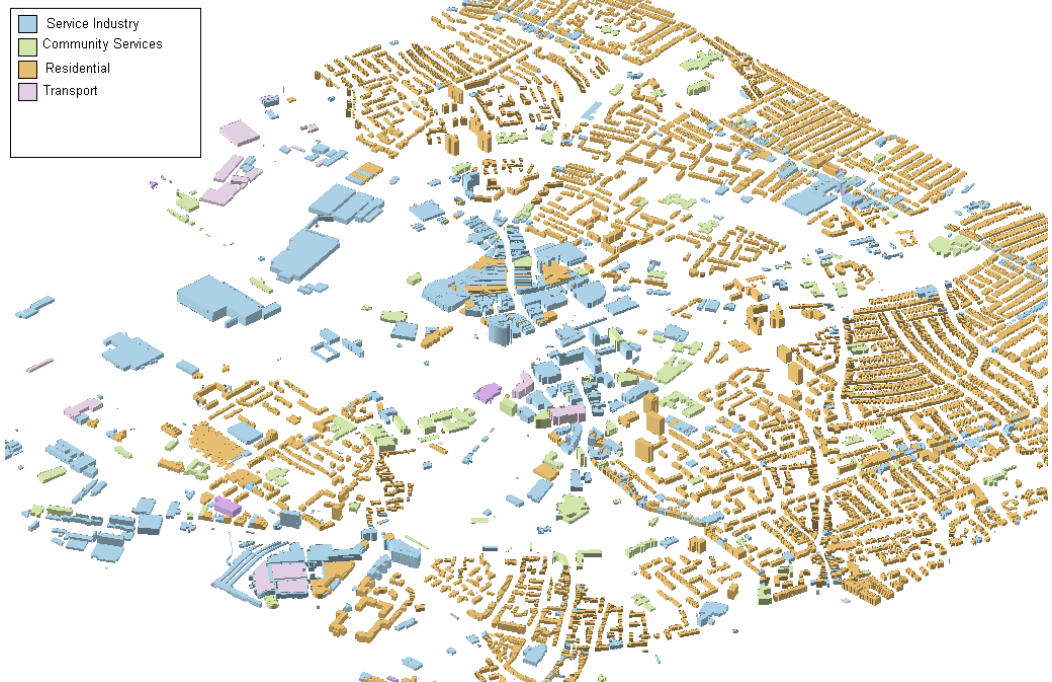
When mapping neighbourhoods individually (such as in Figures 5.11a-d) and stating Coastal Flood Vulnerability (CoFV) and Coastal Flood Risk (CoFR); these levels need 'grounding' or context i.e. an area may have a risk level of 40%, however how does that compare to others? For example the neighbourhood OAE00086546 in St Thomas ward has the highest CoFR level at 0.43, when looking simply at this number, the CoFR seems moderate; however, the average CoFR for St Thomas is 0.10. Therefore compared to the rest of the ward; this is an area that needs extra attention. The context of your research is an important factor to remember when vulnerability and risk mapping is being carried out.

During the timeframe of the project, Ordnance Survey supplied new data that would greatly assist the developing visualisation techniques. New data included a new complete DTM and ortho-rectified aerial photography of all of Portsmouth. During meetings with Ordnance Survey an internal project by Kinley (2010) identified new ways of visualising land use promoted by the Bureau of Portland's 3D methodology of visualising land use data (Figure 5.12). 3D representation of land use gives an improved display of land use information and allows a user to view an areas Z dimensions, therefore also providing a more accurate visualisation of land use (Kinley, 2010). Ordnance Survey utilised the Bureau of Portland's methodology but only as far as creating a vertical data set – OS Building Heights. Kinley (2010) used this dataset and mapped a small area in Portsmouth (Portsmouth High Street) with a land use ontology of only four classes (see Figure 5.13). Before this option was chosen, Kinley (2010) looked to utilise the Portland 3D model to allow various segments of a building to be coloured differently to account for a building's single or multiple uses. However, this was problematic for small buildings with many uses, and green areas that have no vertical dimensions. The other option was to stack layers according to their uses, although this may not accurately represent the proportion of the area that the activity uses (Kinley, 2010). Overlap between land uses is hard to convey and interviews held by Ordnance Survey identified few organisations required this level of detail - only the emergency services.



**Figure 5.12.** Bureau of Portland’s Land Use Methodology (City of Portland Bureau, 2002).

Arc Scene view of Portsmouth, displaying accurate building heights and land usage

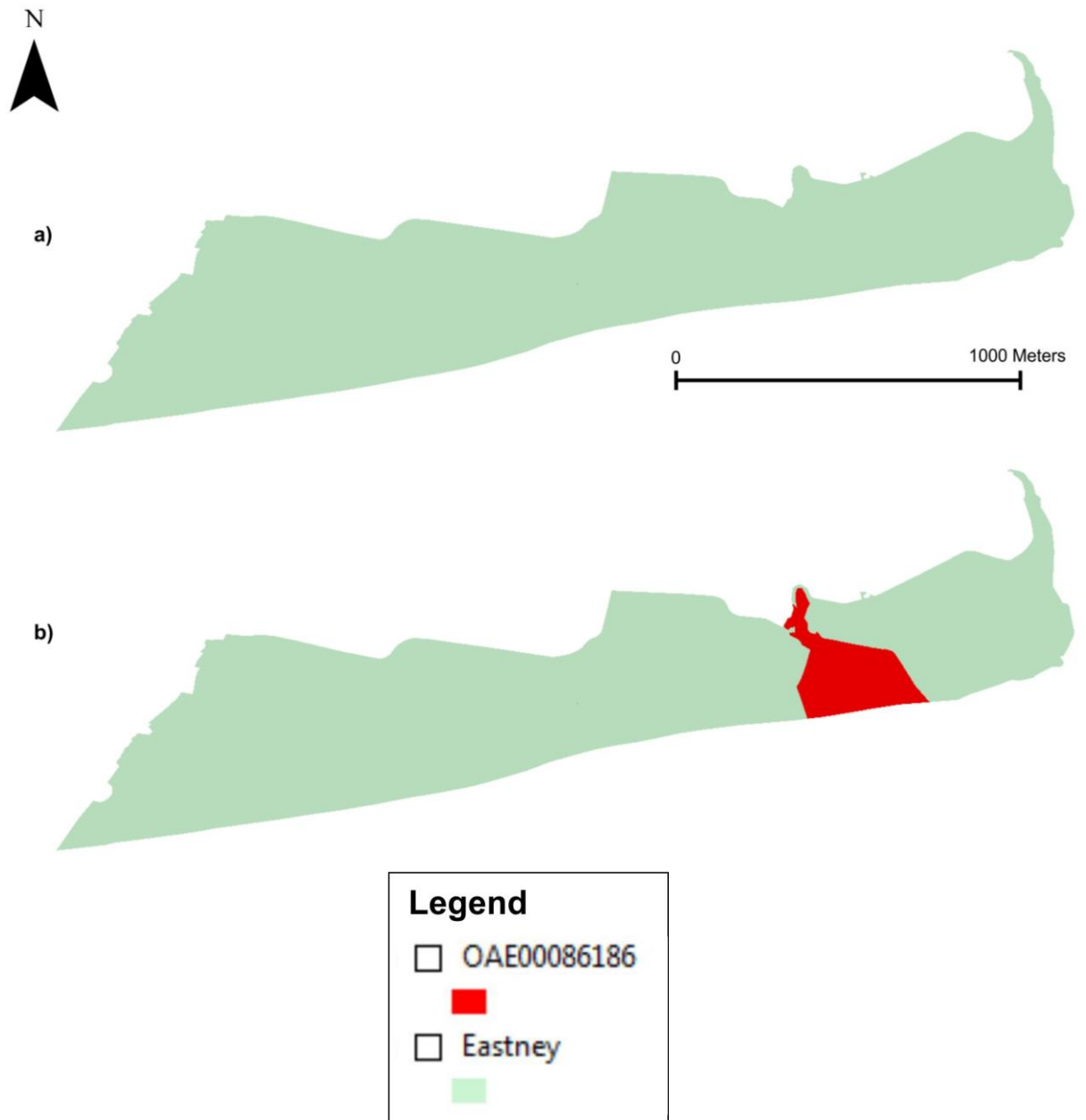


**Figure 5.13.** View of Portsmouth with accurate building heights and land usage (Kinley, 2010).

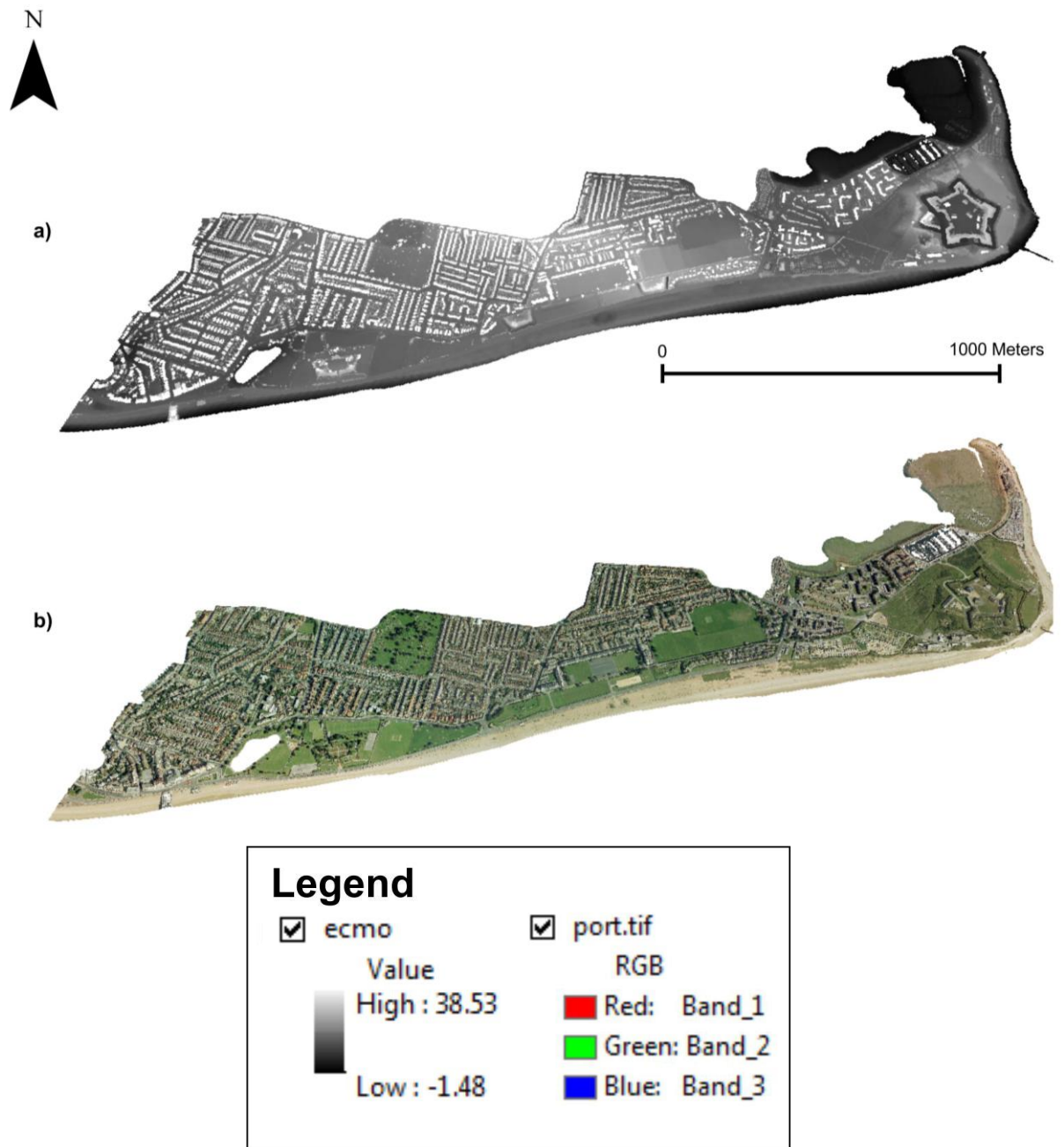


Kinley's and Ordnance Survey's initial 3D work and the new OS Building Heights layer; presented an opportunity to further improve visualisation from the first two visualisation stages (all the steps (1-6) that follow can be seen in Figures 5.14-5.19). Firstly the new Building Heights layer was added into ArcMapper and individually clipped to the three wards. It was then decided that the ward of Eastney was used to trial this visualisation stage. In ArcMapper the OS DTM was extracted by mask to the Eastney OS Mastermap Area ward. Then in ArcScene, the Eastney ward OS Mastermap Area and the **OA6186** OS Mastermap Area were added (Figure 5.14). Then the new Eastney DTM and the Portsmouth geotiff were added; which was given height via the DTM, creating a 3D aerial map of Eastney (please see Figure 5.15). In ArcScene the new Eastney Buildings Height layer was given base heights (z value) via the height data contained in the layer (Figure 5.16). The green areas and transport layers for Eastney were then added (Figure 5.16) as well, along with the clipped Eastney undefended (OP1B) Flood Zone 2 (FZ2) (the same one used for the indexes) (see Figure 5.17). **OAE00086186** was chosen for this visualisation trial as it had the second highest CoFR level within the ward for a FZ2 at 'night' time. **OA6186** was chosen to be presented in the thesis due to its varied and unusual land use, and its geographical position in the ward. Within **OA6186** are many Vulnerable Buildings (mobile homes), a holiday caravan park (which cannot be mapped due to the caravans not being permanent buildings as they are holiday lets), a fair number of high multiple residency buildings, some commercial buildings and economically a poorer area. All would be situated within the flood water from a FZ2 event.

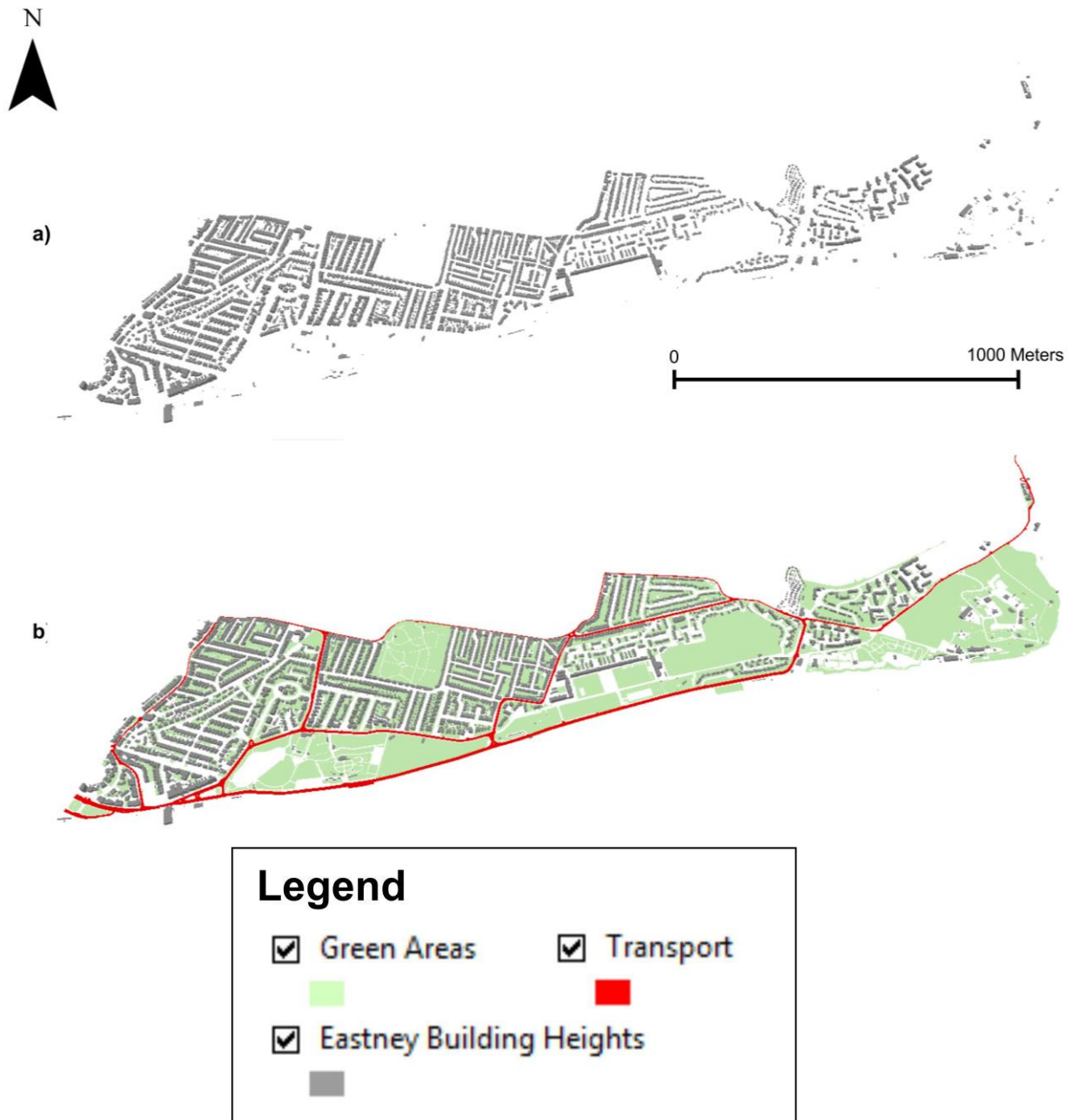
The Eastney building heights layer was clipped to the **OA6186** OS Mastermap Area layer in ArcMap (Figure 5.18) and then the new 6186\_Buildings Height layer was de-selected. In ArcCatalog new geographically referenced (OSGB 1936) empty polygon shapefiles were created and they consisted of 6186\_Commercial and Retail, 6186\_Uilities, 6186\_Multiple Residency, 6186\_Residential, 6186\_Essential Buildings and 6186\_Vulnerable Buildings Night. The 6186\_OS Area Layer was categorised to only show buildings and glasshouse through the Descriptive Group option within the layer. The following point shapefiles (already created during the analysis) were added into ArcMap – 6186\_Multiple Residency Point, 6186\_Dwellings Point, 6186\_Vulnerable Buildings Night Point, 6186\_Essential Buildings Point, 6186\_Commercial and Retail



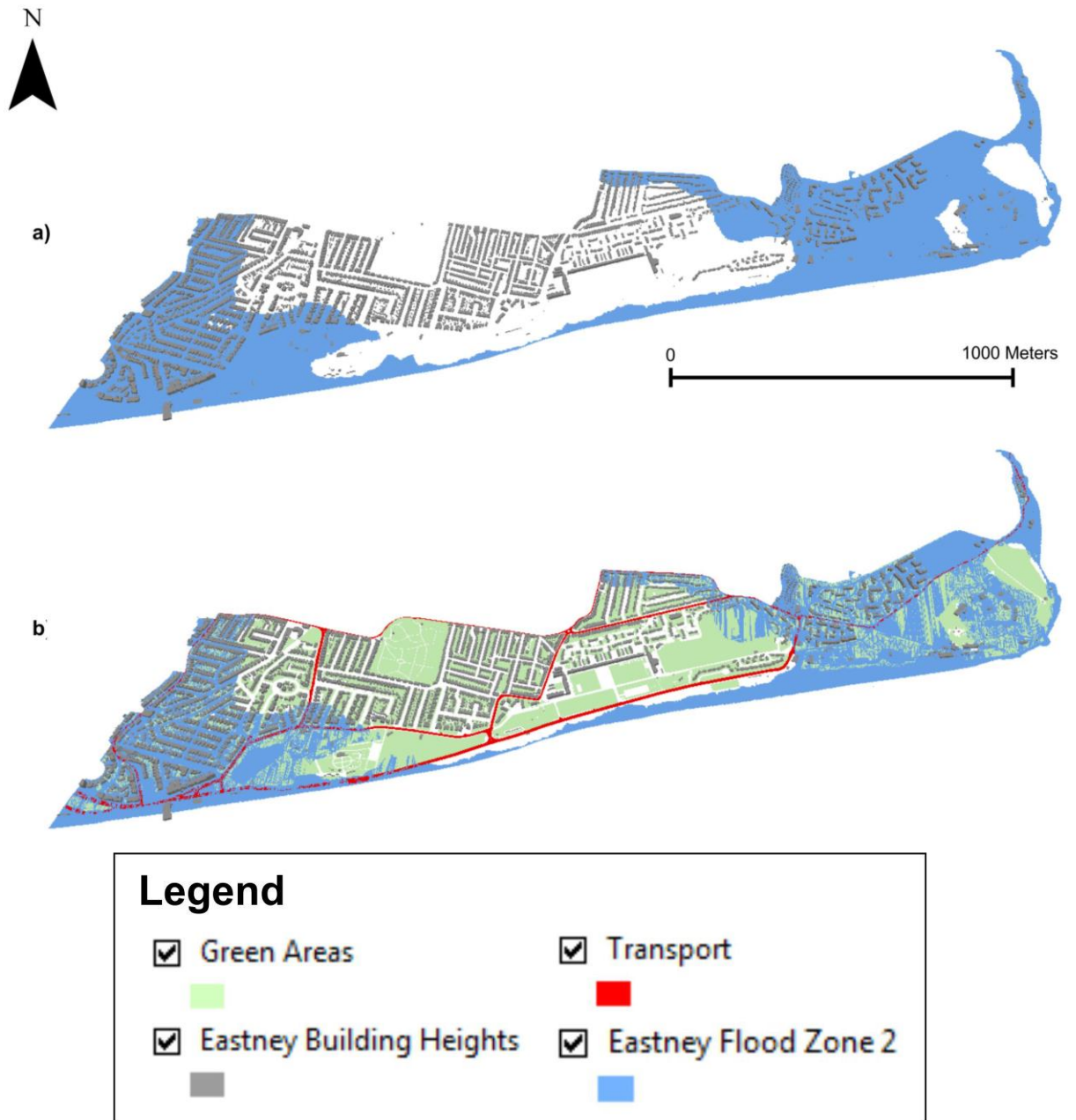
**Figure 5.14.** 3D visualisation trials Eastney Stage 1 – **a)** Eastney ward OS Mastermap Area added (green). **b)** OA6186 OS Mastermap Area added (red) (Source: OS Boundary Line).



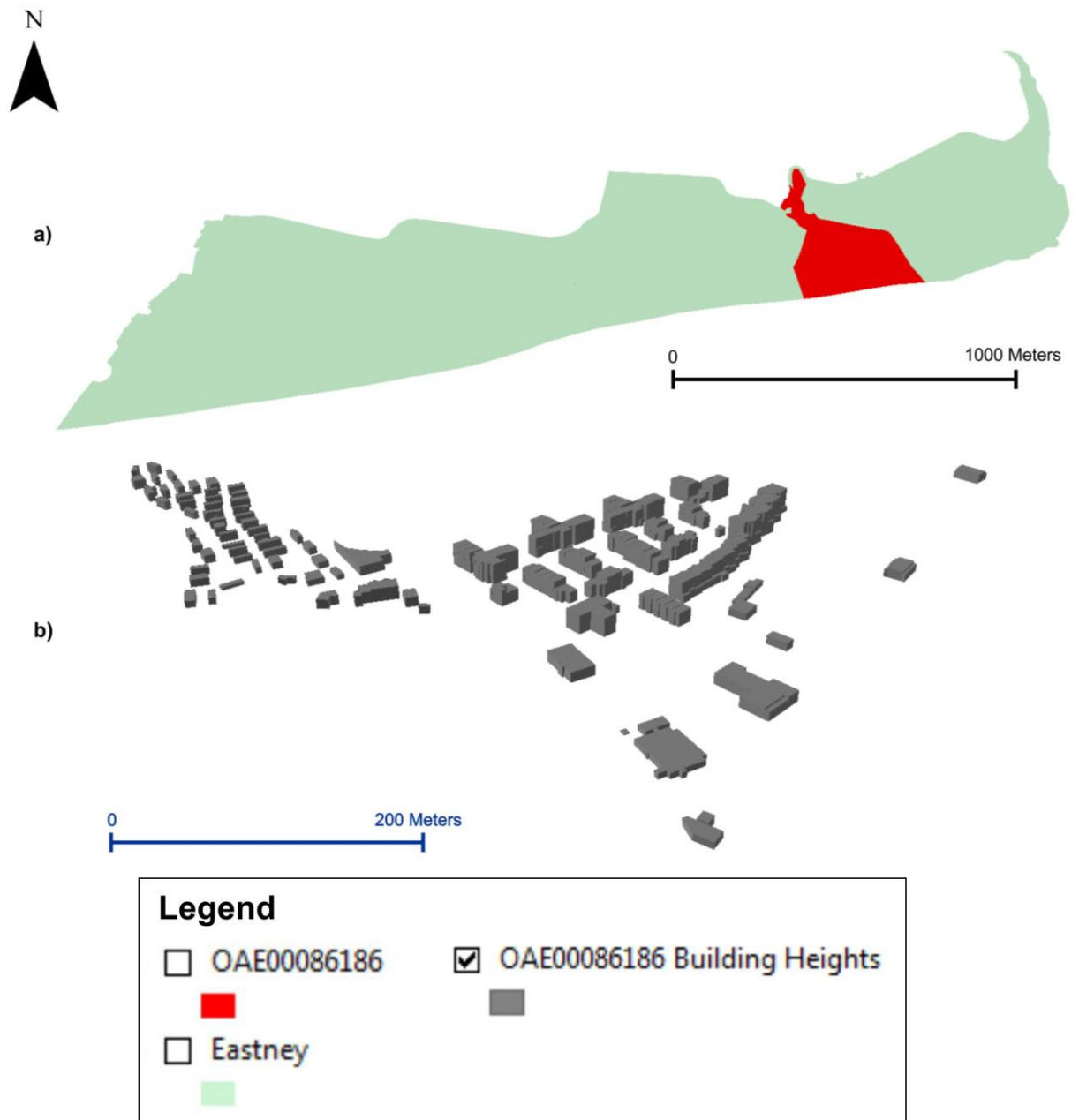
**Figure 5.15.** 3D visualisation trials Eastney Stage 2 – a) Eastney DTM added. b) 3D aerial map of Eastney via Eastney DTM (Sources: OS Derived DTM & OS Aerial Imagery).



**Figure 5.16.** 3D visualisation trials Eastney Stage 3 – **a)** Eastney Buildings Height layer added and given base heights (z value). **b)** Eastney green areas and transport layers added (Source: OS Building Heights).



**Figure 5.17.** 3D visualisation trials Eastney Stage 4 – a) Eastney Buildings Height layer and clipped Eastney undefended (OP1B) Flood Zone 2 (FZ2). b) Eastney Buildings Height, undefended (OP1B) Flood Zone 2 (FZ2), green areas and transport layers displayed (Sources: PUSH & OS Building Heights).

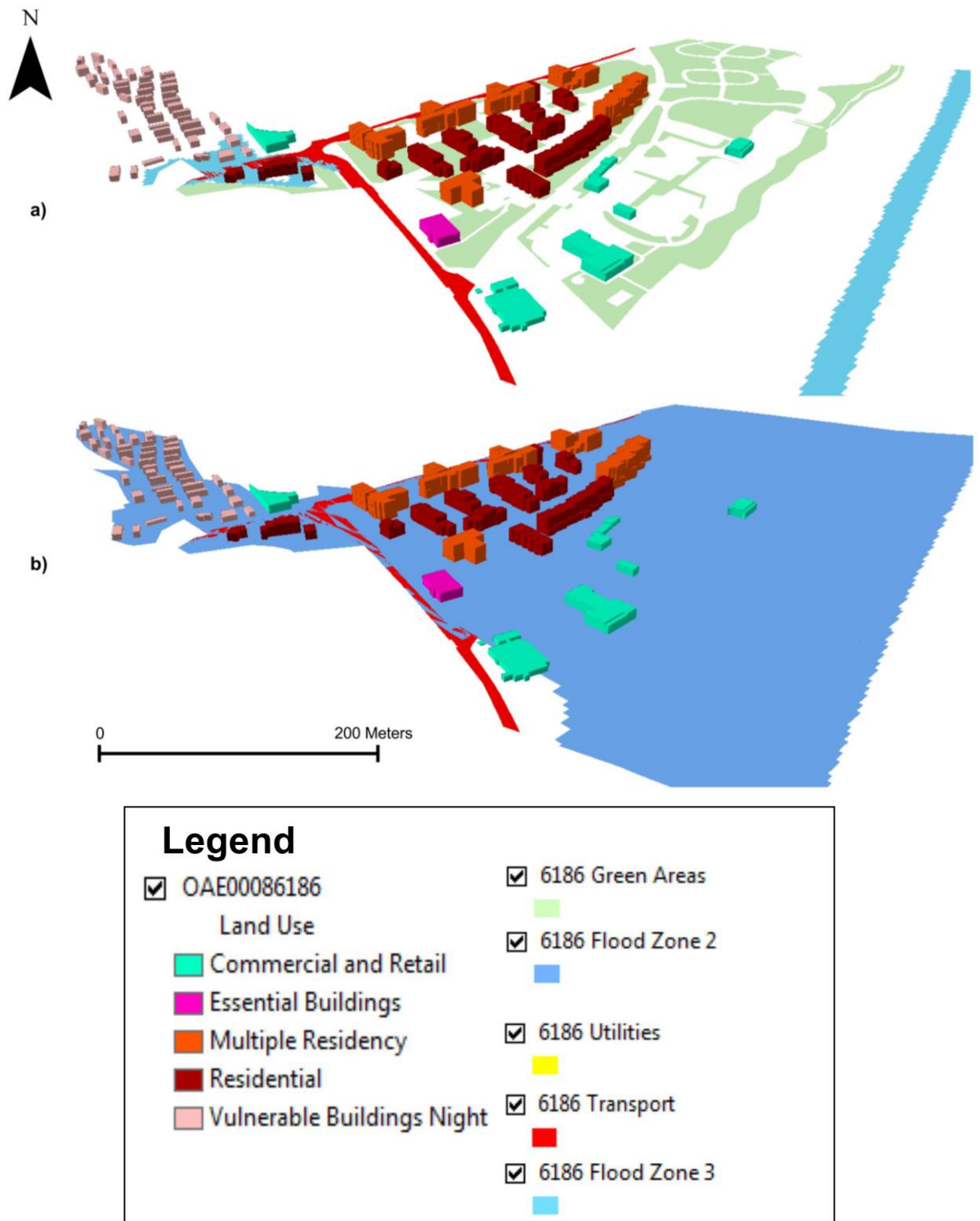


**Figure 5.18.** 3D visualisation trials Eastney Stage 5 - **a)** Identification of **OA6186** in Eastney ward. Black scale bar associated with this image. **b)** 3D **OA6186** Buildings Height layer. Blue scale bar associated with this image only (Sources: OS Boundary Line & OS Building Heights).

Point, and 6186\_Uilities Point. These layers were selected one at a time to edit and create the polygon shapefiles listed previously, hence creating vulnerable land use layers for **OA6186** (Figure 5.19). Once the new land use polygon layers had been created the process of copying this information into the **OA6186** Building Height layer could begin. To re-classify the **OA6186** Buildings Height layer a new spreadsheet was opened within MS

Excel (a sample can be seen in Appendix B) and labelled 6186\_LU. Three columns were labelled as FID, Toid and LandUse. Within ArcMapper the 6186\_Buildings Height Layer is selected and displayed at 40% transparency and placed above all the other polygon layers. Using the identifier tool each building heights polygon is selected and matched with the land use underneath. The FID number and toid code (unique OS building labelling ID) is noted in Excel, and the matched land use is written in the third column. When noting the land use in excel it is important to write in which land use you would rather be displayed first, when buildings share land use. For instance the Vulnerable Buildings Night and Multiple Residency buildings are also Residential buildings. As they are not separate layers (i.e. grouped into the Buildings Height layer) only one will be displayed, therefore, for visual purposes, Vulnerable Buildings Night and Multiple Residency were written above all Residential buildings in Excel. When every building polygon for OA6186 was noted in Excel, the file was saved and then joined to the 6186 Building Heights layer in Arc and displayed via the symbology option to display the land use column. The new Building Heights Multiple land use layer was then checked against the original land use polygon shapefiles to ensure no mistakes had been made, or any building polygons had not been identified/re-classified.

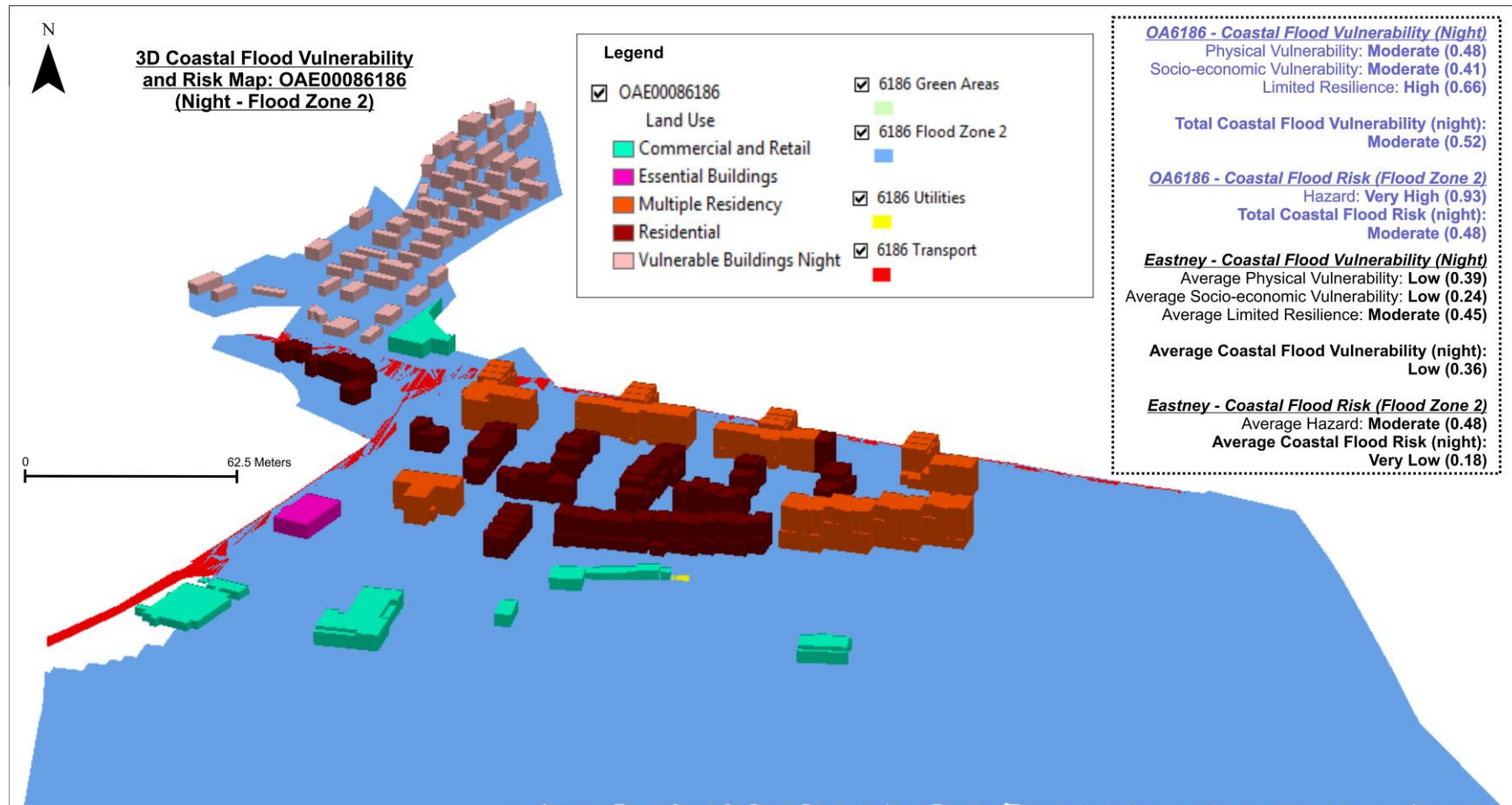
The new OA6186 Multiple Land Use layer was then made three-dimensional by applying base heights that were already contained within the layer (written by OS) and this information was used to extrude the buildings shapes height. This results in the neighbourhood's buildings being presented with height and vulnerability orientated land use in a pleasant 3D manner (see Figure 5.19). These features are useful as they present a platform that identifies vulnerable features in a view that is more understandable and less abstract than traditional 2D maps and the previous examples from the other visualisation trial stages (Bonner, 2013, pers comm; Hampshire Fire and Rescue, 2013, pers comm; Spiller, 2013, pers comm). The Transport and Green Areas for OA6186 were also added as well as the clipped FZ3 and FZ2 (to OA6186) layer (Figure 5.19).



**Figure 5.19.** 3D visualisation trials Eastney Stage 6 – a) OA6186 neighbourhood buildings with height and vulnerability orientated land use presented in 3D. b) OA6186 neighbourhood buildings with height, vulnerability orientated land use, and clipped Flood Zone 2 and 3 presented in 3D (Source: PUSH).



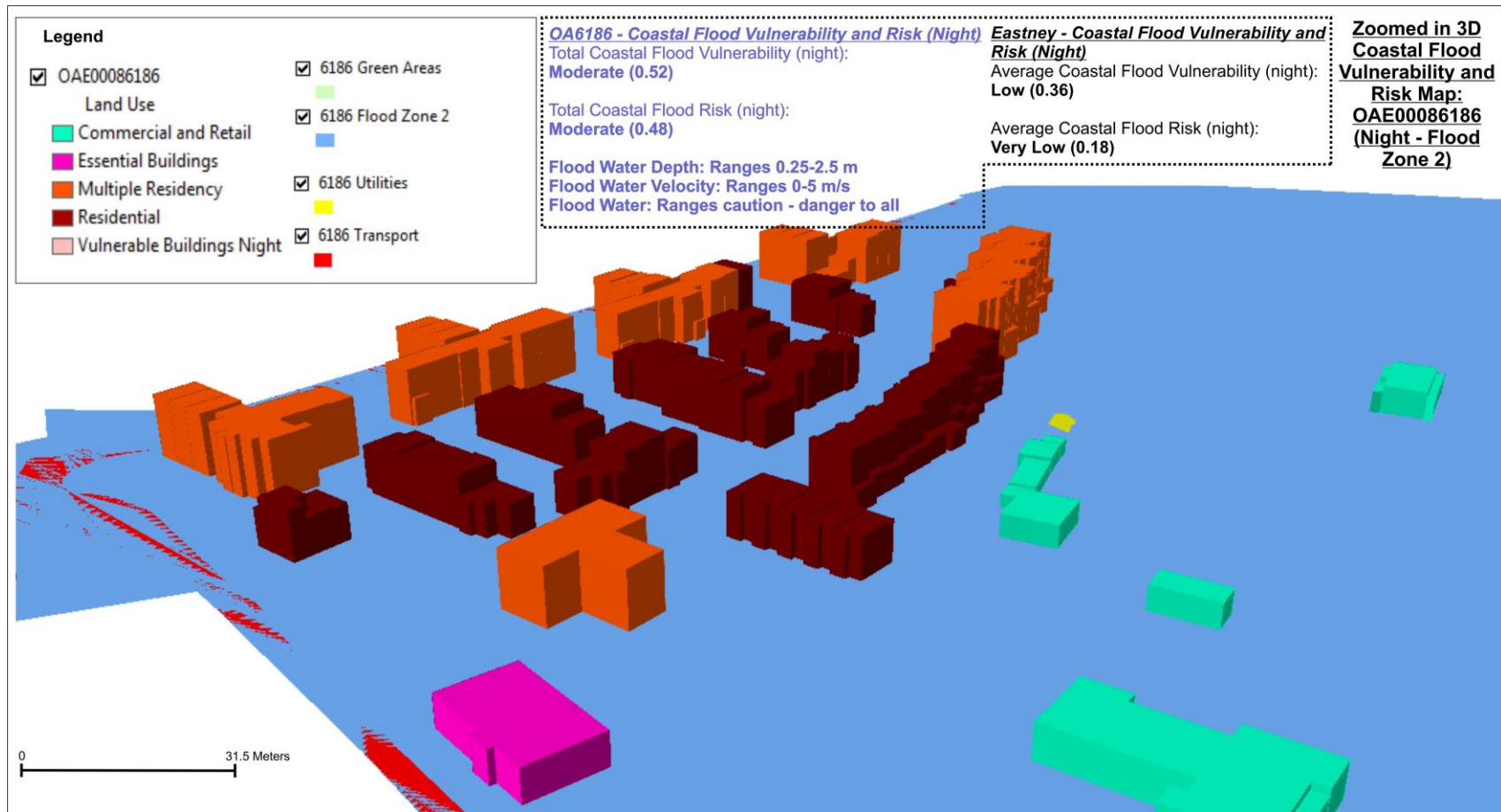
To improve the neighbourhood level CoFV and CoFR visualisation techniques further; Figures 5.20-5.22 present **OA6186** with quantified CoFV and CoFR levels zoomed in. These detailed OA level CoFV and CoFR maps combine lots of information and promote further understanding by showing us more than the sum of this neighbourhood's parts. Figures 5.21 and 5.22 show a further zoomed in view of a segment of **OA6186**. Figure 5.21 shows just the detail of **OA6186** and raises awareness of the physical vulnerability present in this area. Figure 5.22 contains the flood zone (with added water depth and velocity information) and the resulting CoFV and CoFR levels for this neighbourhood, when a flood of this magnitude would inundate this area at night. These maps show the detail that can be shown; the multiple residency and residential buildings in this particular part are large complexes and tall, and compared to other neighbourhoods in the ward the CoFV and CoFR levels are substantially much higher for **OA6186**. The flood water that would inundate this neighbourhood ranges from 0.25-2.5 m with velocities between 0-5 m/s. Meaning some flood water could be extremely deep and fast flowing, and therefore very dangerous and could cause risk to human life. These maps present an understandable platform to not only raise awareness for local people and decision makers, but also assist emergency planners and responders for coordination of preventative, protective and rescue evacuations (Bonner, 2013, pers comm; Hampshire Fire and Rescue, 2013, pers comm; Spiller, 2013, pers comm).



**Figure 5.20.** Night time 3D Coastal flood vulnerability and risk map: OAE00086186 (FZ2). Hazard, vulnerability and risk: **0.0-0.2** – very low; **0.21-0.4** – low; **0.41-0.6** – moderate; **0.61-0.8** – high; and **0.81-1.0** – very high (Source: PUSH).



**Figure 5.21.** Zoomed in 3D re-classified land use map OAE00086186.



**Figure 5.22.** Zoomed in coastal flood vulnerability and risk map: OAE0008618. Vulnerability and risk ranges: **0.0-0.2** – *very low*; **0.21-0.4** – *low*; **0.41-0.6** – *moderate*; **0.61-0.8** – *high*; and **0.81-1.0** – *very high* (Source: PUSH).

### 5.3 Summary

Despite, the European Union Floods Directive, requiring the establishment of flood maps for high risk areas in all European member states by 2013, the current practice of flood mapping still has some deficits; flood hazard/vulnerability/risk maps are also still frequently seen as an informative tool, rather than a communicative tool; the contents of these maps also regularly do not match the requirements of end-users; lastly, flood maps are often visualised in a way that cannot be easily understood by users (Meyer et al., 2012).

Large amounts of data were collected for this research, all transcribed and standardised into Excel spreadsheets in order for indexing to occur, allowing a simple quantitative overview of Coastal Flood Hazard (CoFH), Coastal Flood Vulnerability (CoFV) and Coastal Flood Risk (CoFR). Traditional electronic spreadsheets cannot visually represent the information, mainly due to presentation limits. Visualisation allows a summation of all data into a form that presents answers to the original questions asked. It makes interpretation easier and assists with communication of your findings to all members of society. It helps all coastal delegates, coastal and emergency managers, and policy makers to identify areas that need adaptation or changes in their adaptation strategies; understand what influences vulnerability and risk; know where to concentrate their efforts to reduce impact; assisting with general costings – expenditure and perhaps revenue enhancement.

3D modelling and mapping are being used by an increasing range of consumers, for such purposes as diverse as city planning and architecture, design and advertising, transportation and tourist maps, utility management. 3D mapping offers opportunities for improved data communication, not available in two-dimensional (2D) representations (Bandrova, 2005; Pegg, 2013). It is time to implement this tool to its maximum potential and help to improve our communities' resilience to natural hazards. 3D Coastal Flood Vulnerability and Risk maps are accessible to a wide range of users, from general public to highly skilled specialists/delegates, as they promote a platform for better understanding and displayed realism i.e. they enhance the users understanding of the spatial relationships between features by being more realistic and similar to the reality we see every day; this simplifies the information 'we' take in and creates a less abstract view of the world (Haeberling, 2004; Pegg, 2013). The final examples given in Figures 5.18-5.19, present developed 3D visuals that cross disciplines with regard to assisting our understanding of coastal flood

hazard, vulnerability and risk. They can be used by emergency managers and servicemen in times of crisis; and provide essential information to coastal managers and emergency planners in times of preparation. They can also be used as a simple communication tool for the individual and assist with education and understanding of Coastal Flood Risk, therefore increasing resilience.

Further discussion of the visualisation results, including limitations and recommendations for future research are all presented in Chapter 6 and 7.

## Chapter 6. Discussion

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## Chapter 6. Discussion

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### 6.1 Aims, Objectives and Achievements

The findings presented in this thesis shows that vulnerability assessments in the context of natural hazards, can be based on different approaches. This research sought to understand, assess and map UK Coastal Flood Vulnerability (CoFV) at the most detailed level, within the constraints of data protection. This led to a subsequent analysis of Coastal Flood Risk (CoFR), via the combination of the Coastal Flood Vulnerability Index (CoFVI) and a Coastal Flood Hazard Index (CoFHI) analysis. Three wards within the island city of Portsmouth situated within the Solent region; was chosen to test the methodology. The methodology framework established to create the Coastal Flood Vulnerability Index (CoFVI) and subsequently the Coastal Flood Risk Index (CoFRI) is notably made up of many different approaches used to populate the identified vulnerability factors that measure the three established vulnerability components: physical vulnerability, socio-economic vulnerability and limited resilience.

The methodology's framework attempted to capture the most relevant features of coastal flood risk (pre and post impact), based upon a judgemental selection (informed by other theoretical studies; Cutter, 2003; Kaźmierczak and Cavan, 2011; Lindley et al, 2011, 2012; Balica, 2012a; Balica et al., 2012; Birkmann et al., 2013 and practical applications; Alexander et al, 2011; Lindley et al, 2012; NSSMP, 2012), of aspects that were considered crucial and representative of reality. The scale of study chosen for the analysis was Output Areas (OA), as this represents a level in which principle dimensions of vulnerability are founded and it includes the 'physical' and 'social' composition of an area. OA's can also be seen as the closest form of data level/boundary to a 'neighbourhood'. Post impact, social vulnerability and resilience come to the fore, especially during the emergency phase (Menoni et al., 2012). When an area is recovering, resilience becomes the more prominent component, due to the long term induced, indirect and secondary effects the impact has generated. However, this research emphasises that all components of vulnerability are equally important pre, during and post impact.

The main aim of this research was to create a methodology that would analyse and map the key components of Coastal Flood Vulnerability in order to measure Coastal Flood Risk.



This Coastal Flood Risk assessment could be used to assist creation of usable terms for policy and practical decision-making within coastal and emergency management. Currently, there is an indisputable rise in hazards driven by climate change that has not been matched by improved community or environmental response, resulting in current mitigation strategies and measures being inadequate (Menoni et al., 2012). The UK storm surges and resulting extensive damage in 2014 emphasise these points.

The ward of Hilsea from the city of Portsmouth was selected to develop the methodology at Output Area (OA) level. This included all the methodologies created to extract the necessary data variables that were used to populate the vulnerability factors chosen to represent the three vulnerability components: physical vulnerability, socio-economic vulnerability and limited resilience (Chapter 3). To ensure the methodology's applicability and reduce the complexity of the final Coastal Flood Vulnerability Index (CoFVI), the wards of Eastney and St Thomas were also measured, using the methodology developed when analysing Hilsea. Through the development of the CoFVI and CoFRI this thesis hopes to contribute, to identify and develop methodologies that assist and improve local decision making processes for coastal flood management. This chapter discusses achievements of this research in terms of the aim, research questions and objectives that were set in Chapter 1, as well as the contributions to science. The strengths, weaknesses and limitations of this study are also reviewed.

*1: Can neighbourhood-level coastal flood vulnerability and risk be analysed and quantified via accessible geoinformatic data, within a risk, hazard, vulnerability model i.e. one framework?*

The findings of this research, confirms with the literature (Lindley et al, 2011; Balica, 2012a; Birkmann et al, 2013) that vulnerability can be analysed as an element of exposure, susceptibility and resilience of any system affected by hazards. There can be no assessment of risk without first understanding this concept (Birkmann et al, 2013). By defining vulnerability for this research, evaluation could follow (Cutter et al, 2003) i.e. it became a more tangible concept. This research also verifies work by Lindley et al (2011), Birkmann et al (2013) and Climate Just (2015), that these three components can be brought together into one model and one methodology framework can be created and used to encapsulate

that model (Lindley et al, 2011; Balica et al, 2012; Climate Just, 2015), thus achieving objective one.

This research also established the component of resilience as a key part of a vulnerability assessment, supporting findings from the literature (Lindley et al, 2011; Birkmann et al, 2013; Climate Just, 2015; DEFRA, 2015). Although the source – pathways – receptors model (outlined in Chapter 1) recognises there is more to risk assessments than simply analysing the hazard (source), it does not take into consideration the measurement of resilience. Today 5.2 million people in England and Wales are deemed to be at risk of flooding, and less than 40% of those significantly at risk of flooding will be aware of it and the potential impact flooding can have (National Flood Forum, 2014). Understanding how a community can adapt, respond or recover from flood events (their resilience), is a critical element of determining vulnerability. However, although it is likely that large numbers of communities within high flood risk areas in the UK will have to rely on community flood resilience as their key strategy, currently there is no single flood resilience index to establish the potential efficacy of such strategies. A limitation of this research is the small amount of factors used to measure the resilience component, compared to the other two. Finding effective metrics to assess resilience is very challenging. It appears that the data needed to understand a community's resilience does not exist yet (especially in the UK), despite its ability to identify weaknesses and further target interventions (Cutter et al, 2014).

This research confirms with the literature (Gornitz, 1990; Sullivan et al, 2003; Sullivan and Meigh, 2003; Briguglio, 2004; Connor and Hiroki, 2005; Balica, 2009, 2012a; Lindley et al, 2011; Balica et al, 2012; Birkmann et al, 2013; Climate Just, 2015), that an index approach can be used to measure vulnerability and risk, and that index is made up of different factors. In order to analyse vulnerability, this research identified a set of vulnerability factors to measure the three components that encapsulate vulnerability: physical vulnerability (exposure); socio-economic vulnerability (susceptibility); and limited resilience (Chapter 3), this achieved objective two.

A natural hazard themed land use classification scheme was developed to assist the measurement of some of the vulnerability factors, notably those related to the physical

vulnerability assessment (objective three). This new hazard themed land use classification system identified aspects of the physical environment that are key to a complete assessment of vulnerability. Flooding has far-reaching and long-term consequences for those concerned. Within flood affected communities, people and areas suffer at different levels according to their degrees of exposure, susceptibility or fragility (their vulnerability) (Birkmann et al, 2013). The way in which such factors combine can significantly increase the potential impacts for those at risk (England and Knox, 2015). This research disagrees with Cutter (2003) that we know the least about socio-economic aspects of vulnerability. As many previous flood vulnerability assessments have concentrated on the social aspects (especially UK based) of the assessment (Cutter et al, 2003; Tapsell et al, 2003; Atkins, 2007; Kaźmierczak and Cavan, 2011; Lindley et al, 2011; Balica, 2012b; Balica et al, 2012; Birkmann et al, 2013), or the environmental component of vulnerability (Gornitz, 1990; Balica, 2012b; Balica et al, 2012; Birkmann et al, 2013). However, very little research has occurred to analyse the built environment in which we live, specifically the building type make-up of the urban environment. Liverman (1990), Bogardi and Birkmann (2004), Birkmann (2006b) and Cardona et al (2012) state that vulnerability refers to the propensity of exposed elements including our assets to suffer adverse effects when impacted by hazard events, yet very few examples exist of studies analysing our built environment (urbanisation) when faced with flood hazards. Lindley et al (2011) and Climate Just (2015) have highlighted physical exposure as a component of vulnerability, however only two factors were measured to analyse the whole component – green spaces and building level (i.e. basement level). This research analysed eight physical vulnerability factors, some of which were made up of more than one data variable, leading to a more detailed analysis of the urban make-up.

This research demonstrates the volume and breadth of data available for assessments of Coastal Flood Vulnerability and Risk along the UK coastline. It incorporated the latest climate change projection data, socio-economic data and physical/topographic data into one framework, achieving objective two. Ordnance Survey (OS) Mastermap and the 2011 UK National Census contain a vast amount of information that can be used to measure different attributes of vulnerability. For the majority of the vulnerability factors chosen for this project, the information was available, but required new approaches to calculate relevant information. Although, some factors could not be populated with data, due to it

being too complex to do so (e.g. *Occupation*), other factors were created later in the project's lifetime and established within the methodology (e.g. *Home Population* and *Vulnerable Buildings Day and Night*).

The creation of the hazard themed land use re-classification system (described in Chapter 3), established the significance of OS data within Coastal Flood Risk assessment. Without OSs data, the Coastal Flood Physical Vulnerability (CoFPV) assessment would not be possible. Due to the discovery of the sheer volume of material available within OS data, some could also be applied as data variables within the other two Coastal Flood Vulnerability components (Coastal Flood Socio-economic Vulnerability and Coastal Flood Limited Resilience). The re-classified land use layers created for the Coastal Flood Vulnerability analysis, were also extensively used within the visualisation trails described in Chapter 5, aiding visualisation of Coastal Flood Vulnerability and Risk, creating new and unique maps that could be used within coastal zone management.

This research has also demonstrated the potential of the use of the Environment Agency Flood Zones when measuring Coastal Flood Risk. The potential methodologies used to create the different Coastal Flood Hazard Indexes (results presented in Appendix B) shows that not only can these data be used to understand potential inundation spread (surface area), but also the potential range of velocities and depths of the flood waters.

This project has demonstrated the ability to bring different geoinformatic datasets together to achieve one goal, creating a network of knowledge that can be used between different institutions, universities and non-governmental organisations; encouraging collaborations between stakeholders that have a vested interest in managing the coastline (objective 7). It has also shown that large amounts of data are available for UK vulnerability and risk assessments, to the extent that different flood and time of day scenarios can be applied. This knowledge can be used to communicate Coastal Flood Vulnerability and Risk information, with possible scaling-up to larger areas, such as an entire coastal city.

This research has demonstrated how GIS can be used as a tool to measure and calculate certain vulnerability factors, mostly physical vulnerability. Using GIS it was possible to identify the data needed to measure specific physical vulnerability factors (e.g. multiple

residency buildings, vulnerable buildings, essential buildings), which would not have been seen if just in spreadsheet format.

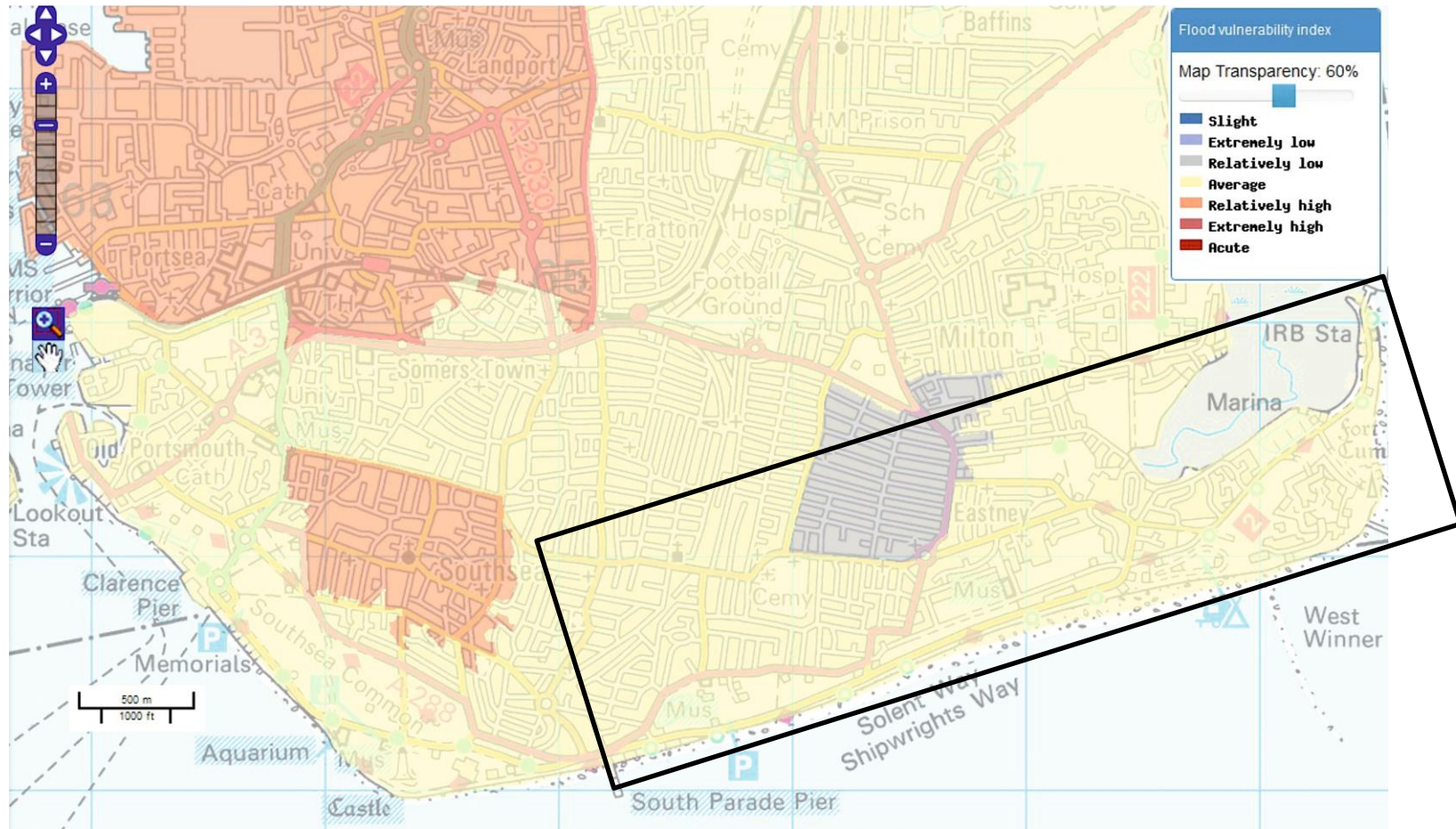
Conversion of all the raw data used within the Coastal Flood Vulnerability analysis was achieved by applying either equation 6a or b (Chapter 4) to standardise the results for all the variables used within each component. The resulting values were equally weighted and combined within their appropriate Coastal Flood Vulnerability component equation (i.e. physical, CoFPV; socio-economic, CoFSV & limited resilience, CoFLR), giving indexes for each component. These indexes were joined to the 2011 OS Boundary Output Area shapefile for each ward. This way of interpreting data via converted to map format provides a way of illustrating and communicating pictorially the degree (colour index of each map) and location of Coastal Flood Vulnerability (and its components) and Risk. These indexes and corresponding maps quantify, pinpoint and visualise critical hotspots within local areas (objective five). These results can be used to improve the preparation measures needed to be taken by all delegates that work within flood management.

This GIS-based assessment not only conveys overall Coastal Flood Vulnerability and Risk results to coastal and emergency managers, but it can also identify critical infrastructure, essential buildings and evacuation routes, which would be of use to the emergency services during the disaster (see final visualisation results in Chapter 5). The results show the differences between floods of different magnitudes (FZ3 & FZ2), but also for different times of day; identifying the different neighbourhoods that become affected due to the different circumstances. The results presented in Chapter 4 show that different inundation levels or times of day change the Coastal Flood Vulnerability and Risk of some of the OA neighbourhoods. The latter involves subtle changes in factors and would not have been noticed without GIS-based assessment.

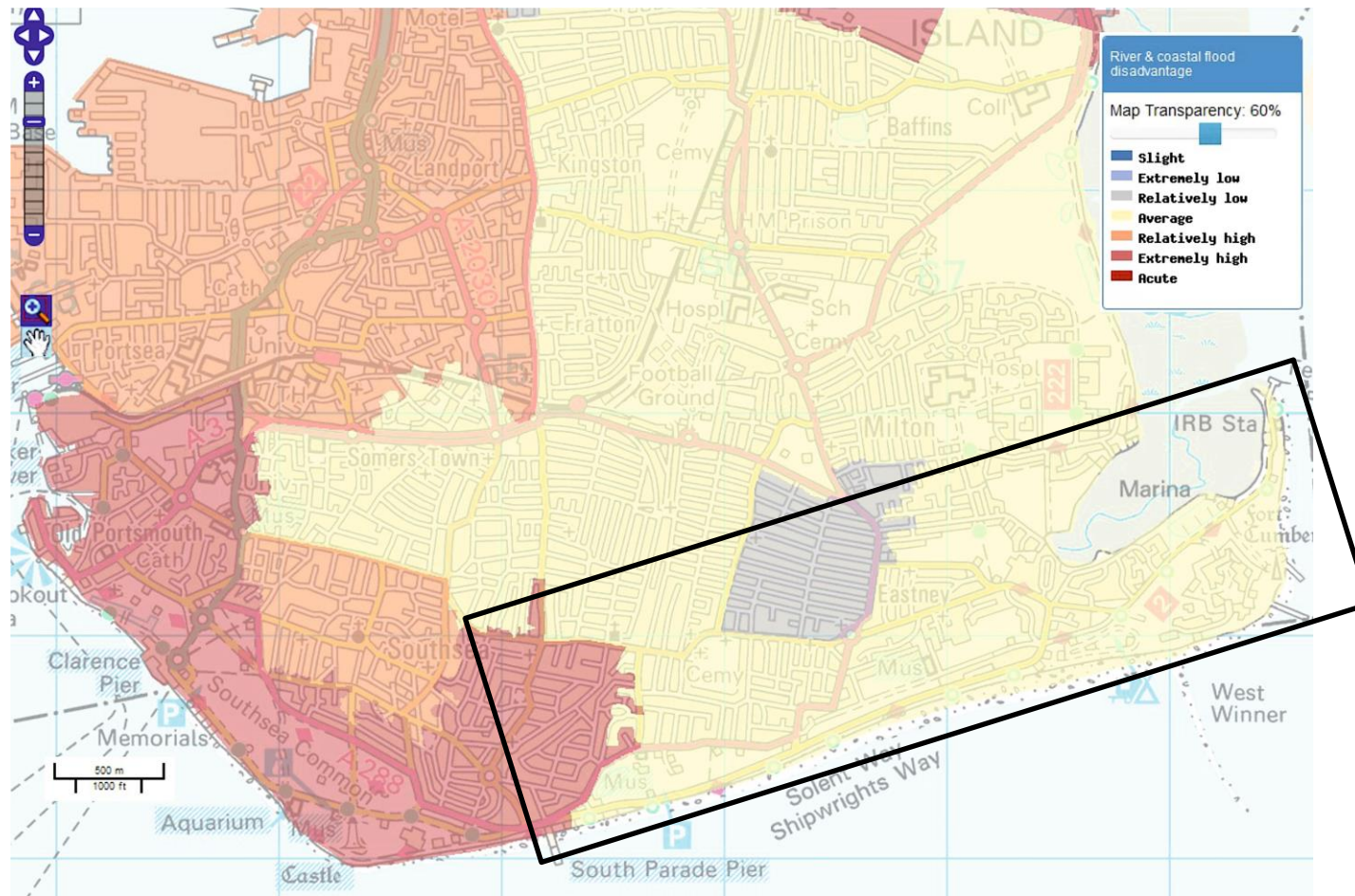
This research confirms GIS-based methodology is transferable, providing an innovative way of capturing, illustrating and communicating physical vulnerability, socio-economic vulnerability and limited resilience (McLaughlin & Cooper, 2010). The methodology also provides vital information in detail, regarding local vulnerability within the city, that can be retrieved, re-produced and utilised by local authorities coastal managers, emergency

services, planning departments and community resilience organisations, such as the Hampshire and Isle of Wight Local Resilience Forum.

This investigation has succeeded to assess coastal flood vulnerability and risk at neighbourhood level (objective four). By assessing at this scale, a detailed analysis of coastal flood vulnerability and risk took place. The methodology framework was applied at this level, producing indexes and corresponding maps identifying vulnerable and at risk neighbourhoods within three wards in Portsmouth. The findings of these results demonstrate that by not assessing at this scale critically vulnerable and at risk areas can be missed. This was identified in Chapter 4 Part B, when the results from this research were compared to the LSFRA (Atkins, 2007). This is demonstrated further in Figures 6.1 and 6.2. These figures show Climate Just's (2015) (adapted from Lindley et al's (2011) work) Flood Vulnerability and River and Coastal Disadvantage Indexes for the ward of Eastney. Despite more vulnerability ranges available in the index (seven) compared to the ranges used in this research (five), the ward of Eastney appears to be entirely at average vulnerability and disadvantage level, compared to the many differences shown by this research's results (Figure 6.3). This is due to the Climate Just (2015) indexes being measured at Middle Output Super Output Area (MSOA) and using a smaller number of factors. In order to reduce vulnerability and the potential for flood related impacts as well as increasing resilience, the scale and physical, social and resilience related components of vulnerability need to be considered, otherwise crucial features are missed and vulnerable and at-risk areas are unidentified.

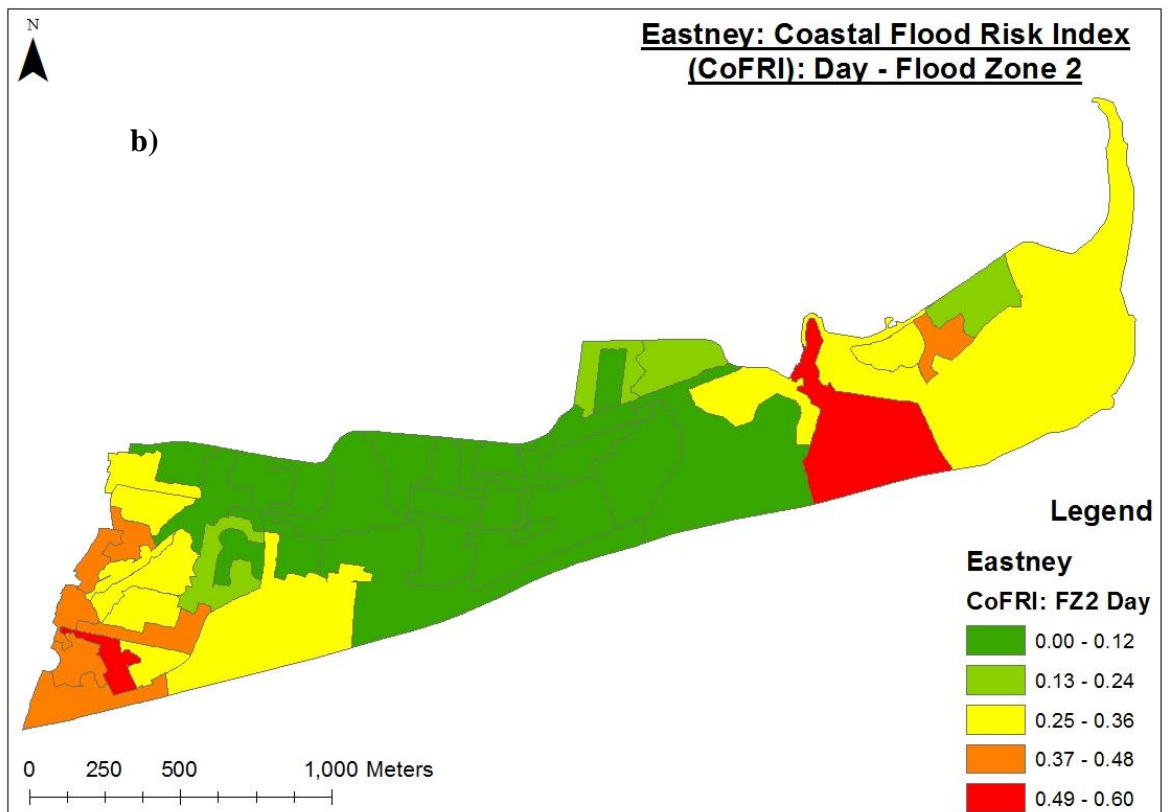
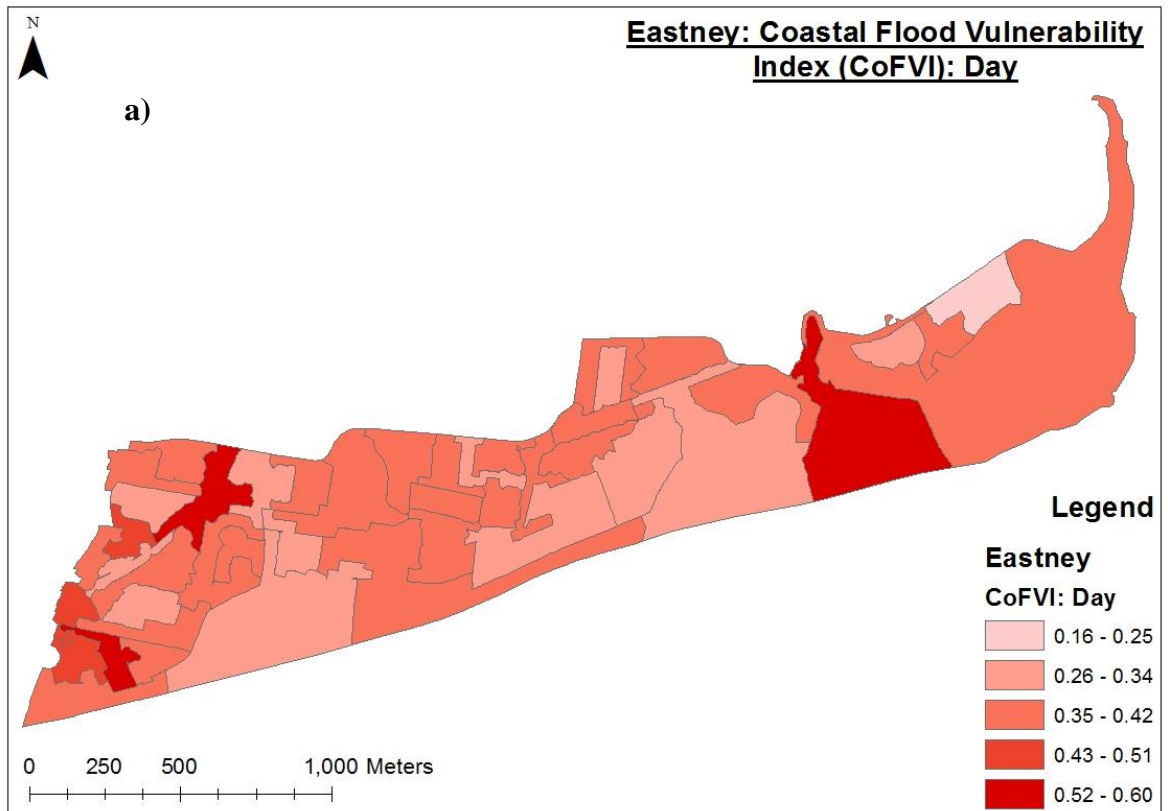


**Figure 6.1.** Flood Vulnerability Index – Portsea Island South (Climate Just, 2015) (Crown Copyright and database rights 2015 Ordnance Survey). Black rectangle represents Eastney ward vicinity.



**Figure 6.2.** River and Coastal Flood Disadvantage – Portsea Island South (Climate Just, 2015) (Crown Copyright and database rights 2015 Ordnance Survey). Black rectangle represents Eastney ward vicinity.





**Figure 6.3. (a) Coastal Flood Vulnerability Index & (b) Coastal Flood Risk Index for Eastney ward at OA level – Day. Vulnerability and risk ranges: 0.00-0.20 – very low; 0.21-0.40 – low; 0.41-0.60 – moderate; 0.61-0.80 – high; and 0.81-1.00 – very high.**

To summarise, coastal flood risk assessments (which have been carried out for the English coastline in the form of Strategic Flood Risk Assessments (SFRA's)) occur in order for the appropriate coastal and emergency management and adaptation strategies to be applied and therefore decrease risk, improve resilience and help sustain a sustainable environment. Vulnerability analyses are part of the SFRA assessments, but as yet, they are lacking in detail (Environment Agency, 2006b; Atkins, 2007; NSSMP, 2010). Through applying this project's vulnerability components within the risk equation (Chapter 2), it was apparent there were many factors that could measure coastal flood vulnerability. To apply those factors an index approach was used and an establishment of the CoFV factors occurred, along with distinguishing which components they applied to. Understanding what the Coastal Flood Vulnerability factors were, enabled the creation of an overall methodology framework to analyse CoFV (Figure 3.5), and the establishment of methodologies to measure each Coastal Flood Vulnerability factor.

The methodology established within this research has enabled multiple factors of Coastal Flood Vulnerability components to be analysed, capturing a detailed view of communities, allowing assessment of aspects that have been neglected by traditional UK flood risk analyses. The methodology improves our understanding of where mitigation of risk is needed within local communities; where vulnerable communities are situated; and where to focus our adaptation investments.

## 2. Can neighbourhood-level coastal flood vulnerability and risk be quantified and mapped for different times of day?

During the vulnerability factors development and analysis stages (Chapter 3), it became apparent flood vulnerability assessments could contain factors that enabled analysis to occur for day and night time. It was decided that a day and night time analysis would take place for Coastal Flood Vulnerability and Risk, as floods at different times of day could have very serious repercussions. Floods at night are more dangerous than during the day as mainly people are unaware of disasters occurring during the night, as most residents would be sleeping. This leads to dangerous situations, with increased risk to life. Darkness leads to disorientation and inability to observe many flood dangers mainly in the form of water depth, contamination and sharp large submerged objects. It is vital to assess CoFV and CoFR at different times of day as floods at different times can result in different levels of

impact due to the different dangers presented. It is key to pinpoint neighbourhoods where these perils may arise in order to improve our evacuation and mitigation strategies and target where our resources are needed.

This approach has never been utilised in other flood vulnerability and risk assessments, and is a very unique feature of this research. The vulnerability factors created to separate a day and night analysis have also not been looked at or measured in previous studies in this way. The separation of a day and night population and vulnerable buildings at day and night are unique aspects of this project. Through this separation the results pinpointed neighbourhoods that were sometimes more or less vulnerable or at risk during the day rather than at night. One might expect all areas to be more at risk at night time, however, in reality these indexes show neighbourhoods fluctuate in vulnerability and risk levels between these times, and some can actually be more at risk during the day than during the night. Understanding which neighbourhoods need the most attention during evacuation is crucial as is where we concentrate our resources and adaptation strategies. This extra level of detail within the research's findings addresses these issues and allows better targeting of interventions to improve resilience, reduce vulnerability and enhance recovery, it is crucial to give as detailed 'a picture' as possible, to assist our ability to inform decision-makers and deliver effective policies.

Lastly, the maps produced by this research to visualise the coastal flood vulnerability and risk indexes, use a traditional 2-D style of representing Coastal Flood Vulnerability and Risk. 3-D visualisation techniques were examined to explore ways that information could be communicated to better understand Coastal Flood Vulnerability and Risk, leading to better public awareness and increasing overall resilience (objective six).

The CoFH, CoFV and CoFR maps produced from the 3-D visualisation trials (described in Chapter 5), showed the potential of visualisation techniques when communicating aspects of risk. This research also displays the different types of data Ordnance Survey has to offer and how it can be applied. The project has also shown the potential via the Channel Coastal Observatory website, which is a very useful free data source that could be utilised by local delegates and researchers. This research presents a basis for further research,

promoting further exploration of the possibilities this area of risk science has to offer, possibly resulting in improvement of education and communication of this information.

## 6.2 Strengths, Weaknesses and Limitations

With regard to limitations and weaknesses within the study, there are many potential weaknesses in using indicators and creating indices, notably the validity of an aggregated method such as used in this study (Balica, 2012a). Indicators are used to represent real life, they assist our comparisons of communities, society, urban areas and coastal zones time and space. There are many different definitions of vulnerability (discussed in Chapter 2), and yet it is a concept that comprises of a multitude of processes and aspects, the understanding of which helps with our understanding of risk and thus helps with our disaster risk reduction activities. There is also an issue with concentrating many aspects of vulnerability into one indicator. The indicators themselves can be seen as subjective – what one perceives as vulnerability, another may not; therefore aggregating indicators increases the subjectivity further, and so even more difficult to analyse and evaluate.

Aggregating various indicators of flood vulnerability and merging them with Coastal Flood Hazard data has produced a Coastal Flood Risk Index (CoFRI). Stakeholders such as the Environment Agency, Local Authorities and coastal zone managers are dependent on the choice of the data that represents these Coastal Flood Vulnerability indicators. Unapprised choices at the first level sieve through and can therefore result in an invalid index. Indices for any natural hazards should be continuously developed as new information and thinking processes are found. This will assure the best results for that time.

With regards to the map data - OS Mastermap now contains OS Sites which removes some of the problems encountered within the land use reclassification methodology (highlighted in section 3.2.2.1). Hospitals and schools that have many buildings associated with them, were previously only labelled by Address Layer 2 via the main building. This led to difficulty when only viewing OS data, i.e. which other building polygons were associated with these facilities? Leading to clarification by aerial photos and normally Google street view. This, although thorough, was time consuming, which is something that the users of this methodology may not have.

A particular weakness of the project was the longer methodology required to measure the CoFPV data Multiple Residency variable, for the factor *Tenure*. Although there is the ability to measure this, it is a complicated process due to there being no complete dataset of this nature. The data layer 'multiple occupancy' can be found within Ordnance Survey's Mastermap Address Layer 2, however, it only refers to residential buildings that share one letter box. For most multiple residency buildings this is not the case, and the only way to map and measure the true extent of these types of buildings was to look at one OA at a time; manually identifying each residential address point, which was time consuming compared to measuring other data variables. It is recommended, due to the importance of this variable, and its uniqueness, that further investigation is taken in future research to identify a quicker methodology for extracting this information.

For the data taken from the 2011 UK National Census, the main limitation is the date from which the data is taken. For this research, all UK National Census used was updated in January 2013, however in another five years this data may not be as true to reality. Nevertheless, no other options with regards to measuring CoFSV are available, i.e. what social data is as freely available and accessible, as the UK National Census? The ability to analyse at OA level via the UK National Census, is as close to individual level that is allowed, without breaking data protection. Therefore using the UK National Census data is the best option available and a step in the right direction, rather than not analysing socio-economic vulnerability at all, which has been proven by many to be an essential component of vulnerability (Cutter et al, 2003; Nicholls et al., 2008; Balica, 2012a; Birkmann et al, 2013).

During the final visualisation trials methodology, it was noted that to create the 3D land use some of the building heights polygons information has to be noted in Excel and matched to land use descriptions. The limitations of this process are firstly, it is time consuming, and it is suggested that only individual neighbourhoods should be done. Secondly, multiple land use information is lost in this type of visualisation.

Within the land use classification stage in the research (described in Chapter 3), a Multiple Land Use layer was suggested as an extra layer due to many buildings having more than one land use, the most common (within the wards examined), being a commercial and

retail building on the ground floor and a dwelling on the upper floor/s. Figure 5.12 in Chapter 5 shows an example from the Bureau of Portland's land use methodology which resulted in a very detailed view of the buildings in that small part of the city, to the extent the different levels (i.e. floors) of different land use's are noted. Multiple land use is an important factor to look at, but it was not seen to have the same level of importance as for example the data variable vulnerable buildings, within the vulnerability analysis. However, for visual purposes perhaps it is an extra feature that should be noted? For instance, the aim of the visualisation trials within this research was to produce maps that would hold useful information for all the different delegates involved in coastal flood risk management. To the emergency services and emergency planners they may not be as invested to know where commercial buildings are, but if there are residential abodes in the upper floors then this is important. Residential buildings were written underneath the other land use layers in Excel and so these land uses are shown first in order for the land use to be joined to the building heights.

There are further negatives to 3D mapping, specifically in the designs of the maps. Cartographic principles for classical 2D mapping, were set out a long time ago as a foundation for successful map creation. They suggest what a map should contain, how features should be generalised to display relevant information to the user in an efficient and clear manner, and what should not be included (Pegg, 2013). There are many writings about the technology used to create 3D mapping products, but yet none that try to determine guidelines for the design and presentation of 3D maps (Haeberling, 2004; Pegg, 2013). Due to this, there are certain issues. Orientation is seen as no longer an issue for 3D maps (within ArcScene there is no ability to add a north arrow), however without orientation a zoomed in areas' placement within a larger geographical area maybe very difficult to place; symbology, annotations and 3D objects will have no general recognition for the user; different levels of detail and abstraction may be confusing for a user; lastly depth perception, view angles and a constantly changing scale again affect the usefulness of the 3D map (Pegg, 2013).

When creating 3D visualisations in ArcScene a lot of the issues noted in the paragraph above were considered. Therefore when producing the final coastal flood vulnerability and risk visualisations (see Chapter 5), certain guidelines were created:

- To always use the same colour scheme for land uses and flood zones as used in the rest of the project.
- To not view areas from ‘underneath’; meaning you can rotate your layers 360 in ArcScene, which unless you are looking at underground features, is not useful and only confusing to a user.
- Do not over complicate a map with many layers which could lead to distracting the user from the main map goals.
- When editing the final maps in Corel Draw to add in a Legend and Scale Bar (these options are not available within ArcScene).
- Give structure to any vulnerability or risk index figures i.e. state the average coastal flood vulnerability level for the ward, to give structure to the neighbourhood’s individual result.
- Lastly when recording the animation, try to make slow long sweeping movements with the map, rather than quick zooming in and out and jittery movements, as they would be unpleasant to view and the user would lose focus and sense of direction.

The Coastal Flood Vulnerability and Coastal Flood Risk indexes produced from this study, along with the other Coastal Flood Vulnerability component indexes; give a thorough and clearer representation of Coastal Flood Vulnerability and Risk within each ward examined, and is the main strength of this study. This methodology highlights where different components of Coastal Flood Vulnerability are concentrated, such as areas that are more physically or socio-economically vulnerable, or where there is greater resilience. This study presents a methodology that produces a more complete picture of the reality of coastal communities that face coastal flood hazards. It provides a unique insight to the sociological and physical makeup of areas at a local level. The resulting maps allow trends to be identified individually and collectively, providing a ‘window’ into the present vulnerabilities of wards, and consequently where key areas of concern are located.

Vulnerability has many aspects and variables, sometimes making it difficult to measure empirically and through quantitative processes. The development of this methodological framework has involved the creation of some innovative data extraction methodologies, – notably a hazard themed land use classification system that was used to create new land classes that measured vulnerability factors quantitatively, e.g. *Emergency Facilities*,

*Essential Buildings, Multiple Residency Buildings, Residential Population Day and Night, Vulnerable Buildings Day and Night, and Transport.* Another innovative aspect of the research is the identification of day and night-time factors, leading to the unique analysis of day and night-time Coastal Flood Vulnerability and Risk. This methodology has focussed on analyses at the most detailed level possible, without breaching data protection; it has established ways of measuring vulnerability factors that could be applied to other natural hazard risk assessments, with scaling-up possible to town, city or district levels.

The trials in visualisation techniques have shown the options available through both OS and CCO data. The new Building Heights dataset provided by OS instigated the final visualisation trial methodology and resulting maps (Figures 5.17-5.19). Producing unique 3D Coastal Flood Vulnerability and Risk maps that could be accessible to a wide range of users; from the general public to highly skilled emergency management specialists, as they promote a platform for better understanding. Contingency planners, emergency responders and crisis managers could also use these maps, before and during a flood event. They can also be used as a simple communication tool for the individual and assist with education and understanding of Coastal Flood Risk.

This study has presented a methodology framework that produces many positive outcomes, yet it has taken a substantial amount of time to reach an applicable and clear approach, with many setbacks and sometimes too many options presented. This research project and the methodology developed has used the most appropriate methods to answer the research questions and objectives set, and achieve the designated main aim.

### 6.3 Summary

To summarise, recent flood disasters in the UK (2007 summer floods, winter 2013-2014 storm surges, and winter 2015 floods) have reminded us of society's increasing vulnerability to the consequences of population growth and urbanisation, technical and economic interdependence, and environmental change. Flooding has far-reaching and long-term consequences for those concerned. Within flood affected communities, people and areas suffer at different levels according to their degrees of susceptibility or fragility (their vulnerability) (Birkmann et al, 2013). However, vulnerability encompasses a broad range of factors including socio-economic i.e. age, health etc; physical characteristics of



the built environment; and also levels of a community's abilities to cope and recover from flood events and the associated social and physical impacts (their resilience). The way in which such factors combine can significantly increase the potential impacts for those at risk (England and Knox, 2015). Thus, high levels of vulnerability combined with high levels of hazard, result in high levels of risk.

Currently the UK government is seeking to deliver £600 million of investment to minimise flood risk. However, a report for the Joseph Rowntree Foundation by England and Knox (2015) shows that the allocation of funding fails to identify communities that are most vulnerable, let alone to prioritise their needs. In order to reduce vulnerability and the potential for flood related impacts as well as increasing resilience, the scale and physical, social and resilience related components of vulnerability need to be considered during the planning and creation of flood adaptive/management projects.

The local Strategic Flood Risk Assessment Social Vulnerability and undefended flood hazard index (presented in Chapter 4), definitely presents forward movement in SFRA's. The identification of very dangerous flood water is an important feature, especially during evacuation. However, when measuring vulnerability by only selecting four social factors gives a very small idea of the reality of the particular coastal community's physical and socio-economic makeup i.e. a blurred vision of the present characteristics. When comparing the SFRA results with this research's, it suggests that with these examples, certain aspects or attributes of vulnerability are not being accounted for, leading to some vulnerable areas not being identified. The most serious example is shown in Eastney. Vulnerable areas such as mobile home areas are critical in emergencies due to their inability to cope with flood water, plus both areas are on the shoreline. In OA6186 there are also large Multiple Residency Buildings, sometimes with one communal exit point, another important feature that increases CoFV.

These comparisons have demonstrated that an applicable methodology has been established within this research, to improve UK Coastal Flood Vulnerability and Risk assessment and mapping. Providing a clearer focus on areas of severe flood vulnerability, and determining key areas of concern to stakeholders involved with coastal flood management.

This research has demonstrated a methodology that can be used to analyse Coastal Flood Vulnerability and Risk for UK coastal communities, at the most detailed level possible with existing national geoinformatic datasets. This project has concentrated on Portsmouth, showing the advantages from GIS-based assessments and the strengths of bringing different geoinformatic datasets together, creating a more complete picture of vulnerable and at-risk areas from coastal flooding, for flood events of different magnitudes, occurring during either day or night.

Past examples of vulnerability assessments for flooding or natural hazards tend to focus on particular components of vulnerability. This research has analysed Coastal Flood Vulnerability by first understanding what that means, then developing a framework that used physical and social data to analyse vulnerability in a factor format at the highest resolution possible. Rather than just using indicators that were readily available, some new methodologies were developed to extract the information needed to measure vulnerability. This has led to the creation of separate results and maps to illustrate the different trends in Coastal Flood Vulnerability components at neighbourhood (OA) level and the different risk levels for different flood scenarios at different times of day, even to the extent of showing the possibility of only measuring Coastal Flood Risk for the most dangerous levels of flood water. Finally, the research has examined visualisation techniques, to assist with communicating this information in a clear and compelling way, to the many stakeholders that are involved in coastal flood management.

This research demonstrates that the CoFVI methodology can be applied at the most detailed level (neighbourhood) possible in the UK, allowing a local level of vulnerability awareness, which in turn could help to save more lives, reduce economic and environmental losses and distribute the financial burden better, by more accurately identifying at-risk neighbourhoods. All data variables used within this methodology can be scaled-up, from neighbourhoods, to towns, cities or districts, although the time scale would be longer due to the volume of data processing. A re-examination of the vulnerability factors identified here may therefore be needed if examining, for example, a coastal city. However, this methodology is applicable; although this methodology took a substantial amount of time when assessing Hilsea (mainly due to methodology updates and trials with

the data extraction), the analysis of St Thomas was very quick (two weeks), due to sound knowledge of what exactly was required to carry out the assessment. It presents a unique high resolution assessment of Coastal Flood Vulnerability and Risk.

The Coastal Flood Vulnerability and Risk analyses of the Portsmouth study areas, provided new knowledge and understanding of what makes communities vulnerable at different times of day, and how this affects risk. These assessments present the scope of Ordnance Survey and UK National Census data, highlighting the datasets that can be used to measure vulnerability and not simply using demographic variables data. This project has identified new factors that can be quantified; leading to finding, using and creating data that has not been previously used in other UK vulnerability assessments. This framework can be re-applied by coastal delegates to assist with future coastal flood preparedness, management and communication. The results highlight areas that have high levels of coastal flood vulnerability and risk; leading to pinpointing of neighbourhoods that need further mitigation and adaptation, thereby increasing overall flood resilience.

The final chapter describes the recommendations for future research and the concluding key themes.

## Chapter 7. Conclusion

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## Chapter 7. Conclusions

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### 7.1 Key Themes

Coastal communities tend to be vulnerable to major hazard impacts, due to their high reliance on coastal ecosystems, increased reliance on seasonal employment related to tourism and high levels of transient groups, infrastructure and communications, all of which are susceptible to damage and disruption from, storms, wave erosion, coastal flooding and sea-level rise (Benzie, 2014). Portsmouth is a large, densely populated coastal city in the Solent region. It is the UK's only island city, with the population concentrated on Portsea Island; a low-lying, highly developed and urbanised area that has historically flooded several times. The Environment Agency and local Strategic Flood Risk Assessments have predicted large areas of Portsmouth (47%) to be inundated when facing a 1 in 200 or 1 in 1000 year flood event. Coastal floods of this magnitude would inundate densely populated, expensive, and socially deprived neighbourhoods in Portsmouth, causing devastation and difficult evacuation, due to only three main road exits available off the island; two of which are predicted to be inundated.

Climate change looks set to increase the number and severity of meteorological hazard events. Therefore, it is vital to measure and map vulnerability to such hazards, highlighting areas of high risk, facilitating better mitigation and adaptation. Vulnerability analyses have significantly evolved in recent decades, yet there is no one consensus within the risk science community about vulnerability or its factors. However, from reviewing theoretical and conceptual vulnerability frameworks (Local SFRA (Atkins, 2007); Cutter et al., 2003; Kaźmierczak and Cavan, 2011; Balica, 2012a; Balica et al, 2012; 2013; Lindley et al, 2011; Birkmann et al, 2013), and the experiences gained during this research, various conclusions can be drawn.

Firstly, the investigation showed that before vulnerability factor creation and methodology framework take place for an index approach; the development of a theoretical framework/model (e.g. risk, hazard, vulnerability model and equation – Chapter 2) to structure the analysis and answer the research question(s) is vital. The conceptual model needs to be developed first, which then drives the factor development and then the

methodology framework. Any vulnerability index is a tool or ‘means to an end’, that ‘end’ goal must first be made clear.

Secondly, it is vital to investigate the characteristics that determine vulnerability for the approach being studied. Factors are valuable tools to quantify and map vulnerability, however, the selection requires consideration of various criteria. This includes hazard type, place of analysis, scale, target audience, and data availability and accessibility. Time is also a consideration and is needed for the factor selection in order to implement the concept. Involving local experts and practitioners is also recommended, as their expertise (and the author’s local knowledge) during the vulnerability factor development stages led to the creation of new factors for coastal flood vulnerability analysis, specifically Multiple Residency Buildings, Vulnerable Buildings (Day and Night), and Home and Residential Population. There are also certainly factors identified within this research that can be replicated within other natural hazard vulnerability assessments. Specifically many of the factors used in this project’s methodology can be used for vulnerability assessments associated with other types of flooding (fluvial and surface), such as Dwellings, Vulnerable Buildings (Day and Night), Tenure, Multiple Residency Buildings, Utilities, Population Density, Green Areas, Age, or Residential Population.

The project findings indicated the scope of data accessible and freely available to be used in an index approach for vulnerability and risk analyses in the UK. Ordnance Survey data and the UK National Census (2011) data in particular is vast, and can be used to analyse many vulnerability factors for different vulnerability components, at a very high level of detail. The research further conveyed the scope of available data by indicating the ability to create factors that enable an analysis of coastal flood vulnerability for day and night time, a unique and original finding of this work. To conclude the available data made it possible to measure vulnerability factors previously not utilised in past assessments i.e. multiple residency buildings, vulnerable buildings day and night, residential and home population.

The Coastal Flood Vulnerability methodology framework developed for this research, indicates that it is a multi-faceted concept that can be used to identify those characteristics and individualities of coastal communities that enable them to cope, recover, and respond to coastal flooding. The detail and breadth of this methodology has enabled an analysis of

coastal flood vulnerability and risk that crucially gives as detailed ‘a picture’ as possible. By analysing at neighbourhood level (a scale not previously used in other coastal flood vulnerability assessments, notably the Local Strategic Flood Risk Assessment (Atkins, 2007) and the UK River and Coastal Flood Disadvantage Index (Lindley et al, 2011; Climate Just, 2015)), this methodology identifies key vulnerable and at risk areas that have not been identified by other assessments. This level of detail is necessary to assist our ability to inform decision-makers, deliver effective policies, and make sound investments. It cannot be represented by a single statistic or a few socio-economic characteristics. This point was affirmed during the vulnerability factor development stage, as most factors required a combination of a number of datasets in order to produce the ‘whole’ picture.

This methodology has collected and collated large amounts of data regarding Coastal Flood Vulnerability. This data has been used to populate the vulnerability factors that are associated to a particular component of coastal flood vulnerability (coastal flood physical vulnerability, coastal flood socio-economic vulnerability and coastal flood limited resilience) according to the final coastal flood vulnerability and risk data model (Figure 4.3, Chapter 4). This methodology has been applied to three electoral wards situated within the island city of Portsmouth, and two key indices have been developed in this work: a detailed coastal flood vulnerability and coastal flood risk index. The indexes assign a numerical value between 0 and 1 to coastal flood vulnerability and risk, allowing for numerical comparisons of vulnerability and risk levels between neighbourhoods within wards. Resulting in vital and improved targeting of vulnerable and at-risk areas, crucial to prioritising interventions to improve resilience, reduce vulnerability and enhance recovery.

Maps for Coastal Flood Hazard, Coastal Flood Physical Vulnerability, Coastal Flood Socio-economic Vulnerability, Coastal Flood Limited Resilience, Coastal Flood Vulnerability and lastly Coastal Flood Risk, have been produced at neighbourhood level for Hilsea, Eastney and St Thomas (Figures 4.4-4.6 & 4.11-4.28). Overall coastal flood physical vulnerability is low to moderate in Hilsea and Eastney, and predominantly low in St Thomas. In all three wards, coastal flood socio-economic vulnerability is principally low with the exception of three neighbourhoods that are high. Coastal flood limited resilience is mostly moderate in Hilsea and Eastney, and low in St Thomas. However, all three wards have neighbourhoods that individually have very high levels of limited resilience.

Critically unlike the coastal flood physical vulnerability maps there appears to be much more pronounced changes within the wards between a day and night coastal flood socio-economic vulnerability analysis. There is little to no difference in coastal flood physical vulnerability levels for a day or night analysis for all three wards, and whatever difference is present (can be seen on Excel spreadsheets), is too small to be seen visually when 5 vulnerability levels are applied to map these results. To conclude, further investigation is required to distinguish more or improved factors that can separate a day and night time coastal flood physical vulnerability analysis.

The combination of these three indexes and finally the coastal flood hazard index, has led to a more comprehensive vulnerability and risk assessment for these wards. The coastal flood vulnerability maps produced indicate Hilsea to have low to moderate overall vulnerability levels and are mostly situated in the east of the ward. For the night analysis one neighbourhood in particular (**OA6300**) has high vulnerability, and this neighbourhood has the highest vulnerability level in the ward for both the day and night analysis. Within Eastney for the day and night analysis the majority of the ward has between low and moderate vulnerability, and these levels differ very slightly between day and night time. St Thomas has also predominantly low to moderate vulnerability, except for the neighbourhood **OA6512**, that has high vulnerability levels for both the day and night time analyses. Only two neighbourhoods in St Thomas visibly change in vulnerability levels for day and night time, again the changes are too subtle to be visible within the display ranges.

Overall, within the Hilsea ward, three particular Output Areas (**OA6294**, **OA6300**, and **OA6296**) dominantly have the highest Coastal Flood Risk levels, with possible inundation described primarily as dangerous for most people, meaning deep or fast flowing. Other neighbourhoods in the south of the ward collectively have higher vulnerability levels compared to the rest. However, the flood zones are not predicted to inundate these areas, resulting in very low risk levels. Within Eastney there is a marked difference between a Flood Zone 3 and Flood Zone 2 event. The latter increases CoFR levels throughout the ward, particularly the eastern end, which would potentially cause many problems due to the higher levels of vulnerability in this area. The neighbourhood **OA6186** specifically as inundation would primarily be deep and fast flowing - depths ranging from 0.75-2.5 m at a speed of 1-5 ms<sup>-1</sup>. For St Thomas, neighbourhoods with high levels of vulnerability (e.g.



OA6512), are not expected to be inundated. However two Output Areas (one to the west – OA6543; and the other to the south – OA6546) have the highest levels of Coastal Flood Risk within the ward for both day and night time for a Flood Zone 3 event. OA6546 risk levels rise even further for a Flood Zone 2 event, and are the highest in the ward however, primarily the water would be shallow.

In conclusion, there is a notable, visible difference in risk levels for each ward between a Flood Zone 3 and 2 event. However, the difference is not as noticeable between a day and night time flood. However, for all day and night time vulnerability results, for each neighbourhood, in each ward, there were differences in levels (between 0.01-0.05). These changes however were sometimes too subtle to be identified via ArcMap, due to the vulnerability and risk ranges used. Nevertheless, this research indicates there are changes in risk levels between floods that occur during the day and at night, and there are critical characteristics in our community ‘make up’ that can identify this important feature. The factors *Home Population* to measure those residing in the area during the day, and *Residential Population* to measure human population susceptibility at night, for the coastal flood socio-economic vulnerability component. Some neighbourhoods that had very high home populations during the day compared to the rest of the ward, had lower overall socio-economic vulnerability level at night, due to a very low residential population. This was an interesting dynamic and occurred in all three wards in certain areas.

To conclude further, communication and dissemination of flood vulnerability and risk information can be explored, and the exploration in visualisation within this research has demonstrated the potential scope of different visual techniques, specifically 3D. To summarise, the dissemination visibly (through mapping) of certain components of vulnerability and risk is possible (i.e. physical vulnerability and the flood zones). The 3D mapping of certain buildings and transport links that either increase or reduce vulnerability, was successful. However, visualising socio-economic vulnerability, elements of limited resilience or indeed overall risk, was difficult. The information was disseminated via text on the map and the various vulnerability or risk index scores shown were given context in order for a user to understand why these levels were significant.

This research has concentrated on the characteristics and demands of vulnerability assessments when analysing coastal communities risk to coastal flooding, at a detailed level, during both day and night time. Resulting in a user friendly and cost-effective framework that was based on publicly available data and which brought the socio-economic, physical and limited resilience components of vulnerability together into one measurement. This has resulted in a unique framework for measuring coastal flood vulnerability that firstly operates at the level of detail necessary to truly deliver effective solutions (neighbourhood level). Secondly, was able to distinguish risk levels to areas if a flood occurred at day or night. This conceptual framework, although complex, provides a valuable basis for vulnerability factor development and vulnerability index creation. This methodology can be utilised by UK coastal delegates and members of local Resilience Forums, to assist coastal flood vulnerability and risk analyses to coastal flooding.

### 7.2 Recommendations for Further Research

This thesis describes a Coastal Flood Vulnerability Index (CoFVI) methodology, identifying factors that assess flood vulnerability at a very detailed scale (neighbourhood level). The research has concentrated on coastal flood hazards, however this methodology could be applied to other natural hazard vulnerability assessments, and even include some of the factors established within this methodology. It would be of interest for further investigation to be taken into the extent that this approach could be used for other flooding hazards i.e. surface water and fluvial flooding. Furthermore, this investigation has concentrated on a coastal city: a rural area may require extra vulnerability factors, or removal of ones used in this particular project.

As some of the differences between vulnerability levels for day and night analyses were very small, it was difficult to identify any differences in the final vulnerability and risk maps. It is therefore, suggested that the method could be developed to include other variables that clearly distinguish the difference between a day and night flood event; further establishing a distinction of vulnerability between the two time zones. Or, use the newly developed ranges by Climate Just (2015) for the improved national flood disadvantage index (developed by Joseph Rowntree Foundation from Lindley et al's (2011) original flood vulnerability index) to map coastal flood vulnerability and risk.

These have seven classes: slight, extremely low, relatively low, average, relatively high, extremely high and acute.

This methodology has great adaptability i.e. it could form the basis for other natural hazard vulnerability assessments. One of the main aims of this research was to analyse vulnerability at the most detailed level possible – Output Area. However, all data variables used within each vulnerability component have the ability to be used at different scales from Output Area, Lower Layer Super Output Area, Middle Layer Super Output Area, Ward or even Local Authority. Nevertheless, for some of the larger scales (especially Local Authority), some variables would be time consuming to measure (specifically some of the CoFPV variables), therefore an adjustment of which variables are used at this scale might need to be applied depending on time constraints. However, this could lead to omissions of important details that complete the vulnerability ‘picture’, resulting in loss of identification of all key areas, leading to reduced resilience. Therefore, further investigation into the vulnerability variables when assessing at larger scales is advised.

Further examination into the CoFV factor *Occupation* is needed. This is a socio-economic vulnerability factor that Cutter et al (2003) recommended should be measured when analysing vulnerability for natural hazards. In the literature it is suggested to concentrate on occupations that involve agriculture, childcare, emergency services, tourist industry i.e. seasonal workers such as hotel work and cleaners. These types of occupations were seen as more vulnerable to natural disaster events in USA, where Cutter et al’s (2003) research was based. However, for the UK, flooding may effect some of these types of occupations, but perhaps not to the same extent as in USA (specifically low-wage jobs, such as cleaners or hotel staff, due to them not being a necessity in the aftermath of a flood event). Also these types of occupations are very difficult to pinpoint within the occupation and industry datasets available via the 2011 UK National Census. This research did identify the variable of Hours Worked (from the 2011 UK National Census) as an indicator of the factor *Occupation*, i.e. areas with large numbers of part-time workers would be more vulnerable, as it would be assumed financially they would not have the means to cope and recover as well as those in full time occupations. However, this variable correlated too highly with *Residential Population* and therefore was removed from the analysis.

Other vulnerability factors that would improve an investigation such as this include '*Experience with Floods*'. This was identified by both Balica (2012a) and Birkmann et al (2013) as a susceptibility component and was included within their analysis. It means a percentage of people who have experienced floods (estimated based on the duration of residence of a specific household in a flood-exposed area i.e. 10 years); where the higher the length of time of residence in flood prone areas means lower vulnerability (Balica, 2012a; Birkmann et al., 2013). Historical flooding data for Portsmouth has only been received via British Geological Survey (BGS) in the form of pdf, and length of residence in dwellings is a dataset not present within the 2011 UK National Census. It is recommended that further investigation is carried out to see if a dataset of this nature could become available or exists. It is also recommended that this could be measured as an example of limited resilience and would be associated with a factor such as *flood awareness*, which is discussed in the next paragraph.

The limited resilience component had the fewest factors and variables for analysis; due to its complexity. Three examples of factors that could be considered for this component are; *flood insurance*, *flood awareness* and *building adaptation measures*. The former example would be a very useful measurement of limited resilience in a neighbourhood, if many of the dwellings in the area do not possess insurance then limited resilience would be high, as dwellers would not have the documentation necessary to assist with their personal and financial recovery from the damage caused by a flood event. However, would this data be freely available and would it be possible to be at OA size to coincide with the other data variables. The second example (*flood awareness*), could consist of numbers of the population having 'grab bags' (bags ready for emergencies containing key documentation, clothing, water, some food and money) or being aware of where to go and what to do if an emergency occurs. Again how could this be measured, do these figures exist, or are these data variable examples that need to be established to ensure a more detailed analysis of resilience in areas. If surveys were required to measure this factor this would be a time-consuming exercise involving ethical review. The last example (*building adaptation measures*), is something that is being brought more into building plans and construction. Adaptation examples include wet-proofing, floatable buildings, dry proofing, raising floor levels, one-way valves, or building regulations. It is seen as a sustainable form of improving resilience for communities in flood zones, and is a practice that is becoming

well established in European coastal communities that have high CoFR e.g. Dordrecht, Netherlands and Hafen City, Germany (Goltermann et al, 2008). However, does this data exist and is it in a form that is applicable at this area level (neighbourhood) to then be integrated into the CoFVI.

Further investigation needs to be made of the Statistics used to decrease the number of variables used for the final Coastal Flood Vulnerability Index (CoFVI) results. It was originally wished to use a multiple regression analysis; however, the necessary data needed to perform this test was not available. Perhaps further investigation of new available data could present the correct y value needed to undertake these tests. Another consideration would be, if larger areas were investigated i.e. the city of Portsmouth, then statistical tests such as a Principle Component Analysis (PCA) may be more favourable.

Further research is suggested regarding weighting the factors. This research has presented an equally weighted analysis, however, it would be of interest to see what CoFV and CoFR results and corresponding maps were produced if a weighted factor analysis was applied. Perceptions of vulnerability and risk can be different from one person to the next, therefore a weighted could result in very different neighbourhoods being highlighted as vulnerable or at risk, compared to what the results this research has produced.

As the methodology attaches vulnerability and risk levels to Output Area boundary shapefiles, it indicates vulnerability and risk levels to be associated with the whole neighbourhood. However, in reality some areas are made up of large green areas, roads etc e.g. OA6291 within Hilsea. Further investigation is required to develop the method where associated vulnerability and risk levels are attached to urbanised areas and displayed as such in resulting maps. The Local Strategic Flood Risk Assessment maps produced by Atkins (2007) give the impression they are more detailed because they have attached the vulnerability levels urbanised areas. In reality the vulnerability results were measured by measuring only four social factors and therefore not a very detailed assessment, however the maps produced might visibly present a different result.

The main recommendations with regards to visualisation techniques for further research include development of questionnaires or structured interviews that offer different

examples of coastal flood hazard/vulnerability/risk maps in different formats i.e. 2D or 3D. It is suggested that 3D mapping offers opportunities for improved data communication, not available in two-dimensional (2D) representations. That could be tested with various stakeholder groups, using a questionnaire to determine their varying perceptions of various map format and colour schemes, both 2D and 3D. This could not be explored further in this research project, due to time constraints.

In summary, this methodology's framework facilitates the creation of Coastal Flood Vulnerability and Risk assessment and maps. Those maps can assist flood management and preparedness, helping to inform users about the many factors that influence overall vulnerability, improving coastal communities' resilience to future coastal flooding events. Further research of the topics covered in this research will improve vulnerability and risk assessment techniques, improving our understanding and moving us towards becoming a proactive society, rather than a reactive society.

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## APPENDIX A – VAMS Overview Document

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VAMS Peer Reviewed Overview Document. Part of 12 month Knowledge Exchange Programme (with ESRC & Ordnance Survey) proposal. Submitted 27<sup>th</sup> March 2014-03-12.  
Parts of this document were used within Chapters 1, 2, & 3

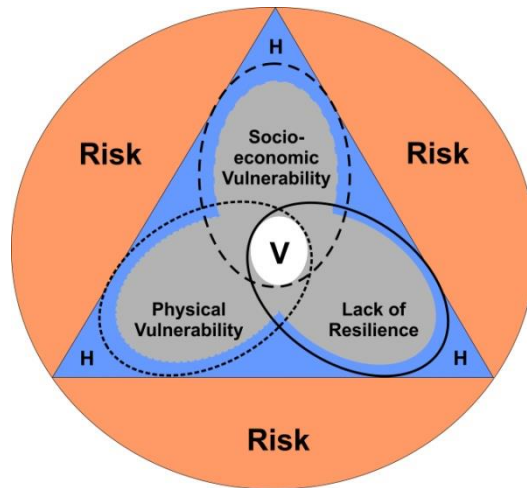
### **VAMS: a Vulnerability Assessment & Mapping System for UK community-based emergency planning and flood management**

Maps showing flood hazard zones are readily available for the UK (e.g. via the websites of the Environment Agency or the Scottish Environmental Protection Agency). However, maps showing the vulnerability of communities to flooding are not readily available, despite the availability of relevant datasets from the Ordnance Survey and the UK National Census.

The aim of the project is to develop a value-added geoinformatic product, the Vulnerability Analysis and Mapping System (VAMS) as a tool to assist flood risk assessment, emergency preparedness and business continuity planning. The project will focus on three types of flood hazard: coastal, fluvial and pluvial, for day and night scenarios.

Assessing and mapping vulnerability is a key step towards risk reduction and promoting a culture of disaster resilience (Birkmann, 2006; Menoni et al., 2012). However, flood vulnerability assessments still focus mainly on climate change aspects, such as sea-level rise, flooding potential and overall risk (Nicholls et al, 2008). Less attention is paid to societal dimensions of risk, such as the physical and socio-economic vulnerability of communities within flood hazard ‘pathways’.

This project will address vulnerability, how it can best be assessed, mapped and used to assist flood risk assessments. *Vulnerability* is here defined as *a degree of susceptibility or fragility in communities, systems or elements at risk, and their capacity to cope under hazardous conditions* (Birkmann et al, 2013). Vulnerability refers to pre-event inherent characteristics of hazard receptors or pathways (i.e. people, infrastructure): it defines the extent to which these receptors or pathways are susceptible to harm from hazards (Cutter et al, 2008; Kazmierczak & Cavan, 2011).



**Figure 1.** Model of risk, hazard, vulnerability equation (H = Hazard and V = Vulnerability)

This research analyses, quantifies and integrates the main components of risk, into one framework, based on the ***Risk = Hazard x Vulnerability*** (*Physical Vulnerability + Socio-economic Vulnerability + Lack of Resilience*) equation, illustrated in Figure 1. The data inputs include flood hazard maps (Environment Agency), physical vulnerability data (Ordnance Survey), socio-economic vulnerability data (susceptibility) (2013 UK Census) and lack of resilience data (2013 UK Census and Ordnance Survey). Those datasets are processed to produce vulnerability and risk maps at a very detailed level: Output Areas within Electoral Wards (Figure 2).

### **Background and Research Questions**

In recent years the UK has experienced high financial costs, severe societal impacts and environmental impacts, due to extreme weather events (UK Government, 2012). The winter of 2013-2014 highlighted the UK's need for improved flood risk preparedness. Climate change is expected to increase the frequency and impact of flood events. The impacts of flood disasters cannot be reduced by solely focussing on the hazard components. Societies must adapt to live with changing environmental conditions by reducing vulnerabilities to hazards.

UK flood risk assessments have scope for expansion and improvement, in terms of detail and communication. Assessing and mapping flood hazard and community vulnerability are of paramount importance when analysing flood risk: to that end there is national coverage of flood hazard maps, *but no national coverage of flood vulnerability maps*. Current flood vulnerability analyses in the UK are patchy and small, analysing only a few social factors.



This research will provide a Vulnerability Analysis & Mapping System that uses neighbourhood-level physical and socio-economic indicators (e.g. tenure, socio-economic status, property type, utilities, household structure, emergency facilities etc, please see figure 2), from UK geoinformatic datasets.

There has recently been a shift in UK emergency planning and crisis response policy, towards better coordination of local government, the emergency services and communities, producing a national coverage of *Local Resilience Forums* (e.g. Hampshire & Isle of Wight Local Resilience Forum, 2013). The Vulnerability Assessment and Mapping System would give the members of Local Resilience Forums a better understanding of flood vulnerability and risk, as well as the ability to model scenarios for possible future climate conditions.

The following research questions will be examined in this project:

1. How can Ordnance Survey digital maps and other geo-referenced data, such as Environment Agency flood maps, be used to assist with the mapping of vulnerability?
2. How can UK national Census data assist with the mapping of vulnerability?
3. How can this research assist with improving the effectiveness of Ordnance Survey geospatial data for emergency planning & crisis response?
4. In what ways can GIS-based assessments of community vulnerability be used to improve the preparedness and response stages of emergency planning and disaster management?

### **Project methodology**

Hazard and vulnerability analysis integrates environmental, physical, social and economic datasets, to assess exposure, susceptibility and lack of resilience to a hazardous process. Ordnance Survey MasterMap data can be used for the identification of the land cover type, including vulnerable assets, while 2011 UK National Census populates social vulnerability (susceptibility) factors. In the UK, such assessments are distributed amongst Local Strategic Risk Assessments, Local Authority Management Plans, Environment Agency Reports, Catchment Flood Management Plans and EU Biodiversity Strategy Reports.

The methodology outlined in Figure 2 has been used in Percival's PhD research to assess coastal flood vulnerability within Hilsea ward, Portsmouth (Figure 3; see also Percival and Teeuw, 2011). The VAMS methodology will be used to assess and map vulnerability and risk, for three types of flooding: coastal, fluvial and pluvial. Hilsea will be retained as a

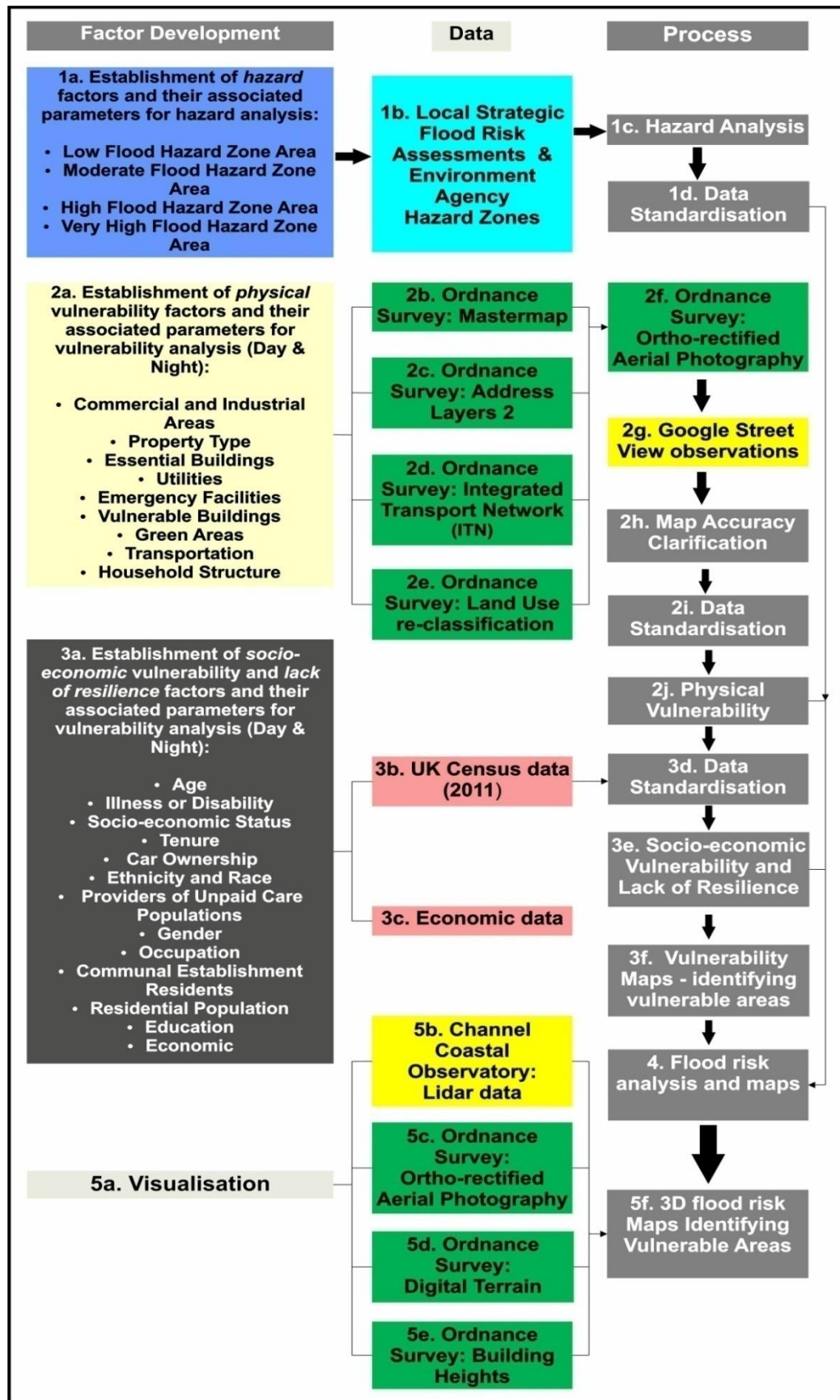


Figure 2. The VAMS vulnerability mapping methodology

coastal test area; a second test site will be selected from a riverine urban location with fluvial and pluvial flood hazards, in consultation with the Hampshire & Isle of Wight Local Resilience Forum.

The main Objectives of the VAMS project are:

1. To extend PhD research (the assessment and mapping of coastal community vulnerability and risk), to the development of a Vulnerability Assessment & Mapping System for flood risk assessment and emergency planning;
2. To derive new added-value applications for standard Ordnance Survey map data and UK Census data;
3. To evaluate the usefulness and accuracy of the Vulnerability Assessment & Mapping System (VAMS), through liaison with decision-makers in the emergency planning sector;
4. To improve the emergency preparedness information that VAMS provides to UK communities, via liaison with stakeholders in Local Resilience Forums and the Environment Agency.

**The VAMS project consists of seven Work Packages (WPs):**

**WP 1** (months 1 & 2): scoping of vulnerability factor requirements for flood hazards, selection of two test areas in Hampshire: one coastal urban (Hilsea), one riverine urban (yet to be selected) . This will be done through desk study and meetings and discussions with the Hampshire and Isle of Wight Local Resilience Forum, particularly local authority emergency planners and business continuity officers.

**WP 2** (starting in month 3, with monthly updates): Design and launch of a VAMS project website, summarising major features, providing related web-links and advertising the VAMS Workshops, with an online questionnaire for UK Local Resilience Forum members, on map types that are useful for flood risk assessment and flood event response.

**WP 3** (months 4 & 5): VAMS analysis and accuracy assessment; working with Ordnance Survey to align the methodology with their data types; thereby simplifying data processing stages. Analysis of Local Resilience Forum online questionnaire responses, with consequent modification of the VAMS methodology and deliverables.

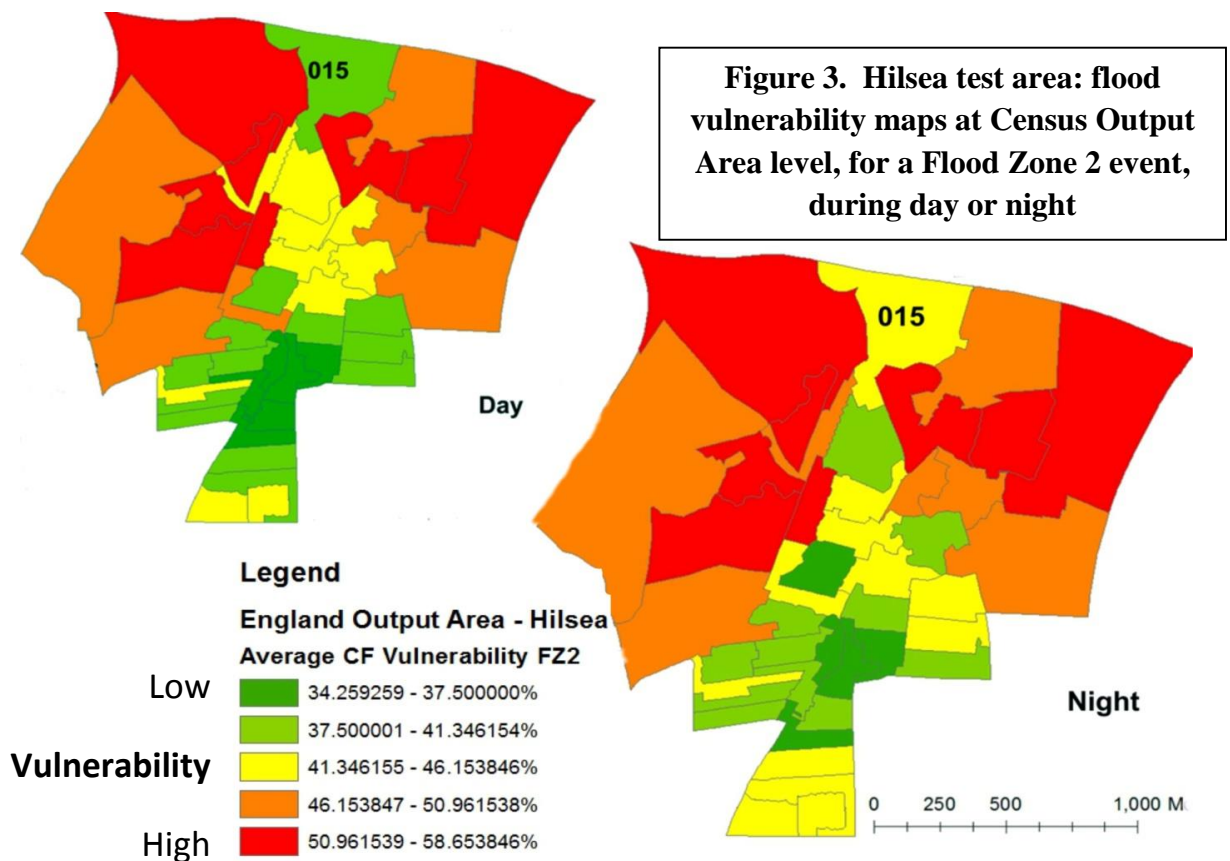
**WP 4** (month 6): organisation & running of a 1-day **VAMS Development Workshop**, Representatives from the OS, EA, emergency services and other members of UK Local Resilience Forums (limited to southern England to optimise delegate travel times and reimbursement costs). Discussion of VAMS findings, focus group survey of VAMS features considered useful by emergency planners; drafting of interim report. Exit poll, assessing project effectiveness and seeking ideas for VAMS development.

**WP 5** (months 7-10): action on Workshop feedback, leading to improvements in the VAMS flood vulnerability and risk analyses.

**WP 6** (month 11): a 1-day **VAMS Assessment Workshop**, reviewing results. This workshop will examine the impacts that VAMS could have on emergency preparedness, risk analysis, policy, and crisis management practice. Delegate provenance: southern England LRFs, as per the earlier workshop. Exit poll, assessing project effectiveness and seeking ideas for VAMS development; followed by an end-of project online questionnaire for UK LRF members, via the project website, examining their views on the usefulness of the VAMS methodology, datasets and maps.

**WP 7** (month 12): publication of a Summary Report, via the VAMS website; two papers for publication in peer-reviewed journals e.g. *Natural Hazards* and *Applied Geography*; these are both widely read and have relatively high impact factors. Illustrated articles will also be drafted for professional magazines e.g. *Alert* and *GEO Informatics*.

The VAMS software will provide an easy to use geoinformatic “ toolbox”, using existing Ordnance Survey digital mapping products and providing guidelines on how the OS, EA and National Census geoinformatic data can be processed to provide useful support materials for emergency planners. For instance; with maps showing population centres, socio-economic groups, land use types, building heights, critical infrastructure, critical facilities and evacuation route options. This VAMS toolkit will also enable geoinformatic modelling of “what if” scenarios for various types of hazard, facilitating decision making. For example, see the Day/Night variations in neighbourhood flood vulnerability illustrated in Figure 3.



**In summary**, the Vulnerability Assessment & Mapping System will:

- Provide a standardised methodology for UK vulnerability assessments and mapping, which will improve emergency planning at local or national level, helping to facilitate community resilience and long-term sustainability.
- Consolidate socio-economic vulnerability analyses and physical vulnerability analyses into one analysis at sub-ward scale.
- Facilitate the Ordnance Survey's testing of new geoinformatic products and improve inter-operability between public and industrial bodies, such as Local Authorities.
- Provide emergency planners working with Local Resilience Forums and the Environment Agency with vulnerability and risk maps, models and information for risk management at neighbourhood level.
- Identify the most vulnerable and at-risk sectors of communities, assisting emergency planners to better target their limited human/economic resources for risk reduction.
- Be used as a tool when communicating/educating communities about the

complexity of vulnerability and risk.

- Assist with the development of adaptation strategies and policies that develop increased local community resilience.
- Provide the UK Government with a tool for reviewing major flood emergencies, providing data and maps for evidence-based reviews of flood management policy.
- *To contribute to the ESRC Strategic Plan (2009-2014)*, by indicating the importance and strength of integrating socio-economic data within flood risk assessments. Without socio-economic data our understanding of the intrinsic characteristics of urban communities situated within hazard pathways would not exist. To measure vulnerability, social and economic factors are essential to a complete and detailed flood risk analysis.

**In conclusion**, climate change looks set to increase the number and severity of meteorological hazard events. We need to measure and map vulnerability to such hazards, highlighting areas of high risk, facilitating better mitigation and adaptation. The VAMS methodology quantifies different types of vulnerability and combines them into a geospatial model of flood risk. The resulting flood vulnerability maps and risk maps will assist the development of UK mitigation and adaptation measures, emergency planning and resilience strategies. Knowledge exchange is essential to this project, it builds on existing relationships formed between the research community, including academic and non-academic users. The results and workshops from this project will indicate the strength of knowledge exchange and how it can maximise the potential of research, helping us move towards a more sustainable and collaborative society. Ethical implications of the main research project have been considered but as the public will not be directly engaged within the research, no ethical review is required. However, feedback from the project stakeholders i.e. OS and members of LRFs will be gained from online questionnaires and exit polls at the project workshops. This has been assessed and approved by the relevant University of Portsmouth ethics panel as no questions are likely to cause any sort of distress.

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## APPENDIX B – Initial Ordnance Survey Data Investigation

### Different Stages of Ordnance Survey's Initial Data Investigation

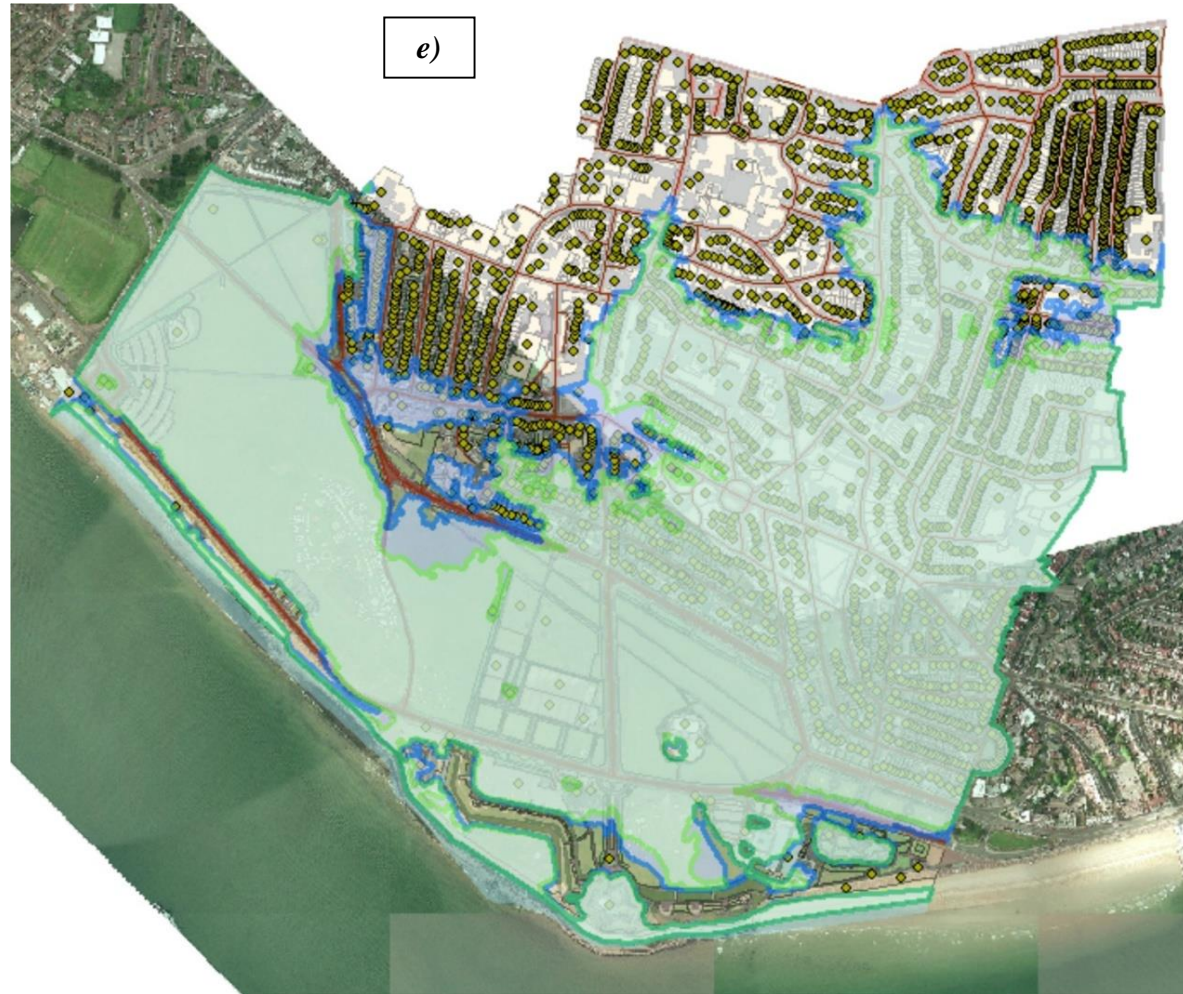
*a)* St Jude Ward Copy; *b)* Clipped Ordnance Survey (OS) Mastermap Area for St Jude Ward; *c)* St Jude OS Area displaying Description Group only.



d) OS Mastermap Layers - OSArea, OSRdLink and OS Layer Address Layer 2; Categorized for St Jude



e) Clipped OS Layers, EA Flood Zones (2 & 3) (with added transparency) to St Jude ward, over available CCO aerial photography



f) St Jude Coastal Flood Hazard map - containing clipped EA FZ2 & FZ3 (with added transparency) over essential OS categorised layers (OSArea, OSRdLink, and Address Layer 2).



## APPENDIX C – Ordnance Survey Data Investigation in ArcCatalog

Data from Ordnance Survey: Essential Mastermap Layers

S\_Percival\_OSMM\_SU\_9\_2.mdb and S\_Percival\_OSMM\_SZ\_9\_2.mdb

Attribute table for **OSArea\_SZ**. Eight examples given (there is > 160,000 individual objects within OSArea\_SZ), essential data group (**DescGroup**) – the land use/cover classification present in Mastermap highlighted by dotted rectangle:

Toid,C,20	Featcode,N,9,0	Version,N,9,0	VerDate,D	Theme,C,80	CalcArea,N,19,1	Change,C,80	DescGroup,C,150	DescTerm,C,150	make,C,20	PhysLevel,N,9,0	Broken,N,4,0	LoadDate,D	shape_Leng,N,19,11	shape_Area,N,19,11
1000000139317840	10203	12	06/05/04	Water	115156.48746000	2003-09-22 Attributes:	Tidal Water	Foreshore	Natural	50	0	22/02/10	1344.68107198000	115156.487500000
1000000139317843	10111	3	22/01/04	Land	28951.198752000	2003-09-22 Attributes:	Natural Environment	Marsh Reeds Or Saltmarsh	Natural	50	0	22/02/10	1030.95540354000	28951.198750000
1000000139317853	10203	18	06/05/04	Water	428038.651952000	2003-09-22 Attributes:	Tidal Water	Foreshore	Natural	50	0	22/02/10	3211.67965091000	428038.652000000
1000000139318026	10056	3	19/03/08	Land	37.45625600000	2006-07-15 Attributes:	General Surface		Manmade	50	0	22/02/10	26.64373272760	37.45625000000
1000000139318027	10056	3	19/03/08	Land	2.64625200000	2006-07-15 Attributes:	General Surface		Manmade	50	0	22/02/10	6.55086181289	2.64625000003
1000000139318028	10056	3	19/03/08	Land	6.56500000000	2006-07-15 Attributes:	General Surface		Manmade	50	0	22/02/10	12.30115298220	6.56499999986
1000000139318029	10056	4	19/03/08	Land	8.66250000000	2001-05-29 Reclassified	General Surface		Manmade	50	0	22/02/10	14.75733745100	8.66249999999
1000000139318030	10056	3	19/03/08	Land	24.89374400000	2006-07-15 Attributes:	General Surface		Manmade	50	0	22/02/10	31.11707056960	24.89375000000

Attribute table (again only first 8 examples due to size of attribute tables) for **OSRdlk SZ** (essential data column is highlighted by dotted rectangle: **DescTerm**):

OBJECTID,N,9,0	TOID,C,16	Version,N,9,0	VerDate,C,12	Change,C,80	DescGroup,C,150	DescTerm,C,150	TopoArea,C,20	Nature,C,80	LnkLength,N,19,11	Node1,C,20	Node1Gra_1,N,9,0	Node2,C,20	Node2Gra_de,C,1	Node2Gra_1,N,9,0	Theme,C,80	shape_Leng,N,19,11
1	4000000023 260376	6	2005-10-10	2002-11-15	Road New Topology	Private Road - Restricted Access	1000002105 861926	Single Carriage way	419.4000000 0000	4000000023 603938	0	4000000023 603933	+	0	Road Network	419.4013461 1800
2	4000000023 260377	3	2005-09-18	2002-11-12	Road Modified Topology	Minor Road	1000002105 292369	Single Carriage way	328.2100000 0000	4000000023 106898	0	4000000023 106982	+	0	Road Network	328.2102841 3900
3	4000000023 260378	4	2005-09-15	2002-10-29	Road New Topology	Local Street	1000002105 756734	Single Carriage way	327.6100000 0000	4000000023 106897	0	4000000023 106978	+	0	Road Network	327.6194009 0300
4	4000000023 260466	5	2005-09-15	2002-10-29	Road New Topology	Motorway	1000000139 499407	Dual Carriage way	468.5600000 0000	4000000023 114138	1	4000000023 106392	+	0	Road Network	468.5633287 2800
5	4000000023 268340	5	2005-09-15	2002-10-29	Road New Topology	Local Street	1000002105 251322	Single Carriage way	172.2700000 0000	4000000023 105992	0	4000000023 603945	+	0	Road Network	172.2757705 6400
6	4000000023 268341	7	2006-03-11	2003-11-20	Road New Topology	Private Road - Restricted Access	1000002694 000920	Single Carriage way	47.1200000 000	4000000023 106066	0	4000000023 106084	+	0	Road Network	47.12782622 610
7	4000000023 268342	5	2006-02-03	2004-03-01	Road New Topology	A Road	1000002105 233926	Dual Carriage way	282.6600000 0000	4000000023 106110	0	4000000023 105977	+	0	Road Network	282.6661361 9200
8	4000000023 268343	6	2006-02-03	2004-03-01	Road New Topology	A Road	1000002105 233987	Dual Carriage way	315.0200000 0000	4000000023 106111	0	4000000023 105978	+	0	Road Network	315.0220741 5300

Attribute table (only 8 examples out of 59,704 given) for OSAddr2 SZ (essential data columns are only shown due to size of attribute table: Organisation, Post code,

Multiple Occupancy, & Base function):

<b>Organisati,C,60</b>	<b>Postcode,C,8</b>	<b>MultOccupa,N,9,0</b>	<b>BaseFunci,C,120</b>
ZURICH INSURANCE PLC	PO1 1ZP	0	PO BOX
PORTSMOUTH WOMENS AID	PO1 5JQ	0	PO BOX
BRIDES OF PORTSMOUTH	PO1 5BZ	0	GENERAL COMMERCIAL
GOLDEN EMPEROR	PO1 2DB	0	GENERAL COMMERCIAL
	PO1 5HH	0	DWELLING
HARTGILL SEAFOODS	PO1 3PU	0	GENERAL COMMERCIAL
	PO1 5JJ	0	DWELLING
	PO1 5JF	0	DWELLING

Attribute table (only 8 examples out of 89,791 given) for OS postal (essential data columns are only shown due to size of attribute table; columns used for analysis are highlighted by dotted rectangular boxes: Permanent Address, Post code, Base function, & Land Use; other columns used in field accuracy testing):

<b>PREM_ADDR,C,254</b>	<b>ORG,C,60</b>	<b>BLD_NAME,C,50</b>	<b>BLD_NUMBER,C,4</b>	<b>POSTCODE,C,8</b>	<b>BASE_FUNC,C,120</b>	<b>LAND_USE,C,4</b>
41A JUBILEE AVENUE, PORTSMOUTH, PO6 4QN		41A		PO6 4QN	DWELLING	U071
29 SULLIVAN CLOSE, PORTSMOUTH, PO6 4SN			29	PO6 4SN	DWELLING	U071
31 SULLIVAN CLOSE, PORTSMOUTH, PO6 4SN			31	PO6 4SN	DWELLING	U071
23 SULLIVAN CLOSE, PORTSMOUTH, PO6 4SN			23	PO6 4SN	DWELLING	U071
25 SULLIVAN CLOSE, PORTSMOUTH, PO6 4SN			25	PO6 4SN	DWELLING	U071
27 SULLIVAN CLOSE, PORTSMOUTH, PO6 4SN			27	PO6 4SN	DWELLING	U071
KINGSLEY BUILDING, ROWLAND ROAD, PORTSMOUTH, PO6 4RD	D G O RESTORATION	KINGSLEY BUILDING		PO6 4RD	REPAIR CENTRE	U091
HAMILTON ROAD, COSHAM, PORTSMOUTH, PO6 4QE	GEMINI RITEWAY SCAFFOLDING LTD			PO6 4QE	OFFICE	U102

Attribute table (only 10 examples out of 1988 given) for **OSnon-postal** (essential data columns are only shown due to size of attribute table: Legend, PAON,

Locality, Base function, & Land Use. Column used for analysis highlighted by dotted rectangular:

<b>LEGEND,C,30</b>	<b>PAON,C,254</b>	<b>LOCALITY,C,80</b>	<b>BASE_FUNC,C,120</b>	<b>LAND_USE,C,4</b>
Waterways	JETTY 87M FROM PORTCHESTER SAILING CLUB, 208 CASTLE STREET. ON WATERSIDE LANE	PAULSGROVE	JETTY	U056
Post and telecommunications	PUBLIC TELEPHONE 8M FROM 344 ALLAWAY AVENUE. 9M FROM ALLAWAY AVENUE	PAULSGROVE	PUBLIC TELEPHONE	U065
Sports facilities and grounds	SWIMMING POOL 81M FROM 22 JUBILEE AVENUE. 67M FROM JUBILEE AVENUE	PAULSGROVE	SWIMMING	U044
Energy production distribution	CHIMNEY AT WASP METAL POLISHING LTD, UNIT 13, TRAFALGAR WHARF HAMILTON ROAD.	PAULSGROVE	CHIMNEY	U061
Storage	TANK 108M FROM DRIVING STANDARDS AGENCY, JAMES CALLAGHAN DRIVE. 16M FROM UNNAMED ROAD	PAULSGROVE	TANK	U103
Post and telecommunications	POST BOX 11M FROM 49 NEWBOLT ROAD. 3M FROM NEWBOLT ROAD	PAULSGROVE	POST BOX	U065
Post and telecommunications	PUBLIC TELEPHONE 6M FROM 65 BROWNING AVENUE. 4M FROM UNNAMED ROAD	PAULSGROVE	PUBLIC TELEPHONE	U065
Energy production distribution	ELECTRICITY SUB STATION 5M FROM 108 PORTSDOWN ROAD. 2M FROM UNNAMED ROAD	PAULSGROVE	ELECTRICITY SUB STATION	U061
Waterways	PORTSMOUTH HARBOUR 956M FROM ST. MARYS CHURCH, PORTCHESTER CASTLE CASTLE STREET. 970M FROM HOSPITAL LANE	PAULSGROVE	HARBOUR	U056
Post and telecommunications	POST BOX 21M FROM 188 SOUTHAMPTON ROAD. 9M FROM SOUTHAMPTON ROAD	PAULSGROVE	POST BOX	U065



Attribute table (only 10 examples out of 1988 given) for **OSMultiOccupancy** (essential data columns are only shown due to size of attribute table):

Perm Address, & Toid:

<b>PREM_ADDR,C,254</b>	<b>TOID,C,16</b>
FIRST FLOOR FLAT, 34 NORTHERN PARADE, PORTSMOUTH, PO2 8ND	5000000100334661
LOWER MAISNETTE FLAT, 34 NORTHERN PARADE, PORTSMOUTH, PO2 8ND	5000000100476885
FLAT 2, 50 NORTHERN PARADE, PORTSMOUTH, PO2 8NE	5000000100521644
FLAT 1, 50 NORTHERN PARADE, PORTSMOUTH, PO2 8NE	5000000100521645
FLAT 2, 92 EMSWORTH ROAD, PORTSMOUTH, PO2 0BS	5000000100523542
FLAT 1, 92 EMSWORTH ROAD, PORTSMOUTH, PO2 0BS	5000000100523543
FLAT 2, 116 STUBBINGTON AVENUE, PORTSMOUTH, PO2 0JG	5000000100523740
FLAT 1, 116 STUBBINGTON AVENUE, PORTSMOUTH, PO2 0JG	5000000100523741
FLAT 2, 64 STUBBINGTON AVENUE, PORTSMOUTH, PO2 0JA	5000000100524140
FLAT 1, 64 STUBBINGTON AVENUE, PORTSMOUTH, PO2 0JA	5000000100524141

**APPENDIX D – Hazard Data Analysis**  
**PUSH Sub Region (PUSH, 2008)**



1 in 20 year tidal levels (Atkins, 2007)

<i>Note: Levels in mAOD to the nearest 0.1m</i>	<b>1990</b> (baseline)	<b>2010</b> (1990 + 80mm)	<b>2025</b> (1990 + 140mm)	<b>2055</b> (2025 + 255mm)	<b>2085</b> (2055 + 360mm)	<b>2115</b> (2085 + 450mm)
Calshot	2.6	2.7	2.7	3.0	3.4	3.8
Southampton	2.7	2.8	2.8	3.1	3.5	3.9
Lee-on-the Solent	2.7	2.8	2.8	3.1	3.5	3.9
Portsmouth Harbour	2.8	2.9	2.9	3.2	3.6	4.0
Langstone Harbour	2.9	3.0	3.0	3.3	3.7	4.1
Chichester Harbour	3.0	3.1	3.1	3.4	3.8	4.2

1 in 50 year Tidal Levels (Atkins, 2007)

<i>Note: Levels in mAOD to the nearest 0.1m</i>	<b>1990</b> (baseline)	<b>2010</b> (1990 + 80mm)	<b>2025</b> (1990 + 140mm)	<b>2055</b> (2025 + 255mm)	<b>2085</b> (2055 + 360mm)	<b>2115</b> (2085 + 450mm)
Calshot	2.7	2.8	2.8	3.1	3.5	3.9
Southampton	2.8	2.9	2.9	3.2	3.6	4.0
Lee-on-the Solent	2.8	2.9	2.9	3.2	3.6	4.0
Portsmouth Harbour	2.9	3.0	3.0	3.3	3.7	4.1
Langstone Harbour	3.0	3.1	3.1	3.4	3.8	4.2
Chichester Harbour	3.1	3.2	3.2	3.5	3.9	4.3

1 in 100 year Tidal Levels (Atkins, 2007)

<i>Note: Levels in mAOD to the nearest 0.1m</i>	<b>1990</b> (baseline)	<b>2010</b> (1990 + 80mm)	<b>2025</b> (1990 + 140mm)	<b>2055</b> (2025 + 255mm)	<b>2085</b> (2055 + 360mm)	<b>2115</b> (2085 + 450mm)
Calshot	2.8	2.9	2.9	3.2	3.6	4.0
Southampton	2.9	3.0	3.0	3.3	3.7	4.1
Lee-on-the Solent	2.9	3.0	3.0	3.3	3.7	4.1
Portsmouth Harbour	3.0	3.1	3.1	3.4	3.8	4.2
Langstone Harbour	3.1	3.2	3.2	3.5	3.8	4.3
Chichester Harbour	3.2	3.3	3.3	3.6	3.9	4.4

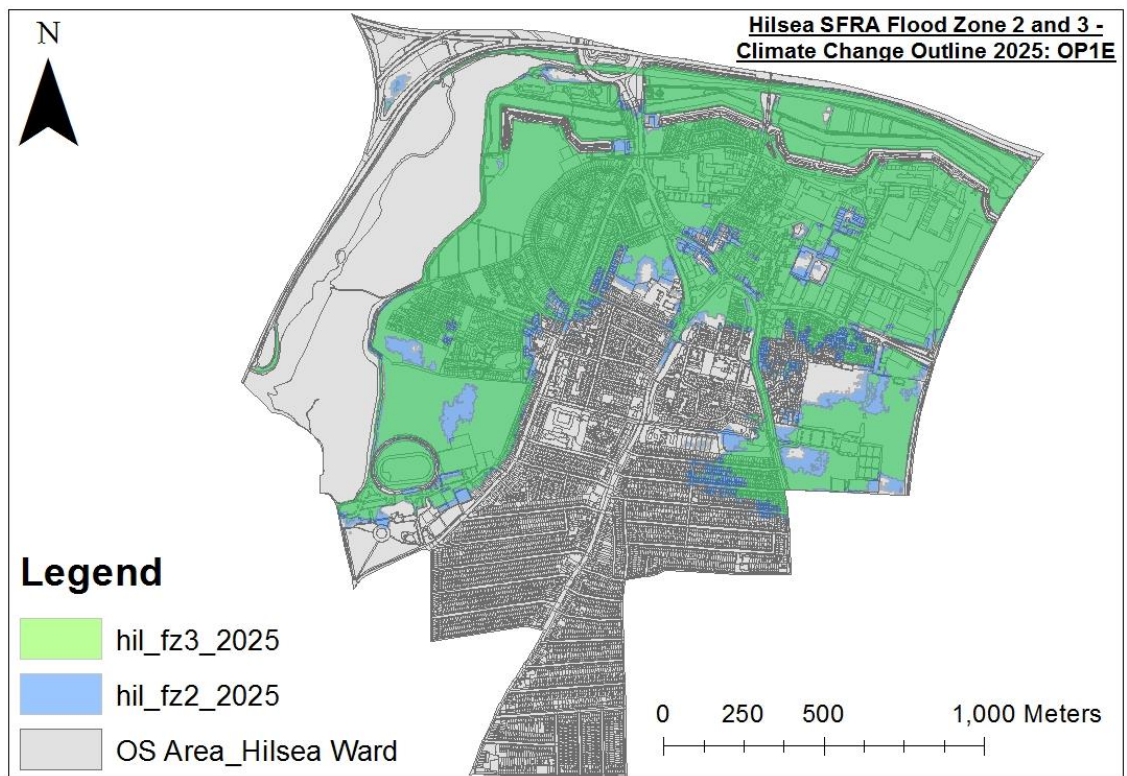
1 in 200 year tidal levels (Flood Zone 3) (Atkins, 2007)

<i>Note: Levels in mAOD to the nearest 0.1m</i>	<b>1990</b> (baseline)	<b>2010</b> (1990 + 80mm)	<b>2025</b> (1990 + 140mm)	<b>2055</b> (2025 + 255mm)	<b>2085</b> (2055 + 360mm)	<b>2115</b> (2085 + 450mm)
Calshot	2.9	3.0	3.0	3.3	3.7	4.1
Southampton	3.0	3.1	3.1	3.4	3.8	4.2
Lee-on-the Solent	3.0	3.1	3.1	3.4	3.8	4.2
Portsmouth Harbour	3.1	3.2	3.2	3.5	3.9	4.3
Langstone Harbour	3.2	3.3	3.3	3.6	4.0	4.4
Chichester Harbour	3.3	3.4	3.4	3.7	4.1	4.5

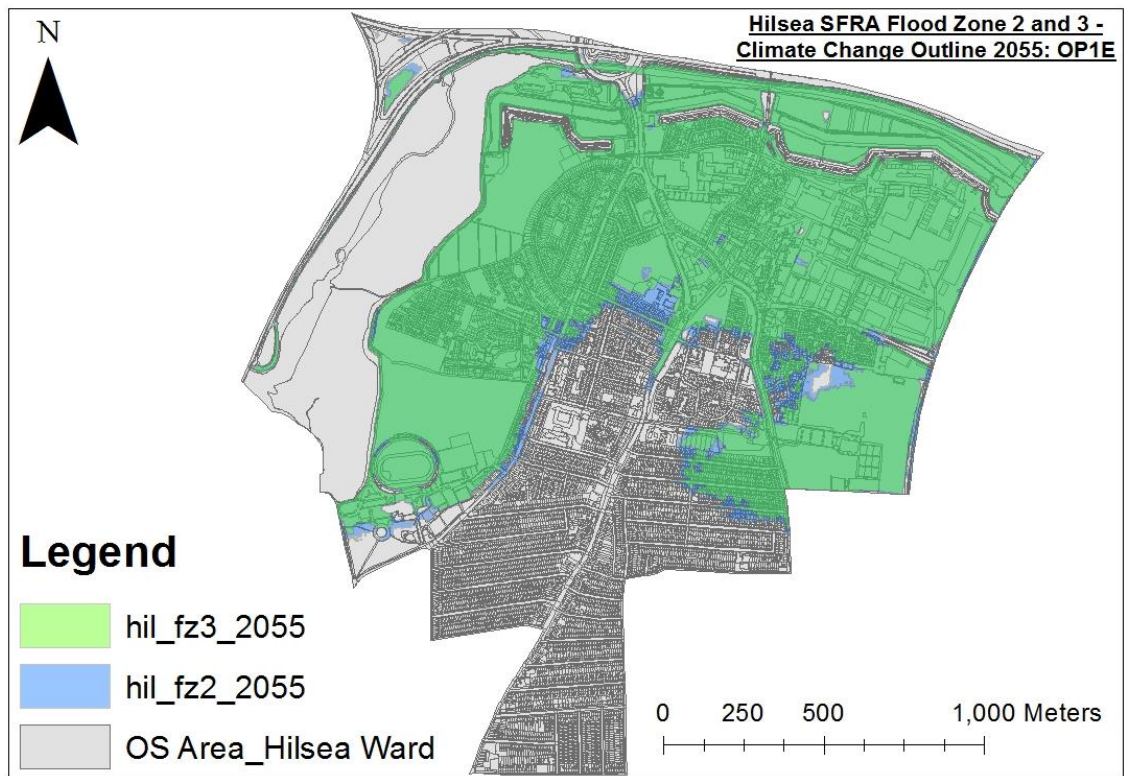
1 in 1000 year tide levels (Flood Zone 2) (Atkins, 2007)

<i>Note: Levels in mAOD to the nearest 0.1m</i>	<b>1990</b> (baseline)	<b>2010</b> (1990 + 80mm)	<b>2025</b> (1990 + 140mm)	<b>2055</b> (2025 + 255mm)	<b>2085</b> (2055 + 360mm)	<b>2115</b> (2085 + 450mm)
Calshot	3.1	3.2	3.2	3.5	3.9	4.3
Southampton	3.2	3.3	3.3	3.6	4.0	4.4
Lee-on-the Solent	3.2	3.3	3.3	3.6	4.0	4.4
Portsmouth Harbour	3.3	3.4	3.4	3.7	4.1	4.5
Langstone Harbour	3.4	3.5	3.5	3.8	4.2	4.6
Chichester Harbour	3.5	3.6	3.6	3.9	4.3	4.7

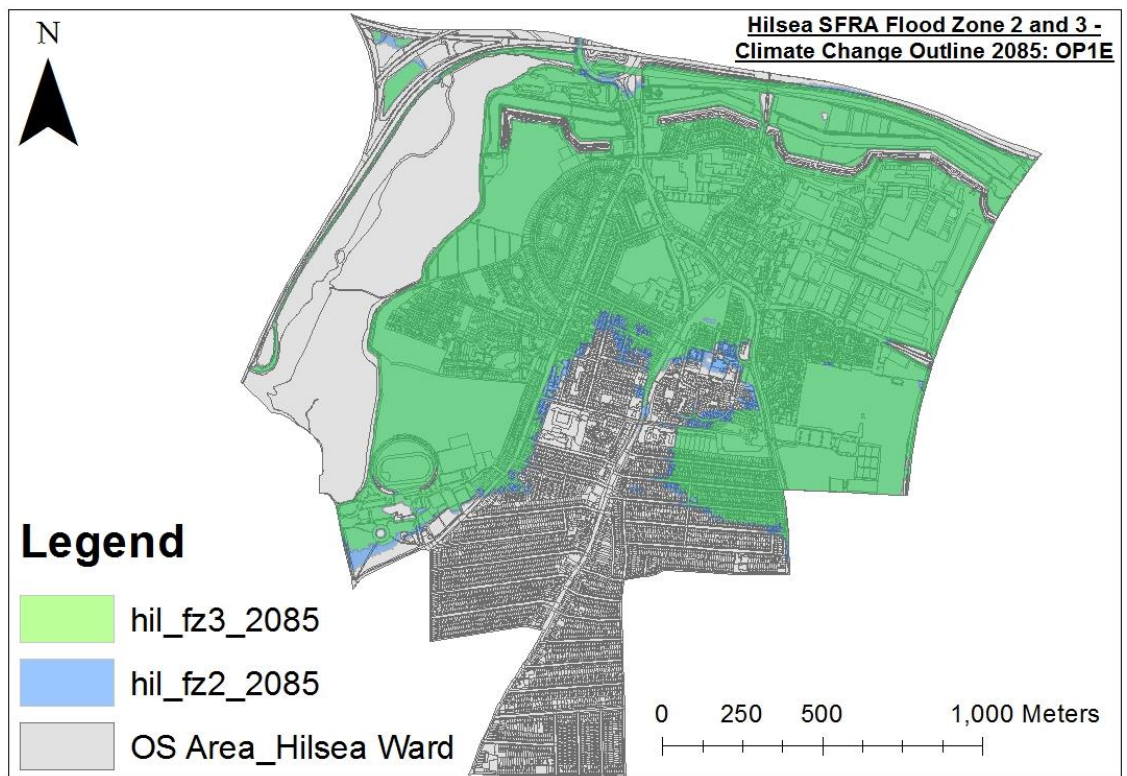
Hilsea SFRA Flood Zone 2 and 3 – Climate Change Outline 2025 (OP1E)



Hilsea SFRA Flood Zone 2 and 3 – Climate Change Outline 2055 (OP1E)



Hilsea SFRA Flood Zone 2 and 3 – Climate Change Outline 2085 (OP1E)



## **APPENDIX E – Physical Vulnerability Factors**

### Physical Vulnerability Factors Reasoning

**Population density:** The higher the density of people exposed to a natural hazard (i.e. in the hazard pathway) the higher the vulnerability (Balica, 2012b; Balica et al, 2012; Cardona et al, 2012; Birkmann et al, 2013). Densely populated areas, create complications in evacuation and more strain on emergency services (Cutter et al., 2003; Kaźmierczak and Cavan, 2011).

**Dwellings:** The value, quality and density of residential construction can affect the potential losses and then the recovery (Cutter et al, 2003; Lindley et al, 2011, 2012; Balica, 2012b). Homes on the coast, can be costly to replace, depending on location (Cutter, 2003). A higher proportion of residential dwellings in an area increase the vulnerability, due to a higher potential for serious injuries or fatalities during the event and evacuation.

**Commercial and industrial areas:** The value, quality, and density of commercial and industrial buildings provide an indicator of the economical status of an area, and perhaps potential losses that could occur in the business community and longer-term issues that can occur when recovery time is in ‘play’ (Cutter, 2003; Davis per comms, 2010). A high proportion of commercial and industrial buildings in an area will lead to a potential higher financial loss and longer recovery time i.e. increasing vulnerability.

**Green Areas:** Green spaces can decrease floodwater through interception, storage and infiltration (Handley and Carter, 2006; Kaźmierczak and Cavan, 2011; Lindley et al, 2011, 2012; Climate Just, 2015). Floodwater of high depths and high onset would saturate green areas over time, depending on soil/surface permeability. However, larger coverage of green areas still reduce vulnerability.

**Vulnerable Buildings:** These buildings were identified by the Hampshire and Isle of Wight Fire and Rescue Service as buildings they would seek out first, due to firstly the vulnerable nature of the buildings themselves i.e. height (bungalows, mobile homes and other single story buildings); secondly of the residents/occupants of those buildings (Hampshire Fire and Rescue per comms, 2013). Mobile homes in general are very easy to destroy and less resilient to hazards. Some buildings that are classed as vulnerable during the day, are not at night e.g. nurseries and schools; as they are not used during this time.

**Essential Buildings:** More essential buildings (churches, community centres etc) in areas decreases vulnerability, as these are buildings that can provide shelter and refuge for large

numbers of people (Davis per comms, 2010; Kaźmierczak and Cavan, 2011; Portsmouth City Council, 2011a, 2011b; Spiller per Comms, 2013).

**Utilities:** Loss of sewers, bridges, safe fresh water, communications, and pumping stations increase potential disaster losses (Kaźmierczak and Cavan, 2011; Spiller per comms, 2013). The loss of extensive infrastructure may place a severe financial burden on a community due to limited financial resources. Loss of communications would also slow recovery time, due to society's dependence on telecommunications.

**Tenure -** Multiple residency can be seen as a more vulnerable household. More than one dwelling in one residency building may acquire more assistance for possible rescue, plus there is always the chance (especially with multiple tenants, such as students) of uncertainty regarding exact numbers of residents (Hampshire Fire and Rescue per comms, 2013). More people can lead to more chaos. Those on the lowest floor or basement flats are more vulnerable due to greater proximity to flood water (Kaźmierczak and Cavan, 2011; Lindley et al, 2011, 2012; Climate Just, 2015). People that rent do so because they are either transient or do not have the financial resources to own their own home. Some renters often lack access to the right information about financial aid recovery, the right insurance documentation, and in the most extreme cases renters can lack the sufficient shelter options when lodging becomes uninhabitable or too costly to afford.

**Transport:** Those that have large distances to travel to work are more likely to use the main roads or railways situated in or around their area. Therefore, those that have long distances to travel may have problems either returning or going to work if these roads or railways are flooded (Kaźmierczak and Cavan, 2011). This could result in people being stranded, or their income disrupted, due to being unable to get to their workplace (Hampshire Fire and Rescue per comms, 2013). Some homes may also be accessible by 1 or 2 ways, and if these are in very high flood risk zones, they could be exceedingly difficult or impossible to get back to. Those that have shorter distances to their workplace can be seen as less vulnerable due to fewer complications if inundation occurs.

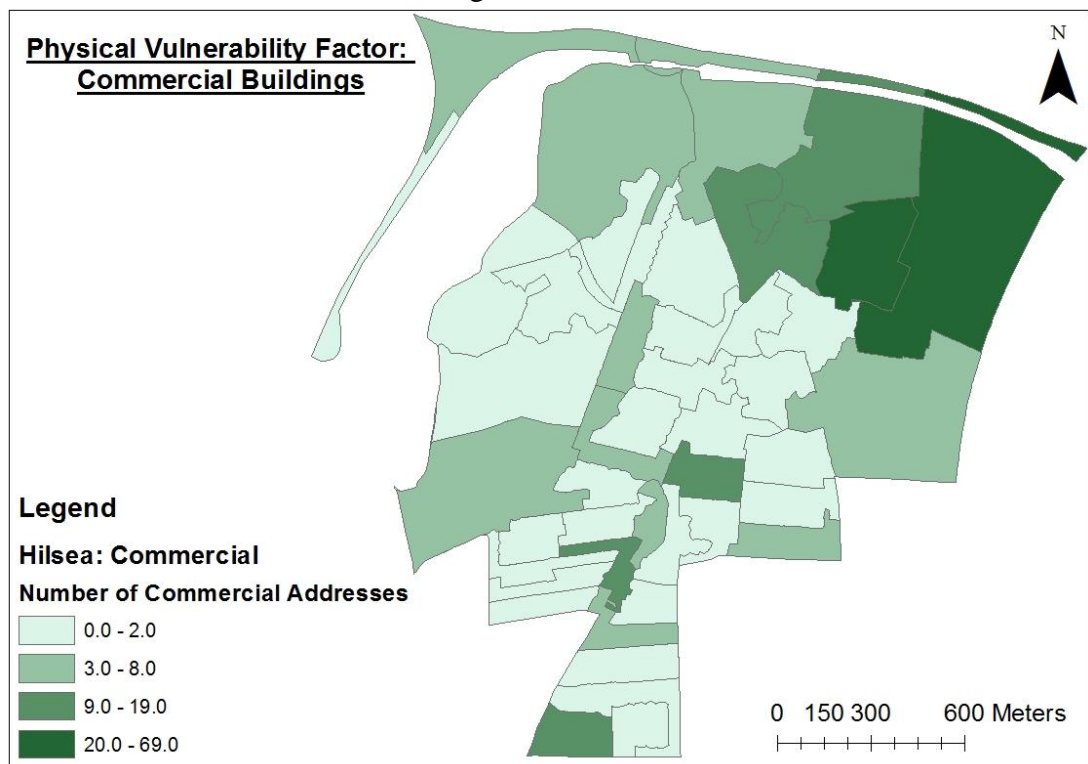


## APPENDIX F – Physical Vulnerability Factor Result Maps for Ward of Hilsea

### Vulnerability Component: Physical Vulnerability (Exposure)

Factor: Commercial & Retail Areas

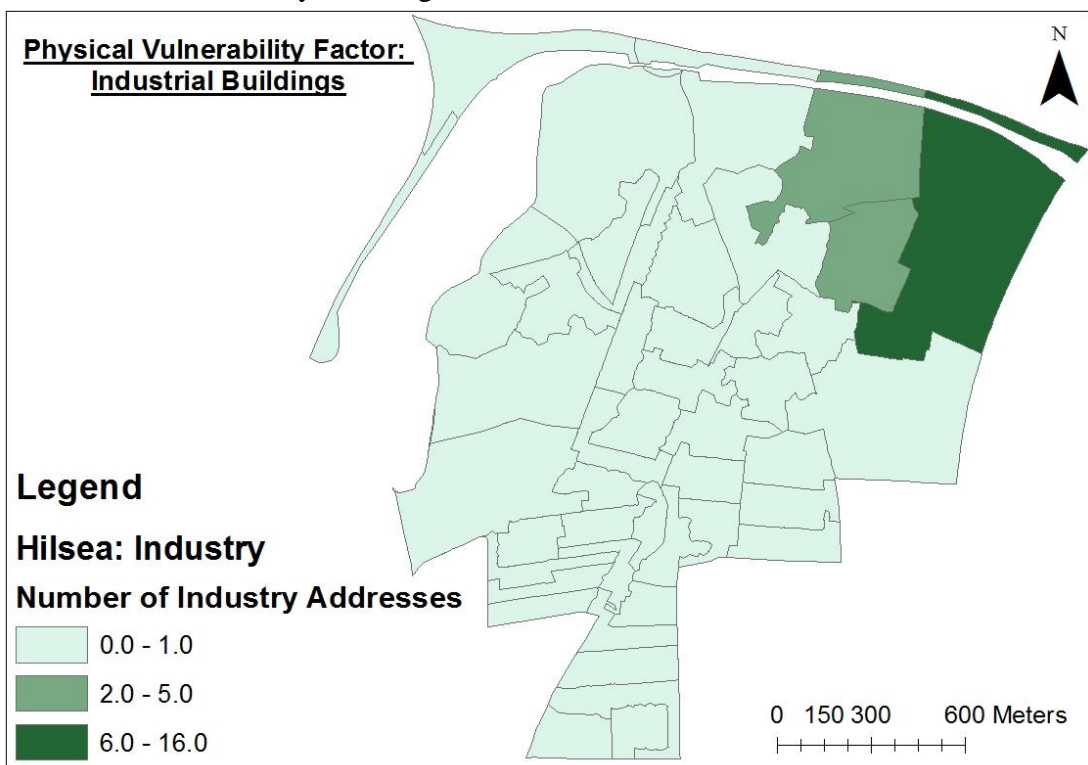
Data Variable: LU Commercial Buildings



### Vulnerability Component: Physical Vulnerability (Exposure)

Factor: Industrial Areas

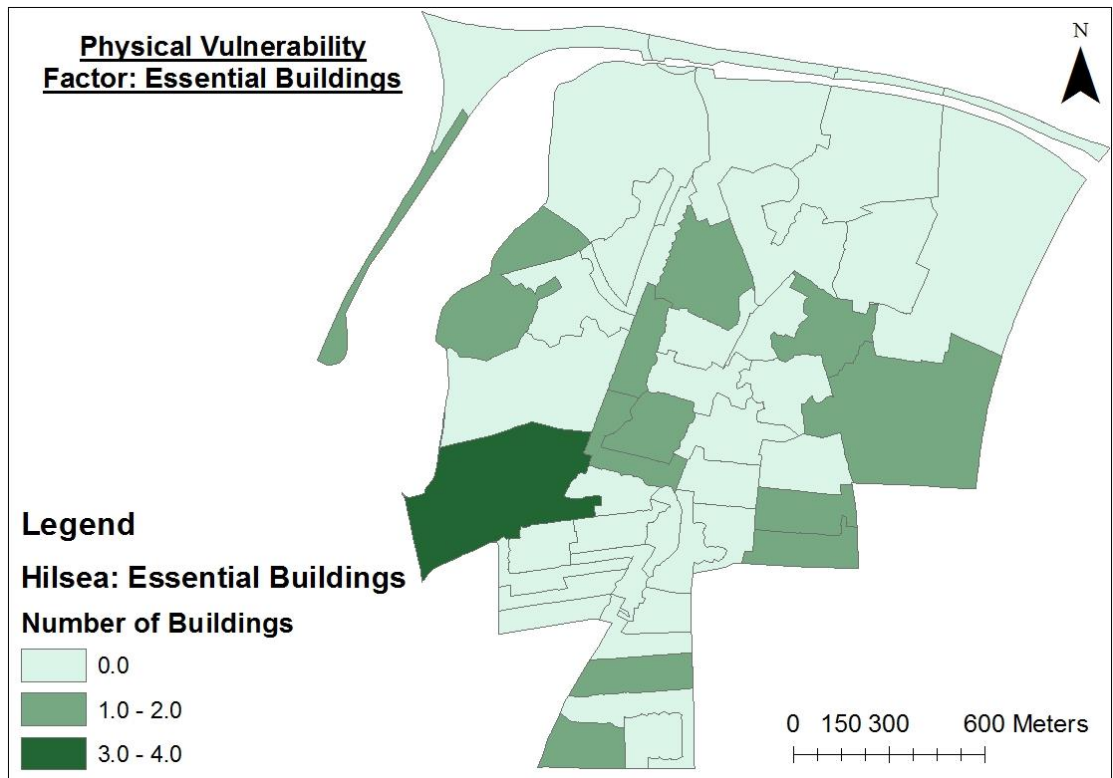
Data Variable: LU Industry Buildings



**Vulnerability Component: Physical Vulnerability (Exposure)**

Factor: Essential Buildings

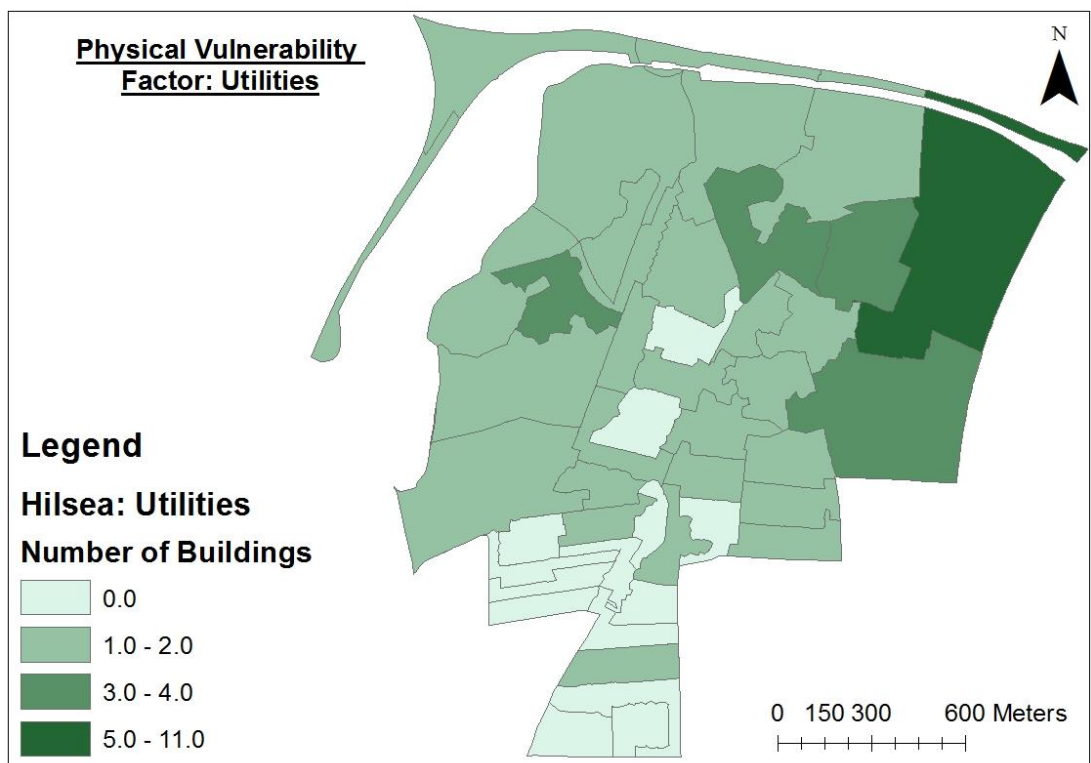
Data Variable: LU Essential Buildings



**Vulnerability Component: Physical Vulnerability (Exposure)**

Factor: Utilities

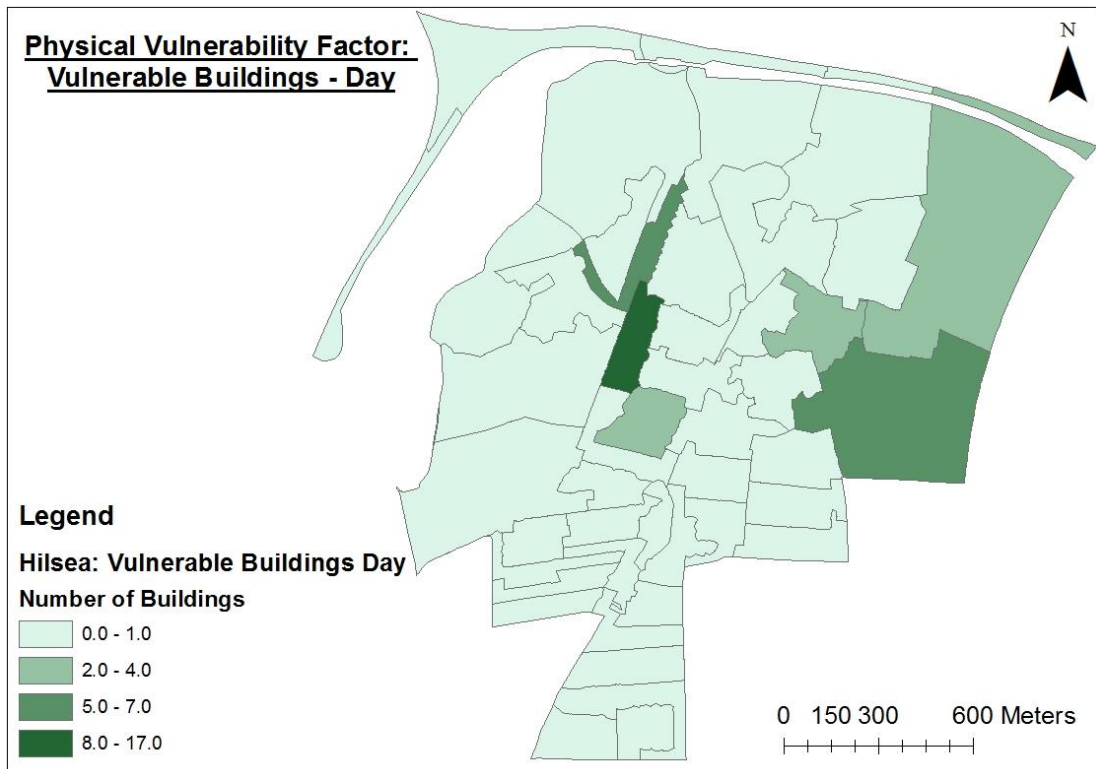
Data Variable: LU Utilities



**Vulnerability Component: Physical Vulnerability (Exposure)**

Factor: Vulnerable Buildings (day)

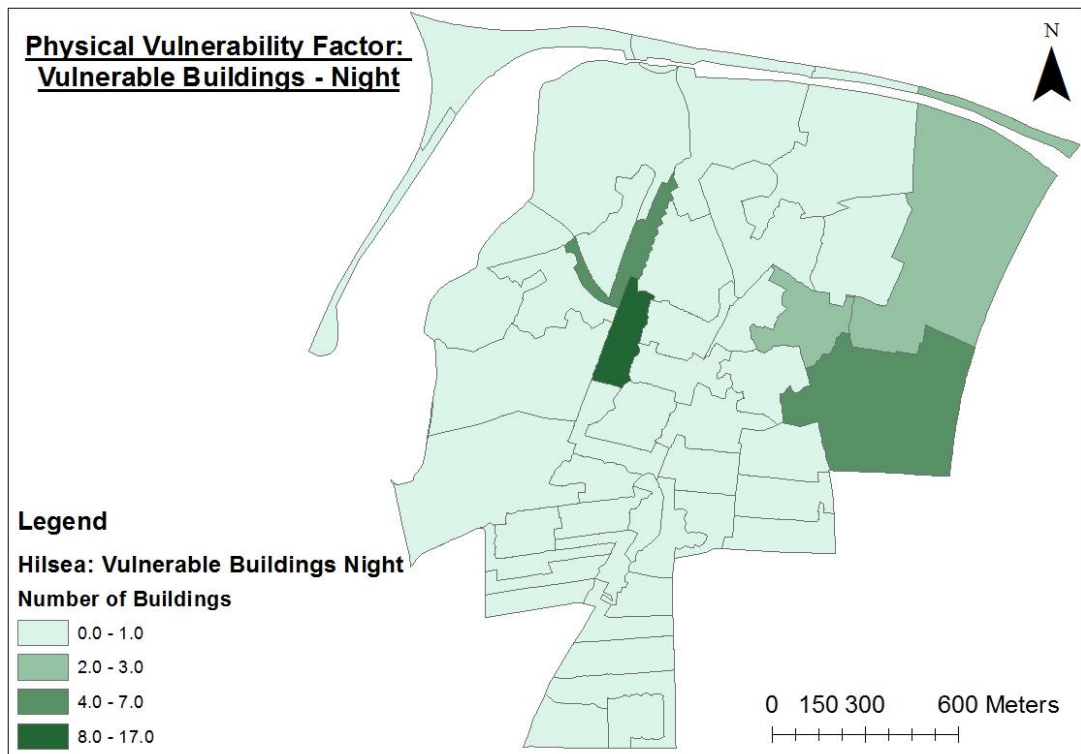
Data Variable: LU Vulnerable Buildings (day)



**Vulnerability Component: Physical Vulnerability (Exposure)**

Factor: Vulnerable Buildings (night)

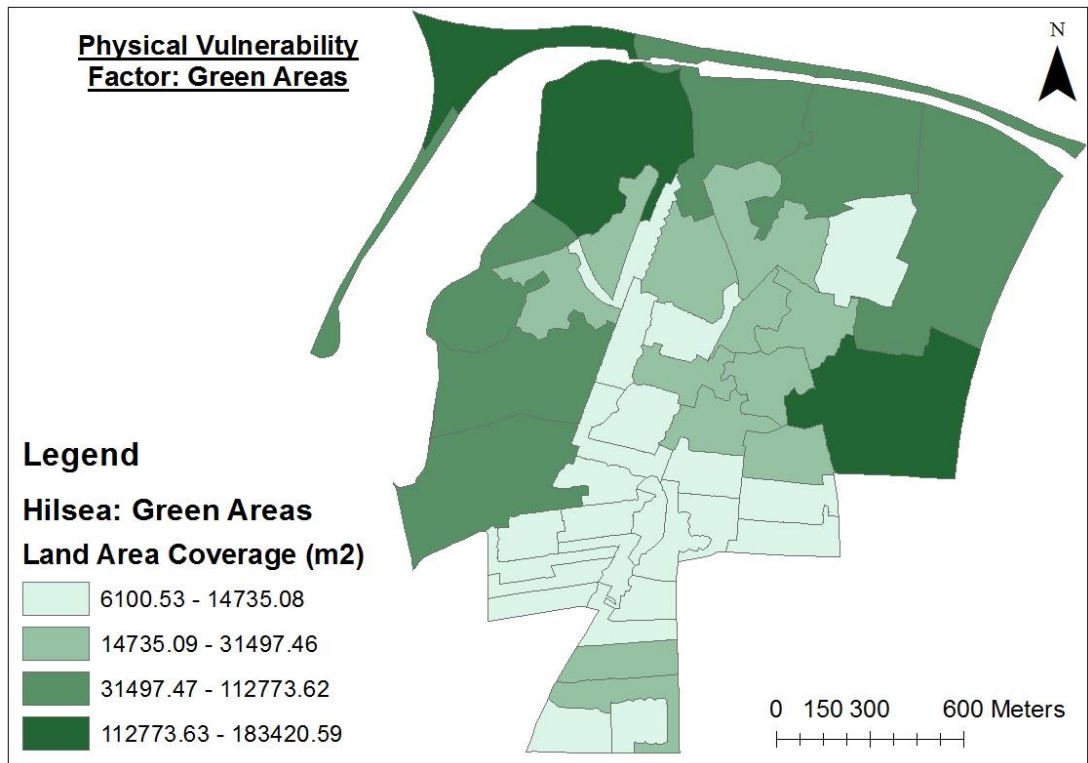
Data Variable: LU Vulnerable Buildings (night)



**Vulnerability Component: Physical Vulnerability (Exposure)**

Factor: Green Areas

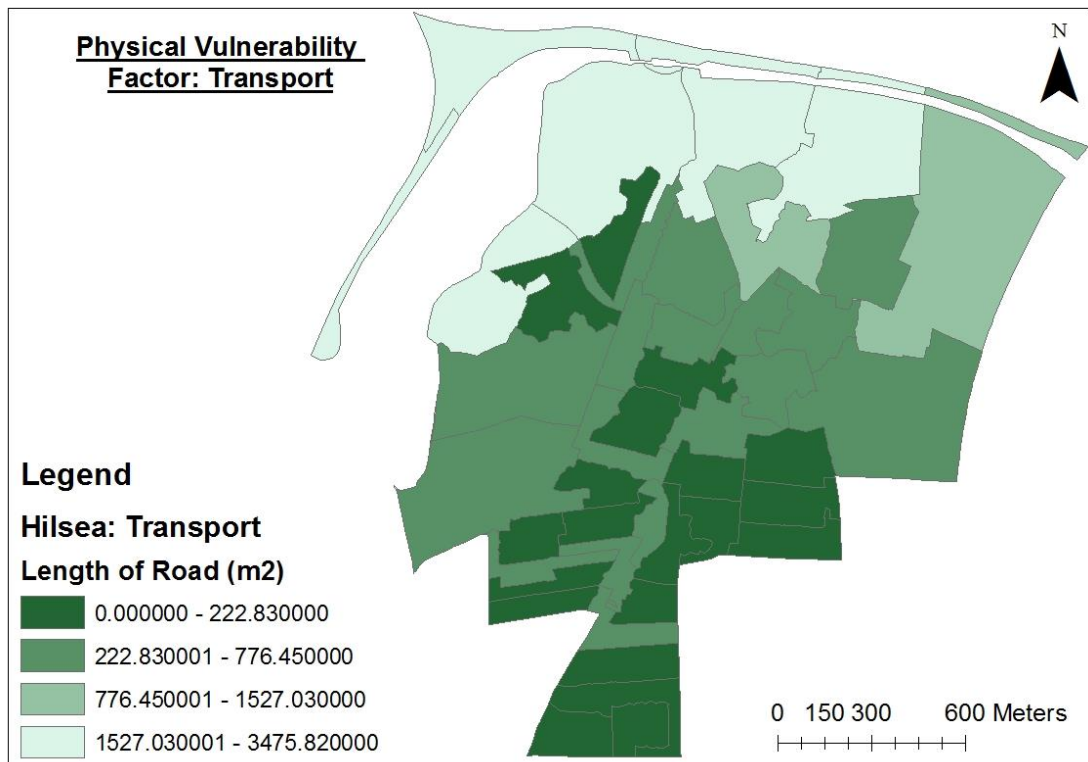
Data Variable: LU Green Areas



**Vulnerability Component: Physical Vulnerability (Exposure)**

Factor: Transport

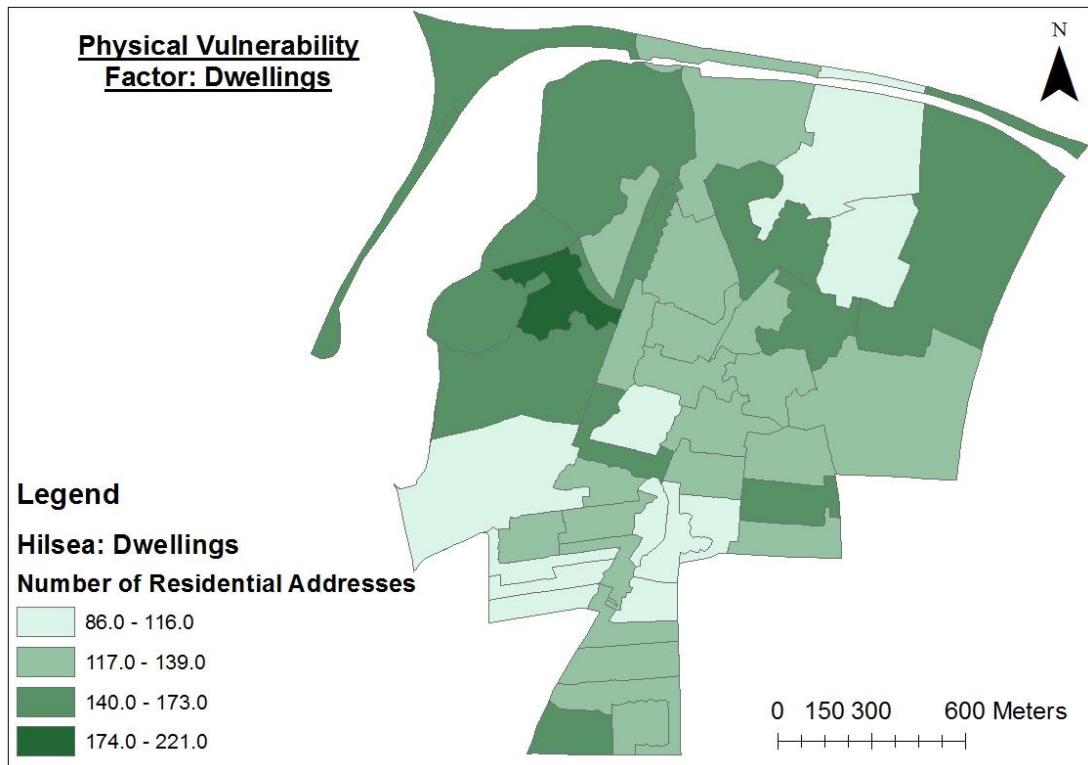
Data Variable: LU Transport



**Vulnerability Component: Physical Vulnerability (Exposure)**

Factor: Dwellings

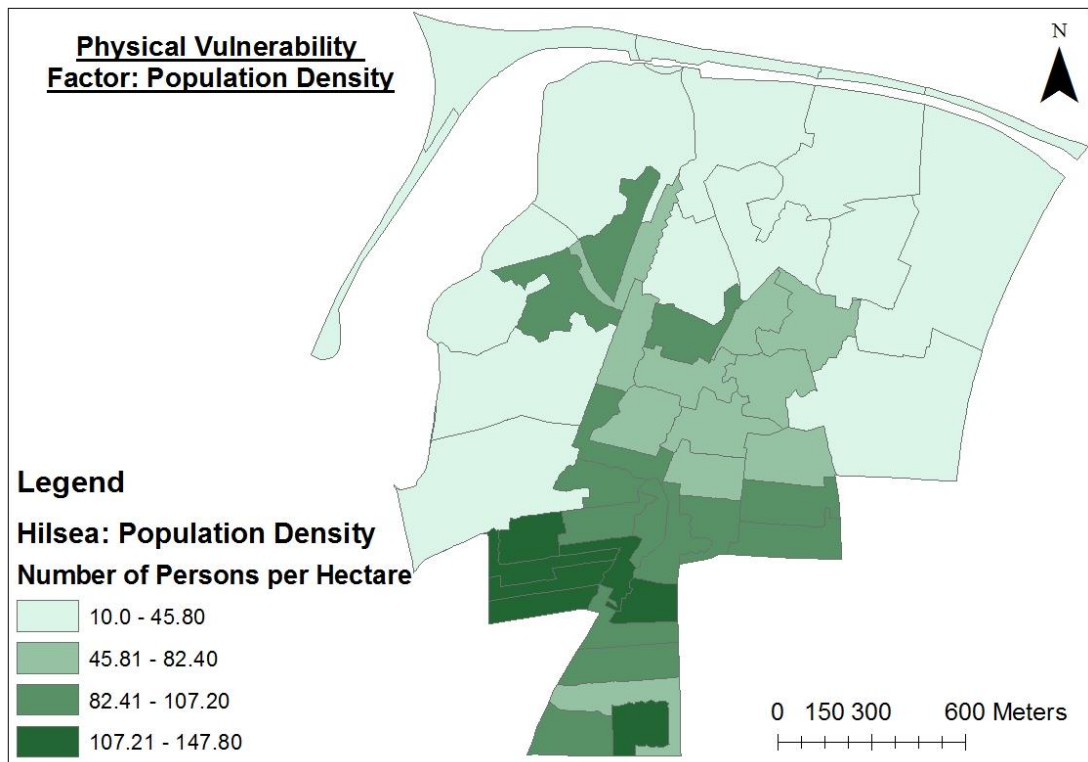
Data Variable: LU Residential



**Vulnerability Component: Physical Vulnerability (Exposure)**

Factor: Population Density

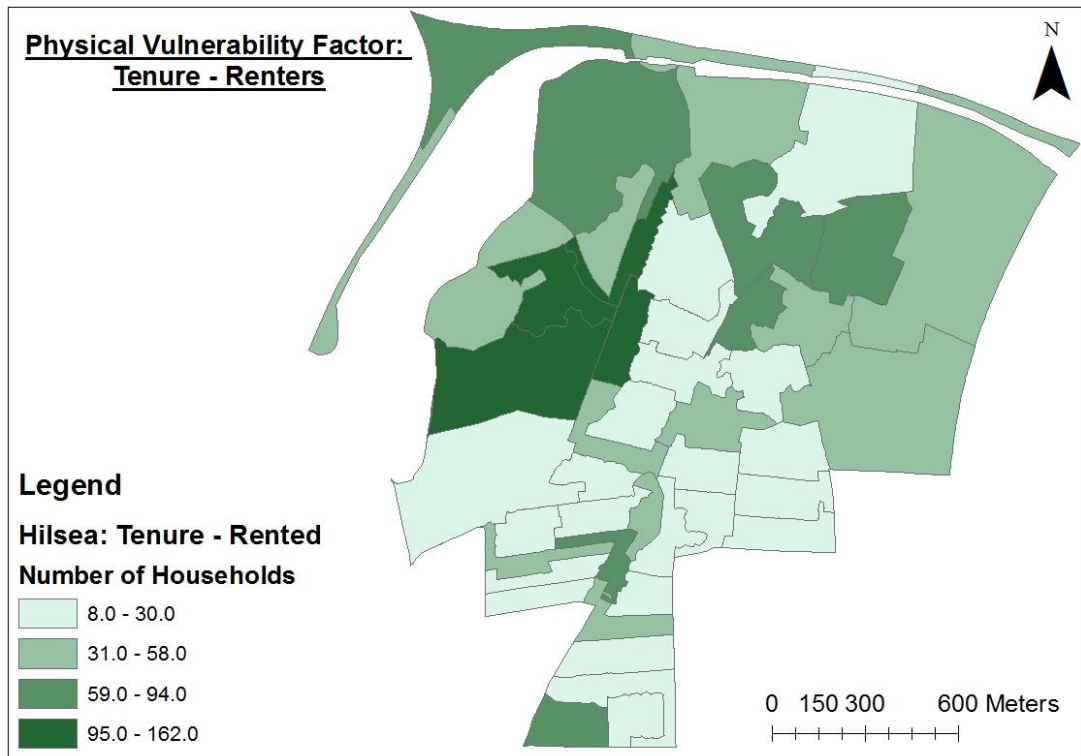
Data Variable: 2011 UK National Census 'Population Density'



**Vulnerability Component: Physical Vulnerability (Exposure)**

Factor: Tenure

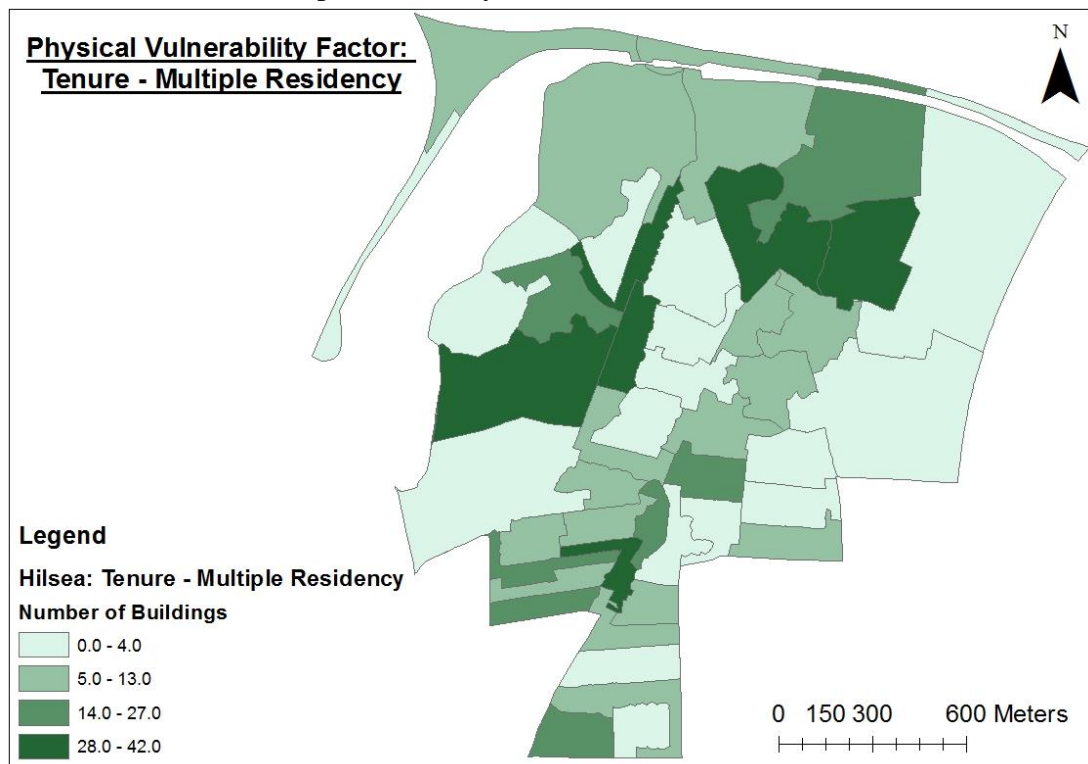
Data Variable: 2011 UK National Census 'Tenure Households'



**Vulnerability Component: Physical Vulnerability (Exposure)**

Factor: Tenure

Data Variable: LU Multiple Residency



## **APPENDIX G - Socio-economic Vulnerability Factors**

### Socio-economic Vulnerability Factors Reasoning

**Age:** Subgroups vulnerable to adverse health effects of floods include the elderly (Thrush et al, 2005; HR Wallingford, 2006a; Pitt, 2008; Lindley et al, 2011, 2012; Climate Just, 2015). However, Tapsell et al (1999 and 2000) commented that the term elderly can be used to describe a wide range of people, some who are not helpless, i.e. those who are newly retired are normally fit and active members of society, and will therefore cope better with the associated traumas from flood events. The age of 75 has been chosen as the threshold for vulnerability with regards to the elderly (HR Wallingford, 2006b; Atkins, 2007; Alexander et al, 2011). Epidemiological research has shown that after this age, there is a sharp increase in the incidence and severity of arthritis and this illness is sensitive to damp, cold and environmental conditions that would follow a flood event (Tapsell et al, 2002). In addition, the diseases that predispose people to hypothermia are more common in those over 65 (HR Wallingford, 2006b). With regards to location Walker et al (2003) found that the financially deprived tended to be situated within the tidal floodplain area and there is correlation between poverty and age. The elderly can become confused, frightened even bewildered by informal flood warnings. The elderly that are non-institutionalised are much more difficult to locate and therefore harder to evacuate (Keys, 1991). However, there is not only the elderly to consider within the *age* factor, children can also be vulnerable. Cutter (2003) describes the two extremes of the age spectrum; children and the elderly as vulnerable to natural hazards. These two age ranges can affect the movement out of harm's way. Both parties may not receive adequate warning, the elderly could have lack of mobility and essential resources, meaning they are socially isolated and have less extensive or effective social networks, and are less likely to receive warnings from friends, family or neighbours HR Wallingford (2006a). Children's parents can lose time and money when they have to care for children because nurseries and schools are affected; children also can have constrained mobility due to their size (depending on their years). During a flood the very old are more vulnerable to the effects of immersion i.e. shock or hypothermia. Tapsell et al (2003) also commented that there is evidence that death can be hastened by the experience of flooding. Lastly isolated and house-bound people, such as the elderly, may have to wait longer for evacuation, as certain service providers may be needed and roads maybe impassable (Kaźmierczak and Cavan, 2011). In summary, both elderly and young

children could therefore increase the burden for care and have a general lack of resilience to flooding, therefore having greater vulnerability than other 'ages' in society.

**Household Structure:** This group includes lone parent families and tends to suffer more stress and trauma as they tend to have less income and must cope single-handedly with both children and the flood impacts. Lone parent families (normally female led) are disadvantaged with regards to adult:child ratios, therefore rapid response or evacuation to a flood could be very difficult, more so if there are very young children. Children are exceedingly vulnerable if in contact with floodwater, due to their size and being physically weaker than adults, there is also the possibility of them being separated from their families in the confusion of these events (Keys, 1991; Tapsell et al., 2002; Cutter et al., 2003; HR Wallingford, 2006a). Due to their increased surface area to body volume ratio, children can lose body heat more rapidly than an adult and therefore have greater risk of getting hypothermia and shock (HR Wallingford, 2006a). Cutter (2003) also suggested large families or single-parent households can have limited financial sums to assist with care for their dependents, and therefore may have to juggle many responsibilities including work and care for family. Single/lone parents may also struggle to find the resources, energy and mental strength to start again after a disaster (Kaźmierczak and Cavan, 2011). All these points affect the vulnerability to the hazard/s and recovery.

**Illness or Disability:** Members of society with limiting long-term illness, health problems or disabilities that limit their daily activities or work are likely to have mobility issues or may be housebound. In many cases this can lead to isolation, and like the elderly, lead to lack of effective community networks, thereby not receiving flood warning information (HR Wallingford, 2006a; Pitt, 2008; Lindley et al, 2012). People with sensory impairments both optical and sound, are particularly vulnerable in terms of receiving and responding to flood warnings. People who have illness or disabilities are likely to be weaker and less able to help themselves during a flood event, support will likely be needed. Research has shown that post flood morbidity and mortality is significantly higher when the flood victims suffer pre-existing health problems (Tapsell et al, 2002; Thrush et al, 2005). For example HR Wallingford (2006a) stated that the mortality rate for hypothermia in healthy individuals is less than 5%, while those with pre-existing illnesses, it is as high as 50%. Contact with floodwater can cause an increase in physical and emotional stress, thereby promoting the chance of myocardial infarction and perhaps as drastic as cardiac arrest among those already have heart conditions.



**Ethnicity and Race:** Research has identified minority groups are disproportionately represented in hazardous areas (Cutter et al, 2003; Lindley et al, 2011, 2012). It was also noted this variable is related to financial deprivation, which is over-represented in UK tidal floodplains (HR Wallingford, 2006a). Ethnicity can also impose language and cultural barriers. For example, ethnic minority groups can be excluded from participation in the earlier planning stages of community disaster planning; they are less likely to receive warnings and perhaps not heed them when they do (HR Wallingford, 2006a). Ethnic minorities may be unable to understand/speak the language of the host country they are in, therefore finding it difficult to understand the emergency procedures in place at times of crisis (Keys, 1991). Cutter (2003) and Lindley et al (2012) also mentioned the possibility that these groups cannot access the correct post-disaster care, funding, and new residency provision.

**Gender:** Women can have a greater problem recovering from a hazard than men; this is often due to sector-specific employment, family care responsibilities, and unfortunately lower wages via gender-specific employment (Cutter, 2003; Pitt, 2008; Lindley et al, 2011, 2012) The average annual salary in the UK is around £5000 less for women.

**Occupation:** Those, whose livelihood depends on resource extraction, could be severely impacted by a hazard event Cutter (2003). For instance fishermen who are self employed and therefore could suffer when their means of production is lost (i.e. damaged by the flood water or stormy conditions) and may not have the capital required for them to return to their work in the time required and therefore may have to seek alternative employment. Migrant and seasonal workers in low skilled service jobs, i.e. housekeeping, au pairs, hotel work or grounds men. Could suffer as disposable income fades away and there is little need for their services when economic conditions are 'tighter'. Those who work less hours (part-time workers) may not have the financial ability to cope after a flood event, unlike those in fulltime employment.

**Economic:** Expensive residential homes in an area, are costly to replace. If you have a general high economic value for an area, the economic loss through flooding would also be high. Expensive residential homes normally cost larger amounts to repair either due to size of the property or the general aesthetics. If large amounts of businesses are established in the area, loss of trade/rates and employment will be expensive to re-build and re-instating. Therefore the higher the economic value of an area, the more vulnerable it will be. Loss of

economic prosperity affects the community (Lindley et al, 2011, 2012; Balica, 2012a; Birkmann et al, 2013; Climate Just, 2015).

**Providers of Unpaid Care:** A person is a provider of unpaid care if they look after or give help or support to family members, friends, neighbours or others because of long-term physical or mental ill health or disability, or problems related to old age (Office for National Statistics, 2011a). This is not paid employment. It is important to note that no distinction is made whether any care that a person provides, is within his or her own household, or outside of the household. Therefore, this results in providers of unpaid care being difficult to locate geographically. If a flood occurred, understanding the whereabouts of this specific section of the population would be difficult, therefore providing problems for emergency services. Those who care for others (like lone parents) may not have the strength, finances, time and energy to make a new start (Tapsell et al., 2002; Kaźmierczak and Cavan, 2011). Therefore, large amounts of providers of unpaid care populations in neighbourhoods, increases vulnerability due to the unpredictability of their whereabouts geographically and their limited ability to recover from a flood; due to the hours they are providing to others and possible need of additional support and resources.

**Communal Establishment Resident:** A communal establishment resident is a person whose place of usual residence is in, managed residential accommodation. This means any person who was living or expected to live in a communal establishment for six months or more. Residents in a communal establishment that have resided for less than six months are included (within the UK National Census) as resident at their home address (Office for National Statistics, 2011b). A communal establishment provides managed residential accommodation, 'managed' meaning with either part-time or full-time supervision. These include sheltered accommodation where the main meal is provided, small hotels, guest houses, bed and breakfasts, inns and pubs with residential accommodation, all accommodation provided solely for students (during term-time); including university owned cluster flats, houses and apartments. Lastly, accommodation available solely to nurses. Not included are the communal establishments' members of staff and families or accommodation rented to students via private landlord. Residents of communal establishments may include people of multi-nationality where English is not their first language, therefore not able to understand the warnings, or know what to do, or where to go in times of flood (Cutter et al., 2003; Kaźmierczak and Cavan, 2011; Lindley et al, 2012). It can be hard to establish how many people are present within a communal

establishment; particularly in student accommodation where many people can be coming or going from the establishment, but have no actual residency in the building. It can be difficult to determine the numbers present within these buildings in times of evacuation. Long-term seasonal tourists (may not have the resources to cope with flooding) also can be situated in buildings like these that are within hazardous regions, i.e. in Portsmouth most of the main hotels, B&B's etc are on the sea front. A higher communal establishment resident population results in higher vulnerability.

**Residential Population:** This is specifically related to the night-time analysis, as there is a higher resident population situated in an urban area at night time, due to sleeping. Also a high portion of that population being at work during the day. Floods at night are more dangerous than during the day (Hampshire Fire and Rescue per comms, 2013); the 1953 North Sea storm surge mainly occurred at night, with 307 deaths in the England, 19 in Scotland and 1800 in the Netherlands, (Met Office, 2014). People are unaware of disasters occurring until the situation is perhaps 'too late' and very dangerous, with increased risk to life (NOAA, 2016). Therefore, a large residential population increases vulnerability. This factor was not measured for the day analysis.

**Home Population:** This is specifically related to residents being present in their areas during the day. Larger home populations increase vulnerability (Cardona et al, 2012), as they are situated within the flood pathway, higher numbers in areas need further evacuation. These numbers are made up of people that are not working (stay at home mums/dads), elderly or employed that work solely from home. The elderly are more vulnerable due to fragility and mobility issues. Households that contain non-workers i.e. stay at home mums/dads; may only have one low level of 'income' financing the family, which could be a burden after a flood event, due to not having the financial abilities to cope and recover. Homes that contain families/partners with more than one job are more likely to have better resources making them less susceptible. The home population gave distinction between a day and night analysis.

The next factor was not used, due to the lack of data to populate it:

*Special needs Populations:* Are difficult to identify – including infirm, institutionalised, transient, homeless etc; even more so to measure; they are invariably left out of recovery efforts; often 'invisible' in communities. Special needs populations are disproportionately affected during a disaster, due to the lack of knowledge about their circumstances in the

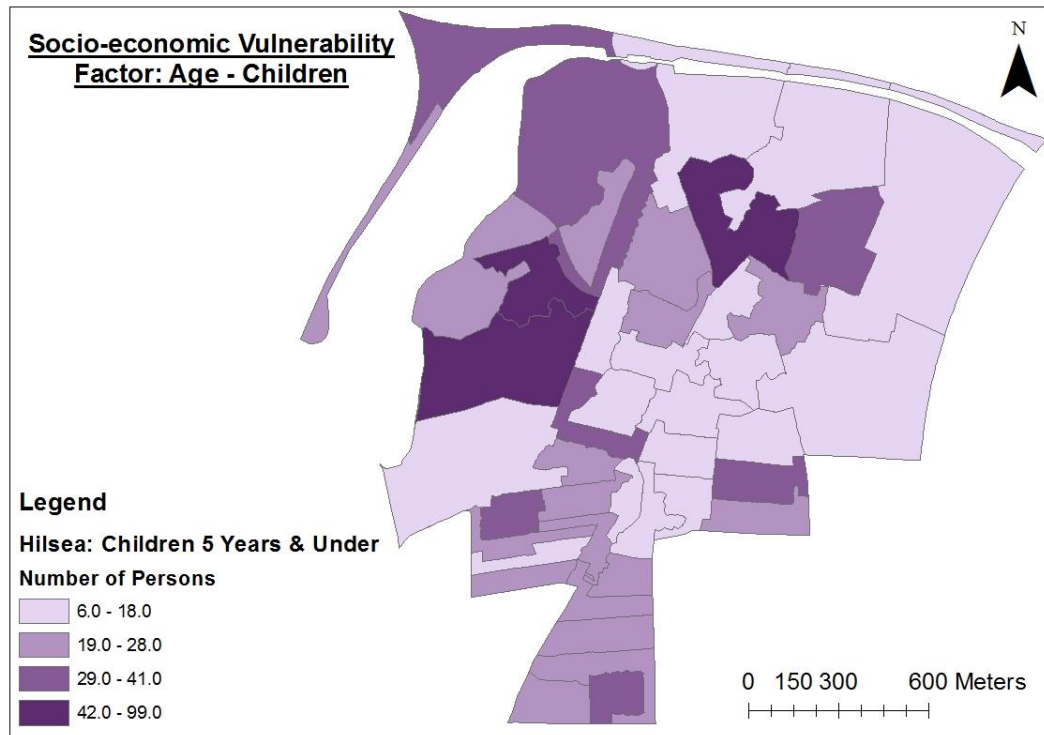
communities. They are generally less likely to receive warnings than residents (HR Wallingford, 2006a; Pitt, 2008), and they are often overlooked during recovery operations (Cutter et al., 2003). If a flood occurred the homeless are more likely to suffer from chronic chest or breathing problems and musculoskeletal problems HR Wallingford (2006a). Homeless people are more likely to have acute health and mental health problems, such as TB and hepatitis, or schizophrenia; they also might suffer from drink and drug problems, or combinations of these health issues. The homeless are often distributed in hazardous areas are difficult to locate as they are only officially counted, when they ask for help from the authorities. Single people are not normally entitled to help, unless they are seen as exceedingly vulnerable HR Wallingford (2006a). There are no comprehensive national figures on the extent of single homelessness (HR Wallingford, 2006a). Counts are taken by local authorities and local homeless agencies of 'rough sleepers', giving a snapshot of the possible numbers on a single night for a specific geographic area. This factor is therefore of limited use, due to lack of data.

**APPENDIX H – Socio-economic Vulnerability Factor Result Maps for Ward of Hilsea**

**Vulnerability Component: Socio-economic Vulnerability (Susceptibility)**

Factor: Age

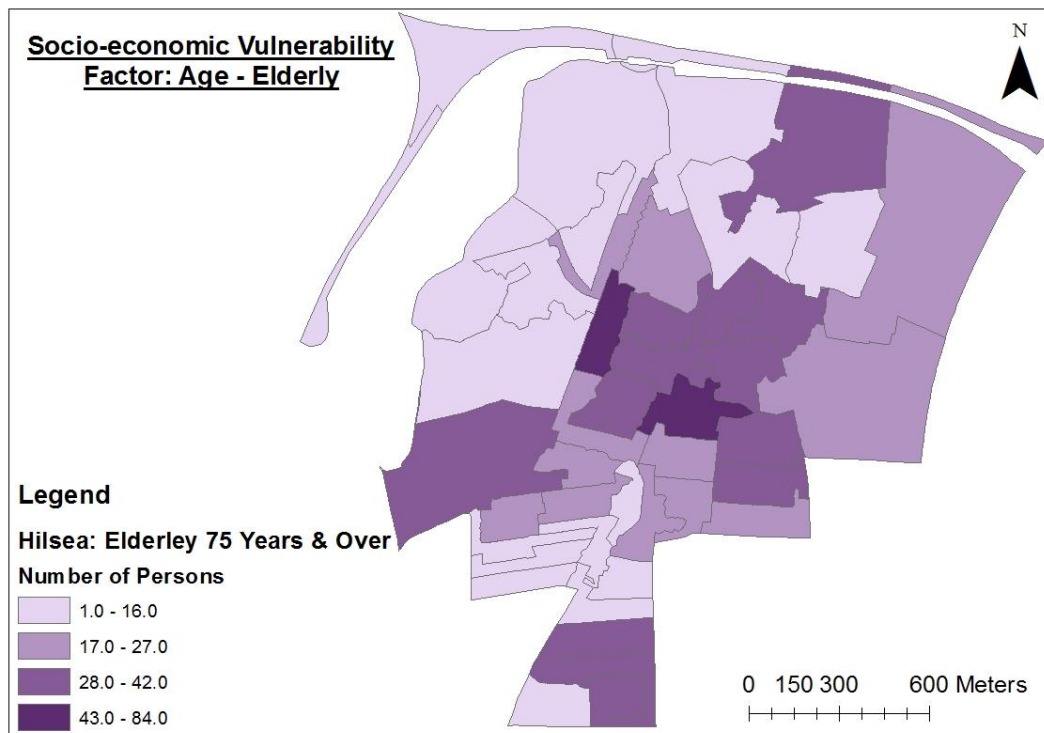
Data Variable: 2011 UK National Census ‘Age by a single year’ (Children)



**Vulnerability Component: Socio-economic Vulnerability (Susceptibility)**

Factor: Age

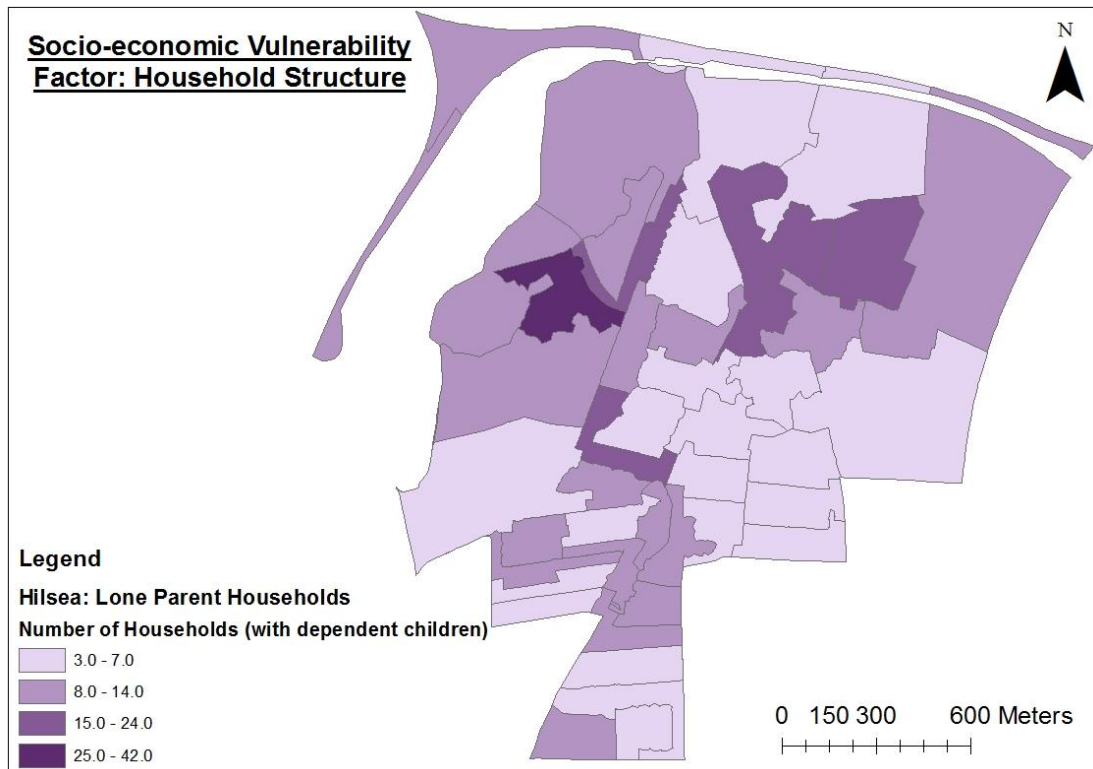
Data Variable: 2011 UK National Census ‘Age by a single year’ (Elderly)



**Vulnerability Component: Socio-economic Vulnerability (Susceptibility)**

Factor: Household Structure

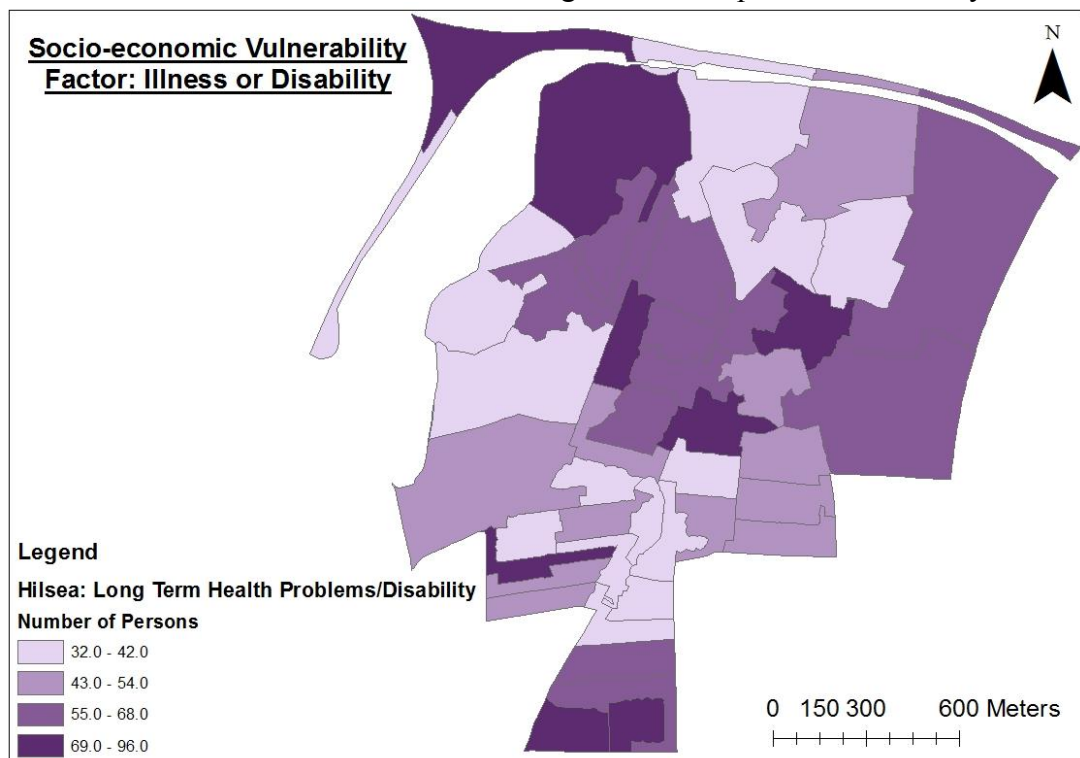
Data Variable: 2011 UK National Census 'Lone parent households'



**Vulnerability Component: Socio-economic Vulnerability (Susceptibility)**

Factor: Illness or Disability

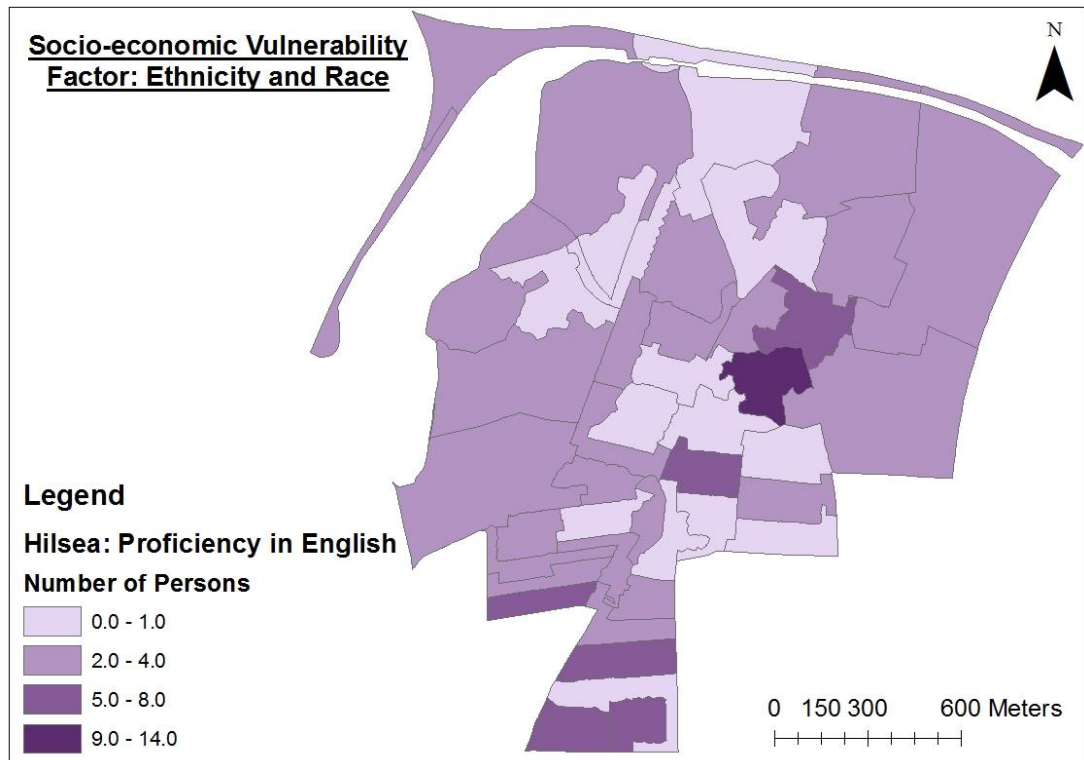
Data Variable: 2011 UK National Census 'Long term health problems/disability'



**Vulnerability Component: Socio-economic Vulnerability (Susceptibility)**

Factor: Ethnicity & Race

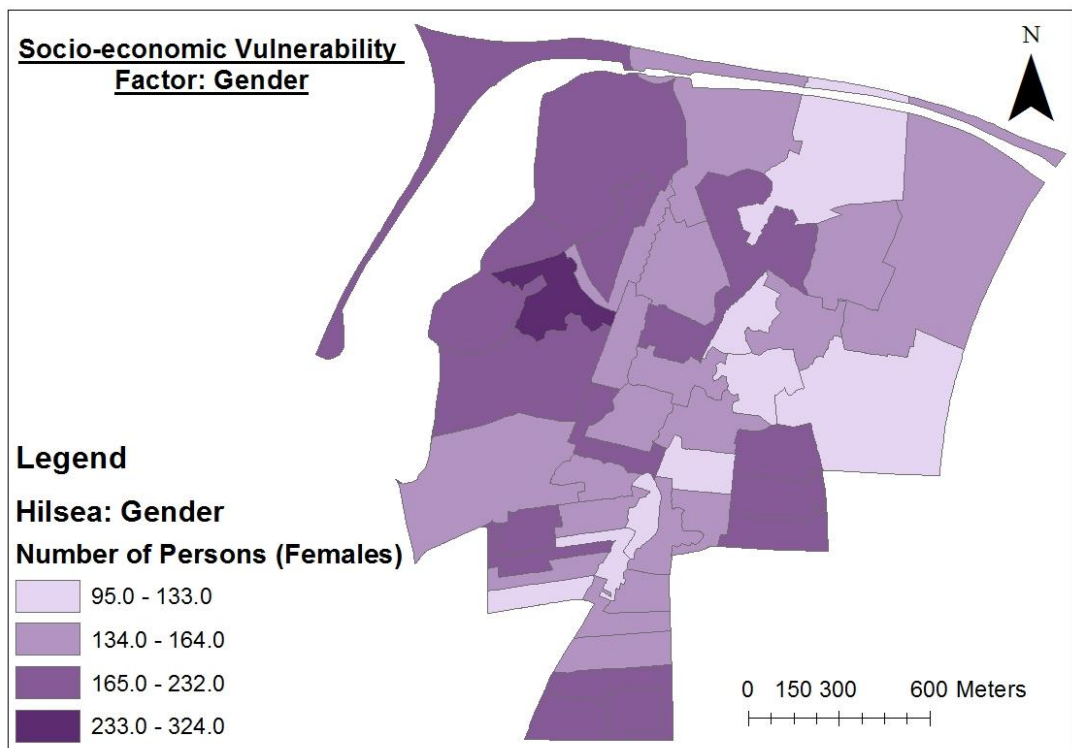
Data Variable: 2011 UK National Census 'Proficiency in English'



**Vulnerability Component: Socio-economic Vulnerability (Susceptibility)**

Factor: Gender

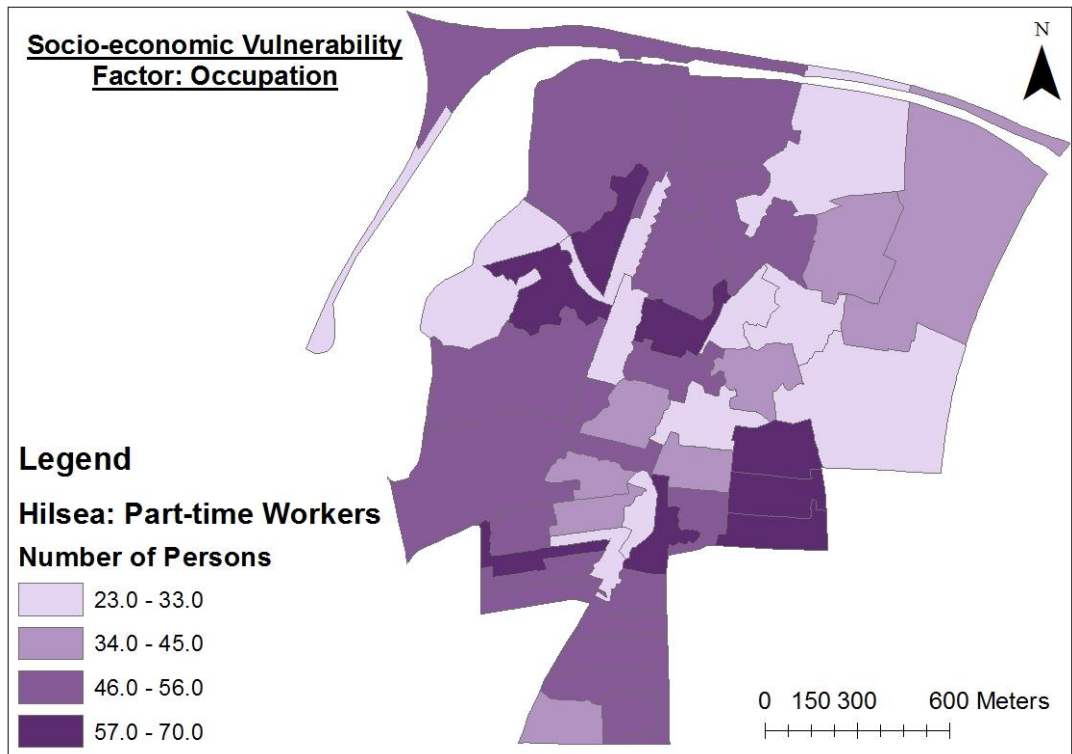
Data Variable: 2011 UK National Census 'Sex' (Female)



**Vulnerability Component: Socio-economic Vulnerability (Susceptibility)**

Factor: Occupation

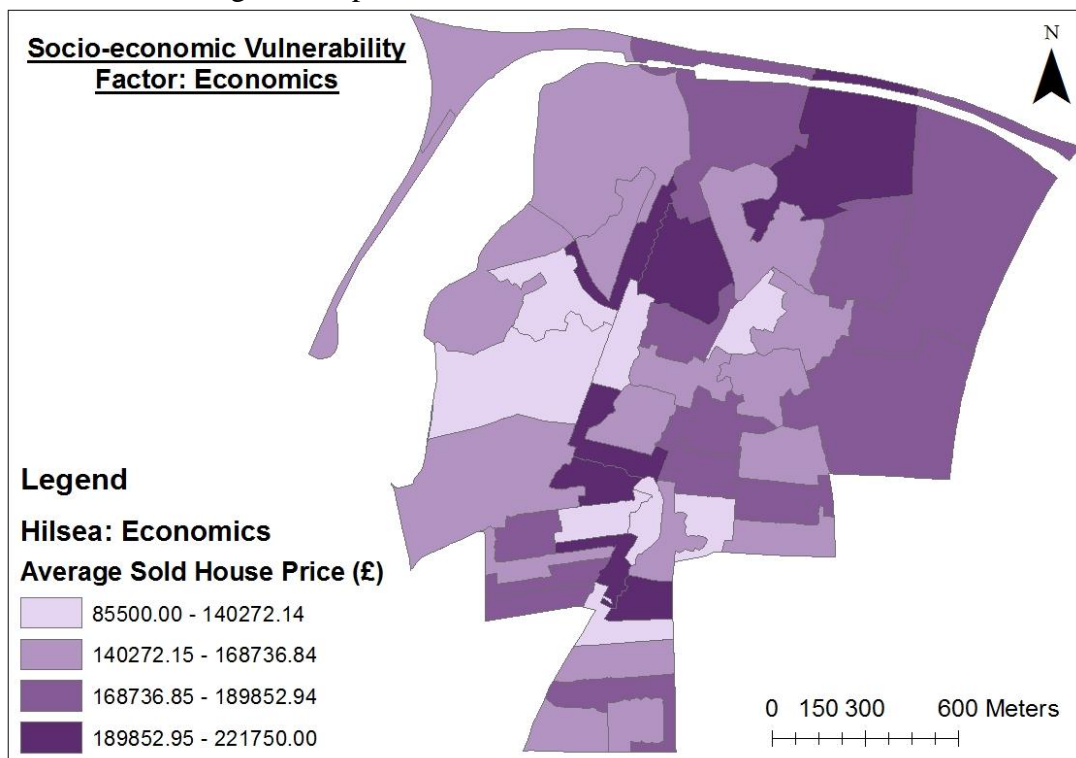
Data Variable: 2011 UK National Census 'Hours worked' (Part-time workers)



**Vulnerability Component: Socio-economic Vulnerability (Susceptibility)**

Factor: Economic

Data Variable: Average house prices

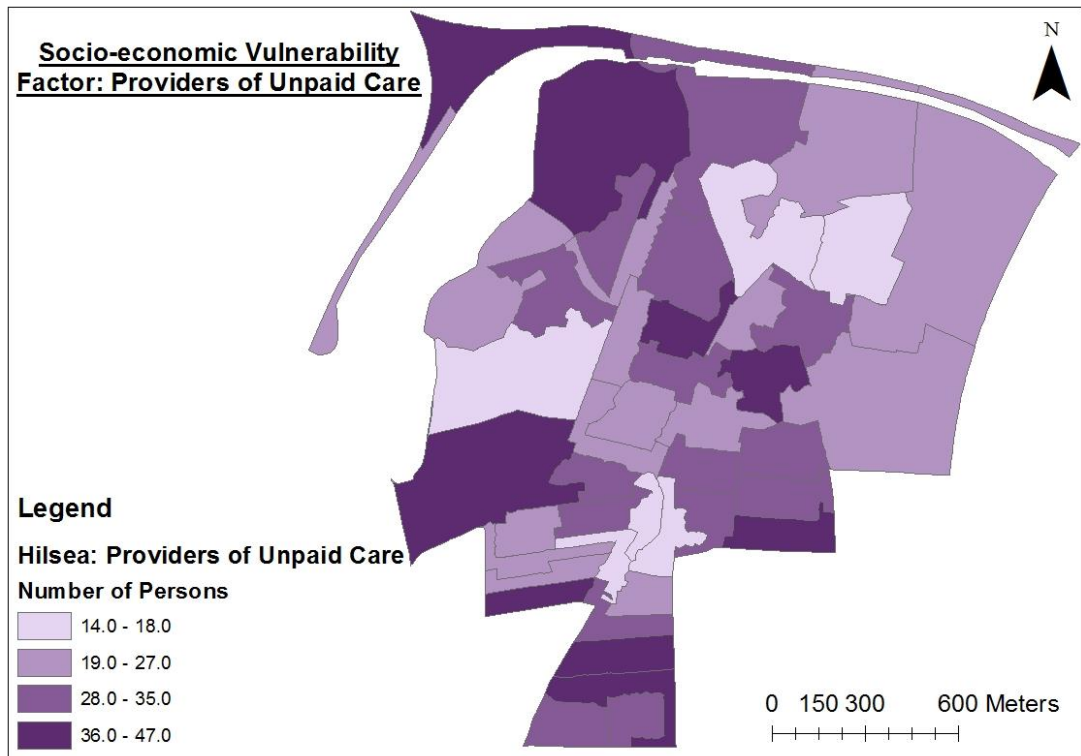




**Vulnerability Component: Socio-economic Vulnerability (Susceptibility)**

Factor: Providers of Unpaid Care

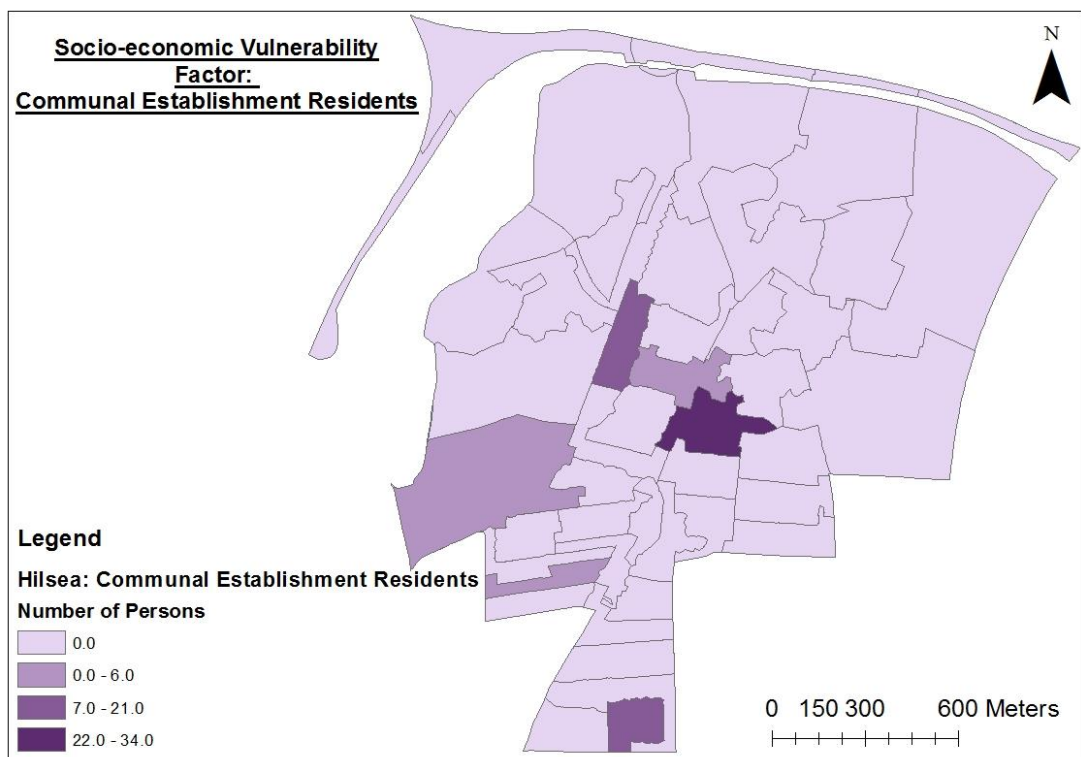
Data Variable: 2011 UK National Census 'Providers of unpaid care'



**Vulnerability Component: Socio-economic Vulnerability (Susceptibility)**

Factor: Communal Establishment Residents

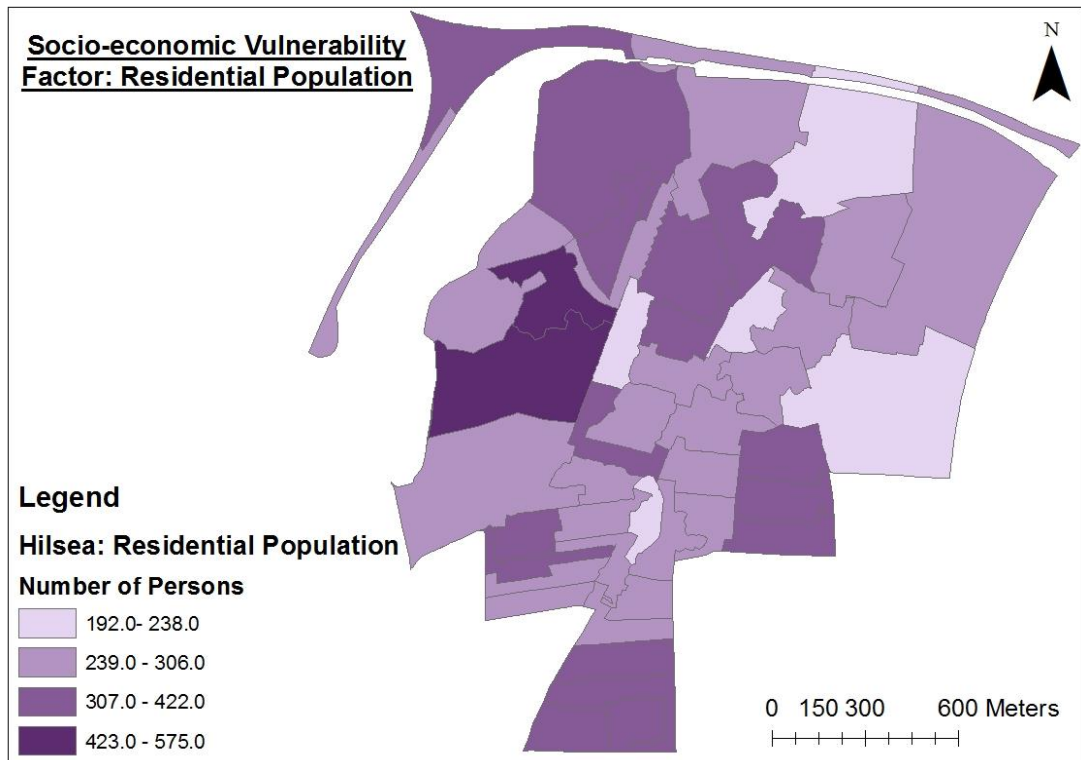
Data Variable: 2011 UK National Census 'Communal establishment residents'



**Vulnerability Component: Socio-economic Vulnerability (Susceptibility)**

Factor: Residential Population

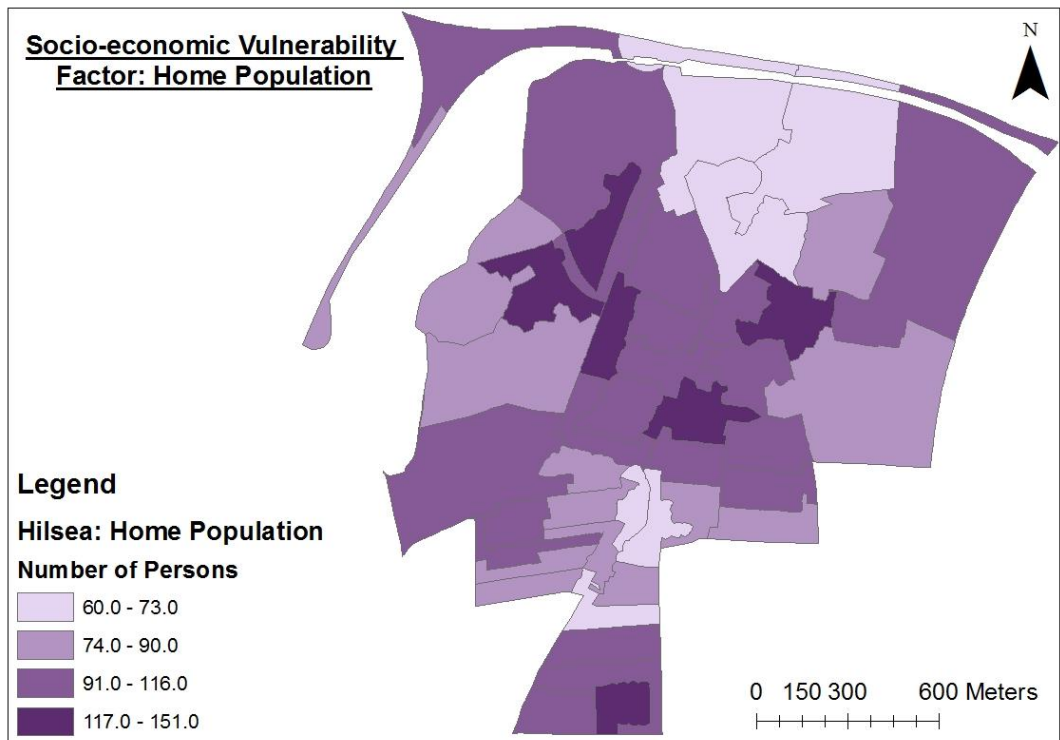
Data Variable: 2011 UK National Census 'Population density'



**Vulnerability Component: Socio-economic Vulnerability (Susceptibility)**

Factor: Home Population

Data Variables: 2011 UK National Census 'Method of Travel to Work' (work mainly from home & not in employment) & 'Age by a single year' (Elderly)



## **APPENDIX I – Limited Resilience Vulnerability Factors**

### Limited Resilience Factors Reasoning

**Socio - economic Status:** This characterises those that are financially deprived and successful. Previous research suggests that there is a curvilinear relationship between socio-economic groups (SEGs) and warning responses HR Wallingford (2006a). People of both high and low SEG are less likely to respond to warnings rather than the intermediate groups. Low income families would require further support post disaster as they may not have the resources, energy or abilities to re start their lives (Clark et al., 1998; Tapsell et al., 2002; Thrush et al, 2005; Pitt, 2008; Kaźmierczak and Cavan, 2011; Lindley et al, 2011, 2012; Climate Just, 2015). Those who are unemployed are included within this factor and if unemployment is already high within an area, there is potential for this to be exacerbated due to a large natural disaster, therefore contributing to a slower recovery from the community to the disaster. These populations decrease resilience in a community.

**Car Ownership:** Households without a car will be immobile during flood events, as it is likely public transport will be seriously affected and may be completely unavailable during and after a serious flood event. Those that own cars can leave the area (Clark et al., 1998; Thrush et al, 2005; Kaźmierczak and Cavan, 2011; Lindley et al, 2011, 2012; Climate Just, 2015), making these populations more resilient. People without cars could be stranded and would need assistance or to be evacuated if deep flood water occurred.

**Emergency Facilities:** The number of emergency facilities in an area helps determine an areas ability to cope with an event and a post event (Kaźmierczak and Cavan, 2011; Portsmouth City Council, 2011a, 2011b). Emergency facilities (including hospitals, police stations, fire stations etc) are there to assist people when an emergency, such as flooding, occurs. If there are none within an area, they have to come from elsewhere; however, floodwater may prevent their path. Secondly in a mass emergency event such as a flood, there may not be enough of these facilities to disperse emergency personal to all the places required, incurring waiting and perhaps increasing risk to life due to ‘lack of man power’. Emergency facilities in areas increase community’s resilience, no emergency facilities decrease resilience.

**Education:** Those with higher educational attainment are more likely to end with higher salaries (Cutter et al., 2003), therefore having more access to technology and information and thereby increasing an individual’s awareness to the risk of living in the area. Resulting in having insurance, property protection measures, knowing what to do in a flood event,

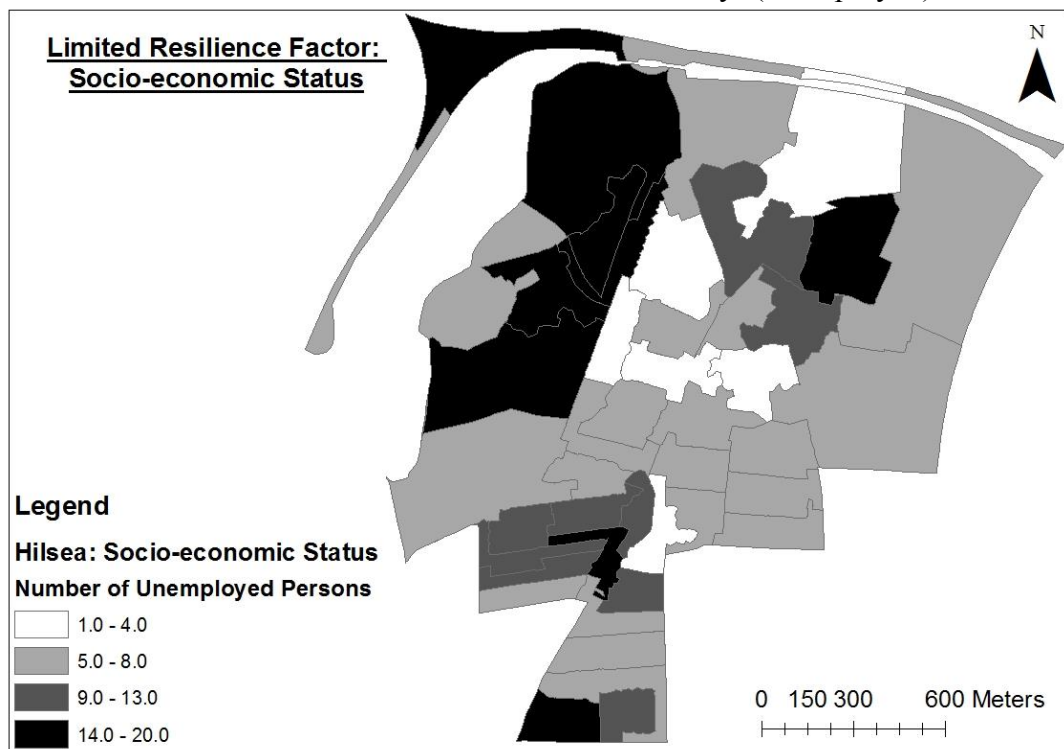
and understanding what and where help is available after a flood. Cutter et al (2003) suggests lower education attainment constrains an individual's ability to understand warning information and access to recovery information, perhaps due to outcomes such as illiteracy. Low education predominantly results in jobs with low salaries, leading to a lack of ability to invest in flood insurance (Tapsell et al, 2002; Kaźmierczak and Cavan, 2011). Low levels of education attainment leads to less resilience, and high levels of education lead to decreased limited resilience, resulting in lower overall vulnerability.

## APPENDIX J – Limited Resilience Factor Result Maps for Ward of Hilsea

### Vulnerability Component: Limited Resilience

Factor: Socio-economic Status

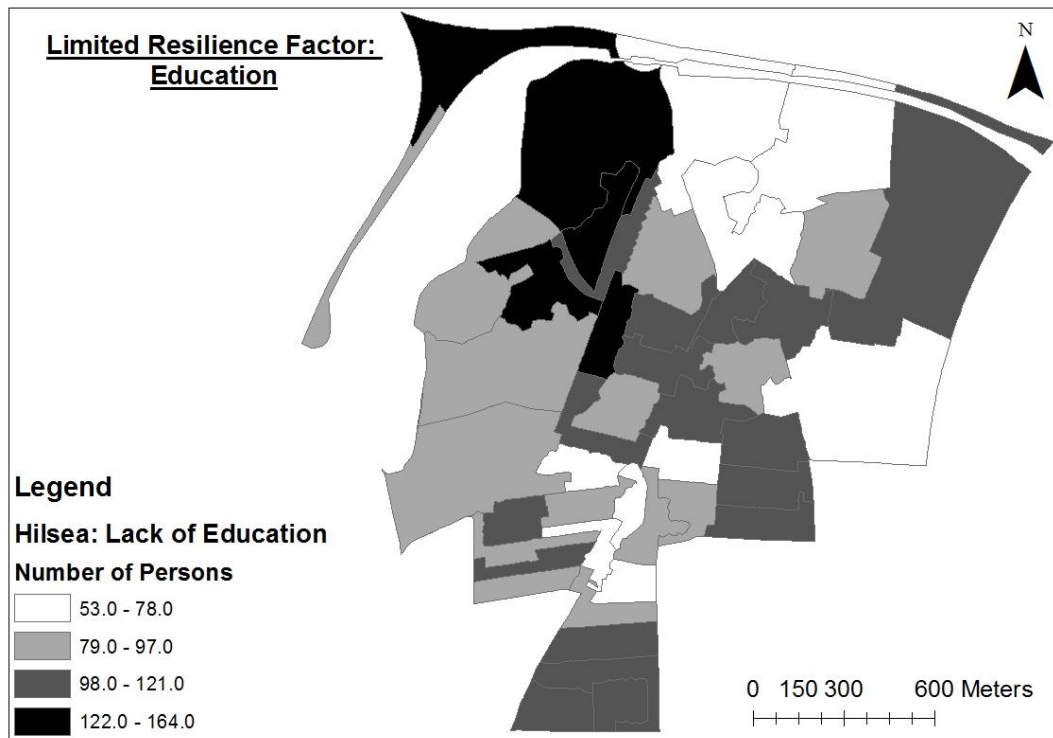
Data Variable: 2011 UK National Census 'Economic activity' (unemployed)



### Vulnerability Component: Limited Resilience

Factor: Education

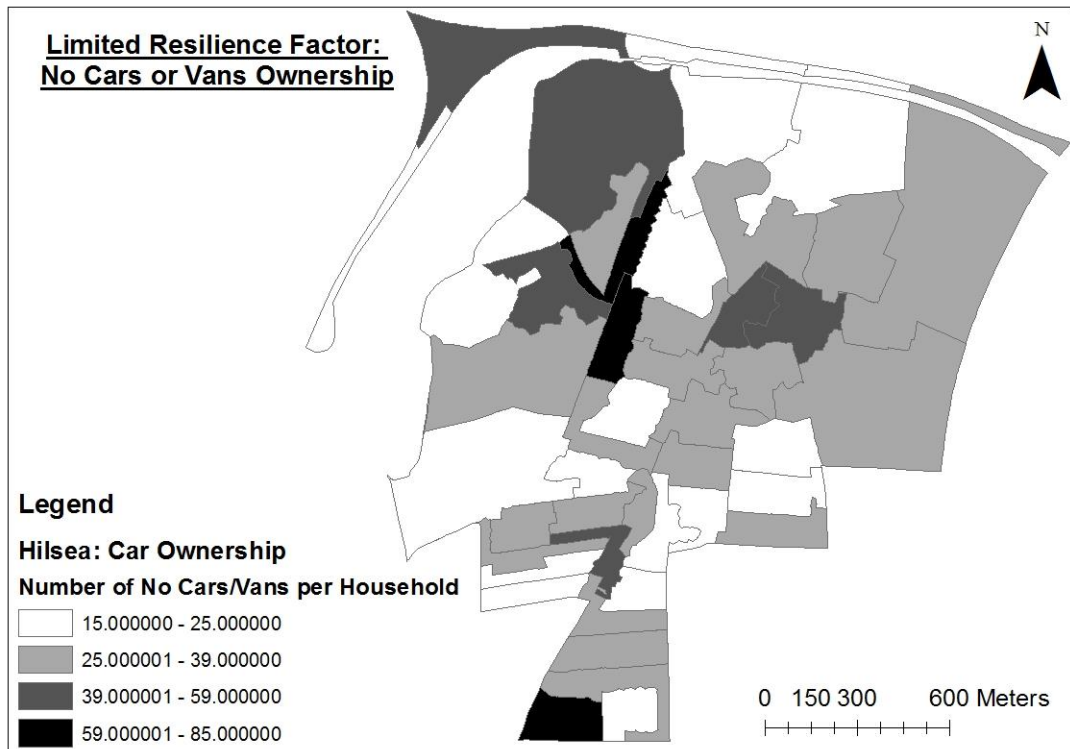
Data Variable: 2011 UK National Census 'Highest level of education' (Either no or low level qualifications (Level 1))



### Vulnerability Component: Limited Resilience

Factor: Car Ownership

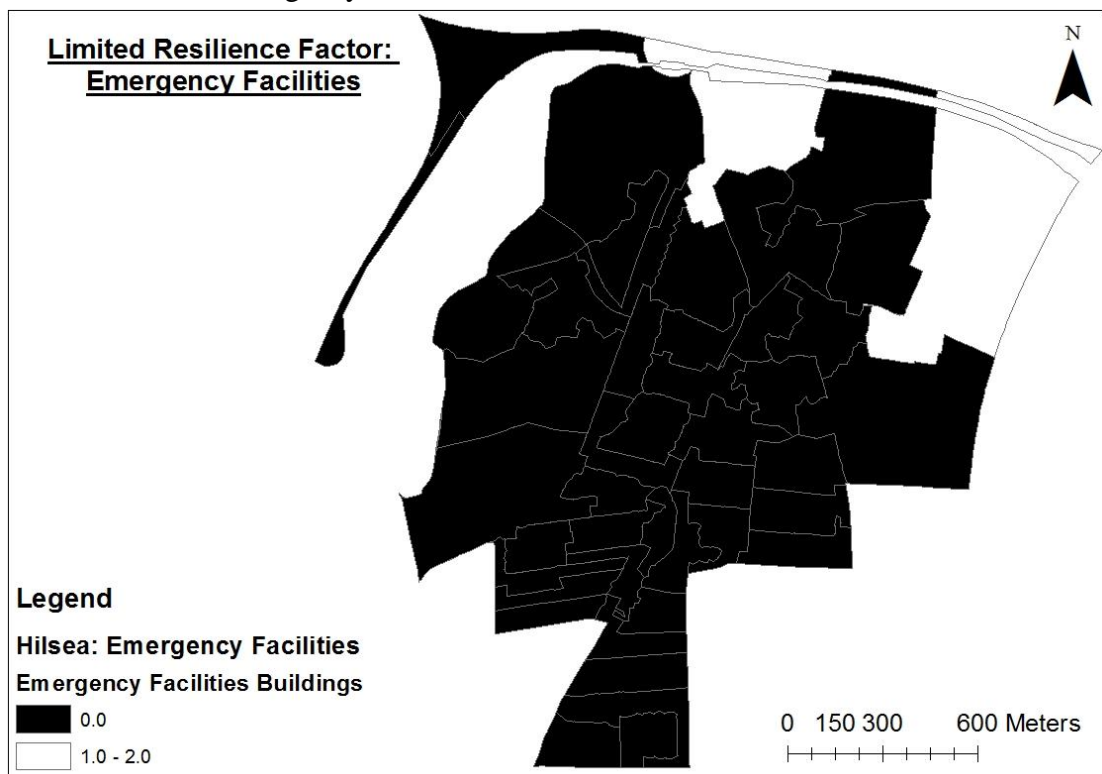
Data Variable: 2011 UK National Census 'No Cars or Vans in Household'



### Vulnerability Component: Limited Resilience

Factor: Emergency facilities

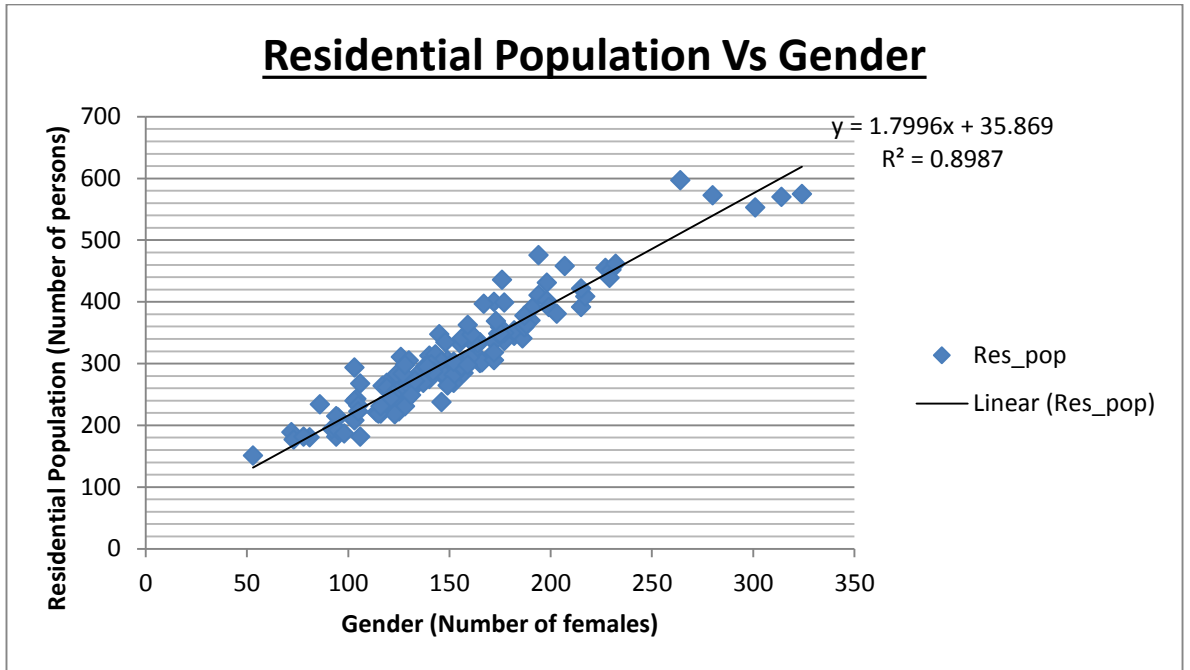
Data Variable: LU Emergency facilities



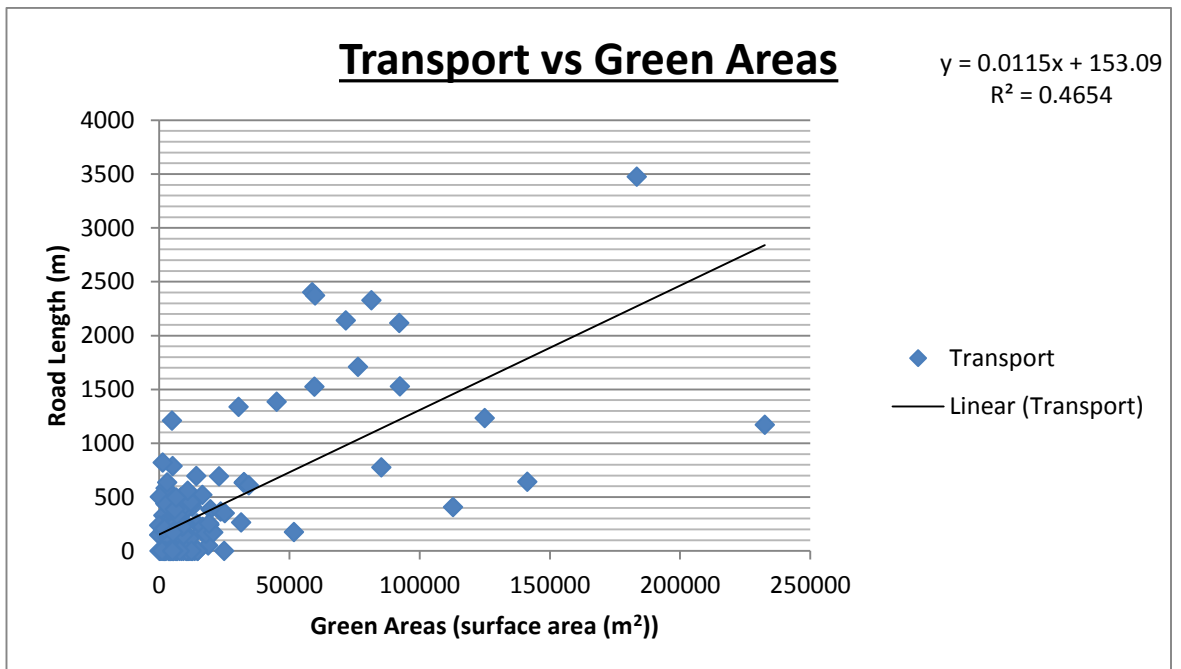
**APPENDIX K - Correlation**

**Correlation Results - Scatter plots**

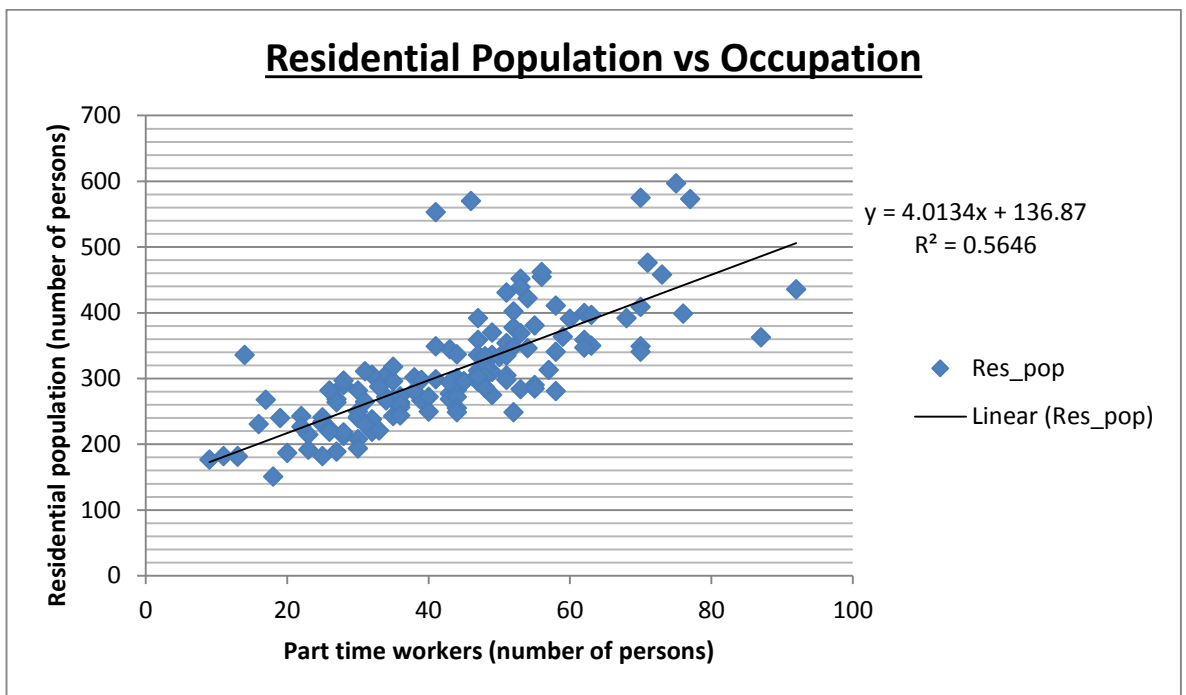
Socio-economic Vulnerability - Residential population versus gender



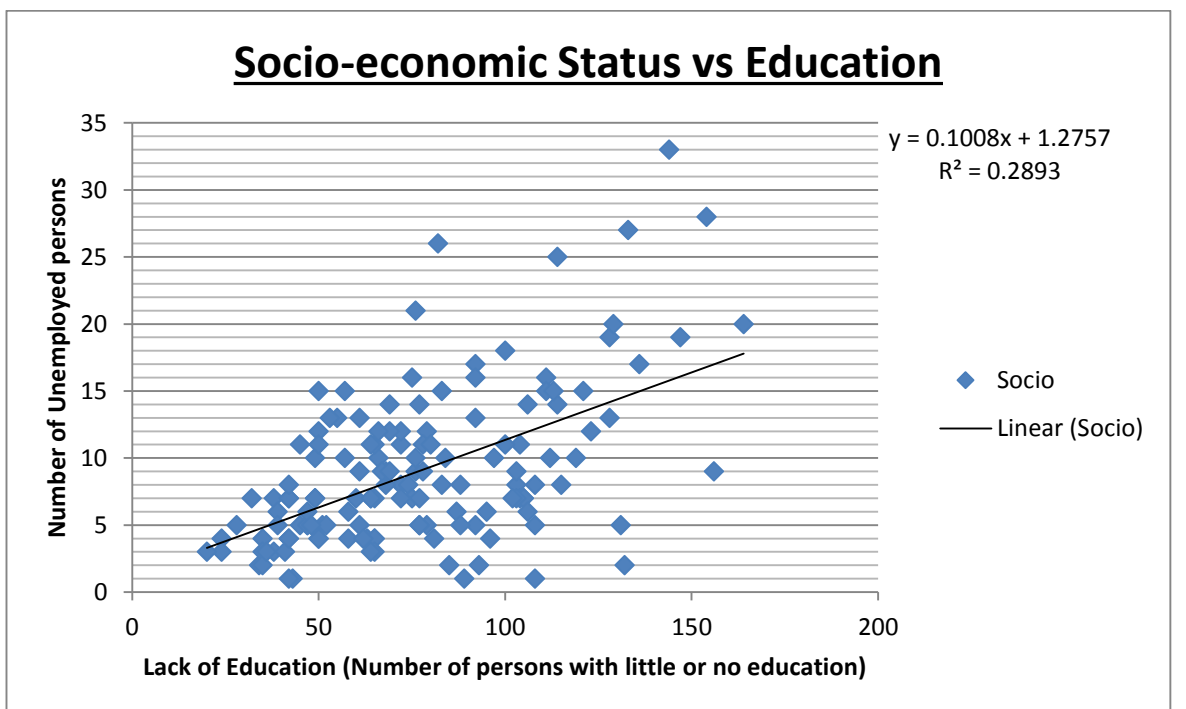
Physical Vulnerability – Transport versus green areas



Socio-economic Vulnerability – Residential population versus occupation



Limited Resilience – Socio-economic status versus education





## APPENDIX L – Coastal Flood Risk Indexes

### Coastal Flood Risk Indexes

This section briefly describes further investigation that took place regarding the flood zone data used to create the CoFHI (Section 4.5.1). The flood hazard layers that were measured for inundation coverage contain different hazard levels; low, moderate, high and very high. If these floods occurred, different levels of the hazard would be present within a neighbourhood, each with different ranges of velocities and depth of flood water. Due to this, it is possible to measure the CoFHI via four flood hazard factors; low flood hazard zone, moderate flood hazard zone, high flood hazard zone and very high flood hazard zone. Therefore, like the original CoFHI, each flood level (low, moderate, high and very high) coverage, was measured and compared to the OA's surface area, using equation H.1:

*Equation H.1*

$$V = \frac{X_i FLS}{X_i S}$$

Where  $V$  = Data Variable;  $X_i FLS$  = Factor Flood Level Surface;  $X_i S$  = Factor Total Surface Area.

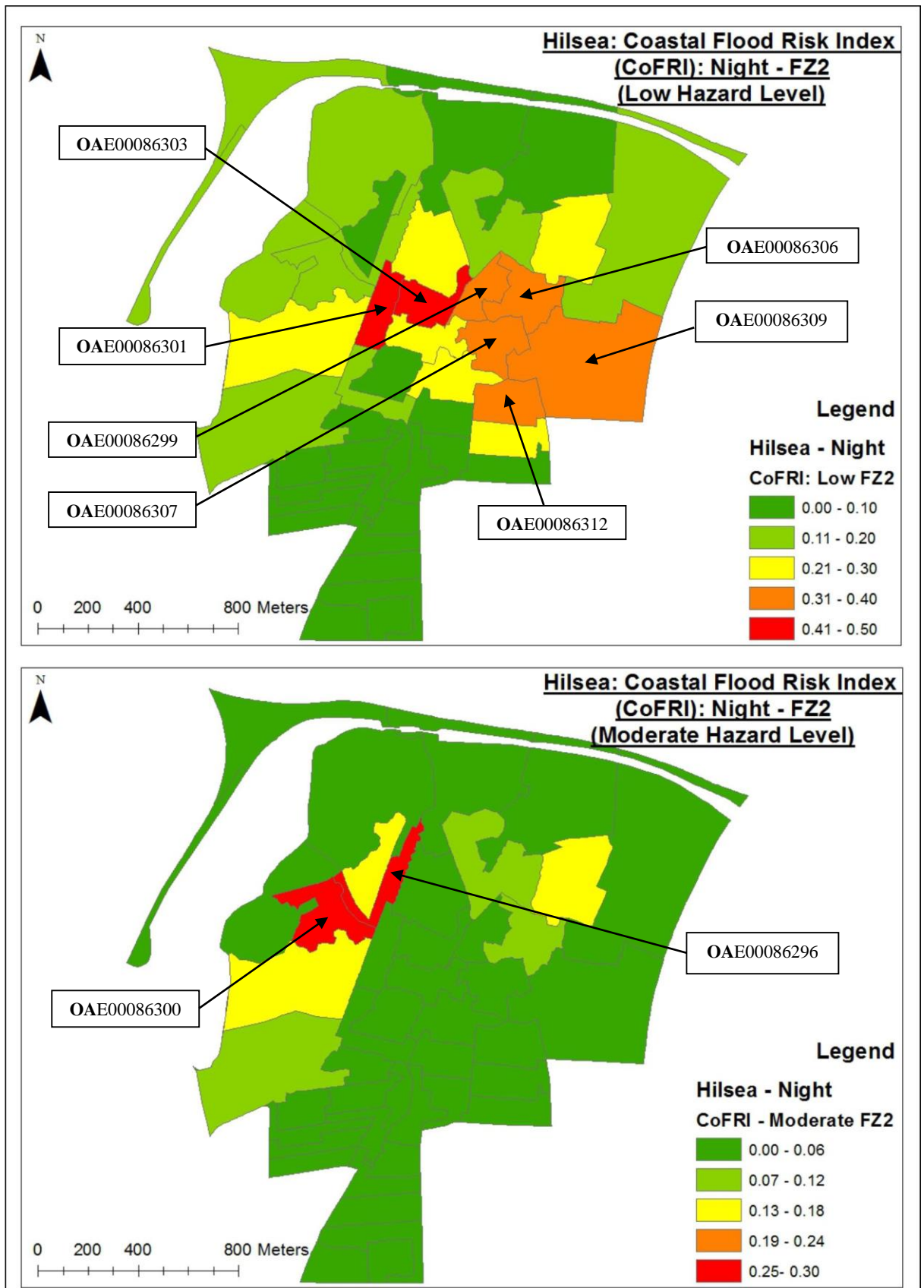
This method resulted in a standardisation of the CoFH figures ranging from 0-1; where 1 means total surface area coverage by the flood zone and 0 represents no surface area coverage by the flood zone. These new CoFHI results for each flood level for Flood Zone 2 (worst scenario), were then only combined with the night CoFVI results for the Hilsea ward (as this was only a trial) in Equation H.2. These new CoFRI results would give the opportunity to pinpoint the potential amount of areas covered by different levels of the hazard i.e. how much of the neighbourhood could be inundated by very high flood water, that would potentially flow at a much higher velocity, be of greater depth and potentially fatal; assisting identification of the most dangerous areas within that neighbourhood.

*Equation H.2*

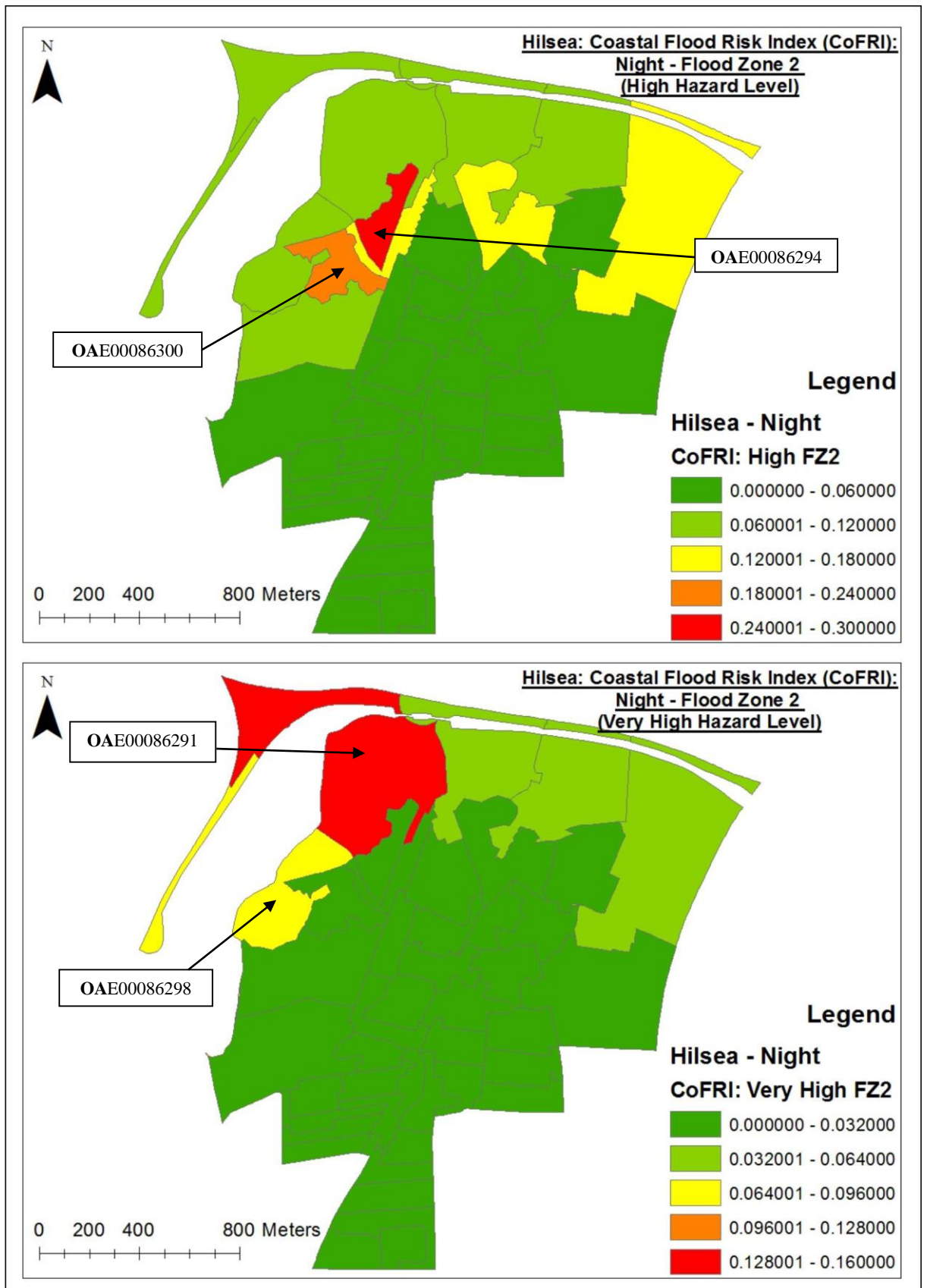
$$\text{Coastal Flood Risk (CoFRI)} = \text{CoFHI Level} * \text{CoFVI}$$

Where  $CoFRI$  – Coastal Flood Risk Index;  $CoFHI$  Level – Coastal Flood Hazard Index Level (*low/moderate/high/veryhigh*);  $CoFVI$  – Coastal Flood Vulnerability Index.

Risk levels are presented at 5 intervals between 0 and 1; 0.0-0.2 – very low risk; 0.21-0.4 – low risk; 0.41-0.6 – moderate risk; 0.61-0.8 – high risk; and 0.81-1.0 – very high risk. All CoFRI results for each flood level of Flood Zone 2 for Hilsea are presented in Figures A and B, with the most affected OAs labelled. The *low* flood level inundates the most OAs within the ward, and produces the highest risk levels. It predominantly causes the highest risk levels to five OAs in the eastern part of the ward, and two in the centre (**OA6303** & **OA6301**). Surprisingly the *high* flood level will inundate many OA's as well; more so than the *moderate* flood level. This is more of a concern as *high* level flood water has potential to have depths of between 0.25-2.5 m and velocities between 0.5-5.0 ms<sup>-1</sup> and is labelled by the EA as 'danger to most'. **OA6294** and **OA6300** have the highest CoFR levels with this flood level. *Very high* flood level presents the most risk for **OA6291**, however the level is 0.15 (very low). Although the CoFR is very low, the flood water present would have a velocity between 1.0-5.0 ms<sup>-1</sup> and depth between 0.5-2.5 m, which would be exceedingly dangerous and life threatening.



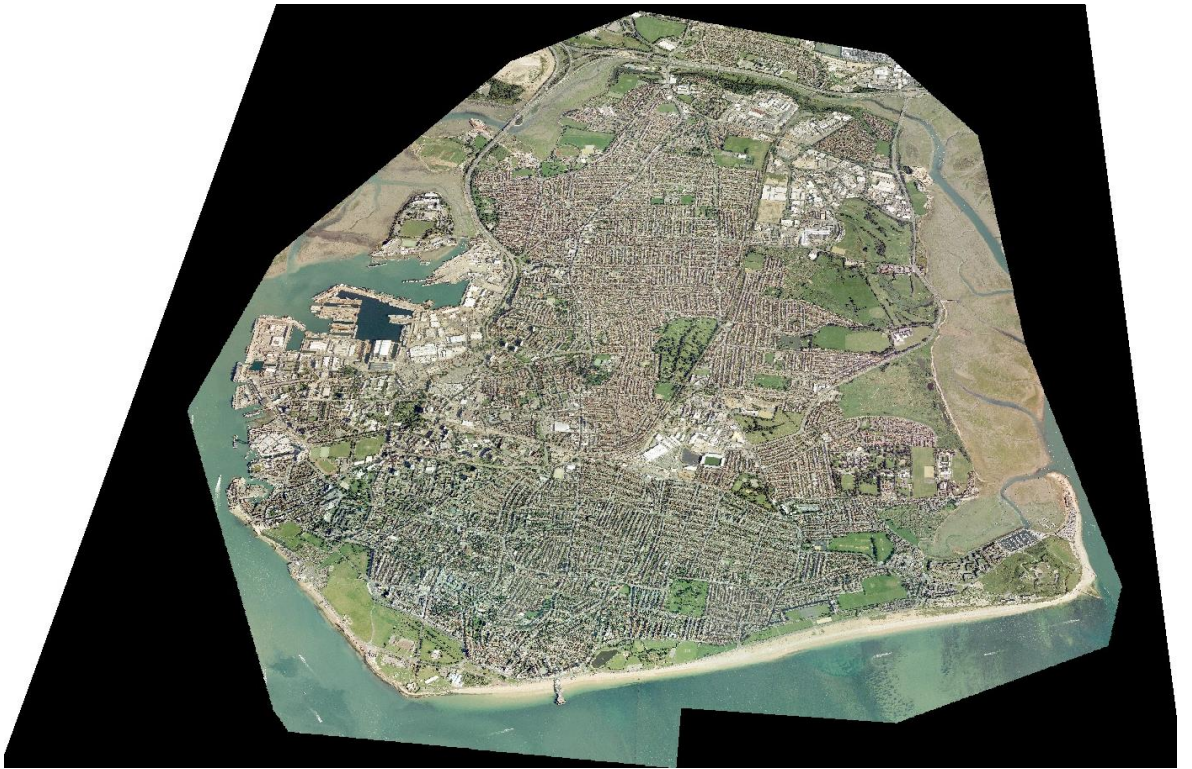
A) CoFRI for Hilsea ward at OA level – Low and Moderate Level: FZ2 Night.



**B) CoFRI for Hilsea ward at OA level – High and Very High Level: FZ2 Night.**

## APPENDIX M – Communication Data

### Merged Aerial Geotiff of Portsmouth



Coastal flood hazard map, with new land use classification of Hilsea ward in 3D.



Reclassified Building Heights Sample for OA6186

<b>FID</b>	<b>Toid</b>	<b>LandUse</b>
144	osgb1000002050946742	Vulnerable Buildings Day
147	osgb1000002050946694	Vulnerable Buildings Day
148	osgb1000002050946674	Vulnerable Buildings Day
181	osgb1000002050946675	Vulnerable Buildings Day
182	osgb1000002050946688	Vulnerable Buildings Day
175	osgb1000002050946633	Residential
177	osgb1000002050946692	Residential
174	osgb1000002050946632	Residential
176	osgb1000002050946681	Residential
178	osgb1000002050946673	Residential

**APPENDIX N - Ethics Review**

**University of Portsmouth  
Ethics Review Checklist**

**To be completed by all Staff and postgraduate students  
undertaking research**

- You are required to undertake an ethics review of your Independent Study Research Proposal. Before completing this checklist please read through the guidelines on the K:drive at: *K:\Science\Staff\Geography\Geography Ethics*
- When you have completed the checklist, submit it via Dr Carmen Solana
- *Ethical review is a University requirement for all research. This form constitutes a light touch fast-track mechanism to identify ethics risks.*

Name of Principal Investigator Sarah Percival

Research Title Solent Coastal Flood Vulnerability & Risk:  
Mapping Impacts on Communities

Please indicate Yes or No:- Yes No

[A] Is the study likely to involve human research subjects or participants?

*If 'Yes', please go to Section [B] on page 2*

*If 'No', please answer the following:-*

- a) Are there risks of damage to physical and/or ecological environmental features?
- b) Are there risks of damage to features of historical or cultural heritage?
- c) Are there risks of harm to any animal?
- d) Could the research outputs potentially be harmful to third parties?

If you have answered 'yes' to a), b), c) or d), then please provide details (in the space below) of how you plan to minimise any risks identified. You may attach additional information if necessary.

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**Now go to page 4 and sign the Declaration (Section D)**

[B] You intend to involve human research subjects. Will your data collection methods involve:-

TICK **ONE** BOX ONLY

- 1. Secondary sources (i.e. data that have already been collected and are in the public domain such as the UK Census of Population, data from web-resources such as ONS Neighbourhood Statistics or the various Government Departments' statistical pages)
- 2. Primary sources (e.g. face-to-face interviews or questionnaires, focus groups or observational methods)?
- 3. Both secondary and primary collection methods:-

If you ticked statement **number 2 or 3**, please go to **Section C** on the next page (page 3).

If you ticked **number 1** then please indicate whether there are any other potential problems relating to research ethics:-

Please indicate Yes or No :-

Yes No

- 4. Are there risks of damage to physical and/or ecological environmental features?
- 5. Are there risks of damage to features of historical or cultural heritage?
- 6. Are there risks of harm to any animal?
- 7. Could the research outputs potentially be harmful to third parties?

If you have answered 'yes' to 4), 5), 6) or 7), then please provide details (in the space below) of how you plan to minimise any risks identified. You may attach additional information if necessary.

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**Now go to page 4 and sign the Declaration (Section D)**



**[C] In terms of the primary data collection methods on human subjects, please answer the following:-**

- Please indicate Yes or No:-
- |   | Yes                      | No                       |
|---|--------------------------|--------------------------|
| 1. Will the study involve NHS patients, staff or premises?  | <input type="checkbox"/> | <input type="checkbox"/> |
| 2. Do human participants/subjects take part in studies without their knowledge/consent at the time or will deception of any form be used? | <input type="checkbox"/> | <input type="checkbox"/> |
| 3. Does the study involve vulnerable or dependent participants (e.g. children or people with learning difficulties)                       | <input type="checkbox"/> | <input type="checkbox"/> |
| 4. Are drugs, placebos or other substances (e.g. food, vitamins) to be administered to participants?                                      | <input type="checkbox"/> | <input type="checkbox"/> |
| 5. Will blood or tissue samples be obtained from participants?  | <input type="checkbox"/> | <input type="checkbox"/> |
| 6. Is pain or more than mild discomfort likely to result from the study?  | <input type="checkbox"/> | <input type="checkbox"/> |
| 7. Could the study induce psychological distress or anxiety in participants, or third parties?  | <input type="checkbox"/> | <input type="checkbox"/> |
| 8. Will the study involve prolonged or repetitive testing or participants?  | <input type="checkbox"/> | <input type="checkbox"/> |
| 9. Will financial inducements other than reasonable expenses be offered to participants?  | <input type="checkbox"/> | <input type="checkbox"/> |

***Please indicate whether there are any other general problems relating to research ethics:-***

- |   |                          |                          |
|---|--------------------------|--------------------------|
| 10. Are there risks of damage to physical and/or ecological environmental features? | <input type="checkbox"/> | <input type="checkbox"/> |
| 11. Are there risks of damage to features of historical or cultural heritage?       | <input type="checkbox"/> | <input type="checkbox"/> |
| 12. Are there risks of harm to any animal?  | <input type="checkbox"/> | <input type="checkbox"/> |
| 13. Could the research outputs potentially be harmful to third parties?             | <input type="checkbox"/> | <input type="checkbox"/> |

If you have answered 'yes' to 2, 3, 8, 9, 10, 11, 12 or 13 then you must provide additional details (in the space below) of how you plan to minimise any risks identified. Please attach any additional materials if necessary.

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**Now go to page 4 and sign the Declaration (Section D)**

**[D] Declaration**

I confirm that the information provided is a complete and accurate record of my plans at present and that I shall resubmit an amended version of this form should my research alter significantly such that there is any significant variation of ethical risk. I confirm that I have read the University Ethics Policy (2007) and Research Integrity circular 28/E7 Nov. 2001 and have read "Research Ethics Guidance, Geography Staff and Students" (available at: L:\science\Staff\Geography\Geography Ethics\Ethics Guidance)

Where necessary, I will also provide a covering letter/information leaflet and/or consent form for the participants in my research.

Signed ..... *Josh Perrod* ..... (Student)

Date ..... *8/01/13* .....

**[E] APPROVAL RECORD** (completed by Departmental Ethics Representative *after* you have submitted the checklist)

Dr Michelle Bloor (Departmental Ethics Representative) will review your submitted ethics checklist and will tick one of the boxes below. If there is a recommendation to undertake more work in terms of ethics consideration (e.g. undertaking to follow procedures to minimise risks or undertaking a more detailed ethics review) then instructions will be included with the returned form. If your proposal is not ethically viable then this will also be made clear and you will be asked to significantly amend and/or rethink your research.

Favourable opinion : INSIGNIFICANT risk

Favourable opinion : INSIGNIFICANT subject to comments listed below

Risks assessed as SIGNIFICANT referred for DETAILED Ethics Review

Not approved – reasons specified below

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Signed..... (Departmental Ethics Representative)

Date .....