

**Examining the environmental justice of
sea level rise and storm tides in New Zealand**

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Abbreviations

ASLR:	accelerated sea level rise
EA:	environment Assessment(s)
EIA:	environmental impact assessment(s)
EIS:	environmental impact statement(s)
ENSO:	El Niño Southern Oscillation
EPA:	environmental protection agency
C:	Celsius
CCC:	Christchurch City Council
CEA(s):	cumulative environmental assessment(s)
CERI:	Comparative Environmental Risk Index
DEM:	digital elevation model
GIS:	geographic information system
IPCC:	Intergovernmental Panel on Climate Change
IPO:	Interdecadal Pacific Oscillation
LiDAR:	light detection and ranging
LINZ:	Land Information New Zealand
m:	metre(s)
MB(s):	meshblock(s)
MfE:	Ministry for the Environment
NEPA:	National Environmental Protection Act
NIWA:	National Institute of Water and Atmospheric research
NZCensus06:	New Zealand Census 2006
NZDep06:	New Zealand Deprivation Index 2006
ppb:	parts per billion
PWC(s):	population weighted centroid(s)
SAT(s):	surface air temperature(s)
SLR:	sea level rise
UCCCRJ:	United Church of Christ Commission for Racial Justice
UK:	United Kingdom
US:	United States
USGAC:	United States General Accounting Office
w m ² :	watts per square metre

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Abstract

Research has established that aspects of the environment are unevenly distributed among social and socioeconomic groups. While an abundance of literature documents environmental inequalities such as toxic sites, air pollution, and access to greenspace in North America and Europe, few researchers investigate coastal flooding as a result of sea level rise and storm tides. Flooding, coastal and fluvial, are the most common natural disasters in the world; and considering sea level rise and coastal squeeze, will likely become more devastating. The impacts of coastal flooding will vary between populations and often those who are vulnerable will bear the brunt of the adverse effects. This research assesses the socio-spatial distribution of sea level rise in combination with storm tides in New Zealand, taking into account factors such as gender, age, income, ethnicity, and deprivation. Results display that the distribution of risk to coastal flooding is disproportionately higher in environmentally vulnerable places, such as coastal urban low-lying areas, and among socially vulnerable populations, such as Pacific peoples, people aged 65 and over, and people of low-income and high deprivation. Research also exhibits variations for each region in New Zealand. Discussion of the results are placed into context with the existing social, income, and health inequalities in New Zealand and the areas where inequality to coastal flooding is the highest. Furthermore, the results are discussed in relation to the policy framework in New Zealand including the New Zealand Health Strategy 2000 and the Resource Management Act 1991. The argument demonstrates that the regulatory framework in New Zealand fails to recognise environmental justice or environmental inequalities. Lastly, the limitations of research are discussed as well as recommendations for further environmental justice research in New Zealand.

1. Introduction

Environmental justice means “equal access to a clean environment and equal protection from possible environmental harm irrespective of race, income, class, or any other differentiating feature of socioeconomic status” (S.L. Cutter 1995, p. 111). The roots of environmental justice developed from the United States (US), when it was discovered that low-income and minority populations were disproportionately affected by commercial and toxic waste sites. Over the last 30 years, environmental justice research has evolved into more contemporary themes, which have examined and demonstrated that environmental inequalities such as air pollution, access to greenspace, weather, and natural disasters are experienced worse by marginalised groups of people.

In the context of this research, the environmental inequalities are sea level rise (SLR) and storm tides in New Zealand. These are particularly important issues in places such as New Zealand because it possesses certain characteristics and populations that exacerbate the adverse effects of coastal flooding. For instance, certain social, political, and economic processes, which interact with pre-existing vulnerable vulnerability, potentially influence ones’ ability to cope and recover from a disaster. A broad range of environmental justice research supports these concepts, specifically to flooding in the US (Mann 2006; Ueland & Warf 2006) and UK (Fielding & Burningham 2005; Walker et al. 2006b), which suggest that people with vulnerable attributes face a higher risk to both coastal and fluvial flooding as a result of underlying social, political, and economic processes.

1.1 The risk of coastal flooding in New Zealand

The Intergovernmental Panel on Climate Change (IPCC) suggest that SLR has steadily risen for the last 21,000 years due to natural events and cycles; however, since the origins of the Industrial Revolution around the year 1750, increased anthropogenic induced greenhouse gases has led to higher global temperatures, resulting in accelerated SLR (ASLR) (Intergovernmental Panel on Climate Change 2007). By the year 2100, sea level could be 0.18 m to 0.59 m above current levels, thus exacerbating coastal flooding and coastal inundation, especially during storm surges and high tides. In New Zealand, predictions are similar and water levels could

be ~2.45 m above current levels, when these events combine simultaneously (Todd 1999).

Globally each year, millions of people experience coastal flooding, often leading to inequalities for vulnerable populations. It is in these communities that the adverse effects will be the most prominent. By the large, the social effects of flooding are categorised as economic, non-economic, physical, and psychological. New Zealand is susceptible to the same adverse effects, especially considering its past flood history, increase in urbanisation along coastal margins (National Institute of Water & Atmospheric Research 2007), and existing social, socioeconomic, and health inequalities (Pearce & Dorling 2006).

Therefore, it would prove beneficial to investigate the environmental justice of SLR and storm tides in New Zealand and determine which areas and social and socioeconomic groups are most vulnerable. Generally, vulnerability to environmental inequalities means the potential for loss, which can vary over time and space (S.L. Cutter, Boruff & Shirley 2003). Places with additional vulnerability to coastal flooding include those with poor and incapable infrastructure (Mileti 1999), urban settings and locations, (Dow 1992), and with a lack of disaster attentiveness such as warning systems and emergency response (Blaikie et al. 1994). Social and socioeconomic attributes of vulnerability reflect those characteristics that interact with pre-existing factors such as income, health and fitness, mobility, and family support. Among the generally excepted are age, gender, ethnicity, income, socioeconomic status, and deprivation (Blaikie et al. 1994; S.L. Cutter, Boruff & Shirley 2003).

The possibility of coastal flooding in New Zealand provides an opportunity to investigate it as a potential environmental inequality in environmental justice research, and up until 2008, there has been no such inquiry. However, recent findings of environmental injustice in New Zealand unveils disproportionate exposure to air pollution (Kingham, Pearce & Zawar-Reza 2007; Pearce & Kingham 2008; Pearce, Kingham & Zawar-Reza 2006b) and hazardous sites (National Health Committee 2002). The existing risk of coastal flooding and the existing environmental inequalities in New Zealand, in combination with international findings of flooding inequalities, necessitates further inquest into examining coastal flooding as an inequality in New Zealand.

1.2 Research aims and objectives

This study investigates the environmental justice of SLR and storm tides in New Zealand using two methods of analyses and two digital elevation datasets in ArcGIS 9.2. The approach explains the spatial distribution of vulnerable populations in potentially hazardous areas. However, taking into account all aspects of cumulative risk including flooding and health is beyond the scope of this thesis. Therefore this project concentrates on certain factors of both social and environmental vulnerability, which often leads to environmental injustice, and places them into context with coastal flooding in New Zealand. Approaching this topic with a spatial investigation will contribute to a better understanding of the locations of vulnerable populations relative to low-lying coastal areas in New Zealand, a basic requirement for identifying inequalities to coastal flooding.

To meet the requirements for this thesis, one research aim is employed:

Examine the environmental justice of SLR and storm tides in New Zealand.

Furthermore, six research objectives provide an outline of research to solve the research aim:

- determine what specific populations and places are vulnerable to coastal flooding in New Zealand;
- design a coastal flooding map in GIS, which incorporates accurate predictions of SLR and storm tides;
- use a multi-method approach to measure and analyse vulnerable populations for inequalities to coastal flooding;
- verify if risk to coastal flooding and associated inequality is consistent in each of the 16 New Zealand regions;
- and test the sensitivity of the primary elevation dataset to resolve whether or not it portrays coastal flooding accurately.

1.3 Structure of the thesis

Chapter 2 deals with the background and history of environmental justice research, with critique of the theoretical components and legislative response of the topic, including vulnerability and the regulatory framework. Chapter 3 outlines the adverse social effects of flooding such as economic, non-economic and physical and

psychological health and provides evidence from past flooding research in both developed and non-developed countries. Moreover, Chapter 4 examines recent trends of SLR and provides evidence of future predictions in New Zealand with discussion of global warming and ASLR; followed lastly by the physical effects of flooding. The preceding chapters describe the background and theoretical context for the methodological approaches described in Chapter 5. Chapter 6 illustrates the results of the analyses, which are discussed in Chapter 7. The conclusion highlights key findings in the analyses and places them in context with potential future research.

2. Theoretical components and background of environmental justice

Environmental quality is an aspect of wellbeing for individuals and communities. Like any component of human welfare, it comprises positive and negative elements that are unevenly distributed amongst populations, thus raising questions of environmental justice (Low & Gleeson 1998). Often, the deprived and otherwise vulnerable populations experience environmental inequalities the worst, which draws attention to their capabilities, or lack of, to respond to disaster. It is also likely that underlying social, political, and economic processes contribute to and exacerbate environmental injustice in the first place.

This chapter provides a background of research necessary to answer the research aim and objectives by describing the theoretical components of environmental justice, the history of the topic, and resulting policy response. This includes what places and people are most vulnerable to environmental inequalities and the expansion of environmental justice into more contemporary themes, specifically SLR and flooding. In addition, a comprehensive review of environmental justice research in New Zealand provides a basis for the necessity of this project. Lastly, a review of policy response and the regulatory framework of environmental injustices in the USA and UK are placed into context with New Zealand's.

2.1 Overview of environmental justice

This section provides an overview of environmental justice, including the theoretical components and history. The core tenet of environmental justice is that marginal populations are subject to disproportionate environmental inequalities, or a

high proportion of negative environmental aspects, and enjoy little involvement in environmental decision making. Therefore, environmental justice research examines whether marginal and/or deprived people bear a disproportionate burden of environmental inequalities; and whether environmental decision making and resulting practices are equitable and fair.

According to L.W. Cole & Foster (2001) and Stephens, Willis & Walker (2007), environmental justice research is an interaction between environmental inequalities, vulnerability, and environmental policies. Environmental inequalities (burdens, hazards, or disasters) are aspects of the environment that are distributed unevenly, whether positively (access to green space), negatively (pollution and flooding), or procedurally (decision making). Levels of inequalities are unique to any given setting and population and depend upon their abilities to absorb and adapt to the impacts of unwanted situations (Stephens, Willis & Walker 2007). However, an environmental inequality is not necessarily environmental injustice for the reason that the inequality itself might not be unjust. Rather, it is the fairness of policy and distribution of inequalities amongst social groups that determines injustice (Walker et al. 2005). Therefore, consideration of the following is relevant for an environmental justice study:

- the degree of inequality that exists;
- the degree to which individuals have been able to exercise choice in their exposure to an environmental good or bad;
- whether or not an inequality has been created through decision making;
- whether or not a pattern of inequality is combined with a higher degree of vulnerability or need amongst a social group, when compared to others;
- and the degree to which those exposed to an impact or risk also have a role in, or benefit from, its creation.

(Stephens, Willis & Walker 2007, p. 9)

This research predominantly focuses on the vulnerability of people and places and how their interactions with environmental inequalities create adverse situations. Hence, environmental injustice often arises and is exacerbated when vulnerable populations disproportionately experience negative environmental inequalities (Figure 2.1) (Blaikie et al. 1994; S.L. Cutter 1996; S.L. Cutter, Boruff & Shirley 2003; S. L. Cutter, Mitchell & Scott 2000; I. Davis 2004; Mileti 1999; J.K. Mitchell 1990;

Stephens, Willis & Walker 2007; Walker et al. 2006b; Wisner et al. 2004; Wu, Yarnal & Fisher 2002).

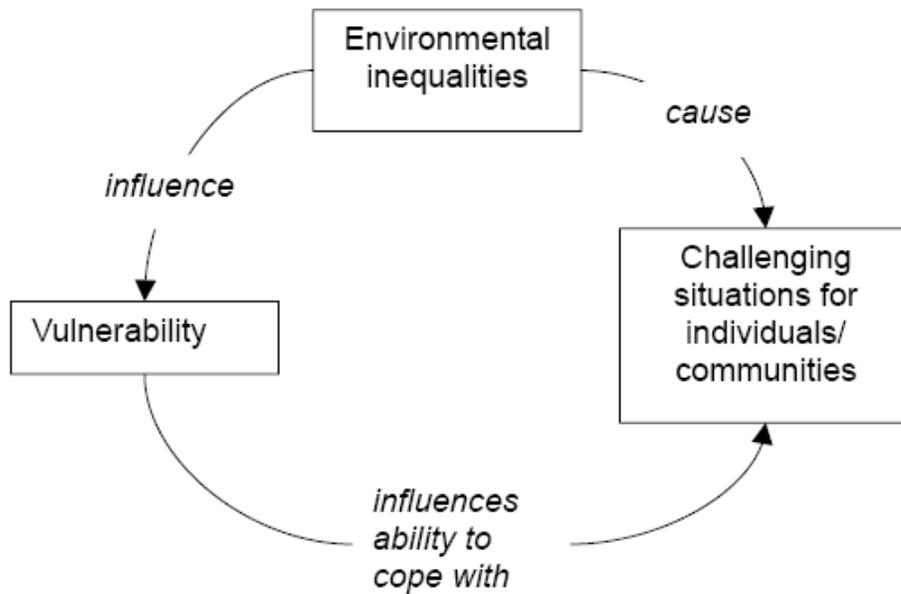


Figure 2.1: The relationship between environmental inequalities and vulnerability (Stephens, Willis & Walker 2007, p. 18).

Vulnerability is the measure of the capacity to weather, resist, or recover from the impacts of an environmental inequality in the short or long term (J.K. Mitchell 1990). There are two common forms of vulnerability in environmental justice research: environmental and social.

2.1.1 Environmental vulnerability

Environmental vulnerability is a measure of both risk and hazard potential that affects people and the places they inhabit (Wisner et al. 2004). Risk is the probability of an event occurring and hazard is the product of that risk combined with vulnerability, exposure, and the capacity of humans' to respond to the event (J.K. Mitchell 1990). However, an environmental hazard does not necessarily result in danger and only becomes a disaster when it adversely affects a population (Blaikie et al. 1994). Hence, levels of environmental vulnerability depend on several factors of place characteristics, which are a result of different landscapes, or the intersection of the cultural and political-economic processes in particular locales (Curtis & Jones 1998). For example: hazard frequency and locational impacts (S. L. Cutter, Mitchell

& Scott 2000); development, infrastructure, and urbanisation rates (Dow 1992; Mileti 1999); proximity and elevation (S.L. Cutter, Boruff & Shirley 2003); and local institutions' disaster preparedness and policy (Blaikie et al. 1994; Boruff, Emrich & Cutter 2005; S.L. Cutter 1996; S. L. Cutter, Mitchell & Scott 2000; Dow 1992; Mileti 1999; J.K. Mitchell 1990; Oliver-Smith 2004; Wisner et al. 2004). With regards to environmental justice, factors of environmental vulnerability develop from discriminatory decision making, such as development, infrastructure, disaster awareness, and policy. The other factors are relevant to biophysical vulnerability, but are spatially and temporally specific, therefore difficult to generalise. A more comprehensive list of indicators related to this project is discussed in section 3.1.1.

Development and urbanisation is a measure of the ability of the built environment to withstand the impacts of environmental inequalities and determines mortality, injuries, and financial impacts (Mileti 1999). Development relates to the value, quality, and density of built areas (S.L. Cutter, Boruff & Shirley 2003). It is a result of urban planning policies, engineered structures, and building codes, all of which define how an area reacts to a disaster. For instance, resilient areas of high value and quality are generally more resistant to damage, but are expensive to repair or replace. In contrast less resilient areas of lower quality are prone more damage, but less expensive to fix or restore (Bolin & Stanford 1991; S.L. Cutter, Boruff & Shirley 2003; S. L. Cutter, Mitchell & Scott 2000; Wisner et al. 2004).

Likewise, population density and urbanisation influence a place's vulnerability and mainly relates to the populations distribution (i.e. urban or rural). Urban areas generally contain higher population densities, which situate more people in a smaller geographical area, possibly in harm's way, thus increases the overall number of people at-risk and complicates evacuation routes (S.L. Cutter, Boruff & Shirley 2003; Mileti 1999). This is especially evident in natural disasters such as earthquakes, hurricanes, and floods. For example, the Kobe, Japan earthquake and Hurricane Andrew in Florida display the catastrophic consequences of urban areas during and after natural disasters (Mileti 1999). In addition, urban areas reduce the availability of high quality housing and force lower quality housing in more vulnerable areas; thus, forcing lower income people to reside in the lower quality, less expensive housing (Dow 1992). In contrast, urban areas reduce impacts through social networking, which provide safety nets outside the affected areas, making it easier for people to escape potential harm (S.L. Cutter, Boruff & Shirley 2003; S. L. Cutter, Mitchell &

Scott 2000). Furthermore, warning systems are more often found in urban areas because agencies, both regional and local, are more likely to allocate mitigation resources to areas that contain higher populations (Mileti 1999).

Furthermore, infrastructure determines a place's ability to endure disasters and will either mitigate or exacerbate disaster, support recovery, or place overwhelming adverse effects on deprived populations (Mileti 1999; Platt 1995). Transportation infrastructure such as roads and bridges are critical for moving people out of harm's way and people are less likely to escape if insufficient. Additionally, appropriate sewer and water systems mitigate environmental health risks and communication infrastructure, or its lack of, determines whether or not warnings spread throughout a community. Reducing the impacts of environmental inequalities requires sufficient infrastructure because complete or partial failure will often influence economic productivity, personal health, and people's everyday lives (Miller 2003).

The preceding often rely on the dexterity of local and national agencies' disaster attentiveness, which involves coordination, planning, and training with community members (Poncelet & De Ville de Goyet 1996). Normally, agencies that lack disaster attentiveness intensify environmental vulnerability, whereas highly organized agencies potentially minimise harm for populations. For example, agencies with proper hazard analysis can identify risk in a community and further create proper warning systems, evacuation plans, and emergency responses to protect their citizens from possible harm (Blaikie et al. 1994; Wisner et al. 2004).

In summary, understanding what areas are environmentally vulnerable is crucial to environmental justice because of the direct relation to policy making. Comprehensive policies often mitigate the adverse effects of environmental inequalities, whereas poor or non-existing mitigation policies and practices often amplify disasters (S. L. Cutter, Mitchell & Scott 2000). However, the environmental vulnerability of a place often interacts with the existing social conditions of the population. Hence, recognising diverse social conditions in environmentally vulnerable areas can increase societal resistance and/or resilience to environmental inequalities, resulting in environmental justice (Blaikie et al. 1994; S.L. Cutter, Boruff & Shirley 2003).

2.1.2 Social vulnerability

Social vulnerability refers to an individual's or group's economic and cultural characteristics and to their ability to cope with environmental inequalities (S.L.

Cutter, Boruff & Shirley 2003; Mileti 1999; Stephens, Willis & Walker 2007). A comprehensive definition is provided by Wisner et al. (2004, p. 11):

The characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist, and recover from the impact of natural hazards. It involves a combination of factors that determine to which someone's life, livelihood, property, and other assets are put at risk by a discrete and identifiable event in nature and society.

Attributes of social vulnerability are generally consistent for environmental inequalities; however, disagreements arise depending on the context. Normally they include characteristics such as age, gender, race/ethnicity, socioeconomic status, and deprivation (Blaikie et al. 1994; S.L. Cutter, Boruff & Shirley 2003; Mileti 1999; Wisner et al. 2004). These broad factors influence many of the fundamental causes of social vulnerability, including the following:

- lack of access to resources, including information and knowledge;
- limited access to political power and representation;
- certain beliefs and customs;
- weak buildings or weak individuals;
- and infrastructure and lifelines;

(Blaikie et al. 1994; S. L. Cutter, Mitchell & Scott 2000; Mileti 1999).

However, these attributes are relative to each location and population, and therefore specific analysis of each is provided below. A more thorough discussion of social vulnerability to coastal flooding is in section 3.1.2.

An understanding of the general indicators of social vulnerability helps reduce inequalities and gives insight into their spatial distribution. A socially vulnerable person is generally someone of low socioeconomic status, low-income, high deprivation, younger and older people, women, and minorities (S.L. Cutter, Boruff & Shirley 2003). These attributes do not necessarily mean that a person who possesses one or more of these characteristics is more vulnerable, rather they interact with pre-existing factors that increase vulnerability such as health, fitness, income, mobility, and family support.

Socioeconomic status mainly consists of income, and to a lesser extent political power, education, and prestige (S.L. Cutter, Boruff & Shirley 2003). Low-income people are more likely to absorb the adverse effects of environmental inequalities and less likely to recover due to low personal capital (Wisner et al. 2004). For instance, they often live in lower-quality housing which is more prone to damage (Mileti 1999)

and less likely to have defence measures built for mitigation purposes (Blaikie et al. 1994). The disproportionate effects on low-income populations were evident in disasters such as Hurricane Surin in Florida, because they could not meet building code standards with their houses and they were less likely to use protection measures to mitigate disaster (Mileti 1999). It also provides evidence to the potential of a disaster to exacerbate poverty as a result of costly recovery processes such as rebuilding structures and health care. In contrast, high-income people are more likely to recover from the adverse effects of environmental inequalities due to higher rates of personal insurance, social safety nets, and entitlement programmes (Blaikie et al. 1994; Wisner et al. 2004). As a result, health effects such as emotional stress, trauma and other psychological impacts are less prevalent in higher income communities and disproportionately higher in low-income communities (Mileti 1999).

Moreover, age increases vulnerability on the extreme ends of the spectrum, for both younger and older people. Children are susceptible to nutritional and other stresses during and after disasters (United Nations Children Fund 1999) because they are less mobile and less able to care for themselves, especially when parents cannot provide the necessary support (Blaikie et al. 1994; Cutler 1985; S.L. Cutter, Boruff & Shirley 2003). For example, Jabry (2002) states that globally, 77 million children under the age of 15 were severely affected by natural disasters and armed conflicts between the years 1991 and 2000. Similarly, older people are more vulnerable to natural disasters as they lack mobility and income, are more likely to have pre-existing medical conditions, and often require assistance from others (Ngo 2001; Taninda 1996). Furthermore, older people are more likely to have psychological, physiological, and physical problems following a disaster, such as the Northridge, California earthquake in 1994 (Ngo 2001).

Within a population, women are generally more vulnerable to environmental inequalities than men. For instance, in the USA, women account for a disproportionate number of deaths from natural disasters (Mileti 1999). This is partially because women are more likely to stay behind and care for children or elders and have a more difficult time recovering due to sector-specific employment, lower wages, and family care responsibilities (Blaikie et al. 1994; S.L. Cutter 1996; Morrow & Phillips 1999). Evidence from Bangladesh suggests that women have a worse experience of natural disasters mainly because of their lower socio-economic status (Cannon 2002).

Considering the effects of environmental inequalities on race/ethnicity, it is often minority groups who suffer from the most. For example, S.L. Cutter, Boruff & Shirley (2003) state that language and cultural barriers pose additional troubles to minority groups for things like post-disaster funding and other relief. Additionally, Mileti (1999) concludes that minority groups are more often of lower socioeconomic status and lower income than non-minority groups and have a selective perception of risk and lower rates of personal insurance, often resulting in a delay in response and recovery. Evidence from the Northridge, California earthquake implies that post disaster relief and affordable housing and accommodation was less available to minority communities due to language barriers and isolation (Bolin & Stanford 1998). Also, in the USA, minorities have the highest rates of mortality and morbidity as a result of natural disasters (Mileti 1999).

In summary, certain environmental and social attributes create diverse levels of vulnerability for populations. The general consensus is that more vulnerable populations are more subject to the adverse effects of environmental inequalities in comparison to non-vulnerable populations. It is typically the vulnerable populations who are of importance within environmental justice research because of the unequal distribution of effects, and being able to identify such populations will likely reduce future injustices (United States Environmental Protection Agency 1998).

2.2 Environmental justice research

This subsection provides an overview of environmental justice, including its historical development, mainly from the US, and its evolution as a research topic into a wider range of themes and other locations around the world.

2.2.1 History of environmental justice

The environmental justice research agenda emerged as a product of the US Civil Rights Movement, the Environmental Movement, and grassroots activism in the 1960s, and 1970s (Anand 2004; Bullard & Wright 1993; Cole & Foster 2001; Walker & Bulkeley 2006). The early movement of environmental justice is sometimes referred to as 'environmental racism' because it typically concentrated on the struggles of minority communities and waste sites that were unevenly distributed near their neighbourhoods, in addition to the fact that white people failed to participate in activism and opposition (Low & Gleeson 1998). This research employs the term

environmental justice because the movement has since transcended into other concerns of social identity such as income, gender, age, and socioeconomic status (S.L. Cutter 1995).

Inaugural environmental movements and activism created momentum for the Environmental Justice Movement as protestors exposed the unfair treatment of minority groups, environmental degradation, and inequalities to the public. However, the exact beginnings of the Environmental Justice Movement are unknown and referring to a single event is difficult because the movement is a compilation of multiple or even hundreds of smaller events by social activists (Cole & Foster 2001).

Protests and activism recognised and disputed the unfair treatment of minority groups and environmental inequalities, however, the Environmental Justice gained acknowledgement when people were actually harmed. For instance, in 1962, Cesar Chavez headed the Labour Movement in the US and protested against minority farm workers exposed to harmful Dichlorodiphenyltrichloroethane pesticides. Thought to be the first protest by a minority group on an environmental inequality, the US government banned certain pesticides in the workplace as a result (Cole 1992). Along with Chavez, other minority reform came from the United Farm Workers who protested for minority labour rights and against environmental toxicity in the workplace (Cole & Foster 2001). Also in 1962, Carson (1962) investigated environmental pollution and carcinogens as a product of petrochemical industries and is partially credited with starting the Environmental Movement in western society (Cole & Foster 2001). Her findings helped create the Environmental Protection Agency (EPA) and the National Environmental Protection Act in 1970, which currently regulate environmental harm in the US.

Progress in the Environmental Justice Movement came over the next three decades with the recognition of discriminatory policy making, site polluting, and toxic facilities in predominantly poor and black neighbourhoods in the US southern states (Walker & Bulkeley 2006). For instance, in 1967, an eight year old African American girl died at a garbage dump in Houston, Texas. This created outrage over the event itself and the dump's proximity to African-American Neighbourhoods. A year later, of Reverend Martin Luther King was assassinated en route to supporting predominantly black garbage workers in Memphis, Tennessee and focused attention on the workers and their poor working conditions (Moore & Head 1994). In 1982, the EPA and the State of North Carolina proposed a landfill site in Warren County, which

had a 65% African American population. The proposal was disputed by the United Church of Christ, the Congressional Black Caucus, and the Southern Christian Leadership Conference and resulted in protests and over 500 arrests (Anand 2004). These aforementioned events created opportunities for academics and social activist groups to examine injustice within the context of geography and investigate whether or not there were disparities in the sitings of toxic and commercial waste sites in the US (Boerner & Lambert 1995; Walker & Bulkeley 2006).

Foundations for empirical research and results surfaced in the 1980s and unveiled consistent correlations between minorities' proximity to commercial and toxic waste sites. For instance, Bullard (1983) examined the city of Houston, Texas for environmental injustices because of its large proportion of black citizens, and because it was the only major city in the USA without zoning. His findings suggested that Houston's solid waste sites were not randomly scattered, rather located near predominantly black neighbourhoods and schools. This was viewed as a result of a discriminatory housing market, lack of zoning, and policy making over the 50 years prior. Similar reports suggested three out of four commercial hazardous waste sites in the southern US are located in communities with higher proportions of coloured people (United States General Accounting Office 1983). Comparable results were soon discovered for the rest of the US (United Church of Christ Commission for Racial Justice 1987).

In summary, the roots of environmental justice evolved from grassroots activism and early empirical research, mainly in the southern US. Environmental justice initially focused on African Americans and other minority communities and their proximity and exposure to waste facilities. Early results displayed these populations were exposed to a disproportionate burden of environmental inequalities, mainly as a result of discriminatory policymaking and poor urban planning.

2.2.2 Contemporary themes of environmental justice research

Just as important as people's proximity to environmental inequalities is the recognition that environmental harm also causes an increase in health disparities in vulnerable communities. In seeking to address these issues, subsequent environmental justice research focuses on more contemporary themes such as air pollution, access to greenspace, and natural hazards and ties them to health inequalities in marginal communities. In addition, research includes more broad social characteristics

including income, gender, socioeconomic status, employment, and age as well as locations outside of the US.

Consequently, air pollution is as a mainstream focus of environmental justice research, mainly due to the recognition that the exposure to pollutants increases mortality and morbidity (Brunekreef & Holgate 2002). Similar to toxic and waste facilities, air pollution exposure disproportionately affects different social groups, causing a concern about health inequalities in socially vulnerable populations. For example, within the USA, Perlin et al. (1995) demonstrate an uneven distribution of emissions in minority communities and Metzger et al. (1995) concludes that Hispanics have higher rates of exposure to ambient air pollution and indoor air pollution. Outside the USA, research displays similar results, such as Jerrett et al. (2001) who state that low-income and unemployment are significant predictors of particulate air pollution in Hamilton, Canada. In Birmingham, England, Brainard et al. (2002) suggest that low-income minorities are noteworthy indicators of exposure to carbon monoxide and nitrous dioxide. Similarly, a national study in England by Mitchell and Dorling (2003) discover that nitrous oxide and nitrous dioxide exposure is higher in areas with higher percentages of children and parents. Comparable results are found throughout the world, including New Zealand, which is specifically discussed in section 2.3.

Similarly, natural resources and access to greenspace result in environmental injustices and health inequalities, mainly from discriminatory planning. Lack of greenspace potentially results in adverse health effects due to a decrease in physical activity and an increase in adverse psychological effects (de Vries et al. 2003). In addition, the authors suggest that in Holland, people of low socio-economic status have less access to greenspace. In Israel, Omer & Or (2005) conclude that higher income, Jewish communities have additional access to greenspace than lower income, Arab communities. Likewise, in Los Angeles, California Wolch et al. (2005) state that higher income, predominantly white communities have additional access to parks because minorities have been excluded from past decision making and wealthier neighbourhoods are more likely to boost funding for parks.

Most recently, environmental justice research focuses on weather related hazards such as extreme temperature exposure and extreme storms. Extreme temperature exposure is the largest weather-related cause of death in the USA, although it relates to a collection of infrastructure, technological, and biophysical adaptations; hence,

vulnerable populations are subject to adverse effects (R.E. Davis et al. 2003). For example, higher rates of temperature-related mortalities in the USA correlate with socioeconomic status, as higher income people can afford proper heating or air conditioning (Curriero et al. 2002). Evidence from Phoenix, Arizona displays that lower income and minority neighbourhoods have an increase in exposure to higher temperatures due to poor living conditions such as housing that intensifies hot temperatures, a lack of green space, and other heat absorbers such as concrete; whereas higher income, predominantly white neighbourhoods minimise heat exposure with swimming pools, air conditioning, and greenspace (Harlan et al. 2006). The Chicago heat wave in 1995 provides sufficient evidence that vulnerable people have disparities in mortality and morbidity. A social autopsy of the weather disaster reveals that communities with the highest death rates are those with high proportions of people aged >65 and African American residents because of the existing health inequalities and heat reducing mechanisms (Whitman et al. 1997), possibly because of lower incomes.

Moreover, extreme storms, mainly hurricanes, illustrate that the most vulnerable countries and populations disproportionately suffer from the adverse impacts, most notably physical damage and post-event diseases. For instance, Parks & Roberts (2006) examine Hurricane Mitch in Nicaragua and display the susceptibilities that low-income countries have on a global scale, as well as the vulnerable people within the nation. The authors suggest that weak infrastructure, deforestation, and poorly managed lands led to high rates of post-event disease from water contamination, flooding, erosion, and landslides, which were more prominent in lower income communities.

Lastly, Hurricane Katrina in New Orleans, Louisiana further supports that vulnerable populations have a higher risk to environmental inequalities. The combination of socially vulnerable populations living in communities with poor infrastructure and planning, led to environmental injustice, especially for the poor, elderly, sick, and minority communities (Allen 2007; Brodie et al. 2006; Kurtz 2007; Rydin 2006). For instance, the Lower Ninth Ward was devastated and contained 98% African-American people, 36% of which were below the poverty line (Brodie et al. 2006). These areas were unable to evacuate due to a lower rate of car ownership and a lack of social networks outside the affected areas (Brodie et al. 2006; Rydin 2006). Consequently, the affected inhabitants suffered from more pronounced health effects

and were less likely to recover due to lower rates of health and house insurance. Furthermore, flooding, as a result of the hurricane, exposed toxic sites which predominantly affected the stranded populations and the minority cleanup workers (Allen 2007). Further investigation into the underlying issues revealed that environmentally unsound development practices along with policies, which failed to account for vulnerable populations, caused more harm to people already devastated by the hurricane itself (Kurtz 2007).

2.2.3 Environmental justice and flood risk

The potential threat of climate change and the aftermath of Hurricane Katrina prompts environmental justice research to investigate populations' risk to SLR, coastal inundation, and flooding. Similar to other environmental inequalities, these are a result of natural, technological, and political drivers, and as a result, vulnerable populations have a higher risk (Fielding & Burningham 2005; Ueland & Warf 2006; Walker et al. 2006b; Walker et al. 2003). However, in comparison to other environmental inequalities few studies focus on this topic and are mainly from the US and UK. Kurtz (2007) states that focusing research on these particular inequalities will equalise citizen participation in decision making and incorporate more diverse needs into the legislative policies, ultimately resulting in environmental justice.

In the US, research primarily focuses on the Southern states because of large low-lying flood prone areas and high rates of population deprivation. For example, in Houston, Texas (Neuman 2003) and New Orleans, Louisiana (Mann 2006), lower-income and generally minority populations are more likely to reside in areas of urban development infill within natural flood zones. Further analysis shows that marginal people live here primarily as a result of urban planning policies and inexpensive property. Similarly, Ueland and Warf (2006) examine 146 cities in the USA, and determine that African Americans and low-income white people disproportionately reside in swampy, high-risk flood areas. The authors explain that low-paying labour jobs and a discriminatory housing market attract these people and prevent them from permanently leaving because their livelihoods are there.

In the UK, several studies examine the socio-spatial distribution of both fluvial and tidal flood risk. For example, in England, Walker et al. (2003) display a general relationship between higher deprivation and higher flood risk. Results show that 13.5% of higher deprivation people are at-risk to flooding in comparison with 6.1% of

lower deprivation people. However, contrasting results arise when the authors examine tidal and fluvial floods separately. For instance, tidal flooding has higher rates of high deprivation populations (18.4% vs. 2.2%), whereas fluvial flooding shows an inverse relationship with deprivation, but to a much lesser extent. Using a more recent flood risk map, Walker et al. (2006b) demonstrate that higher deprivation populations have a higher flood risk. A regional scale analysis displays the disproportionate regional distribution of risk with regions such North East, North West, East of England, South West, South East, Yorkshire, and Humberside having greater risk. While all regions display risk, the authors suggest the regional development of flood hazards over time possibly influences these inequalities.

Likewise, using two different methods of analyses from the previous UK studies, Fielding and Burningham (2005) demonstrate that those people in lower socioeconomic classes and the unemployed have the highest risk of both tidal and fluvial flooding. In addition, the effects of SLR such as coastal erosion, will likely pose a greater threat to vulnerable populations (J.A.G. Cooper & McKenna 2008). For instance, recovery, adaptation, and sea defences for erosion will be more progressive within higher income communities because they can mitigate harm with additional income and extra involvement in decision making processes.

2.3 Environmental justice research in New Zealand

This section describes previous environmental justice research in New Zealand. Few studies focus on environmental justice concerns. Although, similar to elsewhere, environmental justice literature examines more traditional topics such as marginal and vulnerable populations and environmental inequalities such as contaminated sites, water quality, and air pollution. For instance, Salmond (1999) demonstrates that areas of high deprivation contain more hazardous sites than areas of low deprivation. In addition, the National Health Committee (2002) reveal that Maori, children, and older people are subject to poor indoor air quality, whereas Maori have higher exposure to ambient air pollution. In addition, Maori and rural residents have subpar drinking, surface, and ground water.

One area of environmental justice research to receive considerable attention in New Zealand is air pollution. In Christchurch, Pearce et al. (2006b) display a correlation between areas of high deprivation, Asians, and people aged 15-34 and more exposure to particulate air pollution. Similarly, in Christchurch, Kingham et al.

(2007) demonstrate that those areas with high deprivation, low-income households, and higher percentages of Maori, Samoans, and Asians are subject to higher levels of vehicle air pollution. On a national scale, Pearce and Kingham (2008) reveal that exposure to outdoor air pollution is higher in areas of social deprivation and lower income, possibly due to a lack of social concerns within environmental policies.

The existing environmental inequalities in New Zealand are similar to other nations around the globe. However, environmental justice research does not examine SLR or flooding; although literature does separately acknowledge SLR, flooding, and relating vulnerable populations. Hence, it is possible that inequalities exist to flooding in New Zealand as shown from the US and UK. Therefore, it is easy to assume that coastal flooding poses a higher risk to vulnerable populations in New Zealand, but before investigation of such matter can take place, it is appropriate to review the existing regulatory framework to determine if this hazard is acknowledged.

2.4 Policy response for environmental justice

A central theme in environmental justice research involves policy response because of its capability to reduce environmental inequalities. For instance, ample political framework, which aims to protect vulnerable populations can significantly decrease risk or the adverse effects of a disaster. This section reviews the existing environmental justice framework in the US and UK. In addition, it comparatively evaluates New Zealand's policies with these more affluent nations, and suggests how policies can address environmental and social inequalities.

2.4.1 Regulatory framework in the US and UK

Early policies from the US, such as the Civil Rights Act of 1964, prohibits the use of federal funds to discriminate against race, colour, and national origin (Summit-II 2002). Although the act does specifically cover environmental justice, it recognises ethnicity as a vulnerable population. Environmental justice framework which significantly addresses inequalities first surfaced in the 1994, when then President Bill Clinton signed Executive Order 12898, the Memorandum of Environmental Justice, as a result of empirical evidence findings of environmental injustices in the 1980s (Bullard 1983; United Church of Christ Commission for Racial Justice 1987; United States General Accounting Office 1983). The memorandum focuses federal government attention on environmental health conditions in minority and low-income

neighbourhoods and considers environmental justice in regulatory analysis, such as environmental impact assessments (EIAs) and environmental assessments (EAs) (Clinton 1994). As a result, the US EPA incorporates more holistic ways of understanding the distribution of environmental inequalities in marginal communities (C. Wood, Barker & Jones 1997). However, this evolution proved difficult within the existing environmental framework, which was more concerned with negative impacts on the environment rather than inequalities (Stephens, Willis & Walker 2007). As a result, the US Science Policy now administers a more modern framework, which requires the consideration of human communities into components of cumulative effects assessments (CEAs) and EIAs (Table 2.1) (United States Environmental Protection Agency 1997, 1998).

Table 2.1: Incorporating principles of cumulative effects into an EIA; originally from USEPA (1997) and used in Stephens et al. (2007, p. 24).

EIA components	CEA components
Scoping	<ul style="list-style-type: none"> • Include past, present, and future actions • Include all federal, non-federal and private actions • Focus on each affected resource, ecosystem, and human community
Describe the affected environment	<ul style="list-style-type: none"> • Focus on truly meaningful effects • Focus on each affected resource, ecosystem, and human community • Use natural boundaries
Determining the environmental consequences	<ul style="list-style-type: none"> • Address additive, countervailing, and synergistic effects • Look beyond the life of the action • Address the sustainability of resources, ecosystem, and human communities

Likewise, the UK framework by the European Commission EIA Directive (85/337/EEC) and Strategic Environmental Assessments, includes justice considerations such as population, human health, public involvement, access to environmental information, access to justice, community planning, quality of life, social responsibility, and liveability (Office of the Deputy Prime Minister 2004; Scottish Executive Environment Group 2005). However, according to Cooper and Sheate (2002), EIAs in the UK from 1989-2000 were not thoroughly addressed because of narrow methodologies and cumulative effects were interpreted, which can be more understood by using comprehensive scoping within all agencies.

The USA and UK recognise the importance of incorporating vulnerable populations in the regulatory framework and creating environmental justice policies. However, other affluent countries, such as New Zealand, do not consider the basic

fundamentals of environmental justice into their regulatory framework. Doing so will likely decrease health and social disparities in vulnerable communities and create a more just society.

2.4.2 Policy response for environmental justice in New Zealand

Unlike the USA and UK, New Zealand hardly addresses environmental justice, environmental inequalities, and vulnerable populations within its policy framework, especially for SLR. This includes the Resource Management Act 1991 and the New Zealand Coastal Policy Statement 1994, which only mention the indigenous Maori people and protecting their culture and heritage, and to a small degree human communities. Rather, the concerns of these policies are sustainable management practices and mitigation techniques for SLR and coastal management, with an aim to “avoid, remedy, or mitigate actual or potential effects of loss or damage to life, property or other parts of the environment from natural hazards” (Department of Conservation 1994), but not environmental justice or social and environmental inequalities. Health and social inequalities are addressed in the New Zealand Health Strategy 2000, which aims to minimise inequalities in marginal communities. However, there is no mention of the adverse effects as a result of environmental inequalities.

Environmental injustice to coastal flooding in New Zealand is likely to arise unless legislation acknowledges environmental equity (Pearce, Kingham & Zawar-Reza 2006b). Such policies in New Zealand will likely reduce social, socioeconomic, and health inequalities and lead to a more just society (Kingham, Pearce & Zawar-Reza 2007). However, because New Zealand legislation does not include environmental justice or environmental inequalities, steps should be taken to include these considerations with the framework to match the more successful attempts made by the US and UK.

2.4.3 Interpreting environmental inequalities into policies

The development of environmental justice policies require agencies to address inequalities and identify and understand the impacts, so that they can provide strategic tools to mitigate harm, especially for vulnerable populations (Stephens, Willis & Walker 2007). For instance, Faber and Krieg (2002) believes support should originate in government agencies so they can provide resources to overburdened

communities to offset environmental risks. These resources include greater public participation in decision making, laws and regulations to protect individuals, review of current policies, and supplementary involvement from everyone in the community. Similarly, Krieg and Faber (2004) support the preceding strategies but state the process is difficult because people with greater needs are often left out. Therefore, a more cumulative approach is necessary which accounts for multiple social indicators, total environmental inequalities, health impacts, and community based participatory research (O'Fallon & Deary 2002), which is similar to EIAs' and CEAs' contents in the US and UK. Moreover, Fox et al. (2002) demonstrate that a cumulative risk assessment should include social, economic, behavioural, and psychological stresses all of which create multiple contributors of ill health and are essential to assessing environmental justice. However, these are only suggestions of how to include marginalised groups into the regulatory framework. Essentially, a step back should be taken to understand why and how environmental inequalities arise in the first place, especially in less affluent places.

2.4.4 Policy considerations for environmental justice

Outside of framework, Walker et al. (2003) state that policymakers should have an understanding of how the inequality develops in the first place, or 'causality', which can reduce the, adverse effects on vulnerable populations. As demonstrated by Brown (1995) and Bullard (1993) there are two arguments to why inequalities exist, the 'casual' and the 'drift'. The casual argument states that environmental inequalities are deliberately placed in poor and minority communities because industries and government search for low socioeconomic neighbourhoods to build waste facilities, such as those found in Bullard (1983), possibly because these communities are less likely to organise opposition (Bullard 1993). In contrast, the drift argument examines whether or not communities exist after the environmental inequality because minority and low-income people are likely to move to areas with low housing prices, hence discriminatory housing markets (Brown 1995; Lavelle & Coyle 1992). For coastal flooding, the drift argument is more probable because "it", meaning coastal flooding, cannot be placed into a neighbourhood of vulnerable people, rather the people move into known or possibly unknown flood zones, depending on whether or not the hazard is already identified. The drift argument supports the theory that underlying systematic processes contribute to the development of inequalities over time, such as

poor or non-existent urban planning, and thus make sense to consider vulnerable communities are subject to multiple environmental, residential, and other burdens upon the creation of environmental and social policies.

Liu (2001) Walker et al (Walker et al. 2003) state more comprehensive theories (location, risk, neighbourhood, and planning and land use change), that can assess SLR as an environmental inequality, to explain how environmental inequalities arise, housing locate, different people perceive risk, planning shapes land uses, and neighbourhoods evolve over time. For instance, the location theory states more affluent people move away from areas of poor environmental quality, only to be replaced by less affluent people, which is similar to the drift argument. The risk theory claims people perceive risk in different ways depending upon personal and social group characteristics; therefore respond to disasters in their own way. The neighbourhood change theory declares that neighbourhoods have a life cycle in which ageing and decline occurs naturally resulting in more low-cost housing opportunities, thus attracting people of lower socioeconomic status over time. Lastly, the planning and land use change theory suggests that planners act to protect good quality environments by directing environmental inequalities toward areas that are already degraded, hence agglomeration of inequalities in less attractive, lower income areas

Similarly, Baden and Coursey (2002) introduce several scenarios which state time dimensions into the discovery of inequalities, as well as relative timings of sittings of danger and housing (Table 2.2). Of these scenarios, 4 and 6 represent discriminatory intent, 5 is the least unjust, and for 1-3 any charge of discriminatory practice is tenuous.

Table 2.2: Scenarios for the creation of inequalities; originally from Baden and Coursey (2002) and summarised in Walker et al (2003, p. 61).

Scenario	Event 1	Event 2	Event 3	Description
1	Sitting	Danger	People	People move into an area known to be dangerous
2	Sitting	People	Danger	People move into an area which is later determined to be dangerous
3	Danger	Sitting	People	A inequality is sitting then people move into the area
4	Danger	People	Sitting	People live in an area then an inequality known to be dangerous is sited near them
5	People	Sitting	Danger	An aspect of the environment that is not known to be dangerous is placed in a region where people live and is later determined to be dangerous
6	People	Danger	Sitting	A dangerous inequality is placed in a community

To minimise effects of SLR, policies should mostly consider scenarios 1, 2, & 3 to understand why certain groups of people move into vulnerable areas; and scenarios 4, 5, & 6 for improved mitigation and disaster response purposes

In summary, reactive policies to environmental justice should consider multiple scenarios that explain why inequalities arise in the first place. This includes assessing the origins of the inequality, mainly before or after the presence of people, as well as the dangers it poses. A better understanding can create proper environmental and social policies which minimise harm to SLR, especially to vulnerable people, and can help explain policy injustice.

2.4.5 Policy response for SLR in New Zealand

Environmental and social policy response in New Zealand calls for a comprehensive understanding of the widespread environmental inequalities that currently exist in the country. The same is true for SLR policies, which can benefit from a move towards procedural and distributive justice to better incorporate marginalised groups in decision making and reduce environmental inequalities. Procedural justice involves equitable bargaining for vulnerable communities and justice for all peoples; whereas distributive justice focuses on the distribution of inequalities, which should not pose risk to anyone in the first place with proper policy response (Anand 2004; Krieg & Faber 2004). Others state the 'precautionary principle' promotes additional study to activities of concern, reducing harmful activities, and providing incentives for safe behaviour (Faber & Krieg 2002; Krieg & Faber 2004). For example, the town of Boulder, Colorado uses the precautionary principal to mitigate potential flooding, which has proved successful, as flood risk and its adverse effects are lower since the implementation of the plan. (Mileti 1999).

Conversely, it is most likely social groups will not experience the same effects, thus future policies should contain measures such as social impact assessments, which estimate the social consequences that are likely to follow from policy actions (Stallworthy 2006), and better urban planning, which focuses on people in areas of risk (Neuman 2003). These measures can likely increase resilience in areas prone to future disasters all while supporting more sustainable coasts (J.A.G. Cooper & McKenna 2008; Parks & Roberts 2006). Stallworthy (2006), notes that the UK government integrates some of these methods into policy to enlarge a more consistent risk based framework that supports a wider range of economic, environmental, and

social costs and benefits for flood management, however, results are unknown at this point in time.

2.5 Summary of background literature

The Environmental Justice Movement began nearly three decades ago in the southern US with empirical findings of environmental injustice, mainly the correlation of commercial and hazardous waste sites near minority and low-income communities. Since, environmental justice has become a mainstream research topic, which investigates more contemporary themes, and proven it can increase the quality of life of people around the world. For instance, it recognises that exposure to inequalities and unfair treatment in vulnerable communities can potentially cause adverse health effects (Bullard 1993). While adequate investigation continues in traditional areas such as hazardous sites, pollution, access to greenspace, and natural disasters, there is a call to investigate the potential risk of inequalities such as flooding and SLR, especially in the light of climate change. Attempts have only recently been carried out in the UK and to a lesser extent the US. However, flooding and SLR will likely cause more destruction in the future due to an increase in urban areas near coastal flood zones, and possibly inequalities. Therefore, proper analysis and risk assessment can identify those social groups who are particularly vulnerable to SLR and flooding.

In New Zealand, research identifies existing environmental inequalities, but not SLR. This raises concern for research in this area, especially considering that environmental and social policies in New Zealand do not account for these disparities. Identifying such and including them within the policy framework and response will likely increase the populations' resilience, particularly to those who are vulnerable.

3. The social impacts of flooding and populations' ability to cope

Contemporary environmental justice research often links environmental inequalities with implications of health inequalities and populations' risk (Low & Gleeson 1998). This is particularly evident with flooding and coastal inundation, especially after Hurricane Katrina and the current threat of SLR. Similar to other environmental justice research, SLR and its impacts are temporally and spatially

diverse. Current global predictions estimate that 10 million people experience coastal flooding each year due to storm surges and landfall typhoons, and 50 million could be at risk by 2080 because of SLR and increasing population along coastal margins (Nicholls 2004). However, compared to traditional environmental justice research, few studies have comprehensively examined SLR because of its uncertainty and long term effects. Hence, the majority of research identifies what social groups and areas are most vulnerable to SLR, coastal inundation, coastal flooding, and coastal erosion (S. L. Cutter, Mitchell & Scott 2000; Szlafsztein 2005; Titus & Richman 2001; Wisner et al. 2004; Wu, Yarnal & Fisher 2002).

This chapter reviews populations' vulnerability, specifically to flooding and SLR, and the adverse impacts these groups will likely experience if a disaster occurs. The examination provides evidence into what groups and areas will experience coastal flooding the worst, and the results will provide a basis for an environmental justice analysis. The background information presents the information needed to answer the research aim and first research objective: determine what specific populations and places are vulnerable to coastal flooding in New Zealand.

3.1 Vulnerability to SLR and flooding

As discussed in section 2.1, both environmental and social vulnerability contributes to environmental injustice and therefore an environmental justice analysis should consider such components. For SLR and coastal flooding, specific social and environmental attributes can indicate an individual's and group's resilience, resistance, and coping levels (W. N. Adger 2001; W.N. Adger, Paavola & Huq 2006; Blaikie et al. 1994; Clark et al. 1998; S. L. Cutter, Mitchell & Scott 2000; Hennessy et al. 2007; Nicholls et al. 2007; Szlafsztein 2005; Tapsell et al. 2002; Walker et al. 2006b; Wisner et al. 2004; Wu, Yarnal & Fisher 2002). This section examines environmental and social vulnerability to flooding and SLR in relation to the indicators of vulnerability mentioned in section 2.1.

3.1.1 Environmental vulnerability to SLR and flooding

With respect to environmental vulnerability, unsafe conditions may be a combination of factors involving the local economy, and the performance of public actions and institutions; and it is these factors, if inadequate, that can turn a hazard into a disaster (Wisner et al. 2004). Environmental vulnerability to SLR and flooding

is a product of policy and mitigation, such as the indicators mentioned in section 2.1.1, and most notably population density, urban development, inadequate infrastructure and warning systems, discriminatory housing, and poor neighbourhood planning (S. L. Cutter, Mitchell & Scott 2000; Enarson & Fordham 2001; Walker et al. 2006b). These attributes likely increase a person's and areas' overall risk, mainly as a result of poor urban planning and mitigation policies (Mount 1998). For instance, two flooding events in Boulder, Colorado in 1969 and Big Thompson, Colorado in 1976, display the contrasting effects a flood can have because of the environmental vulnerability of a place (Mileti 1999). In Boulder, the effects of flooding were minimal because of proper urban planning and mitigation policies and adequate warning systems, which demonstrate the capabilities that institutions have to reduce impacts. In contrast, the Big Thompson Flood, only 40 miles north of Boulder, was far more destructive and fatal because of inadequate flood planning and warning systems. However, it is difficult to directly compare these events because they are spatially diverse, although they do give an indication to the importance of reducing environmental vulnerability and agencies' abilities to do so. Furthermore, the flooding event itself will have disproportionate impacts, depending on the following variables:

- the rarity of the event;
- the presence or lack of warnings;
- speed of event;
- when the event occurs (night/holiday);
- duration of event;
- depth and temperature of water;
- and the presence of contaminants in the water

(Tapsell et al. 1999, p. 176).

However, regional and national agencies can only account for some of these variables in the regulatory framework, such as warnings and possibly contaminants. In addition, agencies should account for the socio-spatial distribution of populations in higher risk areas, such as in Boulder, Colorado (Mileti 1999).

3.1.2 Social vulnerability to SLR and flooding

Indicators of social vulnerability to SLR and flooding are similar to those in section 2.1.2 and the environmental justice research throughout the previous chapter.

In general, vulnerable populations to environmental inequalities are those with high deprivation, low socioeconomic status and/or lower income, and high proportions of younger people, older people, minorities, and females. These attributes generally correlate with a person's ability, or lack of, to cope with environmental inequalities.

Income is seen as a buffer against SLR, flooding, and its impacts and directly relates to a person's preparedness, awareness, and ability to recover, as evident in England, and therefore low-income people are more likely to experience the adverse effects (Fielding & Burningham 2005). Low-income typically means lower rates of car ownership, which decreases mobility and movement out of harm's way, and personal insurance, which decreases recovery capability because if personal possessions are lost, people will have to work more to compensate for their losses (Clark et al. 1998; Walker et al. 2006b; Wisner et al. 2004). Furthermore, less money decreases opportunity spending on prevention items to retrofit a property and often leads to poor quality housing that is prone to damage. Conversely, Green & Penning-Roswell (1989) suggest that households living at lower levels in England, such as basement or street level flats, are often lower income people, and it is these people who suffer the greatest economic losses during a flood because they are unable to relocate items to a higher floor (Clark et al. 1998). Lastly, flooding often displaces low-income people because their houses are more likely to be uninhabitable. They will have further difficulties acquiring proper temporary accommodation and/or making the home habitable again, especially those without insurance (Pelling 1999; Walker et al. 2006b).

Regarding gender, females are typically more vulnerable because they often make less money than males, such as in the USA (Blau & Kahn 1994) and China (Zhang et al. 2008), and therefore are less capable of successfully recovering (Blaikie et al. 1994; S. L. Cutter, Mitchell & Scott 2000; Enarson & Fordham 2001; Tapsell et al. 2002; Tapsell et al. 1999; Walker et al. 2006b; Wisner et al. 2004; Wu, Yarnal & Fisher 2002). For instance, women have more difficulty obtaining relief and rebuilding their home, yet have to deal with unsympathetic male dominated authorities (Enarson & Fordham 2001). This is evident from post flooding research in the UK, which suggests that insurance companies tend to take advantage of single women and single mothers (Tapsell et al. 2002). Furthermore, these women often lack adequate income for proper childcare, thus intensifying their financial problems, and have extra involvement in recovery processes because they have supplementary

burdens of caretaking for those less mobile, such as children and elderly. Additional post flooding research suggests that females have higher rates of mortalities in Nepal (Pradhan et al. 2007) and from the 2004 tsunami in Asia (Llewellyn 2006). Similarly, post flooding research in Bristol, England in 1968 suggests that women suffer from increased psychiatric effects, however, no reasons are given (Bennet 1970). Lastly, considering climate change and meteorological impacts in Bangladesh, Cannon (2002) states women will be unequally affected due to lower income and exclusion from policy considerations.

Members of minority groups may be exposed to more harsh conditions, mainly due to less income capability, lack of personal insurance, and difficulties in understanding warning systems (Tapsell et al. 1999; Walker et al. 2006b; Wu, Yarnal & Fisher 2002); in addition to confinement to hazardous areas, insufficient housing, and post disaster discrimination when obtaining relief (Clark et al. 1998; S. L. Cutter, Mitchell & Scott 2000). A post flooding study in England demonstrates that Asian communities are more likely to suffer adverse effects because of language and economic difficulties and a lack of knowledge to cope and adapt to the disaster (Tapsell et al. 1999). Also, social exclusion of minority communities can delay warnings to hazardous areas where they reside, such as in Alice Springs, Australia when the broadcasts of flood warnings were not on radio channels that were customarily used by the Aborigines (Keen, Ross & Handmer 1988). In relation, immigrant's have similar exposure to flooding events in comparison to minorities, mainly due to lower incomes, language barriers, and lack of social networks outside of the affected areas (Clark et al. 1998). However, some minority and immigrant groups may have stronger community and social ties with one another, therefore hazard warnings are more likely to be dispersed throughout a community (Walker et al. 2006b).

A person's age influences vulnerability on each end of the spectrum, both young and old. Although age is not an automatic indicator of vulnerability, it typifies those characteristics that determine a person's resilience and resistance to flooding events such as pre-existing health and fitness, mobility, income, and family support (Walker et al. 2006b). Younger people are susceptible to flooding and the health impacts due to physical weakness and differential access to resources (S. L. Cutter, Mitchell & Scott 2000; Wu, Yarnal & Fisher 2002). For instance, authorities often ignore young people (<18), hence, the recovery needs of young people are overlooked and therefore

require additional care from someone who is older, which may increase vulnerability to both them and the caretaker (Clark et al. 1998; Tapsell et al. 2002; Tapsell et al. 1999). This causes a delay in evacuation and other difficulties in the recovery process. Likewise, older people (>60) are sometimes unable to avoid flood events or respond on their own, especially the disabled and/or those who lack mobility and income (Clark et al. 1998; S. L. Cutter, Mitchell & Scott 2000; Walker & Bulkeley 2006; Wu, Yarnal & Fisher 2002). For example, in the USA, people aged over 60 have the highest death rates during disasters, in comparison with all other age groups (Ngo 2001). In England, Tapsell et al. (1999) demonstrate that residents in bungalows, ground floor flats, and mobile homes are more likely to be older people, thus increasing their vulnerability because their homes are more prone to damage. Moreover, two post-flooding studies in England demonstrate that both younger and older people are more likely to suffer from the adverse effects because of these reasons (Bennet 1970; Tapsell et al. 2002). Nevertheless, vulnerability of older and younger people may decrease if they are mobile, have access to a higher income, and social support from family and/or community members.

3.2 Adverse social impacts of SLR and flooding

Effects of SLR and coastal flooding relate to economic and non-economic losses, as well as physical and psychological health. According to Wisner et al. (2004) global flooding, both tidal and fluvial, affects more people and causes higher economic losses than any other natural disaster. This is likely to increase, especially considering the worldwide coastal population is expected to grow from the current 1.8 billion to 5.2 billion people by the 2080 (Intergovernmental Panel on Climate Change 2007) and increasing urbanisation in low-lying areas (Nicholls et al. 2007). In addition, the frequency and intensity of coastal inundation and coastal flooding will increase in many regions of the world as a result (Intergovernmental Panel on Climate Change 2007) This includes more affluent countries, which account for tens of billions of dollars in damage since 1990, and less affluent countries such as Bangladesh and China, which more often result in mortalities and sickness. For example, since 1970, cyclones in Bangladesh have killed nearly 450,000 people (Wisner et al. 2004); and in 1887 the Huanghe River flood in China caused 2 million mortalities (Smith 2000). Flooding events in more affluent countries cause more economic losses such as

Hurricane Katrina, which resulted in ~2000 deaths (Brodie et al. 2006) and recover costs of nearly \$125 billion (Pezzoli et al. 2007).

Economic losses relate to the extent of damage to property, housing quality, and mitigation techniques (Walker et al. 2006b). The amount of loss depends on whether or not a person or family has personal insurance to cover their losses, which is more likely in more affluent communities. Other economic necessities include the cost of temporary or permanent relocation and other expenditures such as living in temporary accommodation, eating meals out, and prescriptions for the sick (Green & Penning-Rowell 1989). Non-economic losses mostly relate to sentimental items that were lost during the flood, which more affect older people (Tapsell et al. 2002).

Impacts on physical health are mainly the result drowning and higher water levels. Since 1900, 6.8 million people have died from drowning and post event related illness (Few et al. 2004). For example, a flooding event in Puerto Rico in 1985 shows that 22% of all deaths were from drowning (Dietz et al. 1990). More so, Jonkman and Kelman (2005) examine 13 floods in Europe and the US and determine that two-thirds off all mortalities were from drowning. Other mortalities, injuries, and infections come after the flood event as people try to escape or return to potentially dangerous environments. For example, Bennet (1970) states post flooding hospital admissions and deaths rates significantly increased for the 12 months after the 1968 Bristol, England floods in comparison to the 12 months prior. Injuries, apparent from the Midwest, US floods in 1993 were mostly strains/sprains, lacerations, abrasions, and contusions, and illnesses such as gastrointestinal, rashes, dermatitis, and heart related (Centers for Disease Control 1993). Similarly, in England, Tapsell et al. (2002) state that likely post flooding effects are diarrhoea, upset stomachs, infections, coughs, laryngitis, pleurisy, and high blood pressure, mostly from living in damp conditions.

Diseases habitually occur as a result of stagnant water and lack of access to clean and sanitised water, and include fecal-oral, vector-borne, and rodent-borne (Ahern et al. 2005). Multiple studies demonstrate post flooding outbreaks of fecal-oral diseases, such as cholera, in non-developed countries such as West Bengal, India (Sur et al. 2000), cryptosporidiosis in Indonesia (Katsumata, Hosea & Wasito 1998), diarrheal in Khartoum, Sudan (Centers for Disease Control 1989), and typhoid in Jakarta, Indonesia (Vollaard et al. 2004). In developed countries, these diseases are less common, but still prevalent, such as diarrheal in Missouri, US (Centers for Disease

Control 1993), gastroenteritis in Lewes, England (Reacher et al. 2004), and poliomyelitis in South Africa (van Middlekoop, van Wyk & Kustner 1982).

The occurrence of vector-borne diseases usually decrease as floods wash away breeding sties, or increase with stagnant water increasing the overall area for breeding and transmission (Ahern et al. 2005; Confalonieri et al. 2007; Few et al. 2004; Intergovernmental Panel on Climate Change 2007; McMichael & Kovats 2000; Wisner et al. 2004). Diseases such as dengue fever, malaria, West Nile virus, lymphatic, filariasis, and arborvirus are a potential threat, especially to non-developed countries; however, higher rates are in developed countries, such as the US (Centers for Disease Control 1993). Comparably, rodent-borne diseases, such as leptospirosis and Hantavirus Pulmonary Syndrome, amplify due to an increase in rodent contact, such as in Missouri, US in 1993 (Centers for Disease Control 2000) and Chonbuk, Korea in 1987 (Park, Lee & Rhee 1989).

Psychological effects commonly occur in the long term and relate to the process of evacuation and recovery, making repairs, cleaning up, dealing with builders, and insurance claims (Ohl & Tapsell 2000). The effects include panic attacks, agoraphobia, depression, tiredness, stresses, posttraumatic stress disorder, and anxiety (Ahern et al. 2005; Few et al. 2004; Tapsell et al. 1999). For instance, Bennet (1970) shows a significant increase in the number of new psychiatric symptoms (anxiety, depression, irritability, and sleeplessness) in women following the 1968 Bristol, England floods. Similarly, Abrahams et al. (1976) demonstrate that for the 12 months following the 1974 Brisbane, Australia floods, irritability, nervous tension, depression, and prescriptions of sleeping tablets and psychotropic drugs all rose, mainly in women. Similarly, Ollendick and Hoffmann (1982) found a large increase for post flood depression in Rochester, New York for both men and women. Lastly, an increase in post traumatic stress disorder is probable, such as the 1993 floods in Missouri, US (McMillen, North & Mosley 2002).

3.3 Adverse social impacts of SLR and flooding in New Zealand

In New Zealand, the physical health threats relate to drowning, diseases, and injury from poor infrastructure, vector-borne diseases, and poor water quality in flood areas (Hennessy et al. 2007; Woodward, Hales & N. 2001). In relation, the National Health Committee (2002) state that New Zealand has a high rate of water borne diseases such as Salmonella, Campylobacter, E. Coli, Giardia, and Cryptosporidium in comparison

to other developed countries. Although, New Zealand will not experience as adverse health effects as developing countries due to more adequate infrastructure, higher topography, and preparedness, but will likely experience high damage related costs. For instance, from 1900 to 2008, 29 significant flood event have occurred in New Zealand, affecting 21,137 people and causing 27 deaths (International Emergency Disasters Database 2008). Moreover, from 1976 to 2004, flooding has caused nearly \$400 million in damage (Walton et al. 2004). In addition, Tait et al. (2002) state that dealing with flood effects will result in increased psychological effects from family stress, loss of income and accommodation, domestic tension, lost time in cleanup, and lost working days.

3.4 Summary of flood vulnerability

Environmental and social vulnerability to SLR and flooding are similar to other environmental inequalities, which provides additional evidence that an environmental justice analysis needs to account for these populations because of the adverse impacts and health effects that associate with flooding. Furthermore, the adverse effects are similar in New Zealand, especially in comparison to other affluent countries. However, identifying areas and people that are vulnerable to SLR and flooding is only a preliminary step in an environmental justice analysis. Chapter 4 provides a more comprehensive risk assessment, including risk of SLR and coastal flooding.

4. The risk of SLR and storm tides in New Zealand

This chapter examines historical SLR and explains its acceleration since the Industrial Revolution. In addition, other sections explain the specific risk of SLR and its effects in New Zealand. Past climate change and fluctuations in sea level are a result of numerous natural interacting systems of the Earth and Sun. Since the origins of the Industrial Revolution around the year 1750, humans have contributed increased levels of greenhouse gases, mainly carbon dioxide, methane, water vapour, and nitrous oxide, into the atmosphere. This causes alterations in its chemical composition, ultimately contributing to climate change because of the gases' abilities to trap radiation into the atmosphere (the greenhouse effect), resulting in an overall warming of the Earth's surface (global warming) and SLR (Intergovernmental Panel

on Climate Change 2007). Using several computer models and greenhouse gas emission scenarios, the Intergovernmental Panel on Climate Change (IPCC) (2007) predicts continuing global warming and SLR up to and beyond the year 2100. However, the effects of SLR are site specific due to the homogenous reactions of each coastal region and oceanic basin; therefore, accurate predictions should address multiple local considerations.

4.1 Climate change processes

This section reviews the variables capable of changing the Earth's climate. Climate is the mean and variability of temperature, precipitation, and wind ranging from months to millions of years (Le Treut et al. 2007). The Earth's climate is a complicated system driven by solar radiation and the atmosphere, including natural processes such as changes in the Earth's and Sun's orbit, volcanic eruptions, surface albedo, vegetation cover, and cloud cover, as well as human induced changes in atmospheric composition. These influence the amount of solar and longwave radiation that the Earth receives and reflects back into space (Figure 4.1) (Le Treut et al. 2007).

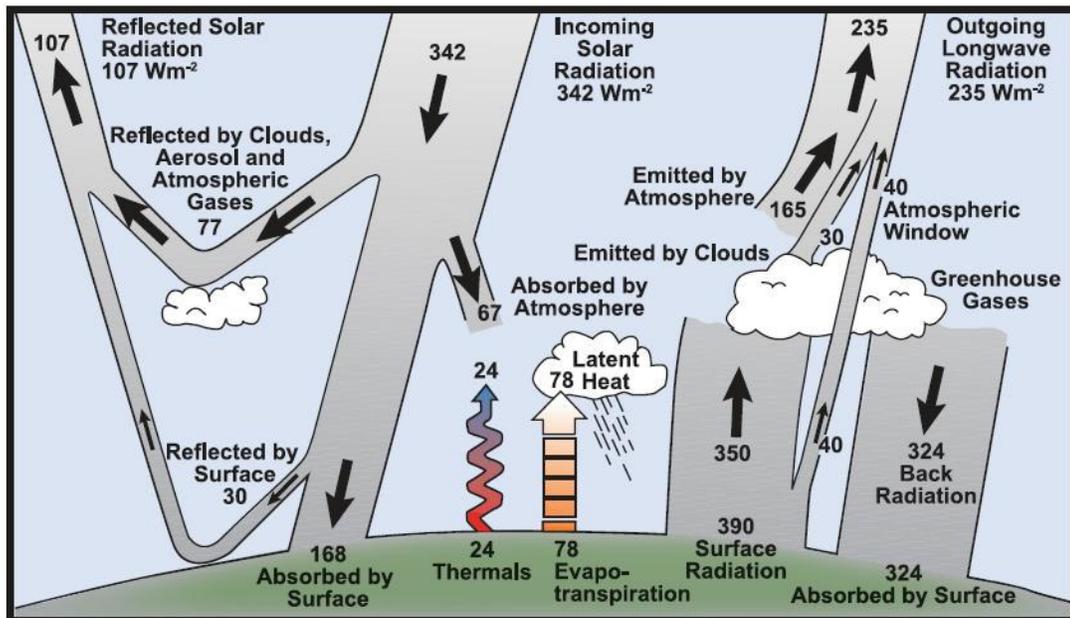


Figure 4.1: The amount of radiation emitted and received by different sources on the Earth's surface and in the atmosphere (Le Treut et al. 2007, p. 96).

The presence of greenhouse gases, primarily carbon dioxide, nitrous oxide, water vapour, and methane, reflects radiation, thus, traps heat to warm the atmosphere, also known as the greenhouse effect. Changes in the abundance of greenhouse gases alter

the energy balance of the climate system, or radiative forcing, which compares how a range of human and natural factors drive warming or cooling influences on global climate and measures in watts per square metre (w m^{-2}) (Intergovernmental Panel on Climate Change 2007). Positive radiative forcing results in warming of the Earth's surface ($+\text{w m}^{-2}$), while negative radiative forcing is a cooling effect ($-\text{w m}^{-2}$).

4.2 Anthropogenic induced climate change and SLR

This section evaluates the changes in the Earth's climate and sea level as a result of anthropogenic induced greenhouse gases into the atmosphere. Since the Industrial Revolution, global radiative forcing is $+1.6 \text{ w m}^{-2}$, mainly from a higher concentration of greenhouse gases in the atmosphere caused by burning fossil fuels (increases carbon dioxide), agriculture production (increases nitrous oxide and methane), and deforestation (decreases absorption of atmospheric carbon dioxide) (Figure 4.2) (Intergovernmental Panel on Climate Change 2007). The positive radiative forcing causes an overall warming of the Earth's climate and increases air and ocean temperatures, melting snow and ice, and rising average global sea level. From 1901 to 2000, global average temperatures increased 0.74°C , with temperature over the last 50 years rising an average of 0.13°C per decade (Figure 4.3).

Absolute sea level change is a result of global warming because higher surface air temperatures (SATs) increase the volume of water in the global ocean through thermal expansion (as water heats up it expands) and/or exchange of water between oceans and other reservoirs such as glaciers, ice caps, ice sheets, and other land-water reservoirs (Bindoff et al. 2007). Historic estimates show that global absolute sea level has risen nearly 120 m since the Holocene climate adjustment and last ice age nearly 21,000 years ago, as a result of natural climate processes and fluctuations. However, official measurements from tide gauges starting around the mid 19th century show faster rates of SLR, especially from 1961-2003 and 1993-2003 when global averages of SLR were 1.7 mm/yr. and 3 mm/yr. respectively (Figure 4.3) (Bindoff et al. 2007). The increased rate, or accelerated sea level rise (ASLR), is caused by an increase in greenhouse gases in to the atmosphere, is mainly human induced, and adds to the existing rate of absolute SLR, which has occurred since the Holocene adjustment. Furthermore, predictions of ASLR for the 21st century are similar to those since 1961, but depend upon several variables, mainly the mitigation of anthropogenic induced greenhouse gas emissions into the atmosphere.

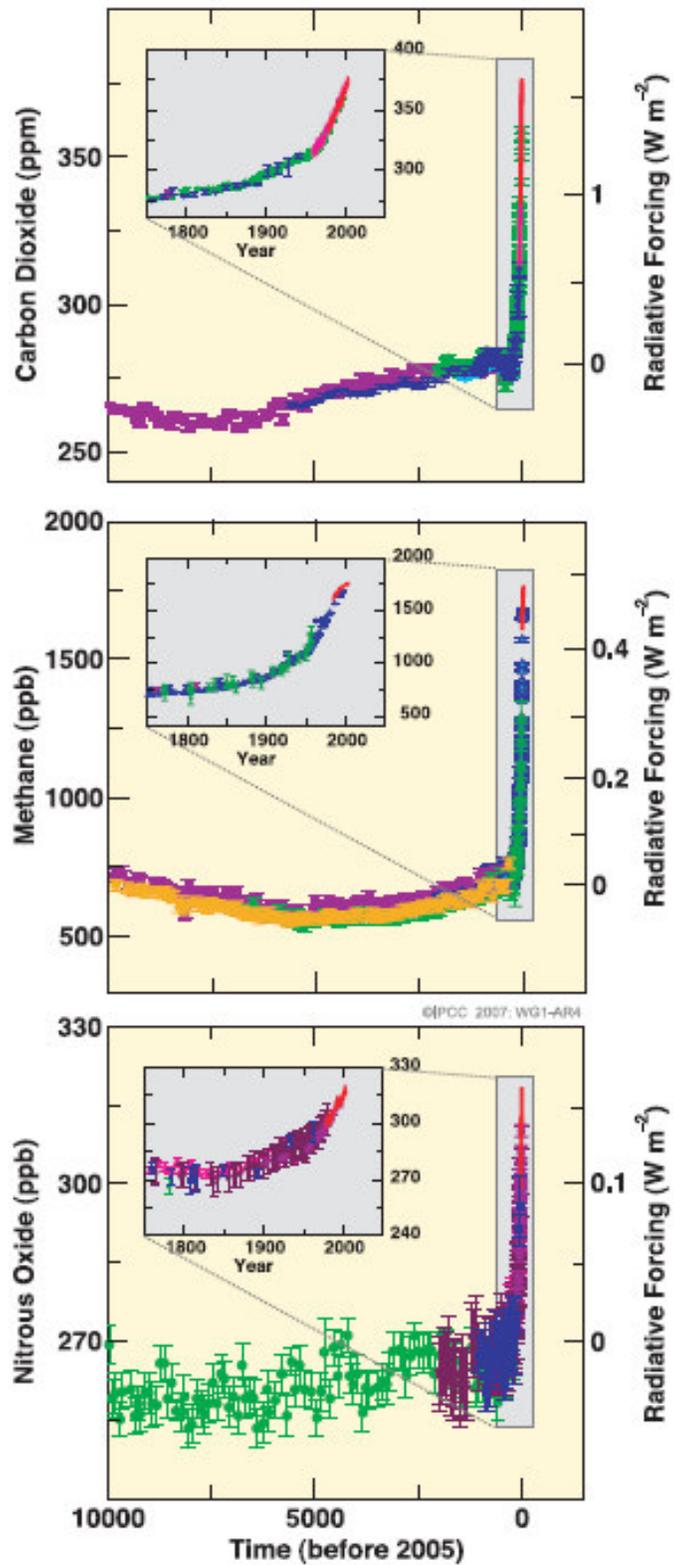


Figure 4.2: Atmospheric concentrations of carbon dioxide, methane, and nitrous oxide over the last 10,000 years (large panels) and since 1750 (small panels), and radiative forcing (Intergovernmental Panel on Climate Change 2007, p. 3).

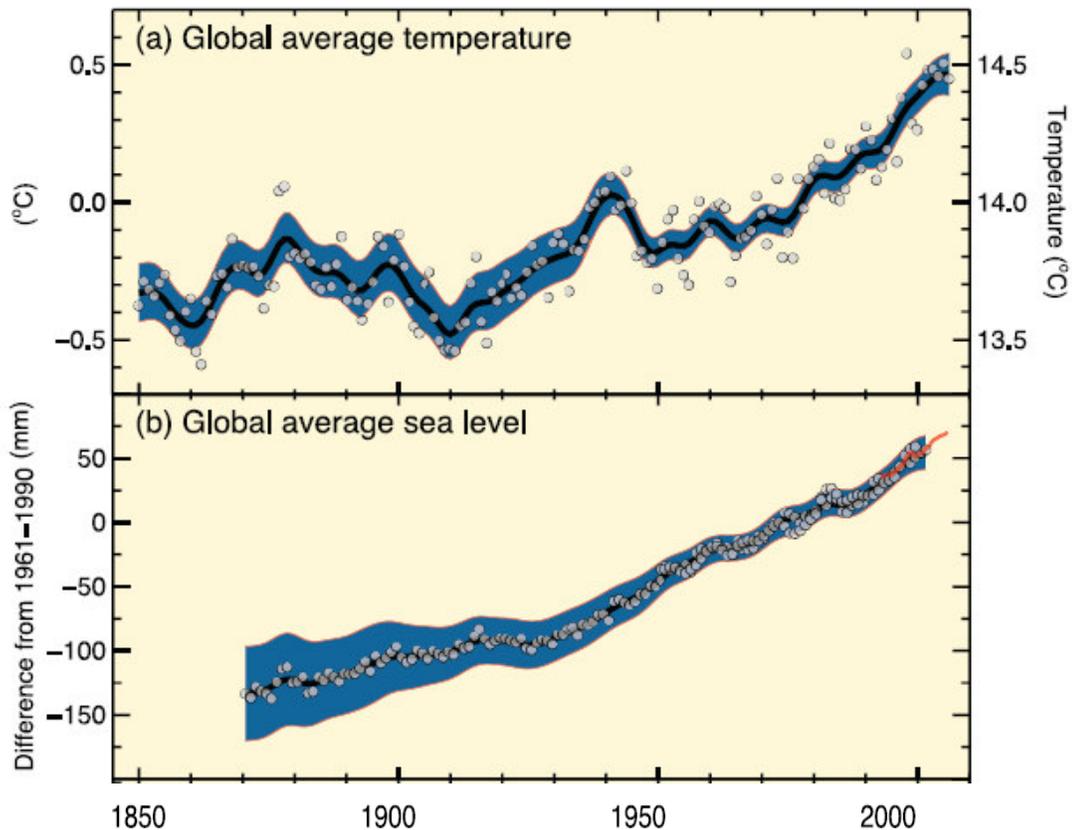


Figure 4.3: Observed changes in (a) global average surface temperature and (b) global average sea level from tide gauges since 1870 (blue) and satellite data since 1993 (red) (Intergovernmental Panel on Climate Change 2007, p. 6).

4.3 Predictions of climate change and SLR

The IPCC uses several modelling scenarios to predict SAT and SLR as a result of greenhouse gas emissions, population, and economic development. The most likely scenarios for anthropogenic greenhouse emissions are non-mitigating, which predict that the amount of greenhouse gas emissions will either stabilise towards the end of the 21st century or continue to increase. These predictions all state that global SAT and ASLR will increase by the year 2100, and all scenarios should be equally considered (Intergovernmental Panel on Climate Change 2007).

During the 21st century, SAT will rise, mainly as a result of higher greenhouse gas concentrations, which increases radiative forcing (Meehl et al. 2007). Predictions of global SAT by 2099, relative to average temperatures recorded from 1990-1999, range from +1.1°C to +6.4°C, with the most likely scenario of +1.8°C to +4.0°C. As a response to higher SATs, global absolute sea level will rise 0.18 m to 0.59 m by 2100 (Figure 4.4), due to a decrease in land glaciers and ice caps, and increase in thermal

expansion, which alone constitutes 70-75% of SLR (Meehl et al. 2007). However, SLR will have vast regional manifestations caused by geologic processes such as subsidence, sedimentation, and vertical land movements such as glacial isostatic adjustment and tectonics, all of which alter the shape and hence volume of ocean basins containing the water (R.G. Bell, Hume & Hicks 2001b; Bindoff et al. 2007; Bird 2000; Ministry for the Environment 2004). In addition, regional differences in SATs will cause variations in thermal expansion rates, and hence, different rates of SLR. These factors can either amplify or reduce sea level, even considering absolute SLR. The term used to describe this is relative SLR, which is a combination of absolute SLR and the regional variations of sea level change that associate with the aforementioned geologic and thermal factors. Therefore, an analysis of relative SLR for a given place should include both the regional manifestations of SLR as well as the absolute SLR predictions.

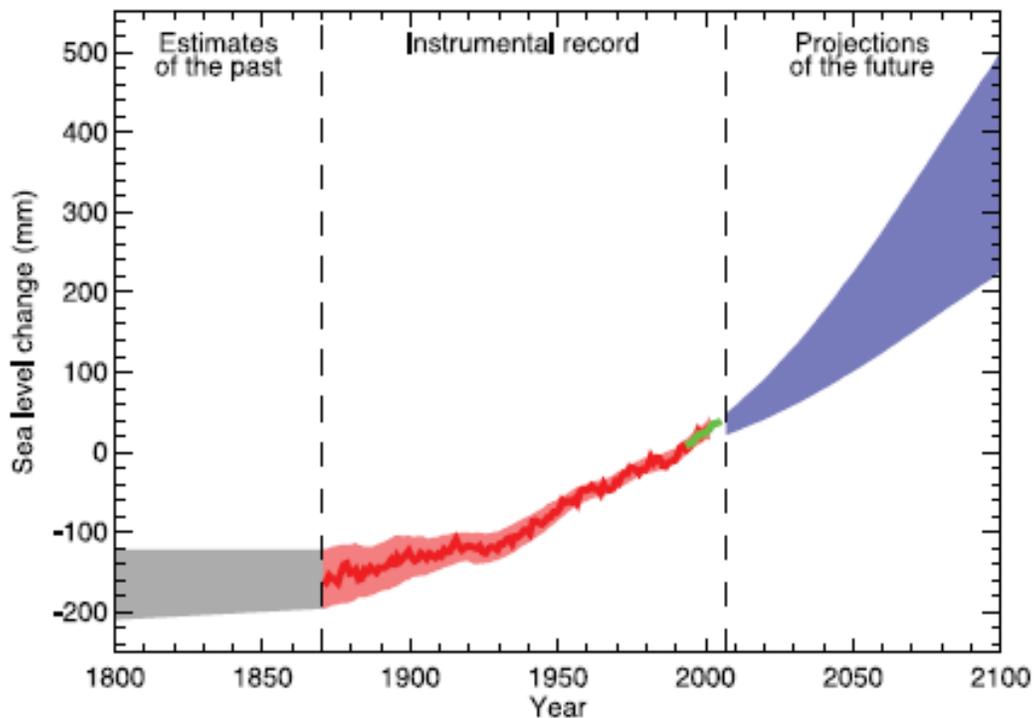


Figure 4.4: Time series of global mean sea level (relative to 1980-1999 mean) in past estimates and projections for the future using a most likely scenario. Grey lines show historical sea level change. Red lines are sea level change from tide gauges worldwide. Green lines show global mean sea level observed from satellite altimetry. The blue shading are predictions of future sea level change through ASLR (Bindoff et al. 2007, p. 409).

Other considerations for relative SLR include temporary variations in sea level from climatic and non-climatic events (Bindoff et al. 2007; Bird 2000; Michael 2007; Ministry for the Environment 2004, 2004b; W. Mitchell et al. 2001; O'Donnel 2007; Tait et al. 2002). Although these events already exist, SLR will likely exacerbate their water levels. Climatic events include storm surges and non-climatic events include tsunamis and both can occur over periods of hours to days. Storm surges are temporary rises in water from atmospheric low pressure systems and high winds (Bird 2000). Furthermore, tsunamis are not a result of SLR, rather are waves which may inundate the coast causing water levels to temporarily increase. However, the scope of this project does not include tsunamis, therefore no further analysis is taken. Lastly, interannual and decadal variability such as volcanic eruptions, the El Niño Southern Oscillation (ENSO), La Niña, the Interdecadal Pacific Oscillation (IPO), and the North Atlantic Oscillation can change relative sea levels over periods ranging from months to decades due to regional atmospheric pressure and wind

4.4 General physical effects of SLR

The effects of SLR are site specific and therefore are difficult to quantify as each location responds differently. Generally, SLR results in the following;

- inundation of low lying coastal and river mouth areas from higher water levels;
- increased coastal flooding due to higher advancing tide lines and storm surges;
- altered rates of erosion, accretion, and exchange of sand and sediment between adjacent sources;
- coastlines prograding or transgressing;
- increased or decreased buffer zones along the coast;
- alterations of groundwater levels;
- and saltwater intrusion into groundwater

(Bird 2000, p. 276).

4.5 Historic and relative SLR in New Zealand

Historical SLR in New Zealand is consistent with global averages, rising 0.25 m since the mid 1800s (Ministry for the Environment 2004). Most likely predictions for absolute SLR in New Zealand, for the year 2100 range from 0.18 m to 0.59 m above

year 2000 levels; which could be modified by +0.1 m to +0.2 m if global ice sheets melt at faster rates (Christensen et al. 2007; Meehl et al. 2007; Ministry for the Environment 2004). However, relative SLR in New Zealand possibly differs by $\pm 25\%$ due to regional differences in thermal expansion rates, oceanic circulation changes, and local differences in vertical land movements (Christensen et al. 2007). For these reasons the Ministry for the Environment (2004) suggest implementing at least a 0.5 m SLR by 2100 into coastal planning and development projects and assessments.

Rates of SLR not only depend upon the previous variables, but also the coastal dynamics and geomorphology of each coast. Within New Zealand there are several types of coastlines: open coast sand beaches, open coast gravel beaches, cliffed coasts, and estuarine shorelines (Figure 4.5) (Ministry for the Environment 2004).

Reactions of these coasts to SLR depend on the following variables:

- elevation of the coast above present mean sea level;
- geology of the coast;
- sediment supply and its availability for beach building and likely change in this supply;
- width of any coastal barrier present;
- coastal setting and orientation;
- vegetation available for stabilisation;
- and shape, slope, and height of pre-existing coastal protection infrastructure

(Ministry for the Environment 2004, p. 14).

Sandy coast beaches in New Zealand generally erode with higher sea levels, although climate change has the potential to change erosion and accretion rates, either positively or negatively, depending on the sedimentation rates of a given area (Ministry for the Environment 2004). In addition, gravel coast beaches will likely suffer less erosion than sandy coast beaches, but erosion is still probable, especially on beaches where wave overtopping is prominent. Furthermore, cliffed coasts will continue to erode, some at faster rates than the current. Lastly, estuarine shorelines will generally widen and deepen with SLR with an overall land movement due to higher water levels and increased erosion along the estuary banks (Bird 2000). This is parallel for New Zealand, especially where sediment supply does not keep pace with SLR, leading to overall erosion (Ministry for the Environment 2004).

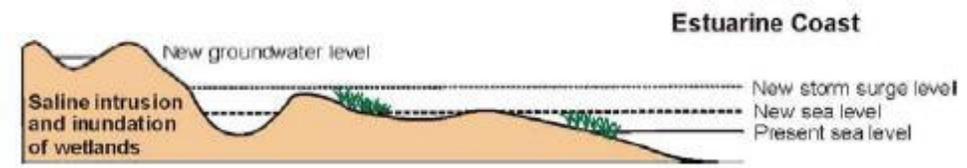
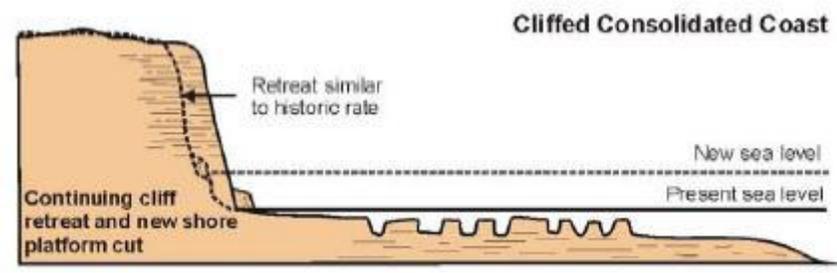
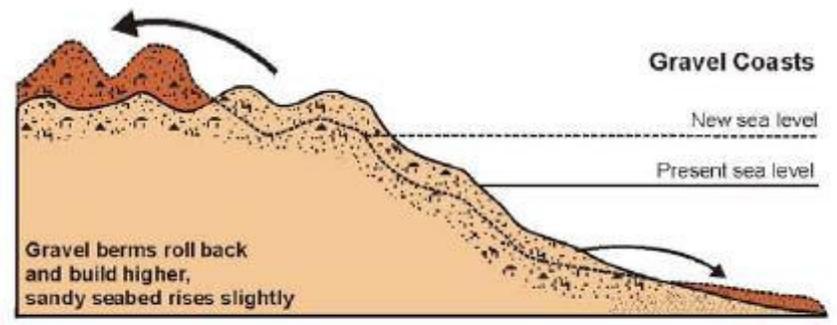
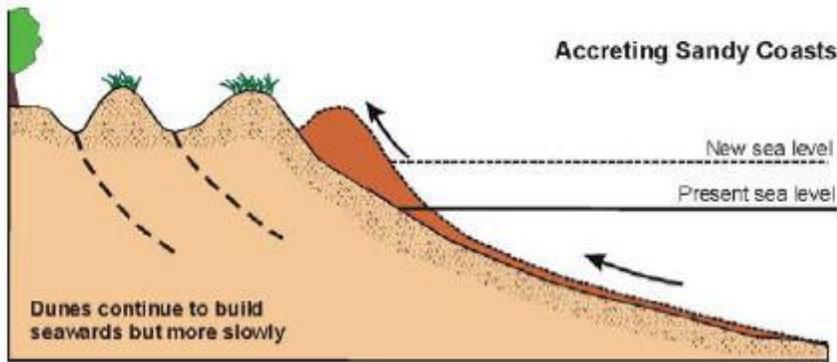
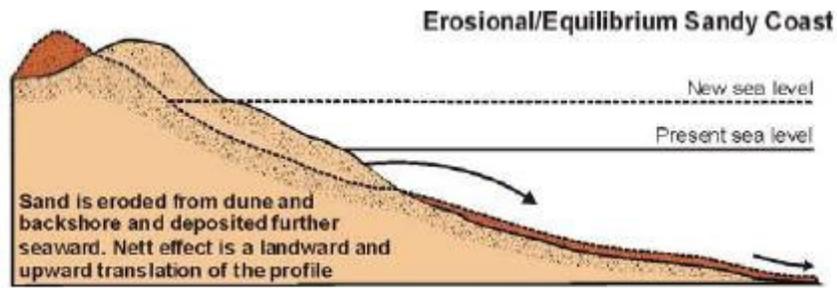


Figure 4.5: The general impacts of SLR on the different New Zealand coastlines. Local geologic conditions may result in other changes (Ministry for the Environment 2004, p. 17).

However, it is difficult to quantify the effects of each coast in New Zealand, and since coastal dynamics is not a study aim or objective, this project does not consider the different behaviours of each coast as a result of SLR. Therefore, this project assumes that higher sea levels will result in higher water levels for all types of coastlines in New Zealand.

4.5.1 Temporary SLR in New Zealand

Temporary sea level fluctuations in New Zealand result from both climatic and non-climatic factors and can last for hours to decades. The fluctuations in combination with SLR can temporarily raise sea levels and pose a serious threat to coastal communities, especially in low-lying areas because of coastal inundation and flooding. Coastal flooding in New Zealand is a result of some or all of the following drivers, which are exacerbated by SLR:

- extreme high tides;
- large waves or swell;
- low atmospheric pressure;
- winds blowing onshore or alongshore;
- long period sea level oscillation such as ENSO and IPO;
- and high river water levels at river mouths, which at high tide can exacerbate river flooding upstream and coastal flooding

(Tait et al. 2002, p. 67).

Furthermore, interannual and decadal sea level fluctuations affect New Zealand such as the IPO, ENSO, and La Niña, which can last for 20-30 years and the latter two for 3-5 years, respectively, and all can potentially raise sea level by 0.25 m in any given month (Ministry for the Environment 2004).

Storm surges in New Zealand generate from onshore blowing winds and low barometric pressures (Ministry for the Environment 2004). Storm surges in combination with a wave run up, wave set up, and extreme high tides result in a 'storm tides' (Figure 4.6). Extreme high tides typically occur when the moon is in its perigee, that is, closest to the Earth in its monthly orbit, and in sync with a spring tide, thus resulting in a spring-perigean tide (Tait et al. 2002). Furthermore, a spring-perigean tide that occurs with a storm surge is potentially catastrophic for low-lying coasts. Consequences of storm tides will be more frequent coastal flooding for low-

lying areas and any SLR increasing the overall probability that permanent coastal inundation and temporary coastal flooding will occur (R.G. Bell, Hume & Hicks 2001b). Examples of past storm tide events in New Zealand are included in Table 4.1.

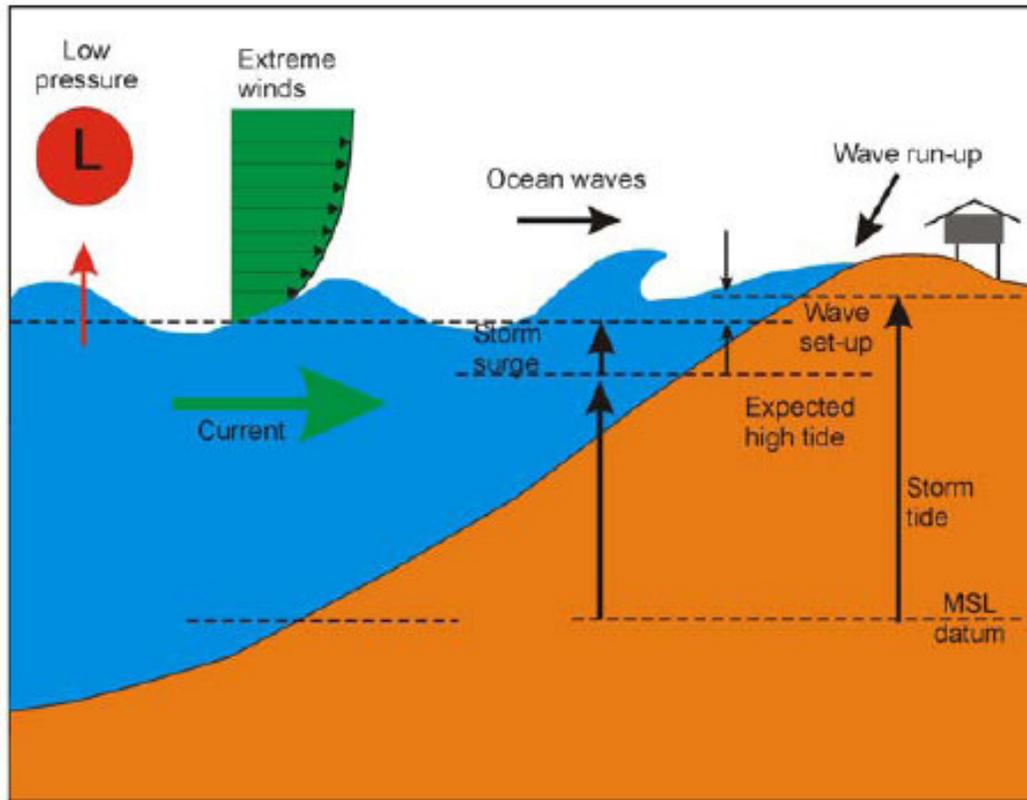


Figure 4.6. A storm tide = high tide + storm surge + wave set up. Final inundation level = storm tide + wave run up (Ministry for the Environment 2004, p. 25).

Table 4.1. Historical storm tides in New Zealand. These measurements were taken at Queens Warf, Wellington (Tait et al. 2002, p. 25).

Storm event	Date	Predicted high tide (m)	Storm surge (m)	Storm tide height (m)
1936 Cyclone	2 Feb. 1936	0.80	~0.9	~1.7
Wahine Storm	10 Apr. 1968	0.63	0.5	1.1

In New Zealand, the largest recorded storm tide is ~1.7 m in 1936. If an event of this magnitude occurs again, and combines with a relative SLR of 0.5 m, then temporary water levels could be as high as ~2.2 m (Tait et al. 2002). More so, a 100 year return tide on the North Island can reach 0.9 m above current sea level. If this 100 year high tide of 0.9 m is combines with a storm surge from the Cyclone of 1936, then a potential storm tide of ~1.8 m is possible for the North Island of New Zealand.

Adding this with a 0.5 m SLR could result in temporarily water levels to be ~2.3 m above current water levels. Other evidence includes a South Island estimate by Todd (1999), who states that temporary water levels could be ~2.45 m above 1994 water levels, but this estimate is highly localised and comprehensively developed with geologic considerations. This estimate includes a 0.5 m relative SLR and a 100 year return storm tide of 1.95 m.

The two preceding estimates give an insight into the possible temporary water heights in New Zealand as a result of relative SLR and storm tides. These water levels will have potentially severe consequences for coastal communities in New Zealand and SLR will likely exacerbate the physical effects mentioned in section 4.4, including other local effects, which are spatially unique to a place's environmental vulnerability.

4.6 Case study: relative SLR in Christchurch City, New Zealand

This section provides insight into the relative SLR for Christchurch City, New Zealand and the physical and social impacts related to coastal flooding. Absolute SLR estimates in Christchurch City are similar to national and global predictions for the year 2100. Predictions of the year 2100 include estimates of 0.09 m to 0.88 m greater than 1990 levels, mainly from thermal expansion (O'Donnell 2007). However, several factors, including subsidence, sedimentation provided by beaches and rivers, and sand storage and topography in the adjacent Avon-Heathcote Estuary, need to be taken into consideration to determine how it will react under SLR (Ministry for the Environment 2004).

In general, estuaries will widen and deepen under SLR with an overall land movement due to an increase in water heights causing an increase in erosion along the estuary banks (Figure 4.5) (Bird 2000). This is parallel for New Zealand, especially where sediment supply does not keep pace with SLR, leading to overall erosion (Ministry for the Environment 2004). Effects of erosion include submergence of low-lying areas from deeper waters and widening and deepening of tidal channels, thus increasing the inflow of water (Bird 2000). However, this process is less likely in the Avon-Heathcote Estuary because the coastal margins are partially modified, which will result in higher water levels, or a squeeze effect, because the permanent margins will stay in place and the water levels will become deeper.

Utilising sedimentation rates, changes in the tidal compartment, and predictions for SLR in the Avon-Heathcote Estuary, Todd (1999) calculates relative SLR to be +0.5 m by the year 2100 (relative to 1994 levels), parallel to suggestions from the MfE (2004). Furthermore, a 0.5 m SLR in combination with a wind set up of 0.1 m and storm tides produce potentially high water levels for the estuary. Utilising all of the variables for 50, 100, and 500 year return periods, water levels in 2100 could be 2.36 m, 2.43 m, and 2.52 m above 1994 levels, respectively. Additional contributions to SLR can occur from subsidence on the Canterbury Plains, which is currently at a rate of 0.1 to 0.2 mm/yr, could result in an extra 0.01 to 0.02 m by 2100 (R.G. Bell, Hume & Hicks 2001b).

The impacts of SLR in Christchurch City are similar to those mentioned in section 4.3 (O'Donnel 2007). Physical impacts as a result of higher water levels from a 0.5 m SLR and a storm tide include erosion, coastal inundation. For instance, a 0.5 m SLR by 2100 will reduce a 500 year coastal flooding return event to that of a 50 year return event, place water levels of a monthly perigean tide to that of a current 50 year return event, and place 490 hectares of land near the Avon-Heathcote Estuary at risk from inundation (Todd 1999). Furthermore, a 0.4 m SLR by 2100 without any storm tide will result in an exceedance of the mean high water springs 93% of the time compared to the current rate of 12% (R. Bell 2001). SLR will also affect the Avon and Heathcote Rivers, the two main rivers that flow into the Avon-Heathcote Estuary. The tidal influence of both rivers will likely extend 2 km further upstream resulting in increased flooding with storm events (Todd 1999). In conjunction, a 0.5 SLR in combination with a 100 year storm tide places 1000 hectares of land adjacent to the Avon River and 430 hectares adjacent to the Heathcote River at-risk to flooding.

The physical effects of SLR and storm tides are likely to damage private property, infrastructure, and coastal heritage as a result of coastal inundation, especially in areas along the estuary such as Lower Linwood, McCormacks Bay, Redcliffs, and the South Brighton Spit (O'Donnel 2007). In addition, a 0.5 m SLR will increase the erosion rates of estuary banks from 0.2 to 9.6 m with the highest rates near the South Brighton Spit and the estuary mouth, possibly effecting private property and protection walls (Todd 1999).

Along the Avon and Heathcote Rivers, higher water levels will result in inundation in the lower 10 km of both rivers, similar to the events that occurred in 1968 and 1992 (Christchurch City Council 2007a). Moreover, Wilkinson & Smith (1995) conclude

that a 0.65 m SLR in combination with a spring tide would likely inundate the areas near Bexley, Travis Swamp, Horseshoe Lake, Avondale, Dallington, Wainoni, Lower Linwood, Ferrymead, and Woolston. In addition rates of river bank erosion will increase.

4.6 Summary of the risks of SLR

Since the Industrial Revolution, increases in the amount of anthropogenic greenhouse gases have resulted in warmer temperatures and ASLR. Up to and beyond the year 2100, global temperatures and thermal expansion will likely result in ASLR. These estimates depend on the local geologic and thermal factors, which will all influence future water levels. For instance, predictions for relative SLR and a 100 year return storm tide on the North Island is ~2.3 m (Tait et al. 2002) , while predictions for the South Island are ~2.45 m (Todd 1999). The main adverse effects have potentially catastrophic consequences for coastal populations, most specifically coastal inundation, flooding, and erosion..

5. Methodology

This chapter discusses the methodology of a quantitative, geographic information system (GIS) and digital elevation model (DEM) analyses of the socio-spatial distribution of risk to SLR and storm tides in New Zealand, in conjunction with the research aim and objectives. This is a multi-step approach at a meshblock (MB) level, which requires the creation and assessment of coastal flood zone boundaries, the determination of populations' demographics within the flood zones, and establishing whether or not the distribution of SLR and storm tides are equally. Lastly, a comparative analysis between two elevation datasets in Christchurch City and Wellington City gives an indication to the sensitivity of the DEM.

5.1 Study areas

This section identifies the demographics in New Zealand and specific examines each region, Christchurch City, and Wellington City (Figures 5.1 and 5.2). According to the New Zealand Census (2006) (NZCensus06), New Zealand is home to 4,049,253 people on a total of ~270,000 km² of land. This project uses similar estimates,

although it excludes some groups of people because they represent a very small ratio of the total population in the NZCensus06. For instance, ethnic groups such as Middle Eastern, Latin American, Africans, and other ethnic groups comprise a small percentage of the total ethnic groups count in New Zealand. Furthermore, the NZCensus06 reports that ethnic and income groups have an overall lower response rate in comparison to the overall population, because some people did not fully complete the questionnaires. Refer to Table 5.1 for the actual measureable population in this research.

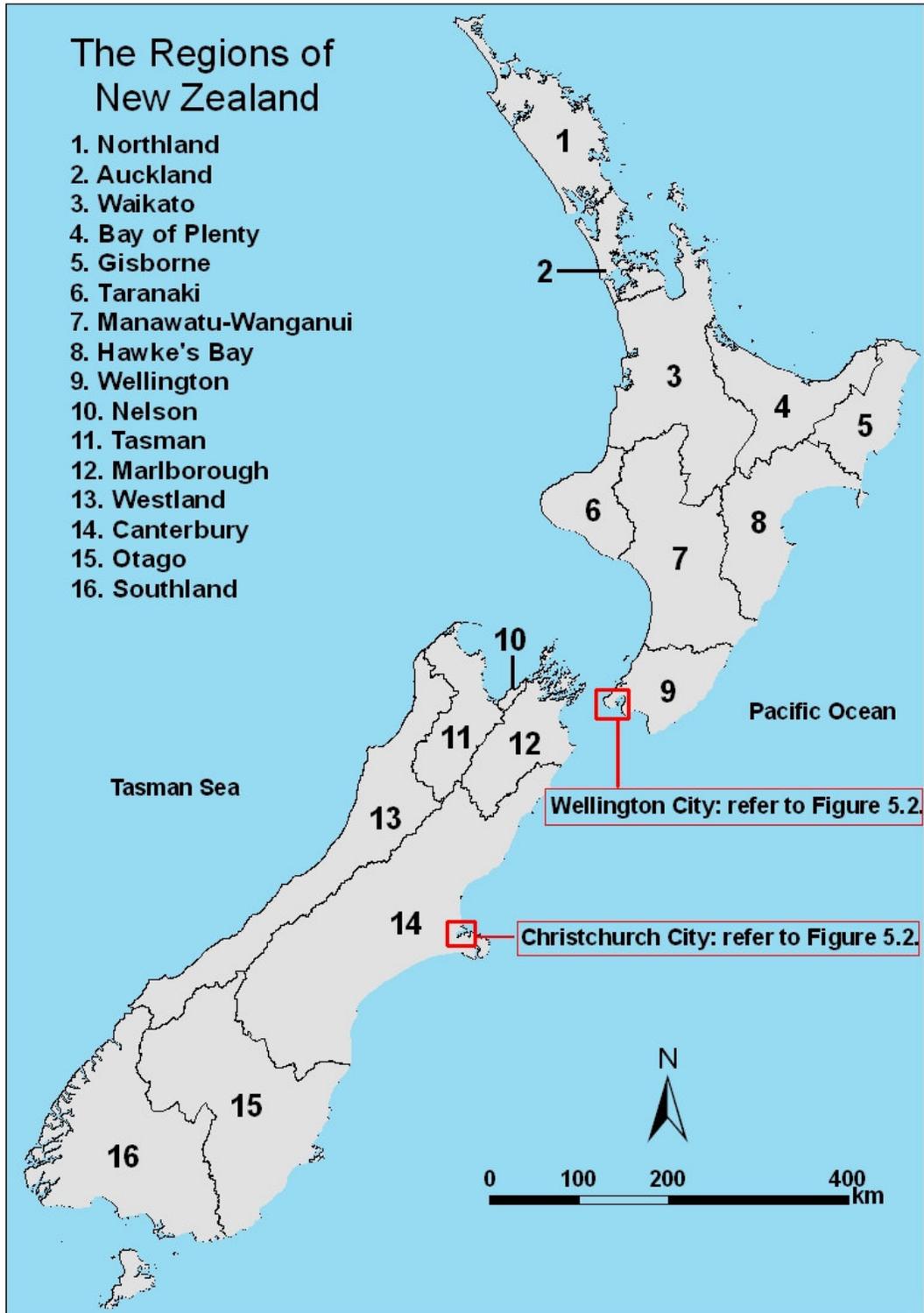


Figure 5.1: Study areas: New Zealand and its 16 regions; including special reference to Wellington City and Christchurch city (Figure 5.2).

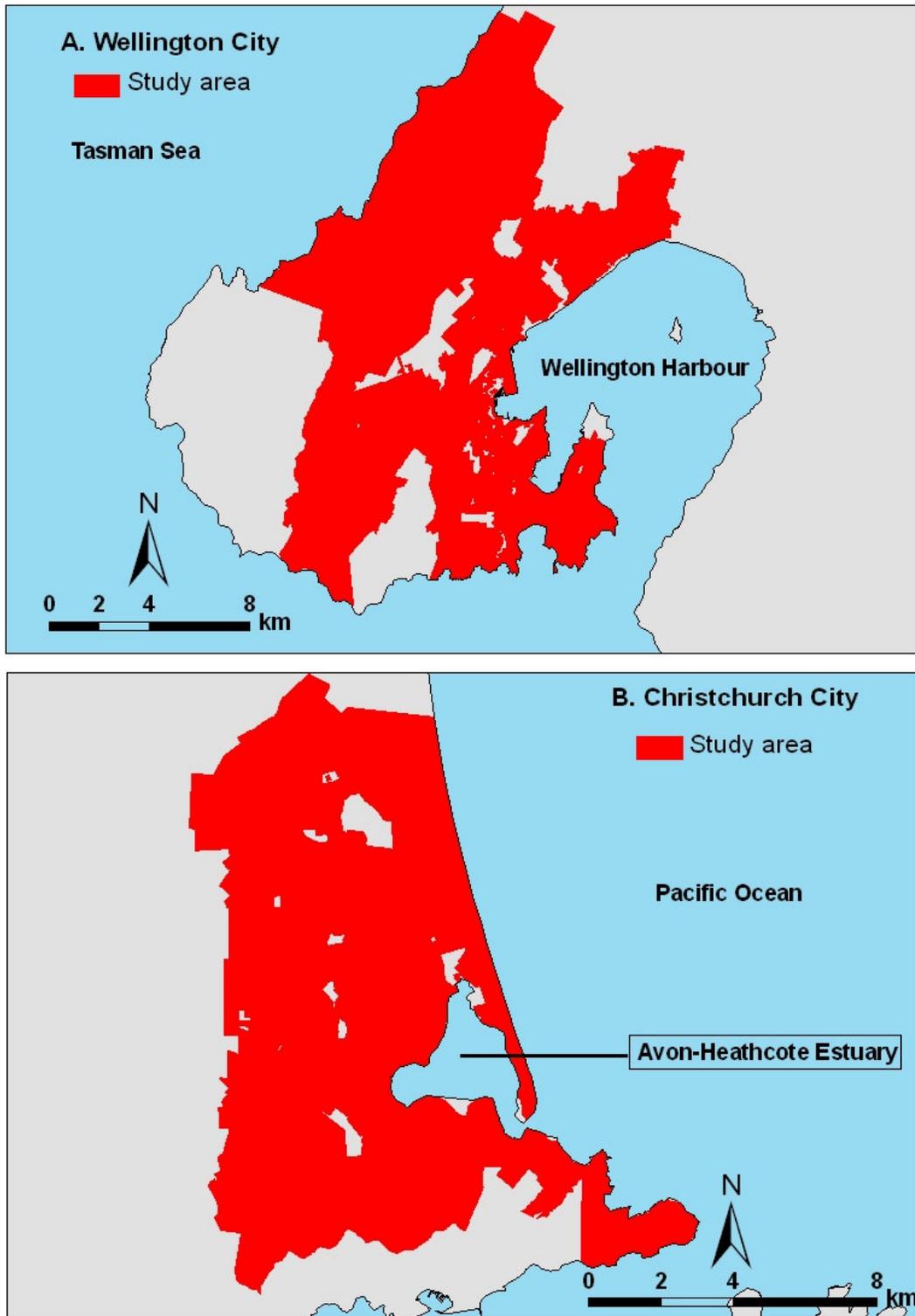


Figure 5.2.: Study areas: A) Wellington City and B) Christchurch City.

Table 5.1: The demographics of the study areas (New Zealand Census 2006).

	Population	% Female	% Male	% Asian descent	% European descent	% Maori descent	% Pacific peoples	% aged 0 to 14	% aged 15 to 64	% aged 65 and over	Median income	Mean deprivation level
New Zealand	4,049,253	51.17	48.83	10.20	67.44	14.71	7.65	21.59	66.36	12.05	\$24,400	5.51
Northland	167,331	50.80	49.20	1.68	64.82	30.86	2.64	23.23	62.17	14.60	\$20,900	6.85
Auckland	1,308,798	51.28	48.72	18.75	56.01	11.01	14.23	22.11	68.01	9.88	\$26,800	5.31
Waikato	384,972	50.85	49.15	5.02	70.57	21.14	3.27	23.03	64.62	12.35	\$24,100	5.82
Bay of Plenty	257,649	51.42	48.58	3.16	66.88	27.30	2.64	23.08	62.11	14.81	\$20,600	6.29
Gisborne	43,488	51.63	48.37	1.70	51.01	44.34	2.95	26.28	61.49	12.23	\$22,600	7.29
Taranaki	103,614	50.89	49.11	2.22	79.99	16.35	1.44	21.83	63.12	15.05	\$23,200	5.68
Manawatu-Wanganui	220,296	51.35	48.65	3.83	73.56	19.81	2.80	21.82	63.77	14.41	\$21,600	6.08
Hawke's Bay	146,952	51.42	48.58	2.55	69.74	23.90	3.81	23.10	63.05	13.85	\$22,600	5.99
Wellington	448,131	51.50	48.50	8.55	70.46	12.90	8.09	20.67	67.88	11.46	\$28,000	5.10
Nelson	42,900	51.37	48.63	2.62	86.22	9.23	1.93	19.37	66.12	14.50	\$23,100	5.56
Tasman	45,234	50.36	49.64	1.45	90.09	7.61	0.85	21.21	64.87	13.92	\$21,600	4.96
Marlborough	48,081	49.52	50.48	2.28	84.47	11.34	1.91	18.64	65.86	15.50	\$23,300	4.55
Westland	29,445	49.58	50.42	1.19	86.96	10.87	1.02	20.47	65.01	14.52	\$20,400	6.61
Canterbury	518,922	51.20	48.80	6.26	83.57	7.83	2.34	19.68	66.33	13.99	\$23,500	4.90
Otago	192,456	51.12	48.88	4.54	86.45	7.18	1.83	17.52	68.50	13.98	\$21,600	4.92
Southland	90,984	50.18	49.82	1.44	84.01	12.75	1.80	21.20	64.71	14.09	\$23,200	5.03
Wellington City	158,598	51.64	48.36	13.54	73.21	7.93	5.32	16.98	74.72	8.30	\$32,500	4.32
Christchurch City	129,648	51.57	48.43	4.94	80.87	10.15	4.04	20.03	67.04	12.93	\$23,400	5.95

5.2 Methodological techniques and datasets

This section explains the steps taken to meet the research aim and objectives; including the analytical methods and descriptions of the datasets. Measuring environmental justice consists of a comparison of the socio-spatial distribution of New Zealand populations to areas at-risk to SLR and storm tides; therefore GIS can facilitate the analysis between social and socioeconomic characteristics and environmental risk (Mennis 2002). Conventional environmental justice approaches in GIS measure whether or not communities with higher risk to environmental inequalities have significantly higher rates of socially vulnerable populations, which are easily administered in GIS. This use of overlay mapping is ideal for identifying the location of environmental inequalities and who/what may be affected (Stephens, Willis & Walker 2007).

5.2.1 Assessing SLR and storm tides

Measuring the environmental justice of SLR and storm tides requires several strategic approaches. First, is the acquisition of a proper dataset to measure the extent and risk to coastal flooding using GIS. An achievable, yet practical method in New Zealand, is to use a national DEM (Gambolati, Teatini & Conella 2002; Titus & Richman 2001). This dataset was generated from Land Information New Zealand (LINZ) 1:50k topographic sources, derived photogrammetrically, and provided by the University of Canterbury, Department of Geography. The resolution of this dataset is 90% of planimetric points are ± 22 m and 90% of vertical points ± 5 m (Land Information New Zealand 2007). The DEM provides reference points of elevation to determine what locations are physically vulnerable to coastal inundation and flooding as a result of SLR and storm tides. Elevation is the single most important factor for identifying those lowlands susceptible to flooding or inundation (Gambolati, Teatini & Conella 2002; Titus & Richman 2001). Although identifying such is only a preliminary step to a cumulative assessment of risk, the results can accurately predict local and national conditions under different scenarios (Stephens, Willis & Walker 2007). More cumulative evaluation requires dynamic flood modelling, including hydraulic and geologic processes, which is beyond the scope of this project.

The DEM dataset was added into ArcGIS 9.2, spatially referenced with the Geographic Datum 1949 New Zealand Map Grid, and output as a binary raster map, which displayed what geographical elevations are affected by coastal flooding. For

instance, if the GIS grid cells were affected by coastal flooding, they were given a value of '1', and further analysed. Each cell is of minimal size, only 2 m x 2 m. In contrast, if an area or cells were not affected by coastal flooding, they were given a value of '0' and no longer analysed because this project is only concerned with the socio-spatial distribution of people within potential flood zones. All elevations, below the heights developed in section 4.5.1, are assumed to be affected:

- North Island – 2.30 m;
- and South Island – 2.45 m.

The analysis assumed that water levels formed a flat plane originating from the ocean; and all cells with elevation points below these levels that were continuously connected to the ocean, were inundated (T.L. Webster & Forbes 2005). Those cells below the elevation estimates, but not connected to the ocean, were not analysed, because it assumed that flood waters would be obstructed and blocked by higher elevations, and therefore could not inundate these areas (Neelz et al. 2005; T.L. Webster & Forbes 2005; T. L. Webster et al. 2004).

The final flood maps provide a geographical reference showing what land areas and cells in New Zealand are likely affected by coastal flooding. In addition, it estimates the amount of land subject to coastal inundation. Both provide an initial spatial estimate, which can be further analysed with population data corresponding to the same area, and determine whether or not environmental justice exists.

5.2.2 Social and socioeconomic data

Data from the NZCensus06 at MB levels provided sufficient social and socioeconomic statistics of populations in inundated areas. MB boundaries were overlapped and spatially referenced with the DEM as shapefiles using ArcGIS 9.2. MBs are the smallest geographical areas, which statistics from the NZCensus06 can represent. In 2006, New Zealand had 41,376 MBs, each with an average area of ~1000 hectares or ~10 km² (Statistics New Zealand 2008). In addition, each MB contains a median of 87 people with higher density populations, therefore smaller area, MBs located in urban locations. Each MB contains a plethora of social and socioeconomic data, relevant to that area, which can be measured to determine environmental justice. Conversely, each MB boundary contains a level of socioeconomic deprivation from the New Zealand Deprivation Index 2006

(NZDep06). This dataset combines nine indicators of vulnerability from the NZCensus06 and applies each MB a single score on an ordinal scale from 1 to 10, where 1 is the least deprived and 10 is the most deprived (C. Salmond, Crampton & Atkinson 2007). Furthermore, each number is divided into deciles; for example, each deprivation score contains ~10% of New Zealand’s population.

Table 5.2: Social indicators of deprivation in New Zealand, according to the NZDep06 (C. Salmond, Crampton & Atkinson 2007, p. 6).

Dimension of deprivation	Variable description (in order of decreasing weight)
Income	People aged 18 to 64 receiving a means tested benefit
Income	People living in an equivalised household with income below an income threshold
Owned home	People not living in an owned home
Support	People aged <65 living in a single parent family
Employment	People aged 18 to 64 who are unemployed
Qualifications	People aged 18 to 64 without any qualifications
Living space	People living in overcrowded households
Communication	People with no access to a telephone
Transport	People with no access to a car

In addition to NZDep06 scores, this project examines the following individual variables of social vulnerability derived from the NZCensus06:

- age (groups include 0 to 14, 15 to 64, and 65 and over);
- ethnicity (groups include Asian descent, European descent, Maori descent, and Pacific peoples);
- sex;
- and total personal income for people aged 15 and over (groups include \$0 to \$5000, \$5001 to \$10,000, \$10,001 to \$20,000, \$20,001 to \$30,000, \$30,001 to \$50,000, and \$50,001 and over).

The preceding variables were placed as attributes into individual MB boundaries in ArcGIS 9.2 to supply social and socioeconomic data for each area. This provides simple statistical information that can be analysed in coordination with the DEM flooding dataset to determine environmental justice.

5.2.3 Assessing inequality to SLR and storm tides

To accurately determine inequality to SLR and storm tide, analysis estimated the socio-spatial distributions of people within affected MBs. This involved two methods; assumed a spatially uniform population in each MB; and used population weighted centroids (PWCs). The former was a multi-step process, and assumed that individuals

were equally distributed in a MBs' geographical area. The first step calculated the population density (people per square metre) of each social and socioeconomic attribute. Next, the existing shapefile for each attribute was converted into a raster map in ArcGIS 9.2 using the 'conversion tools' and 'feature to raster' tools. This displayed and compared the population densities of each attribute in each MB (Figure 5.3), and is required because the flood maps estimated how many square metres are inundated, and therefore to match consistency, the number of people per square metre in each MB was essential. However, this method did not measure deprivation scores because it was not possible.

The next step combined the existing flood raster maps and the population density raster maps and estimated how many people of each social and socioeconomic group were at-risk to coastal flooding. This process required the 'spatial analyst' and 'raster calculator' tool in ArcGIS 9.2. It essentially multiplied the population density raster map of each attribute (Figure 5.3) with the flood raster map (Figure 5.4), and calculated a product that displayed how many people per MB were affected (Figure 5.5). For instance, if a MB contained 100 people, and approximately half of its geographical area was inundated by coastal flooding, calculations assumed that a total of 50 people were affected. The final raster maps displayed individual attribute values for each MB, which represents how many people are at-risk for each social and socioeconomic group (Figure 5.5).

The second type of analysis used PWCs and compared them to the flood raster maps. PWCs were created by the GeoHealth Laboratory at the University of Canterbury in December 2007. One PWC point is associated with each MB to display the mean centre point of the population (Figure 5.6). The placement of the PWC in each MB is determined by averaging the x and y coordinates from the LINZ Core Record System address points of each MB. The amount of people affected by coastal flooding depends on whether or not the PWC was connected to or surrounded by the flood extent. If so, this analysis assumed that the entire MB and its population was affected, and therefore was counted in the statistics. If the PWC was not connected to or surrounded by coastal flooding, then the analysis did not use the MB statistics.

Both methods of analyses, assuming a spatially uniform population in each MB and PWCs, provided two different strategies that determined how many people are affected by coastal flooding. They can also measure the social and socioeconomic statistics of each MB as well as New Zealand and each region. However, to determine

whether or not coastal flooding is an environmental inequality, additional analysis of the aforementioned statistics is needed, and are described in section 5.3.

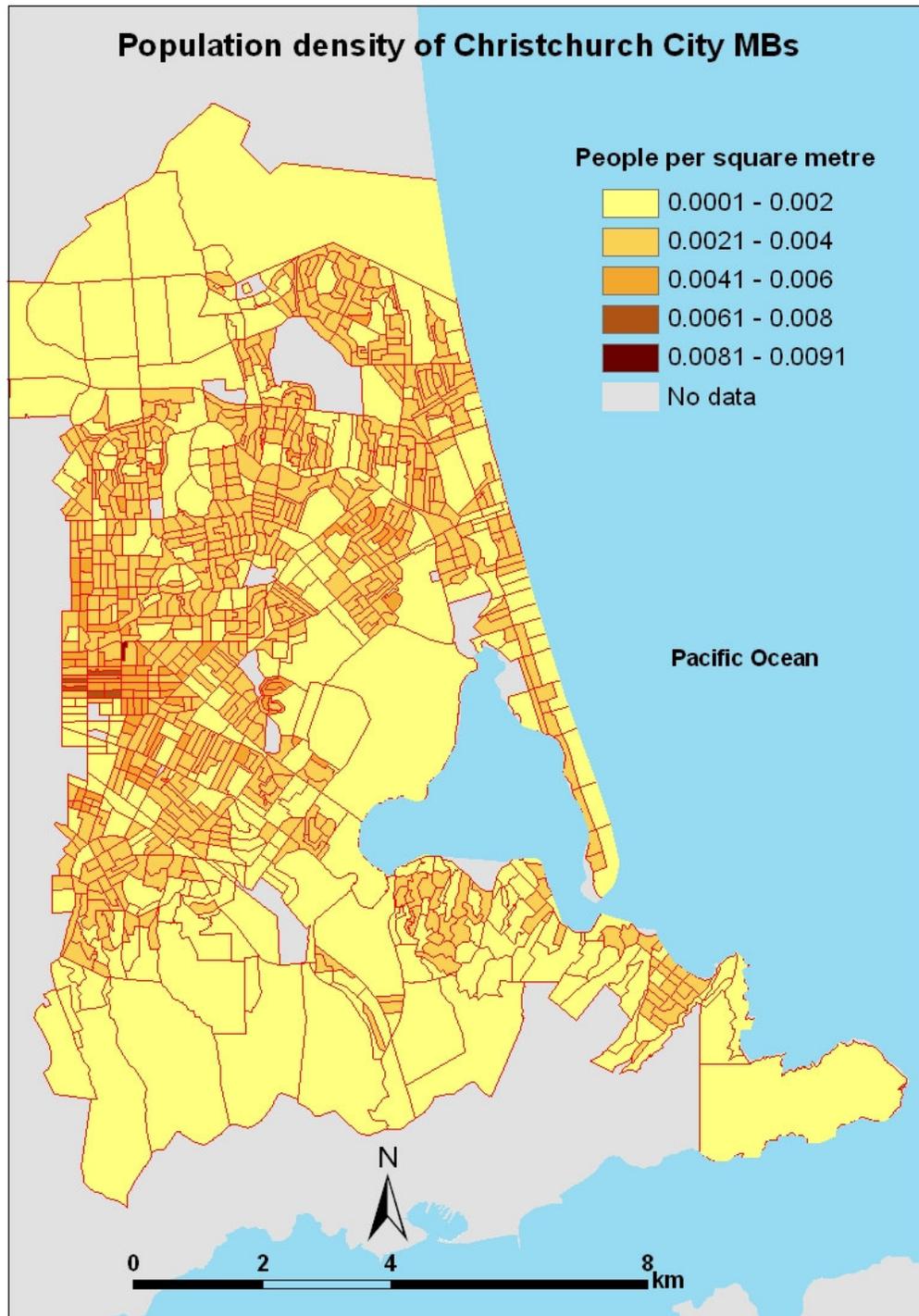


Figure 5.3: The population density of each MB in Christchurch City.

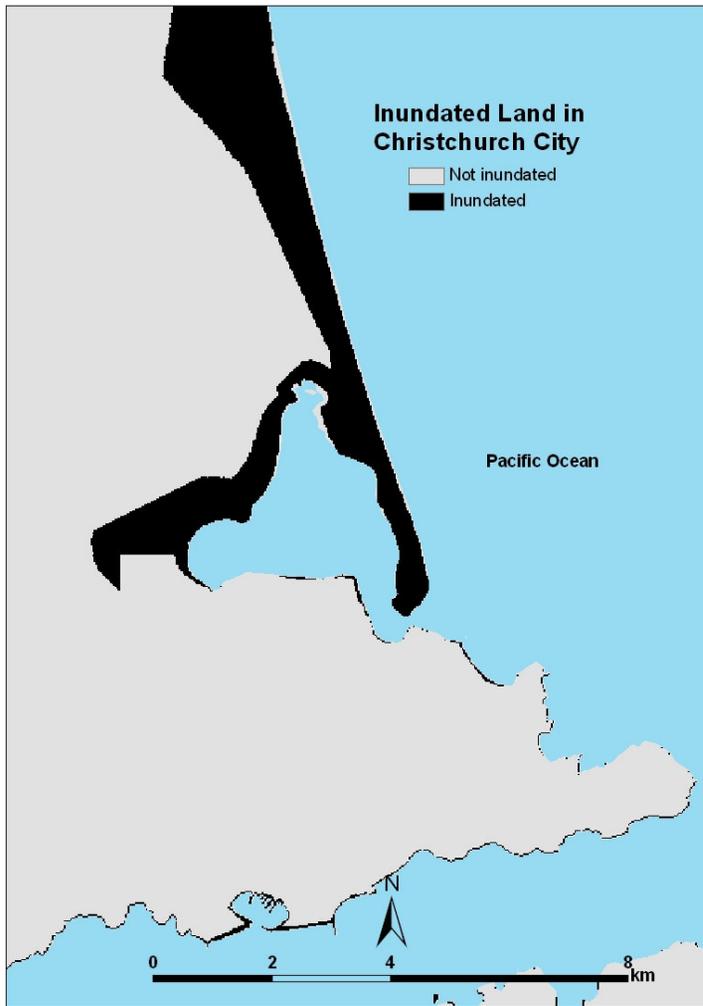


Figure 5.4: Coastal flood extent in Christchurch City

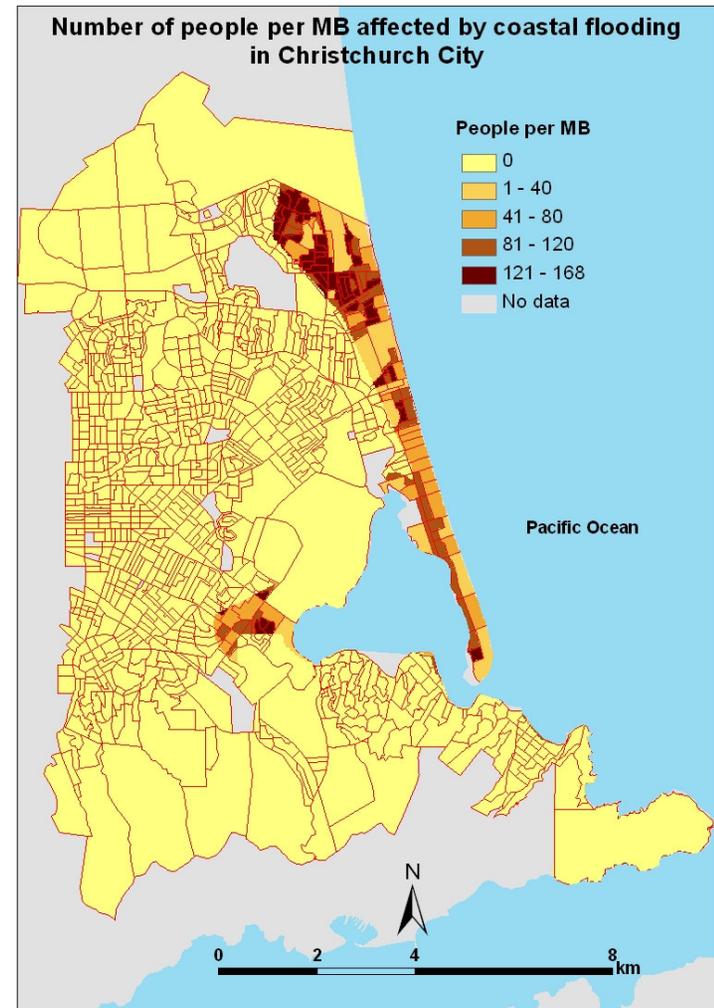


Figure 5.5: Number of people per MB affected by coastal flooding in Christchurch City.



Figure 5.6: MBs and associated PWCs in Christchurch City.

5.3. Indicator of Inequality

Section 5.2 provided an overview to the methods used to determine what areas are inundated, how many total people are at-risk to coastal flooding, and their social and socioeconomic composition. This section provides an outline on the steps taken to measure inequality to SLR and storm tides. The statistical measure, the Comparative

Environmental Risk Index (CERI), is an indicator to the degree of environmental inequality. The CERI is a calculation of the proportion of people at-risk in comparison with the rest of the total at-risk population (Harner et al. 2002; Walker & Bulkeley 2006). In this project, the calculations are developed from both a spatially uniform population in each MB and MBs' PWCs. The CERI is symbolised by the following equation, where X is any particular population.

$$\frac{\textit{Population X at-risk}}{\textit{Total Population X}}$$

$$\frac{\textit{Total population at-risk}}{\textit{Total Population}}$$

Calculations are only able to compare and thus determine inequality at relative levels because each place has unique characteristics that cannot be directly compared to other places (Walker et al. 2003). In other words, 'Population X' and 'Total Population' have to be taken from the same area, whether it's the same city, region, or country. For example, if 'Population X' is derived from Christchurch City, it has to be compared to the 'Total Population' of Christchurch City. In addition, 'Population X' and 'Total Population' must be comparable groups. For instance, if 'Population X' is people of European descent, the 'Total Population' must be the total ethnic counts and not another social or socioeconomic category such as income or gender. Lastly, all variables of the CERI must be from the same method of analysis used in this project, such as a uniformly distributed population or PWCs, and cannot be intermingled.

Resulting CERI values should be ~1.00 for environmental justice. However, differing values, whether positive or negative, results in inequalities. For example, a population's CERI of 1.55 means that the specific group is 55% more likely to be at-risk to coastal flooding in comparison to the same population category in the relative location. Moreover, a CERI value of 0.75 means that they are 25% less likely to be at-risk whereas a value of 1.00 is equal risk. The subsequent groups are measured in the DEM with both a spatially uniform population in each MB and MBs' PWCs:

- females compared to Males;
- people aged 0 to 14 with people aged 15 and over;
- people aged 15 to 64 with people aged 0 to 14 and people aged 65 and over;

- people aged 65 and over with people aged 0 to 64;
- Asian ethnic groups with all other ethnic groups;
- European ethnic groups with all other ethnic groups;
- Maori ethnic groups with all other ethnic groups;
- Pacific peoples ethnic groups with all other ethnic groups;
- individual total personal income groups with all other total personal income groups;
- individual deprivation deciles with all other deprivation deciles;
- and deprivation deciles 1 to 5 with deprivation deciles 6 to 10.

Inequality as assessed by CERI values were calculated for New Zealand as a whole and each of its 16 regions. In addition, CERI values for Christchurch City and Wellington City provide a local investigation of environmental justice and give a chance to test the sensitivity of the national DEM with another elevation dataset in ArcGIS 9.2.

5.4 Testing the sensitivity of the DEM

This section describes the steps taken to determine one of the projects research objectives: test the sensitivity of the DEM to resolve whether or not it portrays coastal flooding accurately. This provides insight into the capabilities of the DEM to measure SLR and storm tides in New Zealand.

5.4.1 Light detection and ranging

The elevation dataset used to verify the DEM is called light detection and ranging (LiDAR). LiDAR mapping is an airborne technique, which measures elevation, amongst other purposes, by emitting laser pulses towards the ground and analysing the return time (Figure 5.7) (Krabill & Martin 1987). Typical vertical and horizontal accuracy of LiDAR is ± 30 cm, which is more accurate in comparison to the national DEM. Errors in LiDAR often result from wharves, steep rock and river embankments, ditches, culverts, dense vegetation, and buildings (Brock et al. 2002; Neelz et al. 2005; T.L. Webster et al. 2001; T.L. Webster & Forbes 2005; T. L. Webster et al. 2004; T.L. Webster et al. 2006). A comparative study performed by Titus and Richman (2001) determine that LiDAR is more advantageous than a national DEM when measuring areas susceptible to SLR and confirm the results using a GPS. However, a study in the US by the Consortium for Atlantic Regional

Assessment (2008) conclude that the average difference between two different DEMs, which are of similar resolution to the DEM employed in this project, and LiDAR at coastal sites is less than 0.2 m.

In New Zealand, the availability of LiDAR is limited in comparison to Canada, and the US. However, it is available in coastal areas such as Christchurch City and Wellington City. Acquisition of respective LiDAR data was through both the Christchurch City Council (CCC) and Wellington City Council. Christchurch LiDAR was obtained from 6 to 9 July 2003 and the dates for the Wellington LiDAR are undisclosed. In order to make the LiDAR datasets compatible with ArcGIS 9.2, files were transformed from x, y coordinates and z vertical files and interpolated into raster maps using the 'data management', 'raster', and 'Mosaic' tools. The Christchurch City LiDAR was spatially referenced with the same coordinate system as the DEM and MB databases, the Geographic Datum 1949 New Zealand Map Grid. Furthermore, Wellington City LiDAR was spatially referenced with the New Zealand Transverse Mercator 1980. This was the original LiDAR coordinate system so to prevent boundary errors, all other maps joined and analysed with the Wellington City LiDAR dataset was projected identically.

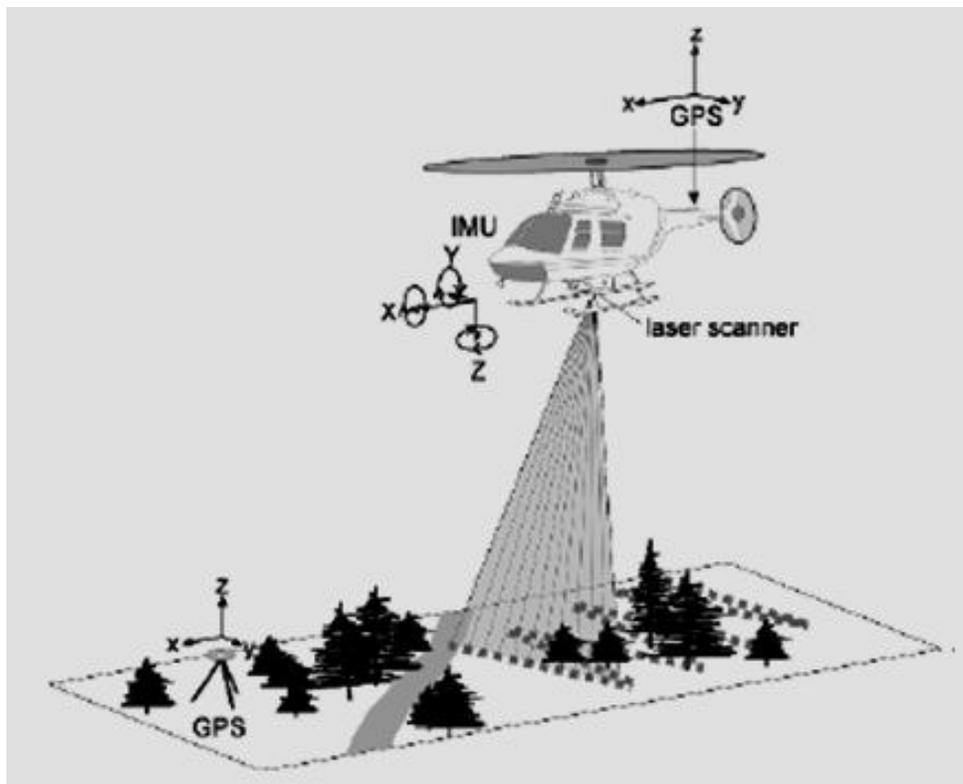


Figure 5.7: LiDAR schematic using an aircraft, global position system (GPS), and an inertial measuring unit (IMU) (T. L. Webster et al. 2004, p. 65).

5.4.2 Assessing environmental justice with LiDAR

Coastal flooding scenarios for Christchurch City and Wellington City are the same as those mentioned in section 5.2.1:

- Christchurch City – 2.50 m
- Wellington City – 2.30 m.

All points below these elevations were treated as flooded, whereas any elevation above these levels was not flooded and therefore not analysed.

The same social and socioeconomic data described in section 5.2.2 was used in correlation with LiDAR, which examined inequality. This required MBs to be selected in ArcGIS 9.2, using the ‘select features’ tool, to match the exact boundaries of the LiDAR coverage. All MBs spatially connected to the LiDAR data were further analysed with those steps described in section 5.2.3 and 5.3.

5.5 Summary of methodologies

This chapter described the approaches taken to solve the researches aims and objectives. First, the social and socioeconomic characteristics of the study areas were described. Second, the methodological datasets are outlined and placed into context with the methodological techniques. Lastly, additional steps described the approaches taken to test the sensitivity of the DEM. These theoretical considerations and methodological evaluations determine the frame of reference in which the results of this study are presented and discussed.

6. Results

This chapter presents the results of the studies aim and objectives. First, the results from the national investigation are presented, followed by a regional analysis. The quantitative results of the preceding are presented in graphs and tables using the two analytical techniques. The second part of the chapter displays the findings of one research objective: test the sensitivity of the DEM to resolve whether or not it portrays coastal flooding accurately, using the same analytical as the DEM. Furthermore, a detailed evaluation of the DEM’s and LiDAR’s spatial display and results explain the differences and similarities of the two datasets, including their capabilities to measure inequality.

6.1 The risk of coastal flooding in New Zealand

This subsection presents the results from the DEM and two spatial estimations of populations in MBs, derived from flooding scenarios in ArcGIS 9.2. An estimate of coastal flooded land in New Zealand includes a total of 1307km². The number of people located within this flood scenario is dependant on the type of analysis used, but is generally higher in places that are low-lying coastal urban or sub-urban centres such as Auckland, Bay of Plenty, and Canterbury. Of particular interest to this thesis are the socioeconomic and demographic conditions in the affected zones, specifically those indicators of social vulnerability developed in Chapter 2 and stated in Chapter 5.

6.1.1 Measuring inequality with a spatially uniform population

Analysis from a spatially uniform population in each MB shows that 83,422 people (2.06% of the total population) in New Zealand are at-risk to coastal flooding. The estimates for each region are given in Table 6.1. In addition, social variables are shown in Table 6.2, and income groups in Table 6.3, both with the associated CERI values.

Table 6.1: The regional distribution of risk to coastal flooding; measured with a spatially uniform population.

Region	Total population	At-risk population	Percentage of regional population at-risk
Auckland	1,308,798	28,983	2.21
Bay of Plenty	257,649	13,245	5.14
Canterbury	518,922	20,965	4.04
Gisborne	43,488	550	1.26
Hawkes Bay	146,952	4560	3.10
Manawatu-Wanganui	220,296	172	<0.01
Marlborough	48,081	351	0.73
Nelson	42,900	558	1.30
Northland	167,331	2213	1.32
Otago	192,456	855	0.44
Southland	90,984	129	0.14
Taranaki	103,619	316	0.30
Tasman	45,234	2887	6.38
Waikato	384,972	2796	0.73
Wellington	448,131	4029	0.90
Westland	29,445	813	2.76
Total of New Zealand	4,049,253	83,422	N/A

Table 6.2: Inequality to coastal flooding by social group; measured with a spatially uniform population. CERI values >1.00 indicates inequality.

Demographic variable	Total population	Affected	CERI
Population	4,049,256	83,422	N/A
Females	2,071,992	42,111	0.99
People aged 0 to 14	761,541	16,018	0.93
People aged 15 to 64	2,341,188	53,296	1.00
People aged 65 and over	425,193	10,688	1.11
Total age count	3,527,922	80,002	N/A
Asian ethnic groups	341,298	4672	0.61
European ethnic groups	2,255,376	53,834	1.06
Maori ethnic groups	491,982	9716	0.88
Pacific Peoples' ethnic groups	255,903	7098	1.23
Total ethnic count	3,344,559	75,320	N/A

Table 6.3: Inequality to coastal flooding by income group; measured with a spatially uniform population. CERI values >1.00 indicates inequality.

Personal income	Total population	Affected	CERI
\$0 to \$5000	327,051	6190	0.85
\$5001 to \$10,000	189,687	3654	0.87
\$10,001 to \$20,000	507,492	12,618	1.12
\$20,001 to \$30,000	374,691	8435	1.02
\$30,001 to \$50,000	559,770	12,970	1.05
\$50,001 and above	443,457	9354	0.95
Total income count	2,402,148	53,221	N/A

The risk of coastal flooding is highest in the regions of Auckland, Bay of Plenty, and Canterbury. When combined, these three regions comprise just over 50% of the total population but over 75% of the at-risk population. Similarly, the following regions display the highest percentages (>3.00%) of at-risk populations: Bay of Plenty, Canterbury, Hawkes Bay, and Tasman.

Inequalities to coastal flooding in New Zealand are apparent in several social groups, including people aged 65 and over (1.11), and Pacific peoples' (1.23). Other vulnerable groups have a CERI value of ≤ 1.00 , indicating lower risk, such as females, people aged 0 to 14, Maori, and Asians; whereas less vulnerable people, such as Europeans, have a higher risk a value of 1.06. Income groups display inequality in groups with a total personal income of \$10,001 to \$20,000, \$20,001 to \$30,000, and \$30,001 to \$50,000. People with either extreme high or low personal income display CERI values <1.00 such as \$0 to \$10,000, and \$50,001 and above.

6.1.2 Measuring inequality with PWCs

Analysis with PWCs determined a total of 63,936 people (1.58% of the total measured population) are at-risk (Figure 6.2). Estimates for each region are provided

in Table 6.4. Furthermore, Table 6.5 shows social groups and Table 6.6 income groups, both with respective CERI values. In addition, Table 6.7 displays the distribution of affected people according to individual deprivation deciles.

Table 6.4: Regional distribution of risk to coastal flooding; measured with PWCs.

Region	Total population	At-risk population	Percentage of regional population at-risk
Auckland	1,308,798	16,581	1.27
Bay of Plenty	257,649	11,847	4.60
Canterbury	518,922	20,016	3.86
Gisborne	43,488	495	1.14
Hawkes Bay	146,952	4311	2.93
Manawatu-Wanganui	220,296	0	0.00
Marlborough	48,081	288	0.60
Nelson	42,900	423	0.99
Northland	167,331	1893	1.13
Otago	192,456	153	<0.01
Southland	90,984	66	<0.01
Taranaki	103,614	48	<0.01
Tasman	45,234	2544	5.62
Waikato	384,972	2448	0.64
Wellington	448,131	2460	0.55
Westland	29,445	363	1.23
Total	4,049,253	63,936	N/A

Table 6.5: Inequality to coastal flooding by social group; measured with PWCs. CERI values >1.00 indicates inequality.

Demographic variable	Total population	Affected	CERI
Population	4,049,256	64,488	N/A
Females	2,071,992	32,613	1.00
People aged 0 to 14	761,541	12,960	0.96
People aged 15 to 64	2,341,188	40,926	0.99
People aged 65 and over	425,193	8481	1.13
Total aged population	3,527,922	62,367	N/A
Asian ethnic groups	341,298	3207	0.53
European ethnic groups	2,255,376	41,925	1.05
Maori ethnic groups	491,982	8244	0.95
Pacific Peoples' ethnic groups	255,903	5745	1.27
Total ethnic count	3,344,559	59,121	N/A

Table 6.6: Inequality to coastal flooding by income group; measured with PWCs. CERI values >1.00 indicates inequality.

Personal income	Total population	Affected	CERI
\$0 to \$5000	327,051	5052	0.86
\$5001 to \$10,000	189,687	3243	0.95
\$10,001 to \$20,000	507,492	10,182	1.11
\$20,001 to \$30,000	374,691	7095	1.05
\$30,001 to \$50,000	559,770	10,536	1.04
\$50,001 and above	443,457	7137	0.89
Total income count	2,402,148	43,245	N/A

Table 6.7: Inequality to coastal flooding by deprivation; measured with PWCs. CERI values >1.00 indicates inequality. Lowest deprivation is decile 1 and highest deprivation is decile 10.

Decile	Total Population	Affected	CERI
1	393,510	3669	0.55
2	385,305	3138	0.48
3	383,331	5043	0.77
4	372,804	6114	0.96
5	359,826	8577	1.40
6	367,278	10,017	1.60
7	361,581	7512	1.22
8	360,567	8358	1.36
9	371,604	6870	1.09
10	361,578	3888	0.63
Total Count	3,717,384	63,186	N/A
1 to 5	1,894,776	26,541	0.82
6 to 10	1,822,608	36,645	1.18

The distribution of coastal flood risk using PWCs is highly concentrated in three regions; Auckland, Bay of Plenty, and Canterbury. In addition, regions such as Hawke’s Bay and Tasman have higher percentages of populations with risk to coastal flooding. Together, these five regions comprise over 75% of the total at-risk population. Inequality in respective social groups is highest in people aged 65 and over and Pacific peoples. In income groups, higher rates are in groups \$10,001 to \$50,000, with the highest CERI value found in \$10,001 to \$20,000 (1.11). Furthermore, inequality in deprivation deciles is highest in areas of middle and high deprivation. Middle deprivation deciles 5 and 6 have the two highest values (1.40 and 1.60), and low deprivation deciles 1 and 2 have the two lowest values (0.55 and 0.48). Additionally, higher deprivation deciles 6 to 10 display a cumulative value of 1.14 in comparison to lower deprivation deciles 1 to 5 of 0.82.

6.1.3 Comparative analyses of the assessment methods

Comparisons of the two methods of analyses display similar CERI values for each demographic group in New Zealand (Figure 6.1). Although both methods estimate the total number of people at-risk differently, they show consistency when measuring inequality, which is the purpose of this project. The largest variations are found in Asians (0.08) and (0.07).

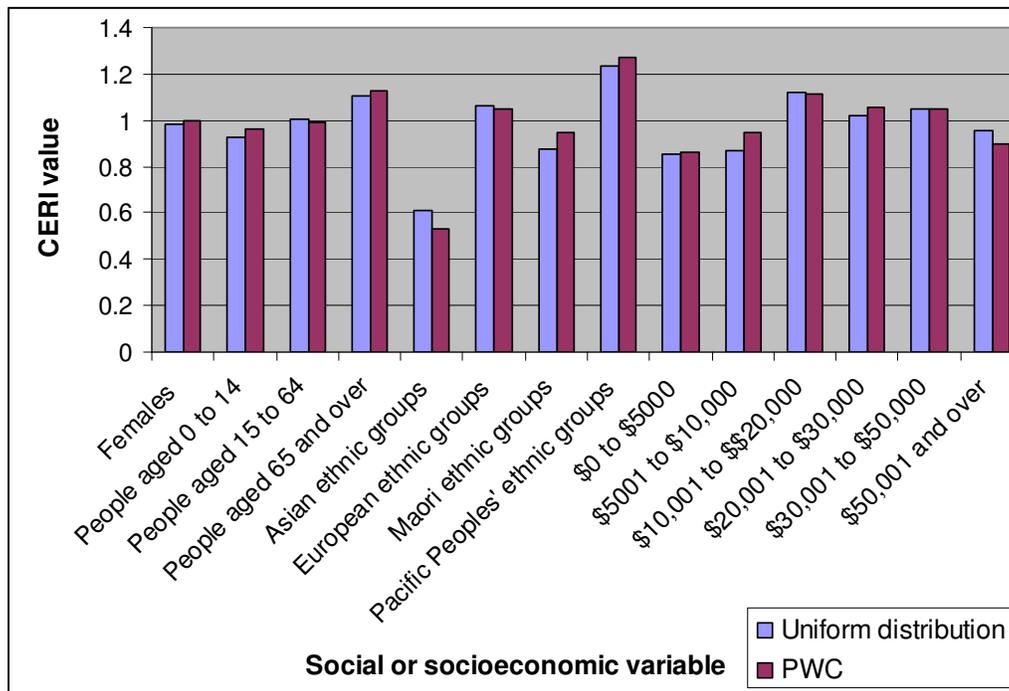


Figure 6.1: Comparative CERI values for demographic groups in New Zealand. CERI values >1.00 indicate inequality.

6.2 Significant risk in New Zealand regions

This subsection presents the variations of risk and inequality for each region in New Zealand, which answers one of the research objectives: verify if risk to coastal flooding and associated inequality is consistent in each of the 16 New Zealand regions. A regional analysis of environmental justice can consider the data across the whole region and how each region contributes to the national pattern (Walker et al. 2006b). The benefit of this analysis is that it accounts for the demographic differences in each New Zealand region. For example, regional contrasts in the total percentage of the populations at-risk reveals that many areas are <1.00% in either one and/or the other method of analysis (Tables 6.1 and 6.4). These regions include Manawatu-Wanganui, Marlborough, Nelson, Otago, Southland, Taranaki, Waikato, and Wellington; therefore the regions will not undergo further analysis because they have a small contribution to the national results. In contrast, Auckland, Bay of Plenty, Canterbury, Gisborne, Hawke's Bay, Northland, Tasman, and Westland show larger percentages of at-risk populations, all >1.00% (Tables 6.1 and 6.4). The considerable differences relate to the size of a settlement and whether or not it is near a low-lying coastal area.

6.2.1 Regional inequality; measured with a spatially uniform population

Given the differences in the regional distribution of risk and inequality, Table 6.8 shows the eight regions where >1.00% of the population is at-risk and their inequalities, according to analysis with a spatially uniform population. There is no general pattern of inequality found in these regions, rather they are quite diverse. However, interpretation of the regional results should not lead to misleading conclusions for the whole country; instead, assumptions should be made for the region only and its affects on the national results. For example, inequality is very high for Pacific peoples in Auckland, but low in most other regions and therefore Auckland contributes to an overall high inequality for New Zealand.

Regional inequalities display large contrasts in each social and socioeconomic group. Auckland is a prime example of environmental injustice because of the strong correlation of higher coastal flooding risk and high CERI values in socially vulnerable populations; such as people aged 0 to 14 (1.02), people aged 65 and over (1.20), Maori (1.21), Pacific peoples (1.58), and lower personal incomes. Other significant inequalities appear in Canterbury and people aged 0 to 14; Canterbury and Tasman and Maori; Bay of Plenty, Gisborne, Hawke's Bay, Northland, and Tasman and people aged 65 and over; and Northland, Tasman, and Westland and personal income group \$10,001 to \$20,000

Table 6.8: The regional distribution of risk and inequality by demographic group; measured with a spatially uniform population. CERI values are in parentheses and values >1.00 indicates inequality

Demographic variable	Auckland	Bay of Plenty	Canterbury	Gisborne	Hawke's Bay	Northland	Tasman	Westland
Females	14,707 (0.99)	6602 (0.97)	10,804 (1.00)	289 (1.02)	2257 (0.96)	1058 (0.94)	1423 (0.98)	452 (1.12)
People aged 0 to 14	6454 (1.02)	2205 (0.74)	4324 (1.06)	89 (0.66)	838 (0.83)	335 (0.83)	395 (0.67)	121 (0.82)
People aged 15 to 64	18,731 (0.94)	8635 (1.08)	13,957 (1.02)	349 (1.11)	3077 (1.16)	1096 (1.02)	1864 (1.04)	521 (1.11)
People aged 65 and over	3374 (1.20)	1996 (1.05)	2426 (0.84)	74 (1.18)	458 (0.76)	298 (1.18)	504 (1.31)	80 (0.76)
Asian ethnic groups	3703 (0.71)	244 (0.65)	482 (0.41)	3 (0.34)	48 (0.45)	9 (0.28)	16 (0.46)	2 (0.24)
European ethnic groups	14,100 (0.91)	9633 (1.22)	16,225 (1.03)	332 (1.27)	3276 (1.12)	1523 (1.21)	2114 (0.98)	626 (1.05)
Maori ethnic groups	3701 (1.21)	1786 (0.55)	1707 (1.16)	169 (0.74)	846 (0.85)	388 (0.65)	247 (1.36)	45 (0.61)
Pacific Peoples' ethnic groups	6271 (1.58)	132 (0.42)	400 (0.91)	8 (0.53)	14 (0.09)	17 (0.33)	16 (0.79)	10 (1.50)
\$0 to \$5000	2783 (0.95)	815 (0.81)	1521 (0.81)	30 (0.70)	346 (0.97)	66 (0.68)	148 (0.72)	27 (0.57)
\$5001 to \$10,000	1421 (1.02)	438 (0.63)	1132 (0.95)	34 (1.14)	166 (0.70)	24 (0.33)	77 (0.58)	33 (0.84)
\$10,001 to \$20,000	3560 (1.11)	2085 (0.94)	3622 (1.05)	86 (0.91)	728 (0.94)	297 (1.38)	598 (1.34)	172 (1.47)
\$20,001 to \$30,000	2644 (1.07)	1424 (0.98)	2398 (1.01)	60 (0.99)	502 (0.98)	133 (1.00)	328 (1.13)	55 (0.84)
\$30,001 to \$50,000	4396 (1.00)	2149 (1.11)	3815 (1.09)	64 (0.87)	793 (1.13)	161 (0.97)	326 (0.90)	88 (0.99)
\$50,001 and above	3540 (0.90)	1717 (1.30)	2224 (0.96)	66 (1.67)	461 (1.11)	104 (1.02)	170 (0.80)	37 (0.68)

6.2.2 Regional inequality; measured with PWCs

The previous subsection displays large regional variations in risk and inequality, which supports the importance of regional analysis because of each place's demographic characteristics. This subsection measures the same regions but using the second method of analysis, PWCs. Similar to a uniform population, the number of people at-risk and levels of inequality are diverse in each region (Tables 6.9 and 6.10).

Regional inequalities, using PWCs, are considerably similar to the previous method. Auckland displays the most injustice with all socially vulnerable populations having CERI values >1.00 such as people aged 0 to 14 (1.09), people aged 65 and over (1.15), Maori (1.43), Pacific peoples (2.04), and lower personal incomes. In addition, Auckland shows increasing inequality with higher deprivation. In fact, the highest deprivation deciles 8, 9, and 10 have the three highest CERI values ranging from 1.39 to 2.15; whereas the two lowest deprivation deciles 1 and 2 have the two lowest values of 0.28 to 0.36. Other significant regional inequalities are in people aged 0 to 14 in Canterbury; people aged 65 and over in Bay of Plenty, Gisborn, Northland, and Tasman; Maori in Canterbury and Tasman; Pacific peoples in Tasman and Westland; and income group \$10,001 to \$20,000 in Northland, Tasman, and Westland. Lastly, inequality in higher deprivation deciles 6 to 10 is shown in Canterbury, Gisborne, Hawke's Bay, Tasman, and Westland.

Table 6.9: The regional distribution of risk and inequality by demographic group; measured with PWCs. CERI values are in parentheses and values >1.00 indicate inequality.

Demographic variable	Auckland	Bay of Plenty	Canterbury	Gisborne	Hawke's Bay	Northland	Tasman	Westland
Females	8748 (1.00)	5985 (0.98)	10,335 (1.01)	249 (0.97)	2187 (0.99)	963 (1.00)	1320 (1.03)	171 (0.95)
People aged 0 to 14	3951 (1.09)	2172 (0.80)	4116 (1.06)	78 (0.68)	831 (0.86)	387 (0.96)	441 (0.82)	72 (1.00)
People aged 15 to 64	10,539 (0.94)	7716 (1.06)	13,383 (1.02)	279 (1.04)	2844 (1.08)	1026 (0.95)	1581 (0.97)	234 (1.02)
People aged 65 and over	1860 (1.15)	1866 (1.07)	2310 (0.83)	81 (1.51)	513 (0.88)	330 (1.30)	495 (1.41)	45 (0.88)
Asian ethnic groups	2160 (0.70)	273 (0.79)	507 (0.44)	6 (0.83)	75 (0.73)	24 (0.77)	18 (0.53)	0 (0.00)
European ethnic groups	6852 (0.75)	8718 (1.20)	15,531 (1.02)	291 (1.34)	3078 (1.10)	1266 (1.05)	2025 (0.96)	255 (1.02)
Maori ethnic groups	2568 (1.43)	1632 (0.55)	1743 (1.22)	117 (0.62)	780 (0.81)	543 (0.95)	258 (1.45)	30 (0.96)
Pacific Peoples' ethnic groups	4752 (2.04)	216 (0.75)	423 (0.99)	12 (0.95)	69 (0.45)	27 (0.55)	36 (1.83)	3 (1.06)
\$0 to \$5000	1635 (1.00)	834 (0.86)	1530 (0.83)	27 (0.80)	351 (0.97)	138 (0.98)	177 (0.76)	21 (0.77)
\$5001 to \$10,000	840 (1.07)	525 (0.79)	1128 (0.97)	21 (0.90)	207 (0.86)	105 (1.01)	144 (0.96)	21 (0.93)
\$10,001 to \$20,000	2079 (1.15)	1920 (0.90)	3429 (1.01)	69 (0.93)	669 (0.86)	324 (1.03)	585 (1.17)	81 (1.21)
\$20,001 to \$30,000	1536 (1.11)	1380 (0.98)	2415 (1.04)	51 (1.07)	534 (1.03)	165 (0.85)	354 (1.08)	39 (1.03)
\$30,001 to \$50,000	2532 (1.02)	2073 (1.11)	3669 (1.08)	54 (0.94)	747 (1.06)	219 (0.91)	381 (0.94)	45 (0.88)
\$50,000 and above	1677 (0.76)	1584 (1.25)	2190 (0.97)	45 (1.45)	510 (1.22)	189 (1.28)	207 (0.87)	30 (0.96)

Table 6.10: The regional distribution of risk and inequality by deprivation; measured with PWCs. CERI values are in parentheses and values >1.00 indicate inequality. Lowest deprivation is decile 1 and highest deprivation is decile 10.

Decile	Auck-land	Bay of Plenty	Canter-bury	Gis-borne	Hawke's Bay	North-land	Tas-man	West-land
1	492 (0.28)	318 (0.43)	2859 (1.03)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
2	681 (0.36)	684 (0.72)	1236 (0.52)	0 (0.00)	0 (0.00)	0 (0.00)	519 (1.77)	0 (0.00)
3	660 (0.36)	846 (0.79)	1755 (0.79)	0 (0.00)	465 (1.33)	0 (0.00)	264 (0.78)	0 (0.00)
4	1479 (0.92)	1725 (1.83)	1422 (0.60)	0 (0.00)	450 (1.28)	96 (0.75)	147 (0.43)	0 (0.00)
5	1326 (0.87)	2058 (1.97)	3066 (1.41)	0 (0.00)	408 (1.08)	477 (2.73)	513 (1.29)	0 (0.00)
6	1659 (1.09)	1983 (1.68)	3051 (1.41)	0 (0.00)	1437 (2.92)	669 (2.79)	375 (1.80)	0 (0.00)
7	1617 (1.08)	1563 (1.31)	2235 (1.26)	372 (8.45)	615 (1.18)	174 (0.80)	288 (0.87)	105 (2.06)
8	2157 (1.39)	1932 (1.48)	2163 (1.22)	0 (0.00)	558 (1.38)	93 (0.39)	198 (0.68)	156 (2.03)
9	3345 (2.15)	474 (0.30)	1869 (1.20)	123 (1.69)	354 (0.78)	258 (0.75)	108 (1.66)	102 (2.48)
10	3138 (1.70)	0 (0.00)	360 (0.41)	0 (0.00)	0 (0.00)	132 (0.44)	132 (4.57)	0 (0.00)
Total	16,554	11,583	20,016	495	4287	1893	2544	363
1 to 5	4638 (0.54)	5631 (1.19)	10,338 (0.87)	0 (0.00)	1323 (0.75)	573 (1.03)	1443 (0.89)	0 (0.00)
6 to 10	11,916 (1.50)	5952 (0.52)	9678 (1.19)	495 (1.39)	2964 (1.17)	1320 (0.99)	1101 (1.19)	363 (1.62)

6.2.3 Summary of the regional analyses

Regional analyses of both methods exhibit large variations in CERI values. Both methods indicate that Auckland has the largest degree of inequality, whereas other regions show inequality to a lesser degree. Thus, analyses display an uneven regional distribution of risk and inequality and their contribution towards the national results.

For coastal flooding, the overall population at-risk is concentrated in the regions with the highest populations; Auckland, Bay of Plenty, and Canterbury. Together these regions comprise 51.49% of the total population (4,049,253) and even more lopsided, 75.75% to 75.77% of the total at-risk population (63,936 and 83,422), depending on the type of analyses. In contrast, regions such as Gisborne, Manawatu-Wanganui, Marlborough, Nelson, Southland, Taranaki, and Westland constitute 19.06% of the total population but only 2.86% to 4.49% of the total

population at risk. Therefore, when subsequent regional analysis takes place, results are often unstable when compared nationally.

The inequalities found in this research are mainly from select regions. For ethnic groups, Pacific peoples have the largest disparities with national CERI values from 1.23 to 1.27. Both methods of analyses clearly indicate that Auckland contains the majority of the total population of Pacific peoples (66.90%) and the population at-risk (82.71% to 88.35). This is not surprising, especially considering 73.49% of Pacific Islanders who immigrate to New Zealand from the Pacific Islands, choose to reside in the Auckland region (New Zealand Census 2006). All the other regions have CERI values <1.00 except sparsely populated Westland, thus indicating the effect that the Auckland region has on the national analyses.

Of additional concern are the high CERI values amongst Maori in the Auckland region (1.21 to 1.43), although nationally they have lower CERI values from 0.87 to 0.95. This is partially due to the fact that 27.92% of all Maori live in the Auckland region, in addition to 31.15% to 38.09% of the total at-risk population. Other regions that contain CERI values >1.00 for Maori are Canterbury and Tasman, which results in 7.36% and 0.62% of the total population and depending on the method of analysis, 17.57% to 21.14% and 2.54% to 3.13% of the at-risk population, respectively.

The highest inequality for age groups is in people aged 65 and over with CERI values from 1.11 to 1.13. The regional distribution is generally consistent because equally high values are found throughout different regions; hence Auckland does not skew the national values as much. In fact, four of the eight regions display comparable results for both methods of analyses including Auckland, Gisborne, Northland, and Tasman. Similarly, the Bay of Plenty only displays this in the PWC method

There is an overall high inequality in the income group \$10,001 to \$20,000. Five regions show this disparity such as Auckland, Canterbury, Northland, Tasman, and Westland. These regions encompass both the lowest median total personal income of \$20,400 (Westland) to the second highest of \$26,800 (Auckland); whereas the New Zealand mean is \$24,400. However, even though Auckland has a high median income, this lower income group has the highest inequality, thus resulting in environmental injustice. Furthermore, Canterbury, Northland, and Tasman all have mean personal income below the national mean but still above \$20,000.

In New Zealand, there is a strong inequality found in deprivation deciles 5 to 9 with related CERI values of 1.40, 1.60, 1.22, 1.36, and 1.12. Further investigation shows similar patterns in most regions with some slight inconsistencies in others. For instance, there is a general relationship with inequality and higher deprivation in Auckland, with deciles 9 and 10 having the highest values of 2.15 and 1.70. Furthermore, Auckland contains the highest proportion of these deciles as well as the vast majority of people at-risk. For instance the region contains 32.96% of the total decile 9 population and 40.16% of decile 10; in addition to 48.69% of the total at-risk population for decile 9 and 80.71% for decile 10. Clearly, these results sway national CERI values, especially bearing in mind the abundance of 0.00 CERI values found nationally in decile 10. Other less populated regions with high proportions of higher deprivation people include the Bay of Plenty (deciles 7 and 8), Gisborne (deciles 7 and 9), Tasman (decile 9 and 10), and Westland (deciles 7, 8, and 9). Canterbury displays interesting results that are consistent with national findings with high CERI values in deciles 5, 6, 7, 8, and 9; but also contains a rarely high CERI value in decile 1 of 1.02. Moreover, the region contains 77.92% of the at-risk population for decile 1 while only having 18.31% of the total population. Similarly, regions with high proportions of low deprivation populations' at-risk are the Bay of Plenty (decile 4), Hawke's Bay (decile 3), and Tasman (decile 2).

This section provides results that indicate different rates of inequalities in each New Zealand region. In addition, it shows the benefits of considering and interpreting the regional results in coordination with the national results, so that misinterpretations are not made. Other mistakes can arise from the elevation datasets and thus far this research only uses the DEM to signify where the coastal flooding will likely occur. To test the sensitivity of the DEM, comparison should be made with another, possibly more precise dataset.

6.3 The sensitivity of the DEM

This section addresses one of the research objectives: test the sensitivity of the DEM to resolve whether or not it portrays coastal flooding accurately. LiDAR for Wellington City and Christchurch City provide sufficient datasets to compare the DEM against. First a comparison of the spatial coverage of flooding for LiDAR and the relative areas of the DEM provides a geographical reference of risk. Second, the same analytical methods from the previous sections will examine inequality to SLR

and storm tides using LiDAR and compare them to the results of the DEM. Comparing both the spatial extent of coastal flooding and the resulting inequality will provide an indication to the accuracy of the DEM.

6.3.1 Analysis in Wellington City with a spatially uniform population

This subsection provides explicit focus on Wellington City (Figure 5.2A) using the same analyses as the above sections. Results indicate that the different datasets display spatially diverse flood areas, hence population statistics are different. However, the flood zones are difficult to portray because the areas are minimal, so a comparable map is not shown. The flood extent and therefore the amount of people it affects depend on the dataset. The DEM shows a total of 529 people (0.33% of the total population) are at-risk while LiDAR estimates 961 people (0.61% of the total population). For demographic comparisons, refer to Tables 6.11 and 6.12.

Table 6.11: Social comparison of inequality in Wellington City by dataset; measured with a spatially uniform population. CERI values >1.00 indicate inequality.

Demographic variable	Affected in DEM	Affected in LiDAR	CERI in DEM	CERI in LiDAR	Total population
Population	529	961	N/A	N/A	158,598
Females	278	480	1.02	0.97	81,903
People aged 0 to 14	87	100	1.01	0.72	26,520
People aged 15 to 64	366	644	0.96	1.06	116,697
People aged 65 and over	56	69	1.33	1.02	12,960
Total age count	509	813	N/A	N/A	156,177
Asian ethnic groups	33	26	0.50	0.27	19,632
European ethnic groups	379	601	1.07	1.15	106,170
Maori ethnic groups	43	55	1.12	0.97	11,511
Pacific Peoples' ethnic groups	28	32	1.09	0.84	7710
Total ethnic count	483	714	N/A	N/A	145,023

Table 6.12: Income comparison of inequality in Wellington City by dataset; measured with a spatially uniform population. CERI values >1.00 indicate inequality.

Personal income	Affected in DEM	Affected in LiDAR	CERI for DEM	CERI for LiDAR	Total population
\$0 to \$5000	40	55	0.88	0.75	14,568
\$5001 to \$10,000	11	26	0.41	0.59	8700
\$10,001 to \$20,000	58	73	1.05	0.82	17,661
\$20,001 to \$30,000	47	61	1.13	0.90	13,395
\$30,001 to \$50,000	87	152	1.06	1.14	26,382
\$50,001 and above	117	215	1.08	1.22	34,854
Total income count	360	582	N/A	N/A	115,560

The two datasets show differences in the total number of people at-risk as well as their levels of inequality, mainly because the flood areas in each dataset are different. This equates to 432, or 82.66%, more people are at-risk when using LiDAR. Moreover, differences in CERI values for social groups range from 0.05 (females) to 0.31 (people aged 65 and over). The DEM displays more groups with values >1.00, including vulnerable groups, such as females, people aged 0 to 14, people aged 65 and over, Maori, Pacific peoples, and income groups from \$10,001 and above. Conversely, LiDAR displays higher CERI values among less vulnerable groups, such as people aged 15 to 64, Europeans, and income groups \$30,001 and above.

6.3.2. Analysis in Wellington City with PWCs

Analysis with PWCs in Wellington provides minimal results, such as only three MBs in the DEM are affected and six MBs in LiDAR. Moreover, only one MB in both the DEM and LiDAR was commonly affected. This equates to 141 people (0.09% of the total population) are at-risk with the DEM and 129 people (0.08% of the total population) are at-risk with LiDAR (Figure 6.2). These figures both include 63 females, which results in CERI values of 0.86 for the DEM and 1.04 for LiDAR. Results do not show remaining social variables because such a small sample size and lack of data in the NZCensus06.

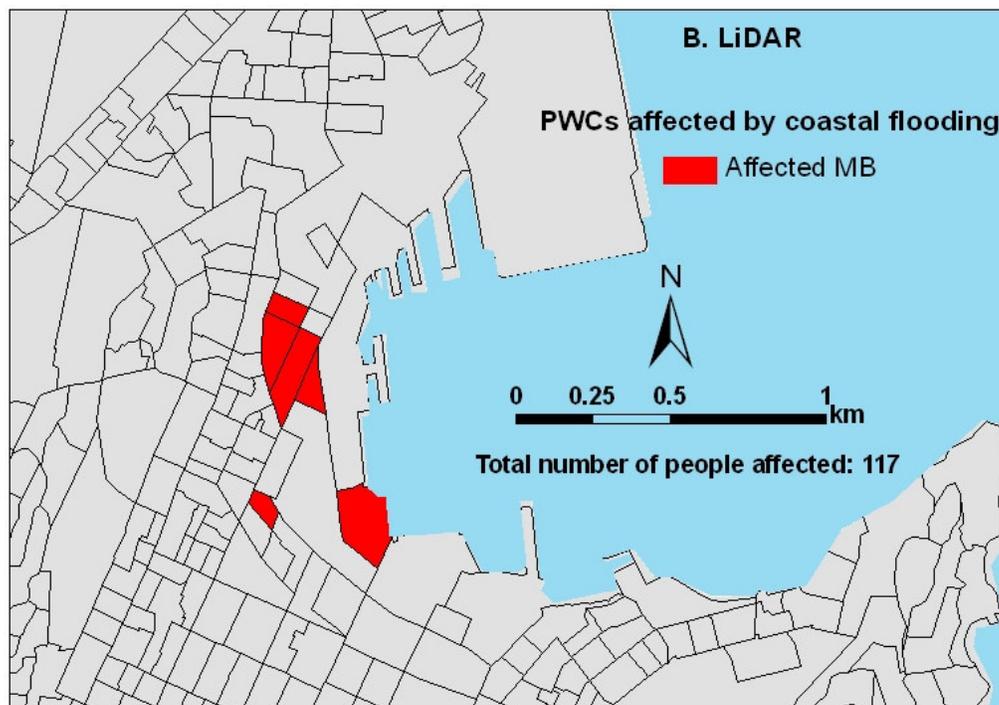
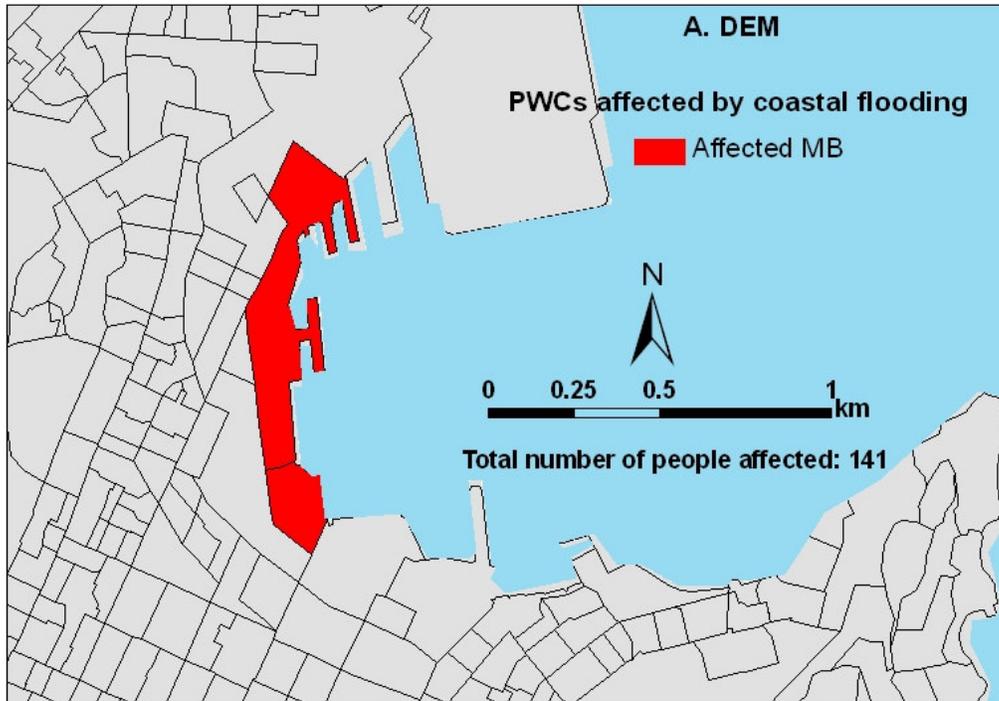


Figure 6.2: Comparison of affected MBs in Wellington City using A) DEM and B) LiDAR.

Comparative analysis of the elevation datasets shows that the DEM estimates less MBs to be affected, but an overall higher population count. This also includes

one additional MB that is located a great distance away from Figure 6.2A, thus bringing the total number of affected MBs to three.

6.3.3 Analysis in Christchurch City with a spatially uniform population

This subsection provides specific focus on Christchurch City using the same analysis as in sections 6.3.1. This is to further test the sensitivity of the DEM in comparison with LiDAR, which supplies addition evidence to its accuracy. In addition, Christchurch City and Wellington City are topographically different and therefore provides an indication to the accuracy of the DEM in two different environments. For instance, Christchurch City is more flat and near a shallow estuarine environment, whereas Wellington City has steeper topography and near a deeper harbour.

The national DEM and LiDAR in Christchurch City display different results due to the spatial differences of the flood extent (Figure 6.3). Hence, inequalities are different for each dataset. The DEM shows a total of 17,079 people (13.17% of the population) are at-risk, while LiDAR shows 24,298 people (18.74% of the population). Furthermore, Tables 6.13 and 6.14 provides a demographic comparison of the affected people.

LiDAR exhibits 7219 more people at risk, 42.27% more than the DEM. In addition, there are some similarities in inequalities but also some very contrasting ones. For instance, the DEM displays people aged 0 to 14 to have the highest inequality amongst age groups, whereas LiDAR shows people aged 65 and over, resulting in differing CERI values of 0.11 and 0.27, respectively. Similarly, CERI values for Asians and Pacific peoples with LiDAR are both +0.24. Lastly, income groups display less disparity but still show differences in CERI values such as \$10,001 to \$20,000 is +0.08 in LiDAR and \$50,001 and above is +0.14 in the DEM.

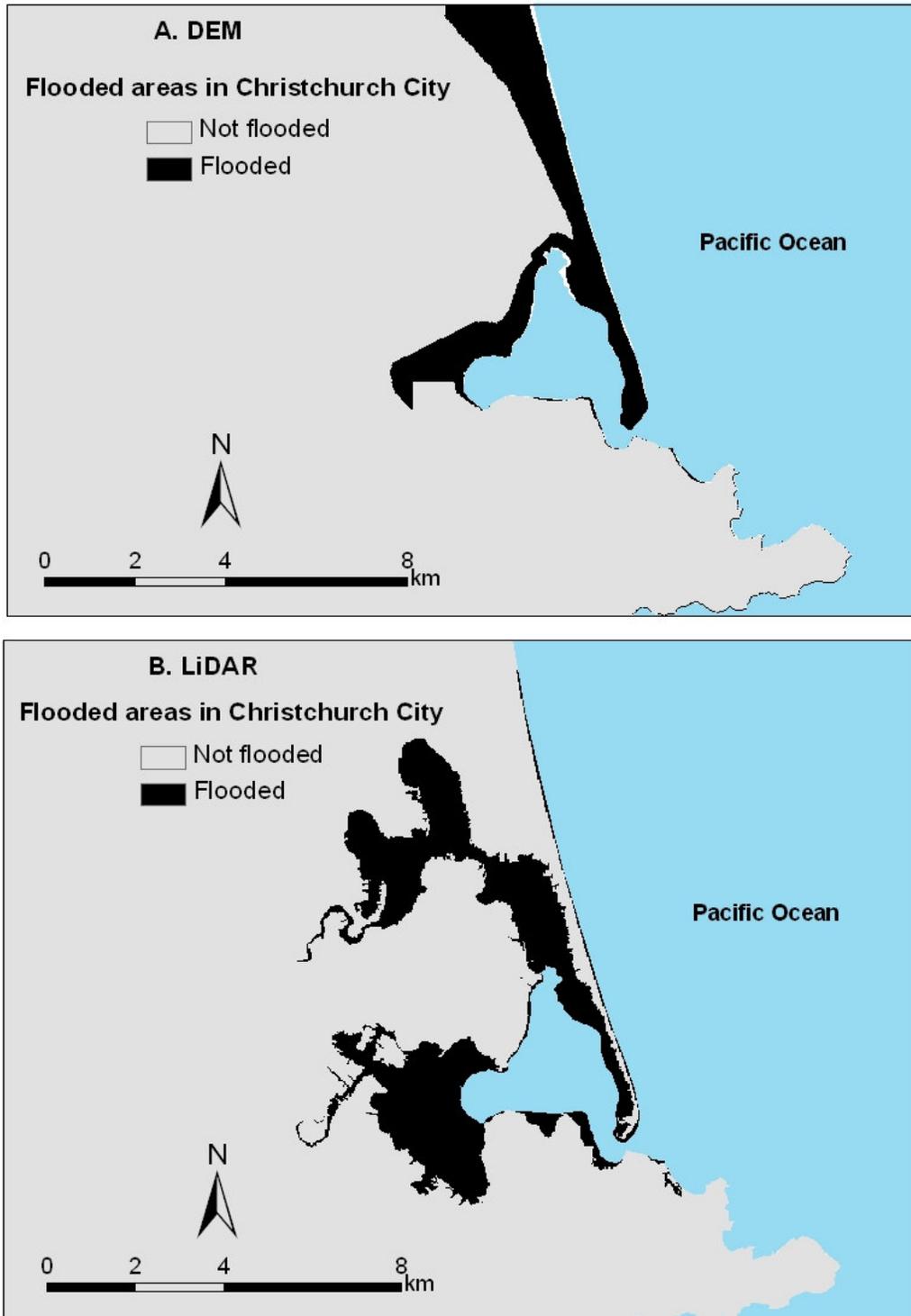


Figure 6.3: Coastal flood extent in Christchurch City with; A) the DEM and B) LiDAR.

Table 6.13: Social comparison of inequality in Christchurch City by dataset measured with a spatially uniform population. CERI values >1.00 indicate inequality.

Demographic variable	Affected in DEM	Affected in LiDAR	CERI in DEM	CERI in LiDAR	Total population
Population	17,079	24,298	N/A	N/A	129,648
Females	8839	12,551	1.00	1.00	66,864
People aged 0 to 14	3489	4484	1.03	0.92	25,803
People aged 15 to 64	11,393	15,935	1.00	0.98	86,331
People aged 65 and over	2054	3788	0.94	1.21	16,659
Total age count	16,936	24,207	N/A	N/A	128,793
Asian ethnic groups	459	908	0.60	0.84	5853
European ethnic groups	13,348	18,184	1.06	1.02	95,892
Maori ethnic groups	1392	2011	0.88	0.90	12,039
Pacific Peoples' ethnic groups	387	852	0.62	0.96	4785
Total ethnic count	15,586	21,955	N/A	N/A	118,569

Table 6.14: Income comparison of inequality in Christchurch City by dataset: measured with a spatially uniform population. CERI values >1.00 indicate inequality.

Personal income	Affected in DEM	Affected in LiDAR	CERI for DEM	CERI for LiDAR	Total population
\$0 to \$5000	1305	1865	0.93	0.93	10,584
\$5001 to \$10,000	960	1402	0.98	1.00	7383
\$10,001 to \$20,000	2960	4512	0.98	1.06	22,887
\$20,001 to \$30,000	2031	2997	0.96	1.00	15,957
\$30,001 to \$50,000	3136	4378	1.05	1.03	22,539
\$50,001 and above	1821	2265	1.06	0.92	13,041
Total income count	12,213	17,419	N/A	N/A	92,391

6.3.4. Analysis in Christchurch City using PWCs

Similar to the previous subsection, using PWCs to analyze inequalities in populations provides different results between LiDAR and a DEM. LiDAR results

show 19,815 people (14.90% of the population) live within a the flood zone, whereas the DEM shows 16,086 people (12.41% of the population). Figure 6.4 is a comparison of the MBs that are affected in both datasets. Furthermore, demographic inequalities are presented in Tables 6.15 and 6.16, including deprivation deciles in table 6.17.

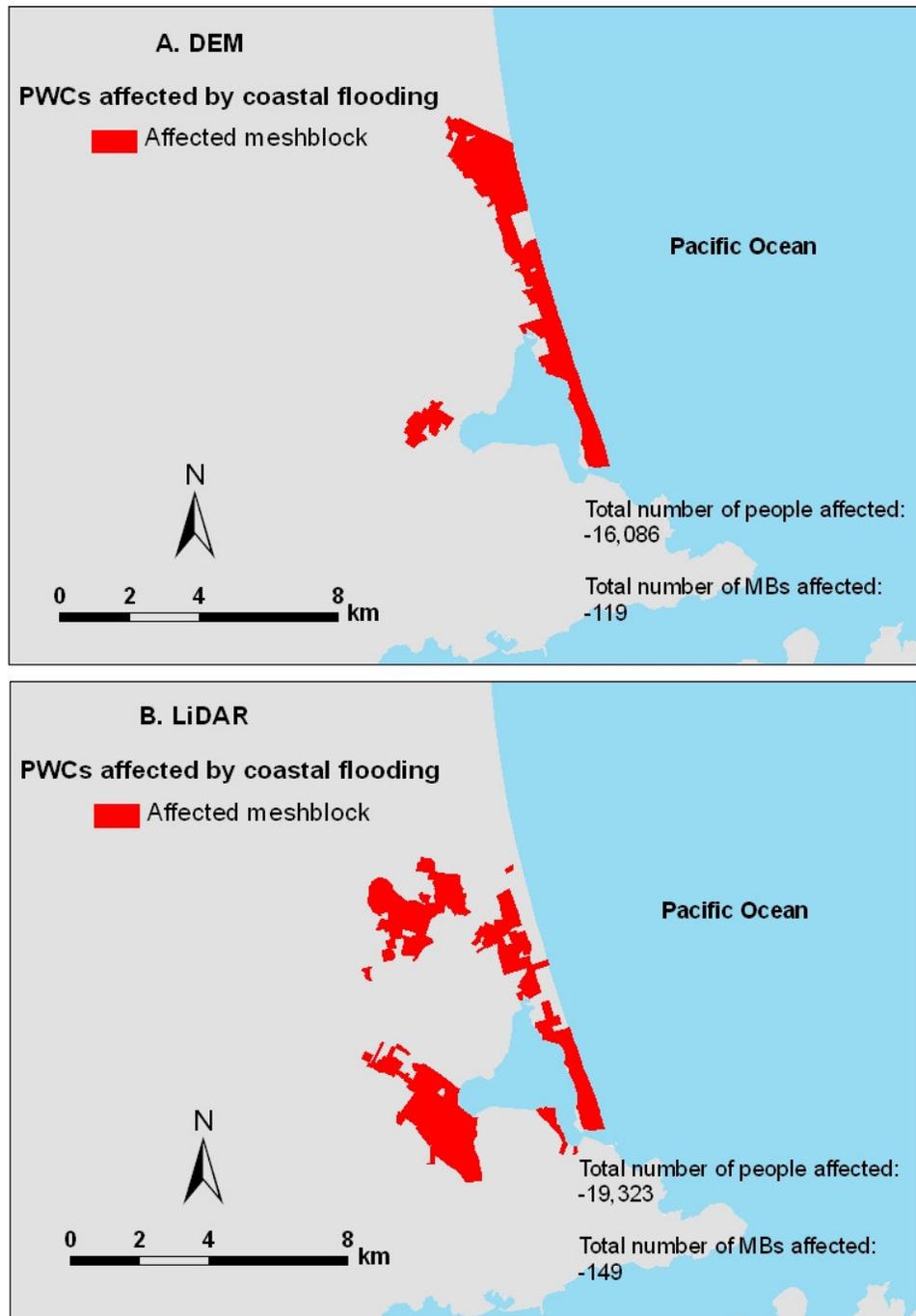


Figure 6.4: PWCs affected by coastal flooding in Christchurch City using A) DEM and B) LiDAR.

Table 6.15: Social comparison of inequality in Christchurch City by dataset; measured with PWCs. CERl values >1.00 indicate inequality

Demographic variable	Affected in DEM	Affected in LiDAR	CERl in DEM	CERl in LiDAR	Total population
Population	16,086	19,323	N/A	N/A	129,648
Females	8358	10,104	1.01	1.01	66,864
People aged 0 to 14	3255	3597	1.03	0.93	25,803
People aged 15 to 64	10,794	12,546	1.00	1.01	86,331
People aged 65 and over	1950	3147	0.94	1.26	16,659
Total age count	15,999	19,290	N/A	N/A	128,793
Asian ethnic groups	459	720	0.62	0.84	5853
European ethnic groups	12,783	14,577	1.05	1.04	95,892
Maori ethnic groups	1401	1506	0.92	0.85	12,039
Pacific Peoples' ethnic groups	378	588	0.62	0.84	4785
Total ethnic count	15,021	17,391	N/A	N/A	118,569

Table 6.16: Income comparison of inequality in Christchurch City by dataset; measured with PWCs. CERl values >1.00 indicate inequality.

Personal income	Affected in DEM	Affected in LiDAR	CERl for DEM	CERl for LiDAR	Total population
\$0 to \$5000	1266	1494	0.93	0.92	10,584
\$5001 to \$10,000	939	1155	0.99	1.02	7383
\$10,001 to \$20,000	2868	3624	0.97	1.03	22,887
\$20,001 to \$30,000	2007	2421	0.98	0.99	15,957
\$30,001 to \$50,000	3024	3531	1.04	1.02	22,539
\$50,001 and above	1779	1917	1.06	0.96	13,041
Total income count	11,883	14,142	N/A	N/A	92,391

Table 6.17: Deprivation comparison of inequality in Christchurch City by dataset; measured with PWCs. CERI values >1.00 indicate inequality.

Decile	Affected in DEM	Affected in LiDAR	CERI for DEM	CERI for LiDAR	Total population
1	2406	1725	1.23	0.73	15,723
2	888	864	0.72	0.58	9978
3	1125	3561	0.92	2.41	9885
4	1155	2238	0.93	1.50	10,002
5	2610	2751	1.77	1.55	11,865
6	2259	2835	1.48	1.55	12,297
7	1668	1338	1.29	0.86	10,458
8	2064	1695	0.95	0.65	17,547
9	1551	1428	0.67	0.51	18,711
10	360	888	0.22	0.45	13,182
Total	16,086	19,323	N/A	N/A	129,648
1 to 5	8184	11,139	1.14	1.30	57,453
6 to 10	7902	8184	0.88	0.76	72,195

Similar to a spatially uniform population, LiDAR displays more people at-risk and contrasting CERI values with PWCs. The CERI values show similarities with some groups and differences with others. Significant differences are in people aged 0 to 14, which is +0.10 in the DEM, and people aged 65 and over, which is +0.32 in LiDAR. Ethnic groups show +0.22 for Asians and Pacific peoples with the LiDAR, whereas +0.07 for Maori with the DEM. CERI values for income groups are fairly constant with the exception of \$10,001 to \$20,000, which is +0.06 with LiDAR and \$50,001 and above, which is +0.10 with the DEM. Furthermore, Table 6.17 shows variations in deprivation deciles. There is no consistent pattern, although the DEM has overall higher CERI values for higher deprivation deciles 6 to 10 and visa versa for LiDAR. For instance, decile 3 and 5 are +1.49 and +0.57, respectively, in LiDAR. In contrast, higher deprivation deciles 7, 8, and 9 are +0.43, +0.30, and +0.16 with the DEM. Other results that show inconsistencies are decile 1 (+0.50 with the DEM), and decile 10 (+0.20 with LiDAR).

The differences clearly arise from the dissimilar flood extents. As a result, flooding affects different MBs in different areas and therefore different population groups. In fact, flooding affects 149 MBs in LiDAR and 119 in the DEM, thus explaining the different population counts. Furthermore, flooding commonly affects 33 MBs in both dataset, equalling a sum of only 4788 people, thus explaining the different CERI values.

6.3.5 Concluding remarks for the DEM

In order to assess the spatial distribution of risk, the physical hazard must be understood within geographical framework to identify the “hazardousness” of a place (S.L. Cutter, Boruff & Shirley 2003). The analysis of the DEM’s sensitivity shows its capabilities to measure coastal flooding and inequality. The LiDAR datasets for Wellington City and Christchurch City provide insight into the accuracy and capability of the DEM to measure elevation points and populations susceptible to coastal flooding. Both comparisons display a different spatial coverage of flooding, and different levels of inequality. Generally, LiDAR estimates more people at-risk and different flood zones. However, some similarities were evident, which shows the partial accuracy a DEM has to measure coastal flooding as an environmental inequality.

Unfortunately, the flood extent in Wellington City is minimal, but Christchurch City’s is larger because of overall lower elevations. In comparison to an existing flood management plan from the CCC, Variation 48, which takes into account SLR and storm tides of similar predictions in this research, it is reasonable to suggest that LiDAR closely resembles the spatial coverage of flooding (Figure 6.5).

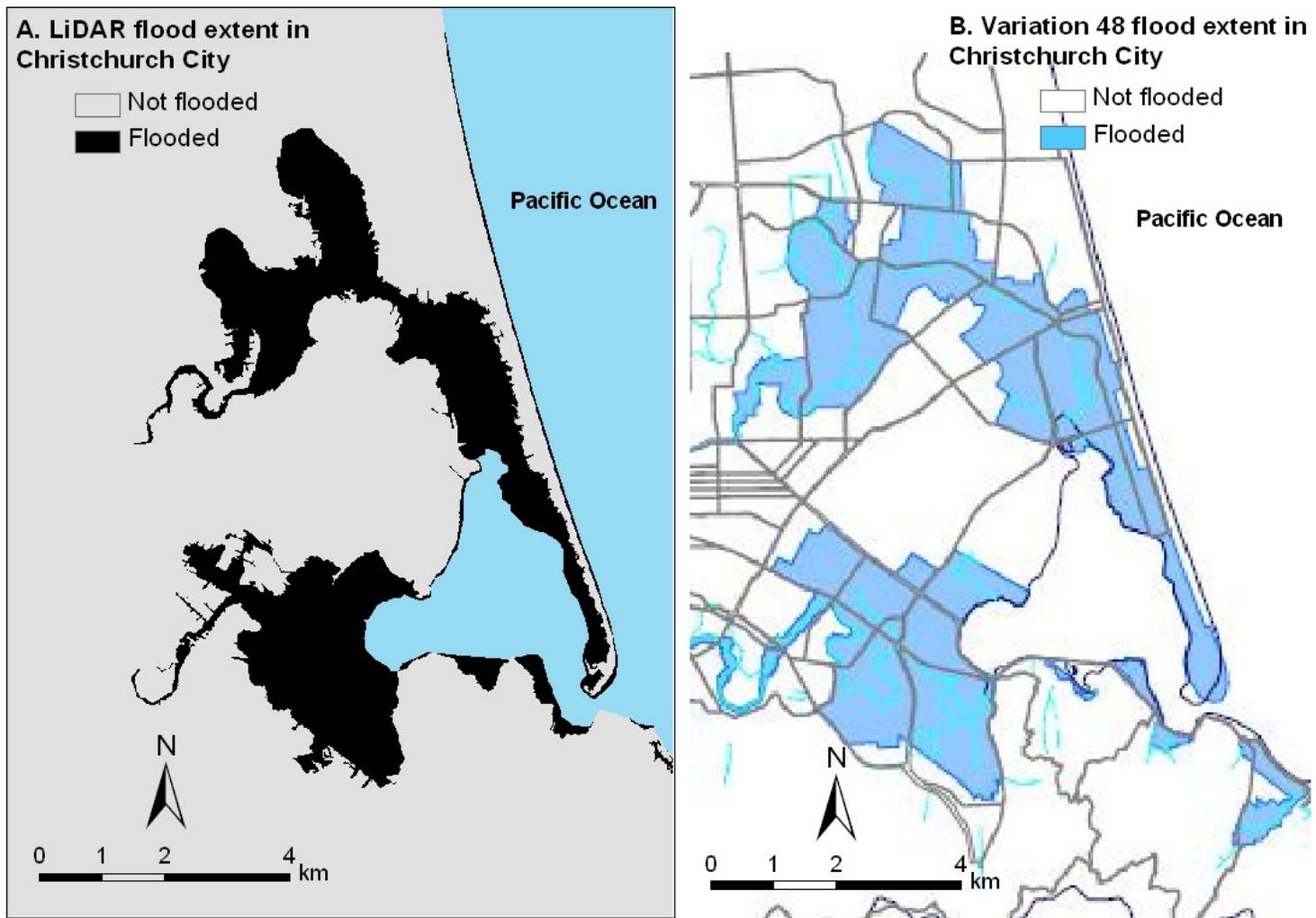


Figure 6.5: Predictions of coastal flooding in Christchurch City with; A) LiDAR; and B) Variation 48 from the CCC.

It is clear that LiDAR closely resembles the flood management plan from the CCC. In fact, the flood extent from LiDAR appears to be an underestimation of Variation 48. A reasonable explanation is that this project did not account for flooding as a result of high river flows from large rain events, which is accounted for in Figure 6.5B, and therefore the flood extent is spatially larger.

Accordingly, population estimates and CERI values in Christchurch City are different with each dataset. Assessment with a spatially uniform population and PWCs both demonstrate that coastal flooding affects more people when using LiDAR. Resulting CERI values show contrasts between each dataset. For instance, lower CERI values are found in people aged 0 to 14 and higher values for people aged 65 and over, Asians, Pacific peoples, and lower income; suggesting that many socially vulnerable populations have a higher risk to coastal flooding when using the LiDAR dataset.

Comparing the LiDAR dataset with the DEM provides an insight into the sensitivity of the DEM and the overall results of this thesis. Most notably, the LiDAR dataset shows a different spatial coverage of flooding that partially resembles Variation 48 from the CCC. Additionally, LiDAR tends to account for flooding that can occur in estuaries and rivers as a result of SLR and storm tides. Comparisons of the CERI values from both datasets also show dissimilarities, in addition to consistencies, which provoke additional caution when interpreting the results from the DEM.

6.4 Summary of results

This section provides the key findings of the analyses according to the research aim and objectives of the thesis.

6.4.1 The environmental justice of SLR and storm tides in New Zealand

National evidence from the DEM and two methods of analyses display similar inequalities among demographic and deprivation groups. A spatially uniform population produce CERI values ranging from 0.61 (Asian ethnic groups) to 1.23 (Pacific peoples'). Furthermore, PWCs' CERI values range 0.48 (deprivation decile 2) to 1.60 (deprivation decile 6).

Of specific importance to this project are whether or not socially vulnerable populations have inequalities, thus CERI values >1.00. Analysis from a spatially uniform population reveals several vulnerable populations with CERI values >1.00; such as

Pacific peoples' (1.23); people aged 65 and over (1.11); and income group \$10,001 to \$20,000 (1.10). Moreover, MBs' PWCs display inequalities among similar vulnerable populations, such as Pacific peoples' (1.27), people aged 65 and over (1.13), income groups \$10,001 to \$20,000 (1.11), and deprivation deciles 6 (1.60), 7 (1.22), 8 (1.36), and 9 (1.08).

6.4.2 Regional distribution of risk and inequality

Separate analysis for each of the 16 New Zealand regions show regional variations in inequality. Percentages of the regional populations at-risk using a spatially uniform population range from 0.14% (Southland) to 6.38% (Tasman); while PWCs show 0.00% (Manawatu-Wanganui) to 5.62% (Tasman). However, no further analysis was taken for regions with <1.00% of their population at-risk. As a result, only eight regions have $\geq 1.00\%$ of their population at-risk; Auckland, Bay of Plenty, Canterbury, Gisborne, Hawke's Bay, Northland, Tasman, and Westland.

Results from the regional analyses demonstrate very interesting and contrasting numbers, especially in Auckland where environment injustice is the most evident. In Auckland, Maori, Pacific peoples, people aged 0 to 14, people aged 65 and over, personal income \$5001 to \$20,000, and deprivation deciles 6 to 10 all display inequality to coastal flooding with CERI values > 1.00 . Other regions show opposite results with less vulnerable people having higher inequality. However, the overall results from the national analyses are striking for the reason that socially vulnerable groups have the highest CERI values, therefore most inequality, in comparison to their demographic groups.

6.4.3 The sensitivity of the DEM

A more precise dataset, LiDAR, provides an insight to the accuracy of the DEM, by comparing Christchurch City and Wellington City. In both places, the spatial coverage of the LiDAR flood extent was different in comparison with the DEM. As a result, there were variations with population estimates and CERI values. With a spatially uniform population, the LiDAR dataset for Wellington City estimates that coastal flooding affects 81.66% more people (432 people). In addition, Christchurch City LiDAR calculates a 42.27% increase (7219 people). Accordingly, each analysis shows different CERI values. In Wellington City CERI values between the two datasets range from 0.05 (females) to 0.31 (people aged 65 and over). The DEM displays that more vulnerable groups have

higher CERI values, such as people aged 65 and over, Maori, Pacific peoples, and lower incomes. In contrast, LiDAR demonstrates less vulnerable people, such as people aged 15 to 64, Europeans, and higher income groups.

The same mode of analysis in Christchurch City indicates the spatial differences between the DEM and LiDAR. CERI values produce more variations between the two datasets, ranging from 0.00 (females and \$0 to \$5000) to 0.34 (Pacific peoples). Opposite to Wellington, Christchurch City displays that vulnerable groups have higher CERI values such as people aged 65 and over, Asians, Maori, Pacific peoples, and lower incomes.

PWCs display very weak results for Wellington City for both datasets; hence it is difficult to compare the DEM's sensitivity. Christchurch City demonstrates that coastal flooding affects 30 more MBs for a total of 149, whereas the DEM shows 119. Of these, the two datasets only share 33 MBs. As a result, LiDAR estimates 3237 more people at-risk, or a +20.12% difference. Consequential CERI values display differences from 0.00 (females) to 0.32 (people aged 65 and over). Also, levels of deprivation show vast inequalities ranging from 0.08 (decile 6) to 1.48 (decile 3). In comparison to the DEM, LiDAR shows higher CERI values in more vulnerable populations such as people aged 65 and over, Asians, Maori, Pacific peoples, and lower income. In contrast, the DEM generally exhibits higher CERI values in less vulnerable people such as Europeans and higher incomes.

7. Discussion

Three key themes emerge from this research, which suggest environmental justice concerns in New Zealand. First, inequality to coastal flooding is highest in areas with high proportions of socially vulnerable populations. Second, coastal flooding is the most prominent in environmentally vulnerable areas. Third, the regulatory framework in New Zealand and higher risk regions fails to consider environmental justice and environmental inequalities. The three themes are further discussed in context with similar studies on environmental justice, vulnerability, and policy; followed lastly by dataset implications and the limitations of research.

7.1 Key findings and interpretations

There are several vulnerable groups and areas with disproportionate risk to SLR and storm tides in New Zealand. This section discusses the significant themes from the analyses in context with vulnerability and explains that groups with the highest inequalities to coastal flooding also have pre-existing health, income, and social inequalities. In addition, it provides policy implications and recommendations for environmental inequalities.

7.1.1 Implications for socially vulnerable people with inequalities

Income levels directly affects an individuals ability to absorb losses and higher levels can enhance their resilience to environmental inequalities (S.L. Cutter, Boruff & Shirley 2003). Moreover, income often relates to a persons level of deprivation. This project demonstrates that several groups with a higher risk to coastal flooding in New Zealand are also those with the lowest income and high deprivation. For example, the national median income in New Zealand is \$24,400 and every group with significant inequalities, either nationally or regionally, are below this threshold. This includes Pacific peoples (\$20,500), Maori (\$20,900), and people aged 65 and over (<\$20,000, but are more likely to receive more income from investments and interest) (Statistics New Zealand 2006). Given the existing income disparities in these groups, it is worthwhile to describe the current position of low-income people in New Zealand, in correlation with the income group \$10,001 to \$20,000, who have the highest inequality for income groups. First, the income group has a low percentage of full time employed people (9.1%) and high percentages of part time employed (29%), unemployed (25%), and considered “not in labour force” (39%) (Statistics New Zealand 2006). In addition, lower personal income correlates with higher rates of single parents in New Zealand. All of these factors affect one’s ability to cope and recover from disaster and will likely exacerbate existing poverty. For instance, people who work less have a lower income and single parents have to allocate their income for proper child care.

Additionally, results display that higher deprivation people in New Zealand have inequality to coastal flooding. Similar to other preceding social characteristics of vulnerable populations, higher deprivation people are worse off in comparison to lower deprivation people (Pearce & Dorling 2006). In addition, social groups such as Pacific peoples and Maori are more often of higher deprivation, especially in the regions with higher inequalities. For instance, 87% of Pacific peoples in the Auckland region, where

inequality is the highest for this group, are in higher deprivation deciles 6 to 10. In addition, the majority of Maori in Auckland, Canterbury, and Tasman are of high deprivation. In fact, 68.11% of the total Maori population in these regions are in deprivation deciles 6 to 10.

7.1.2 Health status of populations with inequalities

The current health status of populations with inequalities is alarming and yields additional concern into the possible increases in health disparities these populations will likely encounter during and after a disaster. For example, people of higher deprivation and lower income have generally poorer health and higher death rates, especially among Maori and Pacific peoples (Blakely et al. 2007; Tobias & Yeh 2006). In addition, people of high deprivation have higher rates of visits with general practitioners, possibly signifying ill health, but a lower rate with nurses (McLeod et al. 2006), possibly from a delay in reaction to necessary health care. These rates are even lower within Maori and Pacific peoples (Pearce & Dorling 2006) who also have existing health inequalities in New Zealand (Jamieson & Koopu 2007; Ministry of Health 2008, 2008b).

Lastly, the health status for people aged 65 and over reveals they are more likely to suffer from adverse health, mainly as a result of decreased health over time and socioeconomic inequalities. This age group has higher mortality and hospitalisation rates for most chronic diseases, infectious diseases, and unintentional injury in comparison with younger people (Wang et al. 2006). In addition, this age group is increasing in population due to the low fertility rates in New Zealand, possibly suggesting higher proportions of this population found in flood zones in the future.

In summary, the existing health inequalities in New Zealand create unease considering that those who possess them also have social and income inequalities, in addition to the highest inequalities to SLR and storm tides. The combination of these inequalities occurring in sync with each other potentially results in an overall social disaster. This provides further proof to the vulnerability of populations with inequalities shown in this research, such as Pacific peoples, Maori, people aged 65 and older, and people of low-income and high deprivation.

7.1.3 Place characteristics of highly affected areas

Discussion has highlighted different forms of inequalities among socially vulnerable populations. This subsection interprets the inequalities from this research in relation to

environmental vulnerability, or the place characteristics, which are a result of different landscapes, or the intersection of the cultural and political-economic processes in particular locales (Curtis & Jones 1998). Higher risk areas often possess certain place features, which potentially exacerbates risk, including urban settings and national and regional policy failure.

Of great importance to understanding the effects of coastal flooding is how the population is dispersed (Mileti 1999). Urban and rural communities can either minimise or exacerbate adverse effects depending on the quality of the built environment, population density, and community interaction a place has. In this research ~89% of the at-risk population reside in urban areas. Generally, urban areas increase risk to coastal flooding because they contain higher population densities, require more comprehensive urban planning to avoid risk for all populations, often have inadequate infrastructure, and create havoc during evacuation processes. These are often the result of increasing rates of urbanisation along the coast and urban planning strategies failing to recognise a flood zone.

In the USA, Mileti (1999) suggests that social and socioeconomic disparities are increasing the fastest along coastal margins due to urbanisation and a evolution of a two-class system, rich and poor (Mileti 1999). For New Zealand, there is no evidence which demonstrate these growth rates. However, regions such as Auckland, Bay of Plenty, Canterbury, and Tasman comprise four of the top five fastest growing regions in New Zealand (Statistics New Zealand 2005). Furthermore, Auckland has the far highest rate, accounting for two-thirds of the total growth in New Zealand by 2026. Three of these regions, Auckland, Bay of Plenty, and Canterbury, are highly urban, have the most people at-risk to coastal flooding (75% of population), and are the three regions with the highest physical vulnerability to hazardous events. For instance areas such as the Bay of Plenty and Auckland have the highest vulnerability to coastal flooding because of ongoing coastal development (National Institute of Water & Atmospheric Research 2007). Similarly, Canterbury, specifically Christchurch City, has high residential building rates in the coastal flooding zones shown in this research (Christchurch City Council 2007b).

If these regions' urban planning strategies allow for continuing coastal squeeze and development, more people will likely move into hazardous areas and depending on the housing market, will attract certain types of populations. Often, urban areas' housing prices decrease as more and more homes are built, thus reducing the sales prices and

attracting low-income people (Dow 1992) and increasing injustice and inequality along coastal margins. This supports previous research, which demonstrates that low-income people reside in flood zones because of poor urban planning policies, inexpensive property, and site specific employment (Mann 2006; Neuman 2003; Ueland & Warf 2006); and even suggests increased segregation of vulnerable communities in New Zealand (Pearce & Kingham 2008), which cluster certain demographic groups together and could result in inequality if a disaster occurred.

It is likely that these processes in New Zealand benefit some demographic groups while adversely affecting others, or will do so in the future if coastal flooding occurs. This gives reasoning to investigate the policy considerations in the regions that have the largest risk, such as Auckland, Bay of Plenty, and Canterbury. It is possible that the root causes of inequalities evolve at different spatial and temporal scales within different agencies (regional and national) and investigation into such matter might give insight the capability a place has to reduce injustice (Walker & Bulkeley 2006).

7.1.4 Policy implications and recommendations

This research highlights that vulnerable populations, environmental and social, disproportionately live in coastal flood zones. This subsection reviews environmental and health regulatory framework in New Zealand, focusing on regions with higher risk, to help explain if political and economic forces in New Zealand create inequalities for vulnerable populations in the first place, thus environmental injustice (Pearce & Kingham 2008).

The New Zealand Health strategy 2000 is the main framework, which recognises health and social inequalities (Ministry of Health 2000). It aims to minimise health inequalities in New Zealand by improving the well being of citizens, especially those who are already marginal. Considerations for different social groups include age, ethnicity, gender, and income, among others. More specific framework considers Maori (the Maori Health Directorate), Pacific peoples (the Pacific Health Disability and Action Plan 2002 and Pacific Health and Disability Workforce Development Plan 2004), and older people (the Health of Older People Strategy 2002). However, there is no mention of environmental justice or health effects as a result of environmental inequalities within any frameworks; rather the frameworks aim to reduce health inequalities. Therefore, in order to reduce health inequalities as a result of environmental inequalities, a more holistic policy approach needs to consider how specific areas can exacerbate health

effects or how does peoples' health varies over time and space. This entails the identification of both vulnerable areas and populations, such as those previously discussed in this project.

Furthermore, environmental framework provides an understanding of flood management and whether or not it considers vulnerable people. However, it is only necessary to review policies in regions with higher risk, such as Auckland, Bay of Plenty, and Canterbury. There appears to be no mention or significant contrasts in regional policy relating to coastal flooding and environmental justice. All regional coastal policy statements, including the Auckland Regional Policy Statement, Bay of Plenty Regional Coastal Environmental Plan, and the Regional Coastal Environment Plan for the Canterbury Region, originate from the Resource Management Act 1991 and are further covered by the New Zealand Coastal Policy Statement 1994. Regarding coastal natural hazards, including coastal flooding, sea level risk, and storm tide events, the New Zealand Coastal Policy Statement objectives are “to avoid, remedy, or mitigate actual or potential effects of loss or damage to life, property or other parts of the environment from natural hazards” (Department of Conservation 1994), which also considers people. Furthermore, framework does not consider environmental justice or any of its key themes, such as environmental or social vulnerability. In fact, the only acknowledgement of any social group is to Maori and protecting their cultural heritage, but specific reference is not made to social and health inequalities relating to natural hazards. However, each regional coastal policy statement does identify that inappropriately placed buildings, increased impermeable surfaces, and continual development along coastal margins exacerbates coastal flooding (Auckland Regional Council 1999). Hence, they recognise urban areas as a potentially dangerous threat.

In summary, policy in New Zealand fails to consider environmental and social vulnerability to environmental inequalities. A more holistic approach should be taken in the regulatory framework, especially in the regions with higher risk. Also, more comprehensive policies, possibly a combination of the existing health and environmental framework, as well as environmental justice considerations, will likely reduce the risk and improve peoples' abilities to cope with disaster. For instance, policy should mitigate the impacts of natural hazards, identify risk, and improve public awareness of potential risks. Bearing in mind these factors in future policy making will likely decrease environmental injustice and lead to equality.

7.2 Relationships with national and international research

This section discusses the results of this thesis in conjunction with national and international findings of environmental injustice and environmental and social vulnerability. First, this research adds to overwhelming amount of literature relating to social vulnerability. It supports the broad vulnerability literature which suggests that certain social and socioeconomic groups are more vulnerable to environmental inequalities, such as minorities older people, and people of lower income and high deprivation; because they possess certain pre-existing characteristics, such as income and health inequalities, which prevent coping and adaptation processes (Blaikie et al. 1994; S.L. Cutter 1996; S.L. Cutter, Boruff & Shirley 2003; Stephens, Willis & Walker 2007; Walker et al. 2006b; Wisner et al. 2004). Furthermore, results suggest that risk is highest in environmentally vulnerable areas, such as urban and low-lying areas, especially when socially vulnerable populations reside there (Blaikie et al. 1994; Clark et al. 1998; Mileti 1999; Szlafsztein 2005; Wisner et al. 2004; Wu, Yarnal & Fisher 2002). Although this research provides quantitative results on the amount of urban areas at-risk, it fails to investigate actual conditions in these areas. However, it provides the background of environmental vulnerability in context with susceptible areas.

Second, while an abundance of research accounts for populations' spatial proximity to environmental inequalities (such as air pollution, hazardous sites, and access to greenspace) and marginal populations struggles for equality, few, if any, studies focus on coastal flooding as a result of SLR and storm tides; rather they focus on current flood risk without accounting for SLR. This analysis adds to these findings and provides evidence for the relationship between the proximity of vulnerable populations and the national and regional risk of coastal flooding as a result of SLR and storm tides. The general inclination is that within every demographic group (ethnicity, income, age, and deprivation), environmental injustice is evident in those groups and individuals who are socially vulnerable.

The results are generally consistent with international environmental justice research, specifically to flooding. For example, results highlight that lower income and higher deprivation people and Pacific peoples have the highest inequality for their respective groups, which is similar to studies in the USA that demonstrate low-income and minorities' correlation with high flood risk (Mann 2006; Neuman 2003; Ueland & Warf 2006). Similarly, in the UK, people who are of low socioeconomic status and high deprivation have a higher risk (J.A.G. Cooper & McKenna 2008; Fielding & Burningham

2005; Walker et al. 2006b; Walker et al. 2003). However, no correlation in the previous studies was made with age groups, such as in this project. These results were more specific than previous flood risk studies because this research took a step back to examine what specific populations in New Zealand are particularly vulnerable to SLR, such as certain ethnic groups, gender, income groups, and age. Furthermore, results from the regional analyses are comparable with Walker et al. (2006b), who demonstrate variations in regional inequality in the UK. However, this project only accounts for tidal flooding and not a combination of tidal and fluvial.

In addition, the results in this project are similar with other environmental justice research from New Zealand. For instance, this research displays high levels of inequality in Pacific peoples, people aged 65 and over, and people of low-income and high deprivation. Other research, which investigates other environmental inequalities, display similar results including a strong relationship between more hazardous sites in MBs and high deprivation (K. Salmond 1999). Another national study demonstrates that, poor air quality disproportionately affects Maori, children, and older people; ambient air pollution is highest among Maori; and poor drinking water is most common among Maori and people of higher deprivation (National Health Committee 2002). However, this research is inconsistent and does not display national inequalities in groups such as Maori and young people, rather only regional inequalities for these groups. Furthermore, national results show that higher levels of particulate air pollution are in areas of high deprivation and high proportions of low-income people and Europeans (Pearce & Kingham 2008). However, the results in this thesis only display inequalities for Europeans in some regions. Other research specifically examines Christchurch City and displays higher vehicle air pollution in areas with high proportions of Maori, Samoans, high deprivation, and low-income (Kingham, Pearce & Zawar-Reza 2007). In contrast this thesis displays inequalities for Europeans and people of higher income and higher deprivation in Christchurch City. Lastly, high levels of outdoor air pollution exposure are more likely in areas with social deprivation and low-income (Pearce, Kingham & Zawar-Reza 2006b), again opposite from results for this thesis. This research adds to the previous research in terms of environmental inequalities and also supports the existing social inequalities found in New Zealand. It also displays the importance of geography and analysing space because of the inconsistent environmental and social inequalities in the different areas of New Zealand

7.3 Implications from datasets

This section discusses the elevation datasets and their capabilities to measure coastal flooding. This research gives an indication to their appropriateness to measure the environmental justice of SLR and coastal flooding. When comparison is made between LiDAR and the DEM in Wellington City and Christchurch City, the spatial coverage of flooding and the inequalities were measured differently. The DEM estimates flooding strictly along the coast; whereas LiDAR takes into account flooding that would occur around other low-lying land features commonly found inland, such as estuaries and rivers. When choosing what elevation dataset to use is particularly important in environmental justice research because of the geographical diversity of demographic groups and environmental hazards (Walker et al. 2006b).

The contrasting results of the datasets, demonstrate the importance of having a high quality dataset such as LiDAR, in low-lying coastal areas with environmental and place settings that exacerbate coastal flooding as discussed in Chapters 2 and 4. This is especially significant in regions such as Auckland and the Bay of Plenty, where they are particularly vulnerable to flooding in estuaries and tidal inlets (Auckland Regional Council 1999; Environment Bay of Plenty 2003). Therefore, analyses in these regions, probable in others as well, would most likely show different results if undertaken by LiDAR rather than the DEM.

The results of this thesis reveal the ability of the DEM to provide a basic analysis for environmental justice and coastal flooding. The initial investigation with the DEM can provide local decision makers the opportunity to assess relative vulnerability across the whole country (N.J. Wood & Good 2004); and the DEM possibly highlights the regions of New Zealand, to examine in greater detail with LiDAR or an equivalent dataset. For example, places such as Wellington City have a lower susceptibility to coastal flooding. In these places, the DEM should serve as a starting point for mitigation planning and community preparedness and due to such a low risk in comparison to other places. Other places more physically vulnerable to flooding, such as Christchurch City, should take additional steps to acquire and utilise datasets such as LiDAR for a more comprehensive hazard analysis.

7.4 Limitations

Applying multiple methods of analyses in accordance with two elevation datasets, this research assesses the environmental justice of SLR and storm tides in New Zealand. The

assessment of the results is confronted with several challenges, mainly the availability of data, accuracy of the datasets, and the accuracy and interpretation of the analyses.

7.4.1 Accuracy and interpretation of analyses

This research analysed coastal flooding as an environmental inequality using two methods of analyses; assuming a spatially uniform population in each MB and comparing MB's PWCs. Both methods produce relatively parallel results, with a few minor exceptions. However, the impact assessment is limited to people's proximity to the coastal flooding and does not account for cumulative effects. For example, people not counted as "affected" might reside in "non-affected" areas adjacent to the flooding extent. Although they will not experience living underwater, they would certainly experience adverse effects (Walker et al. 2003) such as evacuation, disease, contaminated water, and possible relocation. In addition, there is a chance that pockets of deprived or non-deprived people live next to the flood extent and therefore were not accounted for in analyses, although using smaller geographical area units, such as MBs, tends to minimise this. Hence, if a buffer extended the coastal flood zones, resulting inequalities might be different within the buffer zones.

7.4.2 Accuracy of datasets and flood models

As mentioned in Chapter 5, the vertical accuracies of the DEM and LiDAR are dissimilar and therefore the flood coverage is displayed differently. To reiterate, the DEM measures 90% of vertical points within 5 m (Land Information New Zealand 2007), whereas LiDAR measures vertical points within ± 30 cm (T.L. Webster & Forbes 2005). Hence, coastal flooding predictions in both datasets vary, especially in terrain that has a very small elevation gradient such as Christchurch City.

Also, the flood models in this research are only preliminary steps to creating a cumulative flood risk model. A more comprehensive flood analysis includes several additional steps. For instance, this research does not account for any man made flood defences built along coastal margins and simply relies on the elevation models to display such items. In addition, since the creation of these datasets, it is possible that coastal defences were built to prevent the coastal flooding predicted in this research.

Furthermore, the elevation datasets do not include natural or anthropogenic changes in shorelines that occur over time. For example, cumulative maps consider variables such as coastal erosion, wetland accretion, and shoreline protection measures, amongst others

(Consortium for the Atlantic Regional Assessment 2008). This is similar in New Zealand where all coastlines, depending on the coastal type, are either predicted to accrete sediment, thus adding material to coastal beaches and mitigating SLR, erode, thus increasing physical vulnerability to coastal flooding because sediment is being removed from the beach, making erosion more prominent, or remain stable (Ministry for the Environment 2004). The flood maps in this research were rather a first-order assessment, which future analysis can be conducted at a finer scale with geologic and hydraulic processes (Consortium for the Atlantic Regional Assessment 2008).

For the LiDAR dataset only, additional deficiencies may arise in areas of steep slopes and dense vegetation, such as river banks (Neelz et al. 2005). It may have caused an either overestimation or underestimation of the flood extent of up to 1 m. This is particularly important in Christchurch City where high amounts of flooding are predicted along the estuary and river boundaries.

7.4.3 Availability of data

A main objective of this thesis was to investigate and test the sensitivity of the DEM. Because SLR and storm tides predictions are ~2.2 to ~2.4 m in height, projects should use technologies with vertical precision significantly better than these values to generate sufficient coastal flood modelling (T.L. Webster & Forbes 2005). However, due to a lack of LiDAR datasets in New Zealand, such data is limited to only two areas, Christchurch City and Wellington City. Other attempts were made to obtain additional LiDAR from city councils in New Zealand, but were not successful either because it does not exist or no response was given by the councils.

It is difficult to draw accurate conclusions about the sensitivity of each dataset with only two local comparisons, especially bearing in mind the diverse terrain in Christchurch City and Wellington City. If additional datasets are obtained for places with more prominent estuarine or river flooding, then more precise conclusions can be drawn for the DEM's capability to measure environmental justice. The LiDAR datasets here provided an introductory insight into the sensitivity of the DEM. Furthermore, Christchurch City's landscape is relatively homogenous, while Wellington City is rough and steep. This gave insight into the importance of LiDAR in flat terrain such as Christchurch City, but also raises questions about the significant differences between LiDAR and the DEM in estuarine and tidal inlet environments in New Zealand. This is especially the case in Auckland and the Bay of Plenty where a high population coincides

with a physically vulnerable setting, thus signifying the importance of LiDAR in such areas.

In addition, Christchurch City, relative to New Zealand, has an ethnically homogenous population (Pearce, Kingham & Zawar-Reza 2006b). For example, in this research 81% of the total population identify as Europeans. In a more ethnically diverse place such as the Auckland Europeans consist of ~53% of the total population, thus LiDAR would provide more intriguing results and a more precise conclusion could be drawn about each datasets' capability to assess environmental justice and coastal flooding.

7.5 Concluding discussion

The discussion explained and evaluated the environmental justice of SLR and storm tides in the context on national and international findings. In New Zealand, there is statistical evidence from the DEM that socially vulnerable groups in each respective category have a higher risk to coastal flooding, in areas that are environmentally vulnerable, and that regional distributions are contrasting with the national results. Moreover, existing social, income, and health inequalities in these groups provide theoretical reasoning to their difficulties in coping and adapting to hazardous events. Other significant findings include the obvious and numerous inequalities found in the Auckland region, which sways and often misrepresents the national results because of the large total and at-risk populations.

When results from the DEM are tested with a more precise dataset, differences in inequalities arise. The most understandable reason for the differences is the different spatial coverage in the flood extent with LiDAR, especially in estuarine and tidal inlet environments. This explanation is at best tentative and should be further tested in other regions with similar landscapes.

The results are subject to bias and limitations. Problems in this research surface in a few areas:

- populations proximity to flooding was measured and not cumulative and social effects of flooding;
- accuracy and availability of datasets;
- and preliminary assessment of a cumulative flood.

The limitations of the study reflect the challenges to measure environmental justice on a national scale, especially when LiDAR is only available in select, local areas. The

implications of this research are primarily concerned with the inequalities to coastal flooding in vulnerable people, the failure of policy in New Zealand to recognise environmental justice, and the lack of data used to accurately portray risk,. Moreover, this project found evidence of the currently unexplored environmental justice research in New Zealand.

8. Conclusion

This study has examined the environmental justice of SLR and storm tides in New Zealand, gained insight into vulnerable populations and the sensitivity of the national DEM, and discussed the importance higher resolution datasets. This was achieved with two elevation datasets that assessed coastal flooding as an environmental inequality and two methods that determined the socio-spatial distribution of vulnerable areas and groups to the adverse effects. Moreover, a regional scale analyses identified the areas environmentally vulnerable to coastal flooding, how many people are affected, as well as the degree of inequality in each region. The final chapter summarises the key findings of analyses in the context of the research aim and objectives

8.1 Key findings of the analyses

Analysis displaya a total of 1307 km² of land is susceptible to coastal flooding, resulting in 63,936 to 83,422 people at-risk, depending on the method. Both methods of analyses demonstrate that people aged 65 and over, Pacific peoples, those with a total personal income of \$10,001 to \$20,000, and the most deprived have inequalities to coastal flooding. The trends are in accordance with international environmental justice research on flooding from the US and UK, and also national environmental justice results for other environmental inequalities.

The regional distribution of risk reveals the concentrations of social and socioeconomic groups found within each region, which display the uneven geographic distribution of both environmental and social vulnerability (Walker et al. 2006b). For instance, in regions such as Auckland, inequality is highest in the most vulnerable groups, while in others, such as the Bay of Plenty, it is the least vulnerable groups. Furthermore, risk is highest in three highly urbanised regions; Auckland, Bay of Plenty, and Canterbury, which all heavily contribute to the inequalities found on a national scale. This proposes, but my no mean establishes, that there are underlying factors which may have influenced and/or attracted the migration of certain populations to higher risk areas

over time, and led to higher proportions of socially vulnerable people (Walker et al. 2006b).

These results, however, are only provisional, as the DEM has a poor quality resolution. A more precise dataset, LiDAR, shows vast differences in the spatial coverage of flooding as well as the socio-spatial analyses. Comparisons are drawn from Wellington City and Christchurch City, although Wellington City did not demonstrate significant findings because of the lower flood risk. Christchurch City, however, displays a flood extent that was more prominent along estuarine and river bank boundaries and closely resembles the Christchurch City Council's flood management zone. Therefore, for the case of New Zealand, which has limited access to LiDAR, the DEM provides an initial assessment of low-lying coastal areas, which can be further analysed with LiDAR, if necessary and prove beneficial for regions with higher population densities such as Auckland and the Bay of Plenty.

The lack of explanation to why these environmental inequalities exist in the first place and lack of proper datasets reflect the potentials for environmental justice research in New Zealand. The policy analysis in coordination with significant findings identifies the possibilities of future research for environmental justice in New Zealand.

8.2 Future research

This research investigated the socio-spatial distribution of vulnerable populations in relation to the proximity of coastal flooding. Results presented here add to the existing findings of environmental injustice in New Zealand. In context with the previously discussed limitations and the results' implications, it is foreseeable that future research in the areas described below will significantly improve the current understanding of how inequalities arise in New Zealand.

8.2.1 Further exploration into regulatory framework

A major theme in the environmental justice research, which was not employed in this project, attempts to explain how environmental inequalities arise in the first place. This qualitative approach could include several factors that are noteworthy to environmental justice research. Generally, research would clarify how different forces (structural, institutional, political, and economic) have interacted to create differing levels of risk amongst communities, and if disparities are discovered, interpret the significant results

(Kingham, Pearce & Zawar-Reza 2007; Morello-Frosch, Pastor & Sadd 2002; Pearce & Kingham 2008).

Specifically for SLR and coastal flooding, inequalities are most likely to arise as a result of discriminatory housing markets and poor urban planning that fails to recognise flood zones. Future research could use the results presented in this project as a starting point to measure policy injustice. For instance, this thesis has demonstrated vulnerable groups are more likely to be affected by coastal flooding. Concurrent research should take a more qualitative approach and examine why these people live where they do, what attracted them to live in flood risk zones in the first place, and whether or not it is a result of regulatory framework.

There is a call for this type of research, especially in the Auckland region, because of the extreme examples of environmental injustice. It suggests that there are several underlying processes, such as policy, self migration, housing markets, and perception of risk, which can help explain why such high rates of marginalised people live in coastal flood zones. Identifying these issues and refocusing more attention to the social and environmental policies will likely produce interesting findings and even suggest ways in which the health, social, and socioeconomic disparities can be reduced; thus, creating a more just society and minimising the adverse effects.

Addressing flood risk and the underlying issues that explain its socio-spatial distribution will likely improve the well being of less affluent communities and narrow the health inequalities that are often associated with these groups of people. This is especially true for disaster related outcomes because of the unknown factors and the spatial exclusivity of effects, of which are possibly unknown. There first needs to be a proper understanding of risk, vulnerability, and mitigation techniques for each place as this will likely reduce the adverse effects of environmental inequalities and benefit everyone in the community. Determining this requires a comprehensive risk assessment that is strategically addressed in the policy framework. In addition, the policies should be derived from accurate scoping and impact assessments, which will be more accurately analysed with proper datasets and the considerations of cumulative impacts.

8.2.2 Developing cumulative flood risk maps using LiDAR

The spatial extent of flooding used in this research is only a preliminary assessment to a cumulative flood risk. This is because of two reasons; the national DEM has a low vertical resolution in comparison to LiDAR and hydraulic and physical processes were

not taken into account in both datasets. More comprehensive flood models would consider these limitations in order to more accurately assess flood risk as a hazard and an inequality.

This study was limited to LiDAR analysis in two New Zealand cities, Christchurch and Wellington. Although New Zealand has less LiDAR coverage in comparison to Canada and the US, it is likely that the datasets will become increasingly available in national and regional agencies in New Zealand. If so, future research could easily duplicate the methods found in this study but focus on different regions, such as Auckland and the Bay of Plenty.

Advanced flood measurement techniques with LiDAR include accounting for hydraulic and physical processes that are relative to each location. For instance, this research viewed flooding extents to be binary, meaning areas are either affected or not affected, and those that are affected have uniform flood depths. However, more advanced flood models could start with engineer consultation and utilise and discuss methods such as time series inundation and drainage, flood depth maps, and surface flow models, which all consider floods' behavioural processes (Neelz et al. 2005; T. L. Webster et al. 2004; T.L. Webster et al. 2006). This way, assessment includes what areas will flood first and last, which areas have higher water levels, and flow patterns. Considering these will provide more accurate flood model and a more accurate assessment of the social and economic impacts of a flood.

In addition, different coastal processes are likely to occur on different coastlines as a result of SLR, which will result in possible regression or advancement. Anticipating these future changes will create more accurate flood models for research and analysis. For example, future research should consider the following variables for more accurate predictions:

- elevation of the coast above present sea level;
- geology of the coast;
- sediment supply, its availability for beach building, and its likely change in this supply;
- width of any coastal barrier present;
- coastal setting and orientation;
- vegetation available for stabilisation;
- and shape, slope, and height of pre-existing coastal protection infrastructure.

(Ministry for the Environment 2004, p. 14)

In summary, this project only initially views coastal flooding. More cumulative flood risk assessment should consider the inaccuracies of datasets, existing coastal features that alter flooding, and changes in physical coastal processes which exacerbate or minimise flooding. Addressing these considerations will lead to a more accurate interpretation of environmental.

8.3 Concluding statement

In New Zealand, past research fails to recognise SLR and storm tides as an environmental inequality. Thus, the findings of this thesis contribute to the current discussion of environmental injustices already found in New Zealand and further provides evidence into the socio-spatial segregation of neighbourhoods. As a result, national and regional government agencies should perhaps include a more geographical approach to written reports and policy development identifies vulnerable people and areas. In addition, future research should obtain appropriate elevation datasets such as LiDAR, and consider the possibilities of shoreline changes as a result of SLR. This is especially true for agencies that do not have existing flood management plans that are based on high quality datasets. In summary, the increased recognition of coastal flooding, particularly in the light of SLR, and future research in the areas listed below will significantly reduce the adverse outcomes for vulnerable populations and increase their resilience, all while improving the agencies' response capabilities:

- obtainment of higher resolution datasets for all of New Zealand.
- recognize and understand the physical impacts of SLR on coastal areas.
- advancement of environmental justice research in New Zealand should include more qualitative data which examines how people become less affluent in the first place, why they live as they do, and what attracts them to reside in more physically vulnerable areas.
- and acknowledgement of environmental justice and environmental inequalities within regulatory framework at all levels and all research types.

The adverse effects of flooding in New Zealand are prevalent and costly. For coastal flooding specifically, the impacts and people it affects are somewhat of a best guess, particularly with SLR. Therefore, policies should implement a complete understanding of the mitigation processes ranging from reducing vulnerability to increasing emergency response. In conclusion, as long as there are no comprehensive policies for environmental

justice, national and regional agencies, the scientific community, and other main actors in disaster research, response, and relief, will misinterpret injustice and inequality.

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