The effects of high lake levels due to climate change on lakeside communities and adjacent land use
Case study: Lake Ellesmere/Te Waihora

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This research aims to assess the effects of sea-level rise on Lake Ellesmere/Te Waihora's current opening regime and consequently on adjacent land and it's lakeside communities. The research also aims to assess Lake Ellesmere/Te Waihora's lakeside communities' level of preparedness to adapt to these anticipated changes. Unlike other natural hazards that occur abruptly, sea-level rise is incremental and foreseeable, and its effects on coastal areas and communities are expected to occur gradually. Thus, it is crucial to start planning now for future sea-level rise to reduce its adverse impacts on coastal areas and communities. Intermittently closed and open lakes and lagoons (ICOLLs) such as Lake Ellesmere/Te Waihora are vulnerable to the effects of sea-level rise due to their setting within the coastal landscape. The water level of many ICOLLs around the world, including Lake Ellesmere/Te Waihora, are managed by artificially creating a temporary opening through the barrier separating the ICOLL from the sea and inducing premature breakout to protect adjacent land and communities from inundation. The artificial opening is induced when a predefined opening trigger value is reached. The success of the artificial opening is dependent on local sea conditions. As sea levels continue to rise, the continuation of flood management practice in the form of artificial openings for ICOLLs will become challenging due to a decrease in hydraulic gradient between the ICOLL and the sea. Eventually, in order to be able to open Lake Ellesmere/Te Waihora to flow into the sea, the current predefined trigger value will have to increase in height relative to local sea level rise. In the short-term future, this will result in an increase in the risk of temporary inundation of adjacent land. In the long-term future, the increase of the ICOLL artificial opening trigger levels will result in permanent loss of adjacent land and the displacement of communities.

A quantitative risk assessment was carried out to determine the effects of sea-level rise on Lake Ellesmere/Te Waihora's artificial opening trigger levels in the short-term (10 to 30 years) and longer-term (50 to 100 years). This quantitative risk assessment was also able to determine the probable risk of permanent inundation of adjacent land. Geographic Information Systems were used to create contour maps showing the increase in Lake Ellesmere/Te Waihora's current summer and winter artificial opening trigger levels in response to future sea-level rise. These maps are used to determine who will be affected by increasing amounts of sea level rise. Additionally, a qualitative risk assessment was undertaken to assess the level of preparedness of Lake Ellesmere/Te Waihora's communities that have been identified to be at risk of inundation as a result of the anticipated increase in the lake's water levels.

Keywords: sea level rise, inundation, intermittently closed and open lakes and lagoons, vulnerability, risk and preparedness

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Table of Contents

List of Tables

List of Figures

Abbreviations

DROP	Disaster Resilience of Place
ECan	Environment Canterbury
GIS	Geographic information System
ICOLLs	Intermittently Closed and Open Lakes and Lagoons
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature and Natural Resources
LIDAR	Light Detection and Ranging
LINZ	Land Information New Zealand
m.a.m.s.l.	Metres above mean sea level
MfE	Ministry for the Environment
NIWA	National Institute of Water and Atmospheric Research
NZCPS	New Zealand Coastal Policy Statement
RMA	Resource Management Act
SDC	Selwyn District Council
WCO	Water Conservation Order

Chapter 1

Introduction

1.1 Overview

This research is an intrinsic case study, exploring the potential effects of future sea level rise on New Zealand's largest coastal lake; Lake Ellesmere/Te Waihora from a flood management perspective.

Debate over climate change and its effects on our planet started amongst 19th-century scientists. These debates have increased to include decision-makers and planners over the past 200 years and have become a global hot topic over the past century as exposure and vulnerability to the effects of climate change have increased significantly (Harding, 2007). One of the most conspicuous effects of climate change is sea-level rise which is driven by a general increase in global temperature (Parliamentary Commissioner for the Environment, 2015). Coastal lakes such as Lake Ellesmere/Te Waihora are commonly referred to as Intermittently closed and open lakes and lagoons (ICOLLS). ICOLLs are vulnerable to sea level rise due to their setting within the coastal landscape. ICOLLs are coastal water bodies that have an intermittent connection with the ocean, and they comprise thirteen percent of the world's coastline (Kjerfve, 1994). They are separated from the ocean by a coral/sand barrier that opens naturally when there is sufficient water inflow from the catchment to scour an entrance to the ocean through the barrier. Many ICOLLs around the world are opened to the ocean prematurely. The reason for this is primarily to prevent the inundation of low-lying land and communities adjacent to the ICOLL. This is referred to as an artificial opening.

The success of artificial opening regimes relies heavily on local sea conditions. Future sea level rise is expected to hinder artificial openings of ICOLLs and consequently increase the risk of inundation of adjacent low-lying land. Unlike other natural hazards that can occur abruptly, sea-level rise is incremental and foreseeable, and its effects on coastal areas and communities are expected to occur gradually. Thus, it is crucial that ongoing management of ICOLLs accounts for future sea-level rise to reduce its adverse impacts on coastal areas and communities.

1.2 Research aims and objective

This research aims to assess the following:

- The effects of sea level rise on Lake Ellesmere/Te Waihora's artificial opening regime and consequently on the lake's adjacent land and communities; and

- The communities' level of preparedness to the anticipated increase in the lake's water levels.

To satisfy the first aim of this research, exposure to sea level rise is measured to assess who and what will be affected based on the assumption that the current opening trigger levels of Lake Ellesmere/Te Waihora will have to increase at the same rate that the sea level is rising. This assessment was carried out as a quantitative risk assessment, using local sea level records and GIS software to visualise the findings geographically. Once the communities who are at a potential risk of flooding were identified, the second aim of this research addressed the communities' level of preparedness to cope with the anticipated increase in the lake's water levels using a qualitative vulnerability assessment. The qualitative vulnerability assessment involved interviewing individuals within Lake Ellesmere/Te Waihora's communities that were identified to be at potential risk of flooding using open-ended questions constructed based on social indicators established within literature. These indicators are explored in Chapter 2 of this thesis.

1.3 Research Design

There have been no recorded cases worldwide where the artificial opening regime of an ICOLL had to be adjusted due to sea level rise. Due to this, whilst the anticipated effect of sea level rise on the artificial opening regimes of ICOLLs is well established in literature, the extent of the effects is not well understood. The extent of future sea level rise's effects on the artificial opening regimes of ICOLLs will vary significantly between different geographical locations. Based on this, a case study approach was deemed necessary for providing real-life context. Whilst this study is site specific, the quantitative and qualitative tools used in this research can be replicated for the undertaking of similar assessments on the management of ICOLLs from a flood management perspective.

1.3.1 Study Area

Lake Ellesmere , which is referred to as Te Waihora in Maori, is a large, shallow and brackish coastal lake located in the Canterbury region of New Zealand's South Island (Figure 1-1). It is the largest lake by surface area in the Canterbury Region and the fifth largest lake in New Zealand. Lake Ellesmere/Te Waihora is separated from the sea by a 28 km long shingle barrier and this barrier has been artificially opened to sea intermittently since the 1900s. The purpose of these artificial openings was primarily to prevent the inundation of land adjacent to the lake however these artificial openings have also been used more recently to provide for fish migration and water quality management. The current trigger levels for Lake Ellesmere/Te Waihora which signal for an artificial opening are set at 1.13 metres above mean sea level (m.a.m.s.l.) in winter and 1.05 metres above mean sea level(m.a.m.s.l.) in summer. These artificial opening trigger levels for Lake Ellesmere/Te Waihora were set under a Water Conservation Order in 1990.

Figure 1-1: Location map of Lake Ellesmere/Te Waihora catchment. (nzfishing.com, 2018; Chin, 2015).

Due to their setting within the coastal environment, not only are ICOLLs vulnerable to sea level rise but they are also vulnerable to declining water quality. ICOLLs act as sinks that capture contaminates from across their catchment. Like many ICOLLs around the world, Lake Ellesmere/ Te Waihora holds significant ecological and cultural values that many organisations highly value. However, Lake Ellesmere/ Te Waihora has been facing declining water quality since at least 1993. This has caused stakeholders to focus on artificial openings' effects on water quality, which is well-established in the literature. However, whilst the current opening trigger levels do prevent inundation of adjacent land, they are not the most suitable in terms of managing the lake's water quality. This will make the management of Lake Ellesmere/ Te Waihora increasingly challenging as the effects of sea level rise become more apparent. Lake Ellesmere/ Te Waihora was chosen to be the focus of this research because it exemplifies the challenges of managing the artificial openings of an ICOLL under the pressure of increasing sea level rise. The current opening trigger levels of Lake Ellesmere/ Te Waihora are set at a much lower level above mean sea level in comparison to other coastal lakes in New Zealand making it more vulnerable to future sea level rise.

This case study is discussed in further detail in Chapter 3 of this thesis.

1.4 Summary

This research is carried out with the anticipation that the findings may provide the Regional and District Councils with useful information that can be useful for decision making and the future management of Lake Ellesmere/ Te Waihora. This Thesis is organised into six Chapters. The next Chapter, Chapter 2, explores literature on the anticipated effects of sea level rise on artificially managed ICOLLs and drivers of human response to natural hazards and disasters. Chapter 3 discusses the case study area of Lake Ellesmere/Te Waihora in detail and explores the shift in environmental management to artificially open the lake. Chapter 4 outlines the methods used to satisfy the aims and objectives of this research. Chapter 5 outlines the findings of the quantitative risk assessment and the qualitative vulnerability assessment used in this research. The last Chapter, Chapter 6, discusses what the findings demonstrate in terms of community displacement and discusses communities' level of preparedness towards various forms of adaption and how this research could be used to inform future decision making.

Chapter 2

Literature Review

This Chapter explores existing studies research into the effects of sea level rise on ICOLLs as well as literature on the social drivers of communities' preparedness towards natural hazards and disasters. In addition, established quantitative and qualitative assessment models were investigated to identify potentially suitable tools that could be used to undertake this research.

2.1 Anticipated effects of climate change and future sea-level rise on the levels of intermittently closed and open lakes and lagoons

Intermittently closed and open lakes and lagoons (ICOLLs) are brackish coastal water bodies which are separated from the ocean by a sand barrier or berm that closes and opens periodically. The opening and closure of the entrance is naturally driven by coastal morphological processes (wave-driven littoral sand transport) and hydrodynamic processes (tidal inflow and outflows and intermittent flood events). The barrier is opened naturally when there is sufficient inflow into the ICOLL (from rivers, streams, groundwater, rainfall) and the water level in the ICOLL exceeds its holding capacity, overtops the barrier's height and resultingly scours an entrance channel through the barrier. Once opened, wave and tide action start to gradually close the entrance channel.

Although ICOLLs comprise thirteen percent of the world's coastline (Kjerfve, 1994), most existing studies which examine the effects of sea level rise on ICOLLs were found in Australian and New Zealand literature. This is likely due to the abundance of ICOLLs found the areas of New South Wales in Australia and across New Zealand.

Future sea-level rise is expected to result in an upward shift in water levels of ICOLLs across a range of possible levels which are driven by the periodic opening and closing of the barrier as shown in Figure 2-1 below (Haines , 2007).

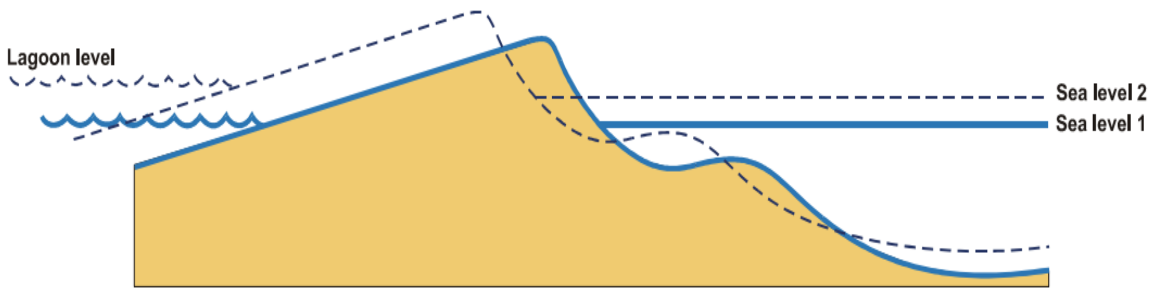

Figure 2-1: Schematic diagram illustrating the anticipated effects of sea-level rise on the berm height. (Haines, 2007)

When ICOLLs are open to the sea, their base water level is controlled by the ocean's water level. Based on this, the water level of ICOLLs is expected to increase roughly at the same rate that the sea level is rising. When ICOLLs are closed, their water level is controlled by the berm height that separates the ICOLL from the ocean and the magnitude of increase of the ICOLL's water level will depend on the relative rate of sedimentation (i.e. the rate at which the berm is built). If the rate of sediment exceeds the rate at which the sea level is rising, the ICOLL will be short-lived and refill. On the other hand, if the sea level is increasing at a rate that exceeds the rate of sedimentation, the ICOLL will be deepened and it's holding capacity will increase.

Historically, the drainage of ICOLLs around the world to access the highly fertile margins for agricultural land-use activities was a common practice (Ramsar Convention, 2014). To prevent the inundation of this reclaimed land, the water level in many ICOLLs is controlled artificially, using heaving machinery to excavate an entrance channel through the barrier separating the ICOLL from the sea to induce a premature breakout to the sea. The operation of artificial opening regimes is driven by predefined opening trigger values (measured in metres above mean sea level) established under local regulatory policies. For the artificial openings to be successful, the hydraulic gradient between the water level of the ICOLLs and the sea level needs to be sufficient to enable the outflow of water towards the sea (Verhoeven & Setter, 2010). The artificial opening regimes of ICOLLs are affected by other climate change variables other than sea level rise. However, the literature consulted in this research focused more on sea level rise as it is the most predictable variable. Future sea level rise will likely hinder the ability to open ICOLLs when their water levels are at their current opening trigger levels. When the opening trigger level of the ICOLL is reached, the hydraulic gradient between the water level of the ICOLL and the sea might not be sufficient to allow for the outflow of water from the ICOLL to the sea and the maintenance of the artificially scoured entrance. As the sea level rises, opening trigger levels of ICOLLs will need to be adjusted to maintain a sufficient hydraulic gradient for an artificial opening to be successful.

2.1.1 Quantitative risk assessment

The risk of an environmental system to disturbance, also referred to as biophysical vulnerability is a function of exposure and social vulnerability. It is usually assessed as a combination of the possibility of an impact occurring and the consequences of that impact, as illustrated in Figure 2-2 below.

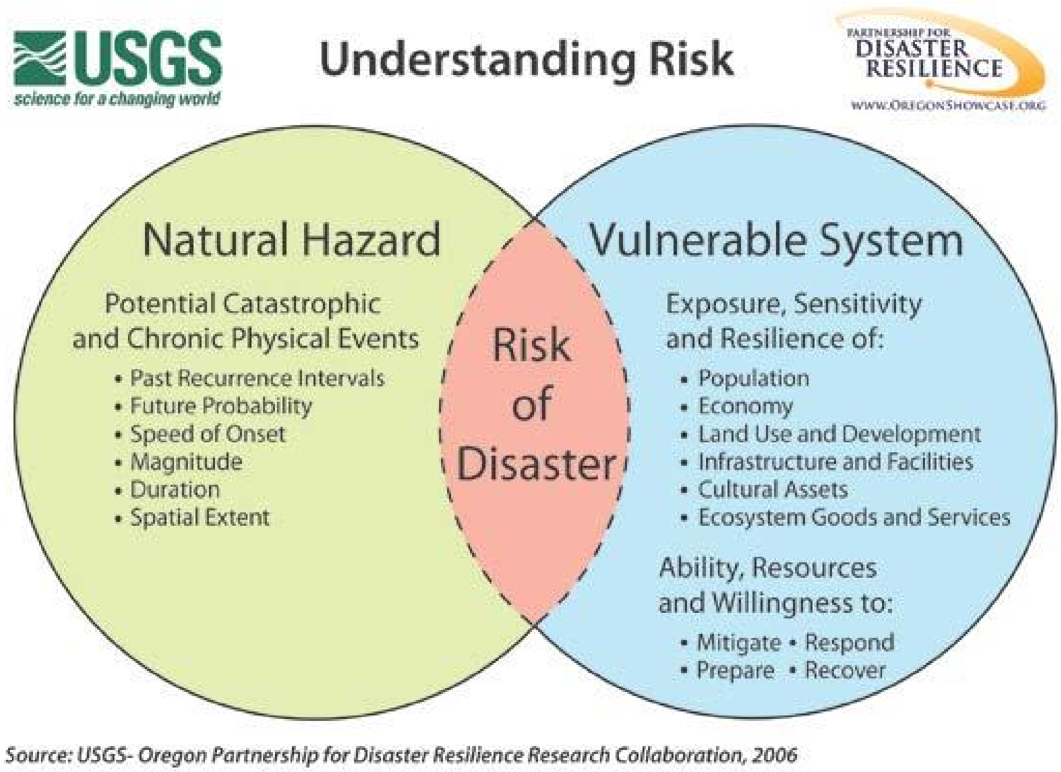

Figure 2-2: The relationship between vulnerability and risk in the context of natural hazards and disasters, and examples of indicators for measuring risk and vulnerability. (Brand, McMullin-Messier, & Schlegel, 2018)

Risk can be further understood by the assessing spatial extent of a hazard and identifying vulnerability from a geospatial perspective (i.e. a community's vulnerability to natural hazards is often exacerbated by their setting within the coastal landscape). This assessment of risk is the first step towards building a sea level rise adaptation plan as shown in the Figure 2-3 below.

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Figure 2-3: The three main steps and their components which are used to develop and implement a sea-level rise adaptation plan (Russell & Griggs, 2012).

Exposure can be defined as the point of interaction between an external stress (typically a natural hazard/disaster event) and a set of natural variables (lakes, rivers, coastline, etc.), social variables (people/communities) and economic variables (infrastructure and assets). Exposure to future sea level rise is measured quantitively commonly using either one or more of the following approaches (Teng, et al., 2017):

- Empirical approaches,
- hydrodynamic models, and
- Simplified conceptual models

Empirical approaches involve the undertaking of experiments to collect and analyse data using statistical and remote sensing models (Teng, et al., 2017) . They are used to demonstrate ground truth supported by observations to either validate or reject a hypothesis. The data obtained from the experiments can also be used to build a hypothesis. The limitations of these approaches lie within the common obstacles faced by researchers in a uncontrolled environment. These obstacles include the interference of environmental variables (i.e. wind, rain and land cover) during the experiments and their impact on data collection. Another common limitation is the design of the sensors, carriers and transmission devices used to gather such data (Teng, et al., 2017).

Hydrodynamic models involve the implementation of physical laws to model fluid motion which stimulate water movement using complex mathematical equations. These models are relatively difficult to implement and require a large set of data (Teng, et al., 2017). However, unlike empirical approaches, hydrodynamic models can be manipulated and used in scenario-based models (Teng, et al., 2017).

Simplified conceptual models are not based on physics laws and do not require a large set of data to implement. An example of a simplified conceptual model is the Bathtub Approach. The Bathtub Approach is an elevation-based method, where areas adjacent to the sea and below a given elevation are mapped (Yunus, et al., 2016). One of the main reasons the bathtub method has been commonly used is that it is simple to implement, only requiring elevation data which is commonly available in the form of a digital elevation model (DEM). Like hydrodynamic models, simplified conceptual models such as the Bathtub Approach are ideal for conducting scenario-based research. In terms of limitations, these models do not take bathymetry, tidal patterns, coastal geomorphology or local climate into consideration which can result in the underestimation of the severity of a hazard (Teng, et al., 2017).

While the strengths and limitations of each approach have been discussed in the consulted literature, within this literature there is limited discussion that compares these approaches. This indicates that the approaches should not be compared and instead should be applied together to obtain the best results. For example, the literature consulted indicates that a large dataset is required to successfully implement hydrodynamic models. Ensuring these datasets are of high quality is crucial for the construction of plausible future scenarios. empirical research approaches are excellent for Obtaining good quality data for the implementation of hydrodynamic modelling. However, the implementation of hydrodynamic models and empirical approaches is often both time consuming and costly. In contrast simplified conceptual models are inexpensive and easy to implement. While simplified conceptual models are considered elementary in nature when compared to empirical approaches and hydrodynamic models, simplified conceptual models provide a useful starting point for the process of incorporating sea-level rise into local flood hazard maps and in local decision-making. Simplified conceptual models are used to identify whether further assessment of natural hazards is required in a defined area and are used to justify from a cost-benefit perspective the implementation of more complex approaches and models (Teng, et al., 2017).

This research focuses on the assessment stage of developing and implementing a sea-level rise adaptation plan, shown in Figure 2-3 above. Taking into account the scope of this research and lack of existing studies on the effects that sea level rise as on artificially managed ICOLLs from a flood management perspective, the implementation of simplified conceptual models is the best approach for to investigate the effects of sea level rise on Lake Ellesmere/Te Waihora’s artificial opening regime.

According to the consulted literature, once the extent of these effects is understood, the next step towards fully understanding the level of risk associated with a natural hazard is to undertake a qualitative vulnerability assessment.

2.2 Social vulnerability assessment

The next step towards evaluating risk in accordance with Figure 2-3 involves assessing the social vulnerability of the elements (i.e. communities, land an infrastructure) which have been identified to be at risk of being exposed to the anticipated natural hazard. The purpose of undertaking a social vulnerability assessment is to determine the socio-economic impact of a natural hazard. This can be achieved by using social indicators of sensitivity and resilience.

The concept of social vulnerability is complex, and its meaning varies across different disciplines (Ciurean, Schröter, & Glade, 2013). Due to these various meanings, Ciurean et al. (2013) have developed a process presented in Figure 2-4 below to select indictors for assessing social vulnerability.

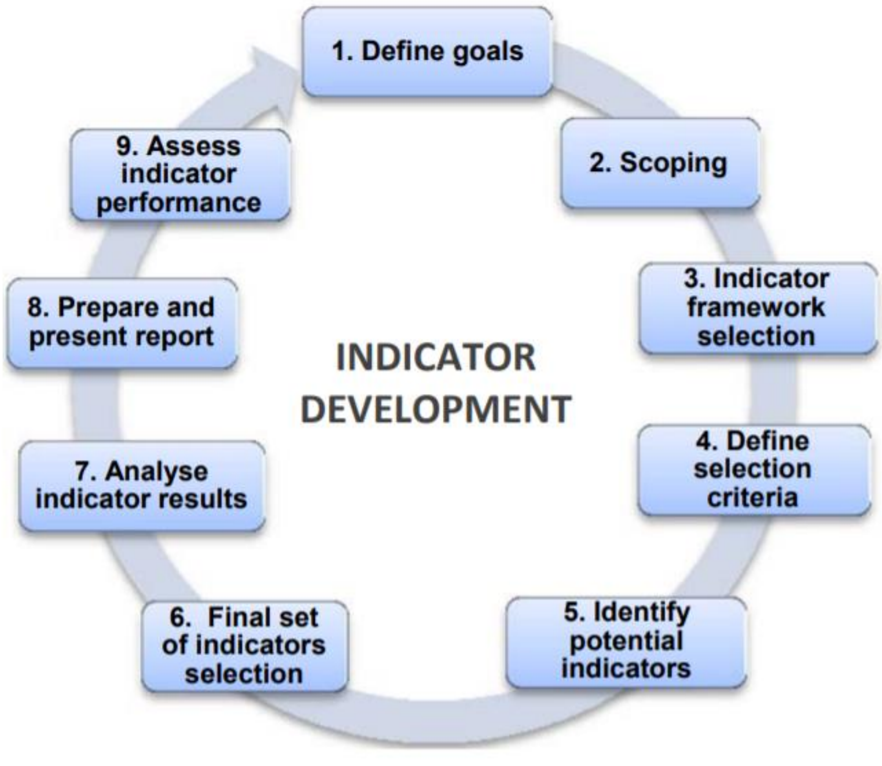

Figure 2-4: Process of developing social indicators for assessing social vulnerability. (Ciurean, Schröter, & Glade, 2013).

In accordance with Figure 2-4, the first steps of the process of developing social indicators are defining the goals and the scope of the subject research. These steps will then dictate the definition of social vulnerability and indicator framework selection.

This research fits within the disciplines of social science, environmental science and the field of natural hazards and disasters. In these disciplines, there is a consensus that social vulnerability is a function of exposure, sensitivity and resilience/adaptive capacity as presented in Figure 2-5 below.

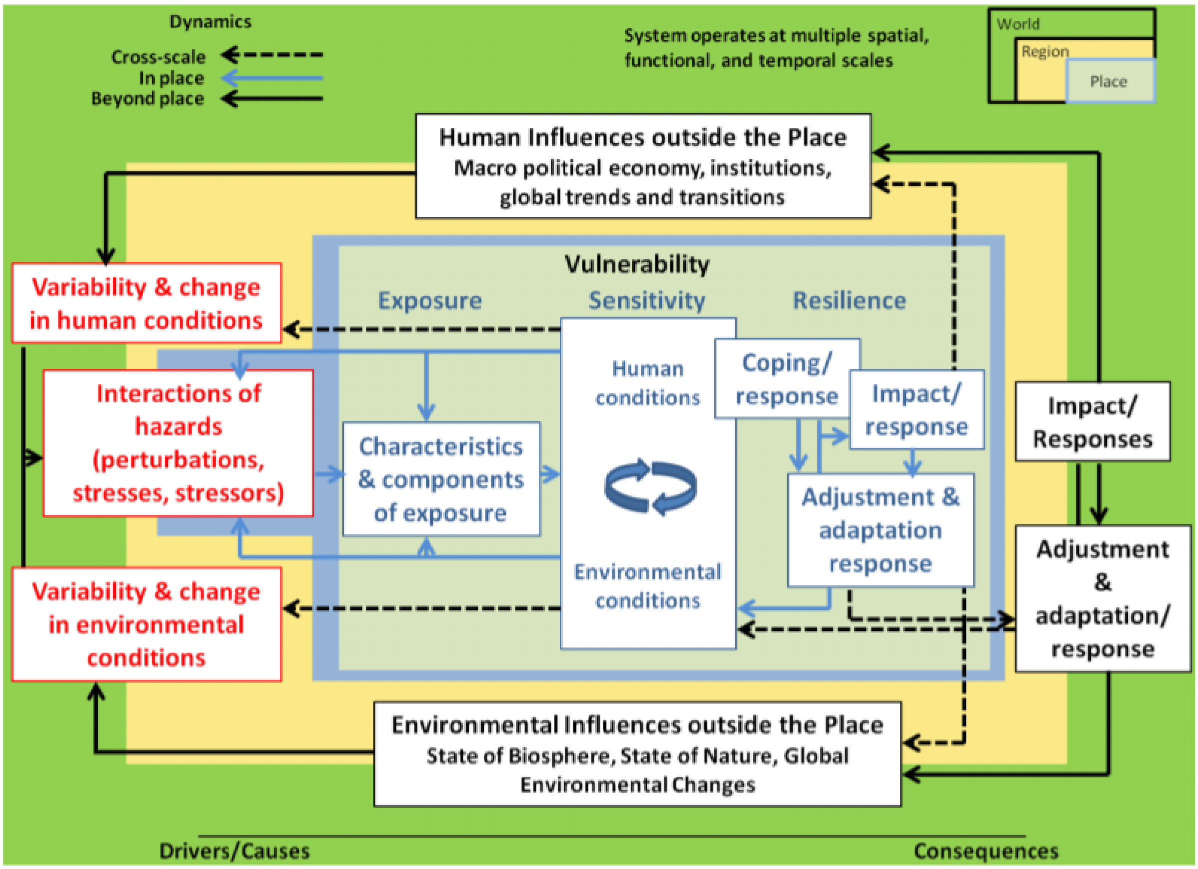

Figure 2-5: Vulnerability framework showing the important dynamic linkages between social and ecosystem/physical vulnerability. (Turner et al., 2003)

After a suitable framework is identified, the next step towards developing these indicators is to define their selection criteria. Defining the selection criteria for selecting social indicators involves establishing the definitions of exposure, sensitivity and resilience/ adaptive capacity within the subject research. Exposure has already been discussed and defined earlier in this Chapter. This section seeks to discuss sensitivity and resilience/adaptive capacity.

Sensitivity can be defined as the degree to which a system is influenced, either adversely or beneficially, by a given exposure to a stressor scenario (e.g. storm, sea-level rise, drought). The influence on a system can be direct (e.g. sea-level rise resulting in saltwater intrusion) or indirect (e.g.

sea-level rise's effect on land use that a community relies on) (Weis et al., 2016). Directs influences on a system are commonly referred to as first-level sensitivity. These influences represent the sensitivity of a natural system and its ability to withstand the bio-geophysical events triggered by climate change (Cenacchi, 2008). This level of sensitivity is assessed quantitatively using hydrodynamic or empirical approach models. First-level sensitivity is not assessed within this research as this research is based on simplified conceptual models where it is assumed that the ICOLL's water level will increase at the same rate as the nearby sea level.

This research focuses on second level sensitivity, which represents natural hazard's impacts on a socioeconomic system. These effects are usually defined by both the sensitivity of the natural system (first-level sensitivity/outcome I) and the community's level of reliance on the goods and services that their natural environment provides (Cenacchi, 2008).

Adaptive capacity refers to the capability of a natural and/or socioeconomic system, region, or community to adapt in behaviour and allocation of resources to mitigate the effects of climate change and absorb potential damages (Intergovernmental Panel on Climate Change [IPCC], 2007).

According to the indicator development plan presented in Figure 2-6, once the selection criteria are defined, the next step towards developing suitable indicators for measuring social vulnerability is to identify potential indicators of sensitivity and adaptive capacity. The potential social indicators of sensitivity and adaptive capacity/resilience are outlined in Figure 2-6 below.

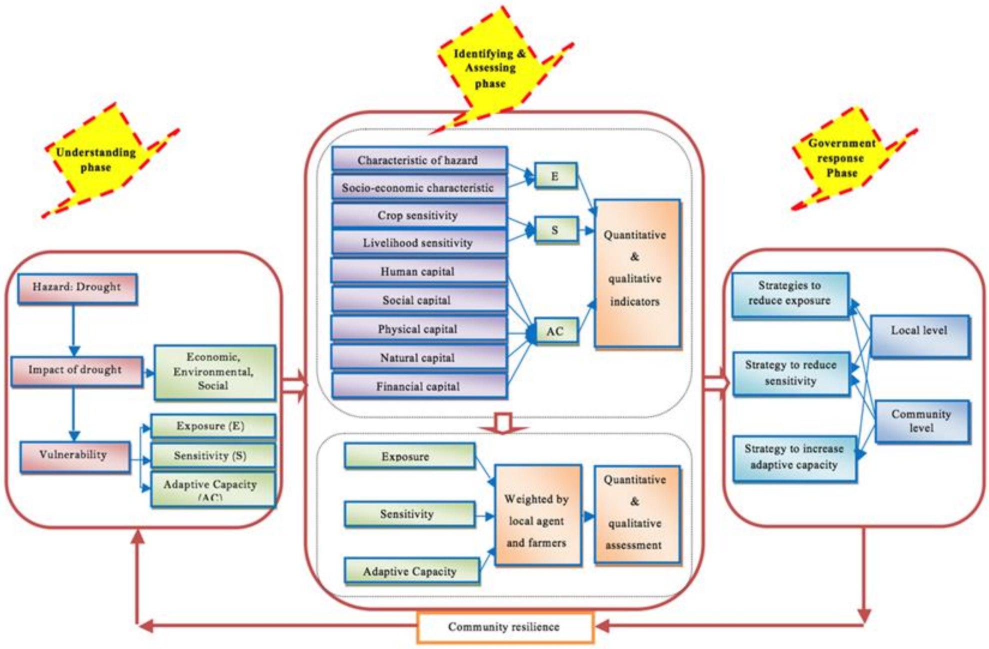

Figure 2-6: Examples of indicators of socio-economic sensitivity and adaptive capacity of farming communities to drought events. (Zarafshani, Sharafi, Azadi, & Passel, 2016).

In addition to the capital based indicators outlined in Figure 2-4 above, other social indicators of adaptive capacity/resilience and sensitivity include but are not limited to the following (Marshall et al., 2010):

- **Perception of risk**
  The ability of a community or an individual to adapt to the effects of climate change is often determined by how risk is perceived. Aspects such as individual and cultural differences in experiences, beliefs, values, knowledge, attitudes and ability to plan and execute plans are all highly influential on the perception of risk and how it is managed.
- **Ability to cope with change**
  The ability of a community or an individual to cope with change is measured by their emotional and financial thresholds.
- **Level of interest in change**
  The level of interest in change refers to a community's or an individual's interest in adapting to the requirements of the future and is influenced by their financial, social and/or emotional flexibility as well as their access to climate technology, expertise and information. Level of interest is a crucial aspect of vulnerability as it defines an individual's or a community's ability to identify the consequences, impacts and possible responses/adaptation options to climate change.
- **Ability to plan, learn and reorganise**
  An individual's or a community's ability to plan, learn and reorganise depends on their capacity for improvisation, experimentation, learning and planning around the anticipated effects of climate change in the future.
- **Attachment to occupation**
  Individuals and communities that use and depend on natural resources such as farmers and fisherman are likely to exhibit a low adaptive capacity and greater sensitivity to foreseeable impacts of climate change due to their attachment to their occupations. The higher the level of attachment to their current occupation, the harder it is for an individual/community to come to terms with the prospect that they no longer will be able to continue in that occupation, losing their main source of income and possibly also their sense of identity.
- **Family characteristics**
  Individuals within the community who use and depend on natural resources may have other family members depending on these resources (e.g. young children and

elderly/sick members of the family) and are less likely to adapt to future changes as they are less able to experiment with adaptation options. For example, farmers who value passing on their farm/occupation to their next generation are less able to accept change in order to adapt in the future.

- **Attachment to place**
  The more attached an individual is to their physical community and/or property (e.g. farms that have been operated by a family for generations), the less adaptive capacity that individual has to effectively respond to climate change. Attachment to place is influenced by identity created around the local community, the sense of pride associated with belonging to the area and the strong interpersonal relationships that exist within it.

- **Business size and approach**
  Larger businesses and individuals working and/or running big businesses have greater adaptive capacity to climate change than small businesses and their employees. Bigger businesses usually have greater financial resources to buffer themselves from unpredictable problems. Individuals who own larger businesses are often more strategic and are thus able to plan, organise and act towards economic incentives instead of focussing on their attachment to occupation and place.

- **Financial status and access to credit**
  The financial resources of an individual within a community has a great influence on their ability to adapt and to respond to changes. An individual with greater financial resources has the capacity to successfully absorb the costs of change.

- **Income diversity**
  Individuals who have multiple sources of income are able to switch between these sources, spread risk and increase their ability to absorb sudden expenses and adapt to changes.

- **Local environmental knowledge**
  Local environmental knowledge allows communities and individuals within a community to detect subtle changes in the environment local to them. The establishment of well-developed local knowledge requires time and adequate financial investment, thus the likelihood of individuals to move and develop that knowledge again elsewhere is low. Individuals with a high level of local environmental knowledge are usually well-adapted to their surrounding environment and natural resources and have a tendency to be less able to adapt and cope with changes.

- **Environmental awareness, attitudes and beliefs**
  Unlike local environmental knowledge, environmental awareness refers to a community and/or an individual that supports resource-protection strategies and values the sustainable and efficient use of natural resources. They are more willing to change lifestyle to adapt to new practices that enhance both their own resilience to the impact of natural hazards as well and their communities' level of resilience to disturbances.

- **Access to technology, climate information and skills**
  An individual who has access to technology, climate information and skills is often able to design well-developed plans and reorganise for the future.

- **Formal and informal networks**
  This variable refers to the likelihood that people might move from their community in order obtain opportunities elsewhere. Networks can be formal through legal structures and government agencies or informal through friends, families and associates. Individuals with stronger, more informed and more effective networks are expected to have a greater capacity to adapt to changes.

Once the potential indicators of sensitivity and resilience/adaptive capacity are identified, the next step is to evaluate potential indicators by considering the criteria developed at an earlier stage. This can be achieved by exploring various social models of sensitivity and adaptive capacity/resilience. The final stages of the process of developing indicators for measuring social vulnerability involves the assessment of the indicator's performance, which is outside the scope of this research and therefore will not be discussed further in this chapter.

Some of the common models established in current literature for assessing adaptive capacity/resilience and sensitivity are outlined below:

- The disaster resilience of place (DROP) model,
- The socio-cognitive model of proactive private adaptation to climate change impacts, and
- The local adaptive capacity framework.

The disaster resilience of place (DROP) model, which is presented in Figure 2-7 below, highlights the effect of a communities' preparedness by measuring both inherent vulnerability and resilience towards the impact of future natural hazard/disaster events and the probability of recovery from these events.

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Figure 2-7: Schematic representation of the disaster resilience of place (DROP) model. (Cutter et al., 2008)

The DROP model shows that when a community is exposed to a natural hazard, coping responses activate (Cutter et al., 2008). Coping responses include predetermined evacuation plans and emergency response plans to respond to the immediate hazard. Those plans intend to absorb the shock of a disaster and minimise the damage of that disaster to some extent. The degree of this extent is referred to as the absorptive capacity. If the absorptive capacity of a community is insufficient for a given hazard event, that event is then transformed into a disaster. If a disaster occurs, the community may exercise its adaptive resilience through improvisation and learning. Improvisation refers to actions, including spontaneous actions which may aid in the recovery process (Cutter et al., 2008). Social learning refers to the diversity of adaptations and the stimulation of robust local social cohesion and mechanisms for communal action. Finally, the level of recovery alters the antecedent condition of the social and natural systems as well as built environments by dictating their vulnerability to future hazard events. Lessons learned from the occurrence of a natural hazard or disaster event can be used to prepare for future events, reducing the vulnerability of that communities' social and natural systems and their built environment.

The DROP model emphasises the role that preparedness plays in enhancing communities' adaptive capacity and resilience. The DROP model does this by highlighting the role of past experiences influence on communities' willingness to prepare.

The other model explored in this research is the Socio-cognitive model of proactive private adaptation to climate change impacts and is presented in Figure 2-8 below.

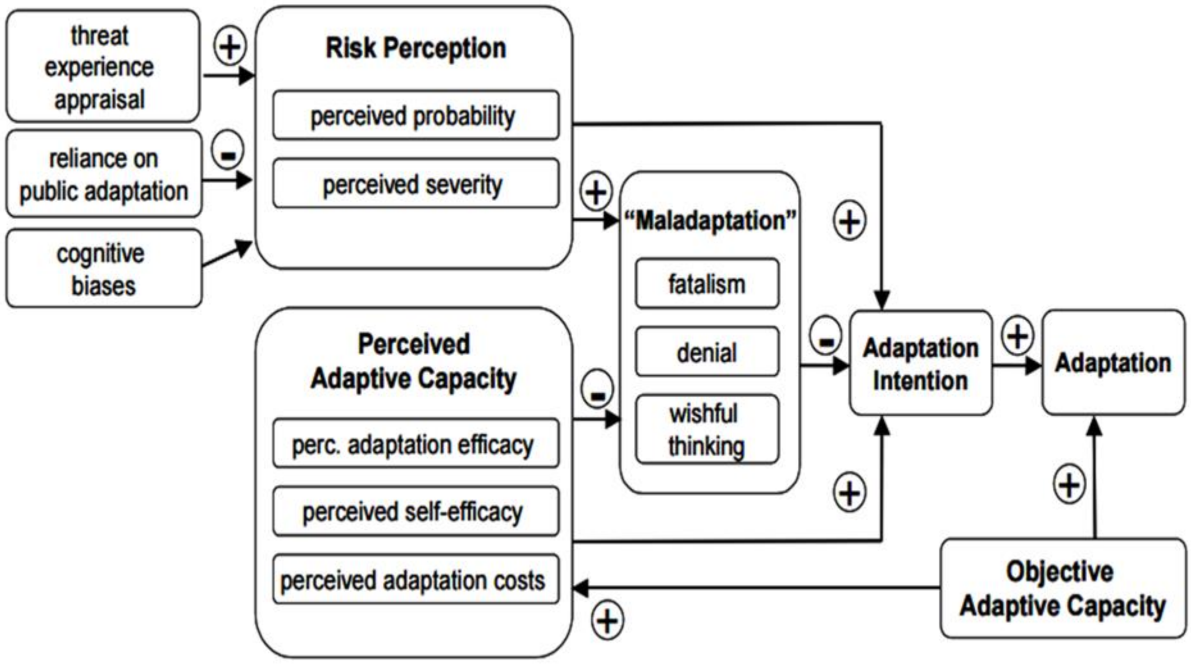

Figure 2-8: Socio-cognitive model of proactive private adaptation to climate change impacts. (Grothmann & Patt, 2003)

The socio-cognitive model also recognises preparedness to be an important social indicator of adaptive capacity. However, this model takes it's assessment of adaptive capacity a step further than the DROP model by identifying the social factors that can affect a community's or an individual's willingness to act proactively and prepare for future natural hazard events. The model seeks to identify what factors affect the motivation of a community or an individual to protect themselves from potential harm associated with these hazards. Grothmann & Patt, 2003, described an individual's or a community's willingness to take proactive measure to prepare for future natural hazard and disaster events to be a function of their risk perception and perception of their adaptive capacity. The socio-cognitive model indicates that an individual or a community first assess their probability of being exposed to a hazard event as well as the potential damage that event poses towards their valuables if they were not to change their behaviour. The second perceptual process is referred to in this model as coping appraisal, also known as perceived adaptive capacity. Coping Appraisal is a process in which an individual or a community evaluates their ability avoid being harmed by the threat, along with the costs of taking such actions of avoidance. This process occurs after the risk perception process and only occurs if a specific threshold of threat appraisal is reached. Coping Appraisal has three subcomponents: perceived adaptation efficacy, perceived self-efficacy and perceived adaptation costs.

Perceived adaptation efficacy refers to an individual's belief that protective actions or responses are effective in protecting oneself or others from being harmed by a threat. On the other hand, perceived self-efficacy refers to the individual's perceived ability to perform or carry out these adaptive responses. Perceived adaptation costs are the costs of implementing a risk-reducing adaptive/preventative response to a hazard. Costs in this context refer not just to monetary costs but also to time and effort costs. Even though costs and self-efficacy are related, in this model the importance of differentiating them conceptually is recognised. It is useful to know if it is either self-efficacy or high response costs that provoke an adaptive response to be undertaken an individual.

Lastly, an individual's response to a threat is based on the outcomes of the threat's appraisal and coping appraisal processes. There are two main types of response: adaptation and maladaptation responses (Grothmann & Patt, 2003). An adaptive response is a response that is taken if the perception of the risk and perceived adaptive capacity is believed to prevent damage or increase benefits. For example, precautionary actions like avoidance of expensive investment on flood-prone land. In contrast, maladaptive responses, such as the denial of a threat's existence in the form of wishful thinking and fatalism, are responses that do not prevent monetary or physical damage in the case of a climate change impact, but do prevent negative emotions in relation to the perceived risk of those impacts such as fear. Maladaptive responses are usually taken when an individual's risk perception is high, but their perceived adaptive capacity is low (Grothmann & Patt, 2003).

Maladaptive responses are a type of adaptive response as adaptiveness is a question of "best fit". For example, for an ill or poor individual who has little means of preventing flood damage proactively or reactively, denial of the risk of flooding can be seen as an effective adaptive coping strategy (Grothmann & Patt, 2003). In this case, although denial would not be considered as an adaptive response in the sense of preventing damage, it will protect this person's psychological well-being before a flood. The term adaptation is used to describe responses that prevent or mitigate physical damage, while maladaptation is used to describe those response that prevent psychological damage (Grothmann & Patt, 2003).

Besides adaptation intention, the socio-cognitive model also highlights the importance of objective adaptive capacity (e.g. time, money, knowledge or social support) in enabling effective preparedness to adapt to anticipated future hazard events. The socio-cognitive model presents a sound example of the key variables required for building objective adaptive capacity at a community scale, which can be scaled down to an individual household.

Finally, the third adaptive capacity/resilience model explored in this research is the local adaptive capacity framework, shown in Table 2.1 below.

Table 2.1: The main five elements used in the local adaptive capacity framework to a assess the adaptive capacity of a community. (Africa Climate Change Resilience Alliance, 2010).

Characteristic	Features that reflect adaptive capacity
Asset base	The financial, physical, natural, social, political and human capitals necessary to prepare a system to respond best to a changing climate. This category incorporates the importance of different kinds of capital, often informal, non-monetary or reliant on social networks. [Physical capital: sand dams, flood defence schemes, boreholes, etc; financial capital: household savings, access to financial loans, livestock and household wealth, etc; natural capital: forest resources, access to water resources, etc.]
Institutions and entitlements	The ability of system to ensure equitable access and entitlement to key resources and assets is a fundamental characteristic of adaptive capacity. Entitlement to the key resources needed for adaptation can be differentiated according to age, ethnicity, class, religion and gender (among other groups). It follows that an institutional environment that allows equitable opportunities to all groups, particularly the marginal and most vulnerable, to the impacts of climate change, is essential to building the capacity to adapt. Representation and participation in key institutions is also essential to enabling an equitable distribution of resources. Access to key resources, participation in decision-making processes and empowerment are key elements of this characteristic. [Examples: Local norms that regulate access to natural resources or water points (e.g. whose animals, and how many, are allowed at which water point during which season); religious rules that prevent women from ploughing; social norms that encourage wealthier households to support poorer neighbours in times of stress or crisis, etc.]
Knowledge and information	Successful adaptation requires information and understanding of future change, knowledge about adaptation options, the ability to assess them, and the capacity to implement the most suitable interventions. In the context of climate change it is important to ensure that systems are in place to distribute relevant information at both national and regional scales. In addition, forums must be made available for dialogue and discussion among all stakeholders. [Examples: Flood early warning systems; meteorological data and forecasting; climate impact data].
Innovation	A key characteristic of adaptive capacity relates to the system's ability to support innovation and risk taking. Innovation can be planned, technically oriented and geared towards large- scale innovations; or it can be autonomous, local-level initiatives that help people adapt to changes to local climate. An enabling environment that promotes and allows for experimentation and the exploration of niche solutions is required to take advantage of new opportunities and to confront challenges presented by climate change. The environment also needs to protect against the risks of failure associated with innovation. [Examples: changing crop types, adopting new farming practices, switching livelihoods, taking advantage of new opportunities presented in the face of a changing climate].
Flexible forward-looking decision-making and governance	Informed decision-making, transparency and prioritisation are all key elements of adaptive capacity. Ensuring that local organisations are well-informed of future climate trends enables them to take measures to plan for their impacts. Similarly, flexibility to allow systems – and the institutions that govern them – to evolve and adapt to a changing environment is a crucial characteristic of adaptive capacity. [Examples: land-use regulations that protect floodplains while allowing moderate use, and that are reassessed every planning period against new, climate-change evidence; regulations that have requirements that the land owner/user report on certain changing conditions].

This framework was developed as part of the Africa Climate Change Resilience Alliance. The local adaptive capacity framework characterises and assesses communities' adaptive capacity to the anticipated effects of climate change based on five elements: asset base; institutions and entitlements; knowledge and information; innovation; and flexible forward-looking decision-making and governance. This framework provides an improved perspective on adaptive capacity that examines the processes through which a system adapts, unlike traditional capital-based approaches which focus on what values the system exhibits that enables it to adapt.

2.2.1 Adaptation options

There are three primary pathways for adaption to sea level rise. These pathways are presented in Figure 2-9 below and they include retreat, accommodation and protection.

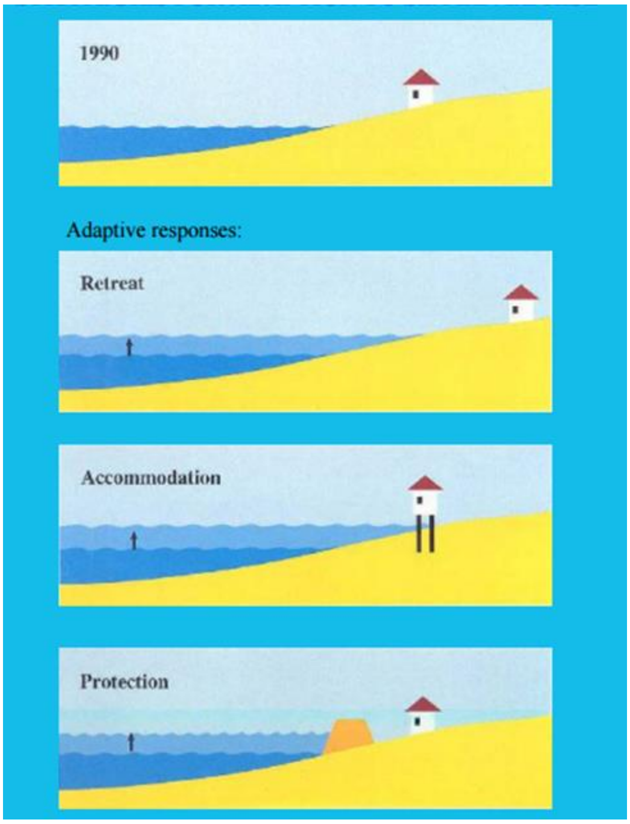

Figure 2-9: The three main adaptation options to sea-level rise. (Dronkers et al., 1990)

Retreat refers to the abandonment land in response to sea level rise. This choice is usually made under the circumstance where accommodation measures come with an excessive financial cost or environmental impact (Dronkers et al., 1990). Accommodation refers to the change of land use to better adapt to the anticipated impact of future sea level rise. This option revolves around adapting land use to the changing environment by change of lifestyle, which might not be viewed as ideal. This option usually involves raising houses' floor levels and altering land use (i.e. from agriculture to aquaculture) and improving evacuation and emergency procedures (including building emergency flood shelters). In contrast, protection involves the building of hard solutions such as sea walls and dikes, as well as soft solutions such as dunes and vegetation, to protect low lying land and communities from inundation (Dronkers et al., 1990).

2.2.2 Adaptation through managed retreat

The managed retreat approach is becoming an increasingly popular approach worldwide for managing and adapting to future sea-level rise. Managed retreat is seen as a more sustainable approach than hard engineering approaches as it improves flood risk management and provides a more affordable coastal defence. Managed retreat approaches also prevent ecosystems from being squeezed between development and the advancing sea as this approach allows for the creation of intertidal habitats.

The most common mechanisms for the managed retreat approach for future planning and new developments are setbacks, density restrictions and rolling easement policies. Setback policy strategy refers to the establishment of a minimum distance from the shore which new building developments must not exceed. Density restriction strategy refers to the general limitation of new building developments in hazard-prone zones. Rolling easement policies allow for new building development on the condition that no effort should be taken (i.e. building of new flood defences) to protect the development from the rising sea. These strategies may all compromise elements of an integrated coastal management policy worldwide in the future. Box 2.1 below summarises a few worldwide examples of managed retreat in established policies for adapting to future sea-level rise.

Box 2.1 Examples of managed retreat and related measures as adaptation to sea-level rise

- **Canada:** Estimates of future coastal retreat were used to adopt a variety of setback policies in some provinces such as New Brunswick, where the entire coast of the province was remapped to delineate the landward limit of coastal features. This limit defined the setback for new development in the province.
- **Barbados:** A minimum building setback along sandy coasts at 30 m from mean high-water mark and along coastal cliffs the setback at 10 m from the undercut portion of the cliff was established under a national statute.
- **Aruba and Antigua:** Established setback at 50 m inland from high-water mark.
- **Sri Lanka:** Minimum setbacks of 60 m from line of mean sea level are regarded as good planning practice based on setback areas and no-build zones identified under the Coastal Zone Management Plan.
- **United Kingdom:** the concept of managed realignment was endorsed as the preferred long-term strategy for coastal defence in some areas by the House of Commons in 1998.
- **United States:** Various forms of rolling easement policies to ensure that wetlands and beaches can migrate inland as the sea level rises have been implemented in the states of Maine, Massachusetts, Rhode Island, and South Carolina.
- **Australia:** Several states have coastal setback and minimum elevation policies, including those to accommodate potential sea-level rise and storm surge. In South Australia, setbacks take into account the 100-year erosional trend plus the effect of a 0.3-m sea-level rise to 2050. Building sites should be above storm-surge flood level for the 100-year return interval.

Source: Adejuwon et al. (2001)

Implantation of managed retreat in New Zealand

There are examples in New Zealand where coastal communities have either chosen to take proactive actions or retreated or where forced to retreat. These examples include Muriwai Beach in Auckland, Ōhiwa Spit in Bay of Plenty, Pourewa Point in Aotea Harbour, Te Kopi in Wairarapa, Waihi Beach in Bay of Plenty, and Wainui Beach in Gisborne District. For all of the seven cases, protection and defence work has been tried and failed due to the onset of erosion. Muriwai Beach in Auckland was the only place out of the seven locations where managed retreat took place where property owners were forced to abandon their houses. Managed retreat has been implemented in the form of a deliberate formal strategy, where the regional and district councils adopted recommendations to accommodate coastal erosion by a gradual process of retreat in 2004 (Turbott & Stewart, 2006).

2.3 Summary

This chapter presented the literature that was explored in this research to obtain information on the following subjects:

- current understanding of sea level rise of artificially managed ICOLLs,
- quantitative tools for measuring the risk of exposure to the anticipated effects (i.e. flooding) of future sea level rise,
- qualitative tools for measuring vulnerability and communities state of preparedness to future sea level rise, and
- adaption options in response to future sea level rise.

Chapter 3

Case study: Lake Ellesmere/Te Waihora

Worldwide, the management of ICOLLs has proven to be particularly challenging due to their setting within the coastal environment and their ecological, cultural and economic values (Hughey, 2010). They act as the sinks of their catchments, capturing upstream flows and contaminants from various land-use activities, which subjects them to declining water quality and fisheries (Hughey, 2010). ICOLLs are usually highly valued by various organisations and are often subject to indigenous peoples' rights (Hughey, 2010). Historically the reclamation and drainage of ICOLLs' fertile margins was a common practice for creating productive agricultural land (Hughey, 2010). The protection of these reclaimed margins from inundation continues to be a challenge today.

Lake Ellesmere/Te Waihora was chosen to be the subject of this research because it presents an excellent example that typifies the immense and diverse management challenges of ICOLLs nationally and worldwide.

3.1 Lake Ellesmere/Te Waihora catchment

Lake Ellesmere/Te Waihora is an expansive, shallow and brackish coastal Lake located along the east coast of the Canterbury region in the South Island of New Zealand (Varona, 2012) (Figure 3-1).The Lake Ellesmere/Te Waihora catchment covers an area of 26,708 km^2, composed of 777 km^2 of hills and 1,295 km^2 of plains. Lake Ellesmere/Te Waihora occupies seven percent of its catchment, receiving flows from at least 32 drains, five main rivers and groundwater (Kitto, 2010). The lake receives approximately 840 million m^3/year of groundwater and around 271,395,360 m^3/year from the Selwyn River, the LII River, the Halswell River, the Irwell River and the Kaituna River (Kitto, 2010).

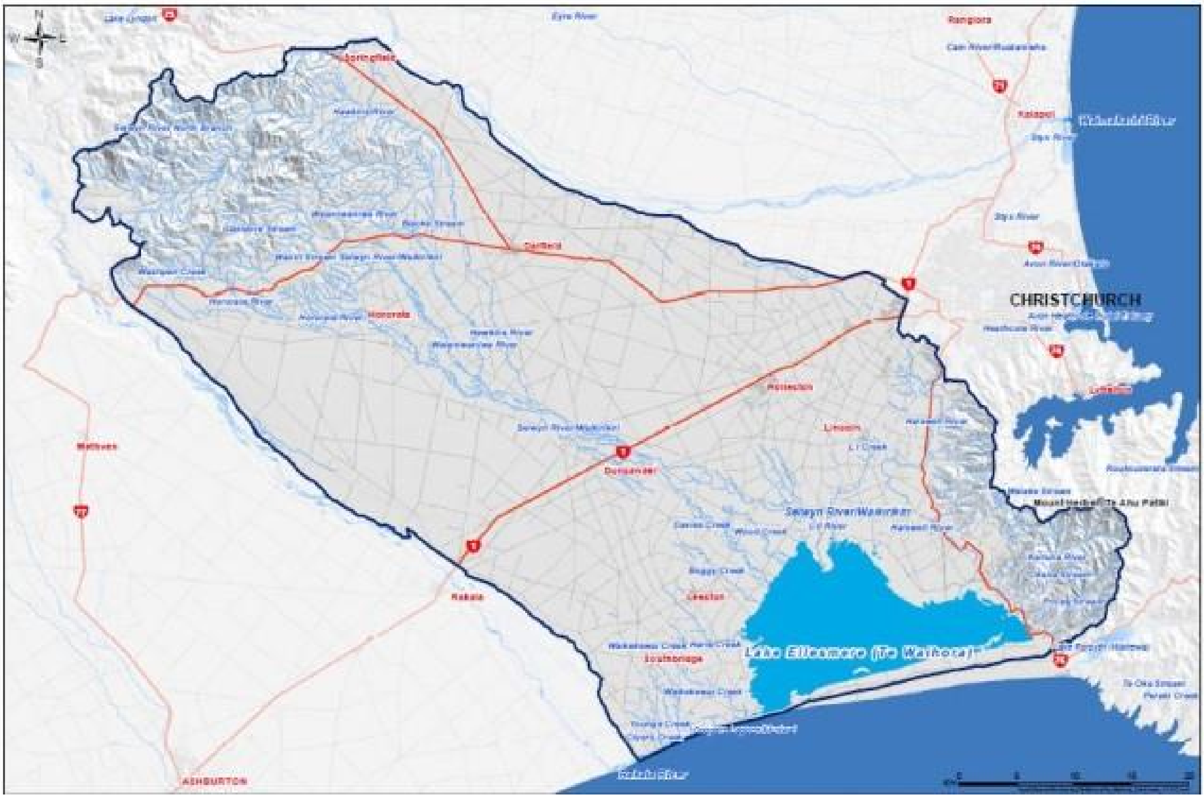

Figure 3-1: The Lake Ellesmere/Te Waihora catchment. (Waihora Ellesmere Trust, 2015)

Lake Ellesmere/Te Waihora is recognised internationally for its significant wildlife habitat and rich biological diversity (Golder Associates, 2011). Nationally, the lake is highly valued by various organisations and recognised for it is economic, ecological and cultural significance (James, 1991). The lake has no natural outlet to the sea and is separated from the sea by a 28 km long shingle/sand barrier referred to as the “Kaitorete Spit” (Lettink, Cree, Norbury, & Seddon, 2008). The lake is periodically opened to the sea using heavy machinery to scour an opening channel through the Kaitorete Spit. This opening acts primarily to protect adjacent productive land around the lake from inundation but also to maintain the lake’s water quality and to facilitate fish migration. The opening regime seeks to maintain the lake water level at an average of 2 metres above mean sea level (m.a.m.s.l.). Without human intervention, the lake water level can reach up to 3 to 4 m.a.m.s.l. before naturally breaching the barrier and discharging out to the sea.

3.2 Climate change and the lake’s water levels

As the sea-level rises along the Kaitorete barrier, the swell and storm waves riding on a progressively higher sea level are expected to build-up the barrier by sediment supplied from the lower foreshore. The barrier’s height is expected to increase at a similar rate to sea level rise. In time, given the lack of a backshore ridge at the outlet, over-washing processes are expected to result in the barrier retreating and rolling landward. However, the scale of the retreat is expected to be minor given the steep nature of the foreshore. In the meantime, the lake's water level is expected to increase in relation to adjacent land at the same rate that the sea level is rising (Renwick et al., 2010).

The success of the artificial opening of Lake Ellesmere/Te Waihora is based on the number of days that the opening can be maintained (Haines & Thom, 2007). Sea-level rise will present less favourable conditions to achieve successful openings in the future and could even result in increasingly delayed openings. Sufficient gradient (referred to as hydraulic gradient) between the lake's water level and sea level is required to initiate the opening and maintain it (Renwick et al., 2010). As the sea level rises, this hydraulic gradient will decrease. As a result, the current opening trigger levels will need to be adjusted to maintain a sufficient gradient to enable the outflow of water from the lake to the sea (Renwick et al., 2010).

The scale of effects of sea-level rise on the lake's water levels can either be inflated or condensed based on effects that climate change has on the lake's hydrological cycle and the local climate. Based on climate data from 1990, it is likely that the Canterbury Region is going to experience an increase in temperature of approximately 0.9˚C by 2040 and an increase of temperature of approximately 2.0˚C by 2090 (Renwick et al., 2010). The Canterbury Region is expected to experience an increase of approximately 20–40 days annually where maximum temperatures exceed 25˚C. As temperature increases, evaporation loss from the lake will increase, resulting generally in lower lake water levels. However, the effects of changes in the lake's evaporation due to climate change will be minor on the lake's artificial opening regime.

Rainfall will vary locally within the region due to climate change (Renwick et al., 2010). The region is expected to become wetter in the west and drier in the east, with greater amounts of rainfall in the ranges and less rainfall on the plains. Rainfall is projected to decrease in coastal Canterbury, large alpine-fed rivers such as the Waitaki, Rangitātā, Rakaia, Waimakariri and Hurunui rivers could have increased flows due to greater rainfall in the headwaters (Renwick et al., 2010). This will cause a higher volume of water to enter Lake Ellesmere/Te Waihora via inflows from the catchment. In addition to an increase in rainfall, temperature and evaporation in the region, projected climate change is also expected to affect wind intensity, which can temporarily increase the lake's water level (Renwick et al., 2010).

Overall, the effects of climate change on the lake's hydrological cycle and local climate is expected to result in a net decrease of the lake's water levels.

In addition to the biophysical effects of projected climate change on Lake Ellesmere/Te Waihora, the anticipated increase in local temperature due to climate change is expected to result in an increase in water demand across the Region. The increase in demand of water and resulting pressure on surface water and groundwater resources will result in a decrease in volume of water flowing into Lake Ellesmere /Te Waihora from the catchment. The effects of increasing temperature due to climate change and increase in water demand on surface water has already been experienced in the Canterbury Region, where surface water flows have started to deplete significantly. To restore this depletion of surface water flow, Christchurch City Council and Selwyn district council have established the Central Plains Water Enhancement Scheme in 2004 (Central Plains Water Limited, 2017) to recharge surface waterways using groundwater. This restoration of surface water flow means that the volume of water flowing into Lake Ellesmere/Te Waihora will be maintained or increased by human intervention despite the effects of climate change in general on the biophysical characteristic of the lake.

3.3 Governance and management

The opening regime of Lake Ellesmere/Te Waihora plays a fundamental role in facilitating the migration of fish, maintaining water quality and protecting adjacent land from inundation. However, not all of these services have always been valued equally by decision makers and community groups involved in the management and operation of the lakes' artificial opening regime. The management of the lake's artificial openings has evolved significantly over the 20th century in response to a shift in environmental views and attitudes. There has been a shift from focusing on utilising productive land to the preservation of swamps and wetlands (Varona, 2012). Historically, the opening of Lake Ellesmere/Te Waihora to the sea has been carried out by generations of the Māori tribe/local iwi; Te Rūnanga o Ngāi Tahu, for decades prior to the arrival of Europeans. The local iwi used flax sticks and shovels to open the lake to the sea and protect their settlement at Taumutu (Ngāti Moki Marae) from inundation and to facilitate the migration of eels to the sea (Varona, 2012). Historical records indicate that the local iwi used to open the lake to the sea when the lake's water level reached 2.7 m.a.m.s.l. Upon the arrival of Europeans in the early 1800s, the Canterbury Association was formed to provide guidance to the European Settlement in the Canterbury Region. The Association's leader at the time; Robert Godly, envisaged the future of Canterbury's economy to lay in pastoralism, which led to the commencement of extensive modification of land across the plains (James, 1991). By 1853 around 100 sheep farms consisting of over 100,000 sheep occupied the Canterbury Plains (James, 1991). By 1868 settlers realised that the soils of the lower catchment surrounding the lake are lighter and more fertile than the soils of the Central Plains (James, 1991). This led to the extensive drainage and reclamation of the swamps and wetlands margining Lake Ellesmere/Te Waihora. By 1894 there were around 418 drains across the Central Plains and the lower catchment, which included the construction of the 5 km long Halswell Canal. Local statutory government bodies took over the responsibility of periodically opening the lake to the sea until 1944, when the North Canterbury Catchment Board was formed. During this period, the lake's water level was maintained at a relatively lower level than the level maintained earlier by the local iwi. The lake was artificially opened when its level reached 1.13 m.a.m.s.l. in winter and 1.05 m.a.m.s.l. in summer to prevent the inundation of the reclaimed margins of the lake.

The North Canterbury Catchment Board focused on improving drainage across the catchment, which led to the construction of two lower level ocean discharge culverts to increase the overall drainage capacity. By 1980, around 2,200 farms occupied the Central Plains.

In 1985 the New Zealand Wildlife Service released its Fauna Survey Unit Report No. 4, titled *Lake Ellesmere: A Wildlife Habitat of International Importance* (O'Donnel, 1985). The report identified the wildlife values of Lake Ellesmere/Te Waihora, which meet all of the criteria set by the International Union for Conservation of Nature and Natural Resources (IUCN) to be ranked as an outstanding wildlife habitat for the national wildlife habitat inventory compiled by the New Zealand Wildlife Service. The report identifies Lake Ellesmere/Te Waihora and its margins to be New Zealand's largest and most important wildlife habitat of its type, supporting approximately eight native and endemic bird species which were not recorded anywhere else in New Zealand and were considered to have a vulnerable or threatened conservation status. Moreover, the lake's wildlife habitat was also recognised internationally for supporting a number of overseas migratory waders. In the meantime, further reclamation and drainage scheme proposals were made by both community groups and individuals, including the Nutt's stop-banking and the Osborne pumping scheme to improve drainage in the lower part of the catchment.

The Minister of Internal Affairs exercised his statutory duty of administering the Wildlife Act 1953 in light of the information released by the New Zealand Wildlife Service, and in response to the proposed reclamation and drainage schemes. The Minister applied under the Water and Soil Conservation Act 1967 (replaced by the Resource Management Act (RMA) 1991) for a Water Conservation Order for Lake Ellesmere/Te Waihora on 27 June 1986 to protect the lake's significant wildlife habitat. The application was approved, and the National Water Conservation (Te Waihora/Lake Ellesmere) Order 1990 came into force on 2 July 1990.

3.4 National Water Conservation (Te Waihora/Lake Ellesmere) Order 1990

Water Conservation Orders (WCOs) are applied to water bodies that are deemed to have outstanding amenity and/or intrinsic values. Any person or group can apply for a WCO under the

Resource Management Act 1991 (Ministry for the Environment [MfE], 2016). A WCO provides the following:

- preservation of the water body's natural state; and
- protection of the characteristics that contribute to the water body's significant ecological, recreational, historical, spiritual, or cultural values (including outstanding significance in accordance with tikanga Māori).

WCOs can restrict regional councils from issuing discharge and water permits. Regional policy statements as well as regional and district plans must be consistent and give effect to the provisions of the relevant WCOs (MfE, 2016). However, a WCO's statutory powers are limited in relation to existing permits.

The National Water Conservation (Te Waihora/Lake Ellesmere) Order 1990 (National Water and Soil Conservation Authority, 1990) recognises the international and national significance of the lake's wildlife habitat and seeks to protect it by:

- preserving the natural state (water quantity) of the lake by preserving the existing artificial opening regime and only allowing the lake to be opened when its level reaches 1.05 m.a.m.s.l. (from August to March inclusive) and 1.13 m.a.m.s.l. (from April to July inclusive);
- prohibiting the stop-banking and drainage of the lake's bed below 1.13 m.a.m.s.l.;
- allowing for the lake to be opened in early spring to facilitate fish migration; and
- allowing the closure of the lake opening when the lake has dropped to tidal levels.

Prior to the WCO coming into effect, the North Canterbury Catchment Board opened the lake to the sea once its level exceeded 1.13 m.a.m.s.l. in winter and 1.05 m.a.m.s.l. in summer. These artificial opening trigger levels were based primarily on the need to protect reclaimed land from inundation. The amendment of these artificial opening trigger levels under the provisions of the WCO was restricted by the presence of notified uses (National Water and Soil Conservation Authority, 1990). Notified uses are land-use activities dating back to 1967, when the Water and Soil Conservation Act came into effect, and cannot be affected by the WCO's provisions as they are deemed to be perpetual rights (National Water and Soil Conservation Authority, 1990). Thus, these opening trigger levels were preserved under the 1990 WCO. However surprisingly, regardless of this restriction, assessment of the benefit of possibly higher opening trigger levels on the lake was not considered in the process. At that time, the focus was on preventing any further drainage and on the detrimental effects of low lake levels (National Water and Soil Conservation Authority, 1990).

The North Canterbury Catchment Board operated the lake's opening regime under the National Water Conservation (Te Waihora/Lake Ellesmere) Order 1990 as well as a number of resource consents upon the dissolution and replacement of the Board by the Canterbury Regional Council/Environment Canterbury in 1989. During that period, the local iwi were granted ownership of the Crown-owned portions of the lake bed and a few surrounding areas under the Ngāi Tahu Claims Settlement Act 1998. In 2005, the Department of Conservation and Ngāi Tahu signed a joint management plan that allows Ngāi Tahu to have greater input into the management of the lake's bed. The Te Waihora Joint Management Plan was significant as it was the first statutory joint land management plan between the Crown and iwi.

3.5 WCO amendment 2011 and co-governance

Today Lake Ellesmere/Te Waihora and its catchment are co-governed by multiple organisations, some of which have statutory responsibility while others are involved based on a wide range of interests. The co-governance approach was first established in 2006, when Environment Canterbury (ECan, the current regional council) negotiated a protocol for opening the lake to ensure that the views of those who are affected by the opening regime are heard (Lomax, Johnston, Hughey, & Taylor, 2015). This approach has since evolved significantly to cover the entire catchment.

In 2010, the Department of Conservation and Ngāi Tahu applied for amendments to the 1990 WCO (Waihora Ellesmere Trust, 2015). Some of these amendments were administrative in nature while others regarded the inclusion of additional outstanding characteristics, features and values to be protected by the order (Smith, 2010). The amendments applied for the following to be included:

- adding the Māori name Te Waihora to the title of the order;
- changing any reference made in the order to the Soil Conservation Act 1967 to the Resource Management Act 1991;
- changing the means of recording when the lake may be opened from 1988 mean sea level to the 1937 Lyttelton datum as this datum was considered to be more accurate;
- providing for an additional lake opening between 1 April and 15 June to facilitate fish migration;
- amending the level at which damming, stop-banking and polderisation can occur;
- addition of the following further outstanding characteristics, features and values to be protected by the order:
  - indigenous wetland vegetation;
  - customary fisheries;
  - Ngāi Tahu historical, spiritual and cultural values and significance in accordance with tikanga Ngāi Tahu, including in respect of kaitiakitanga and mahinga kai.

On 2 September 2011 the amendment was passed. Shortly after, a long-term relationship agreement was signed between ECan and Ngāi Tahu to manage the lake and its wider catchment collaboratively.

This collaborative agreement was not signed as a formal joint agreement under the RMA but as more of a voluntary collaboration that sought to bring together the tikanga (customary system of values and practices) responsibilities of Ngāi Tahu and the statutory responsibilities of the local councils. Later, the Selwyn District Council (SDC) joined the agreement in 2014, followed by Christchurch City Council in 2016.

3.6 Current opening regime

Prior to 2014, ECan was the sole consent holder for resource consents that authorised the artificial opening of the lake to the sea. In light of the cultural values recognised through the amendment of the WCO in 2011, ECan and Ngāi Tahu agreed to apply for joint resource consents. Today the lake's opening regime is regulated by a WCO and a number of resource consents held jointly between Ngāi Tahu and ECan (Te Rūnanga o Ngāi Tahu, 2014).

The opening of the lake is currently restricted to the following under section 4(2) of the WCO.

2) A resource consent may be so granted—
   a) to allow the lake to be artificially opened to the sea whenever the lake level—
      i) exceeds 1.05 m.a.s.l. during any period commencing on 1 August and ending with 31 March next following; or
      ii) exceeds 1.13 m.a.s.l. during any period commencing on 1 April and ending with 31 July next following:
   b) to allow the lake to be artificially opened to the sea at any time during any period commencing on 15 September and ending with 15 October next following:
   c) to allow the lake to be artificially opened to the sea at any time during the period commencing on 1 April and ending with 15 June next following:
   d) to allow the lake to be artificially closed from the sea whenever the lake level is below 0.6 m.a.s.l. during any period commencing on 1 October and ending with 31 March next following.

The area of land that benefits directly from lake openings is approximately 14,000 hectares (Kitto, 2010) and is known as Lake Ellesmere/Te Waihora's flood zone marked by a 2.74 m.a.m.s.l. contour line (Figure 3-2). The flood zone is used by SDC to guide the appropriate floor level for development near the margins of the lake. This flood zone takes into account the effect of the southerly winds on the lake's water level. The southerly wind lash has been estimated to increase the lake's water level by as much as 1.6 m (Kitto, 2010).

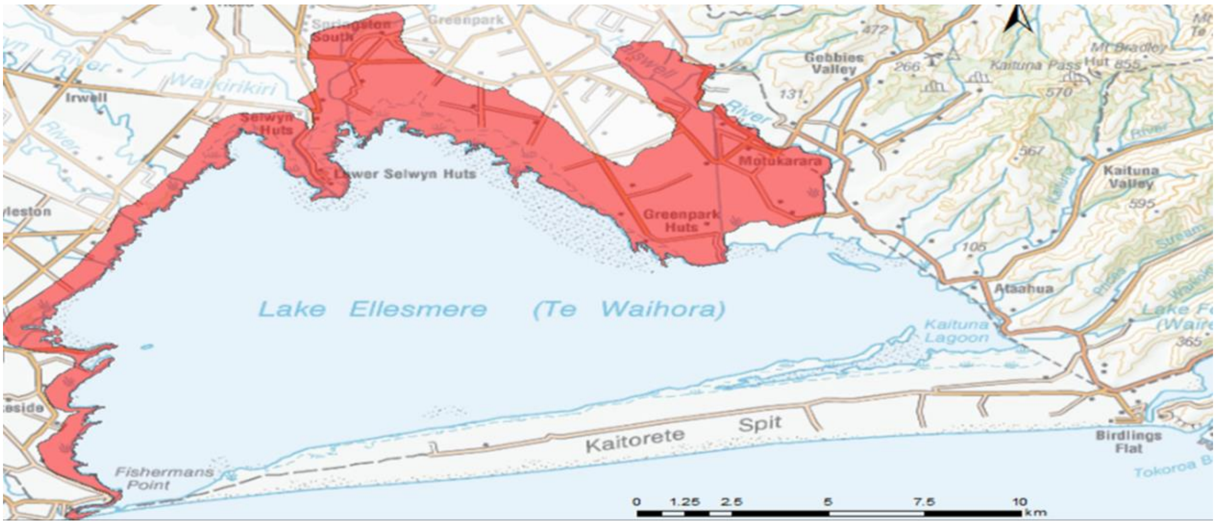

Figure 3-2: Lake Ellesmere/Te Waihora's flood zone. (Canterbury Maps, 2015)

Prior to the commencement of the lake's opening, ECan and Ngāi Tahu engage and consult with eight other stakeholders. These stakeholders collaboratively act under what is known as the lake's opening "Protocol", which is a guide that seeks to enable collaborative and transparent decision making by providing a forum where each group of interest can have their say. The Protocol was negotiated in 2006 upon the renewal of the resource consents that authorised the artificial opening of the lake to the sea.

Currently, once the views of each of the stakeholders are heard, ECan and Ngāi Tahu act collaboratively to make a decision of whether artificial opening is possible with the help of technical experts who provide advice on the suitability of the weather and sea conditions at the time.

3.7 Statutory requirements and responsibilities

The national and regional significance of this research stems from the need to have sound data that can assist local government in making informed decisions and meeting their statutory duties. These decisions and duties include taking a precautionary approach to managing the effects of future sea-level rise.

In relation to future planning and decision-making processes, regional and territorial authorities in New Zealand (district and city councils) are bound by six key national statutory instruments to take into consideration the effects of climate change and natural hazards. These key statutory instruments include the Local Government Act 2002, the Civil Defence Emergency Act 2002, the Building Act 2004, the RMA and the New Zealand Coastal Policy Statement (NZCPS) 2010 (Hart, 2011).

Given the scope of this research, only the RMA 1991 and the NZCPS 2010 will be discussed further in this thesis.

3.8 Summary

This research seeks to provide sound data to assist Lake Ellesmere/Te Waihora's decision makers in making informative decisions to meet their statutory obligations under the RMA and the NZCPS in relation to planning for future sea-level rise. Lake Ellesmere/Te Waihora was chosen to be the focus of this research because it provides an excellent example of the challenges that decision-makers are likely to be faced with when it comes to managing the effects of sea-level rise on artificial opening regimes of ICOLLs. In relation to Lake Ellesmere/Te Waihora, these challenging aspects stem from the outstanding significance of the lake to local stakeholders. This is reflected in the current co-governance approach which is used to manage the lake and its catchment. The lake's opening regime seeks to account for the lake's ecological, economic, recreational and cultural values and to cater towards the interest of a number of groups. The lake's water levels are expected to increase in response to sea-level rise, which will trigger the need to adjust the current opening regime. This will increase the risk of flooding of adjacent land in the near future and permanent loss of productive land in the long-term. However, this increase in Lake Ellesmere/Te Waihora's water levels may be beneficial for water quality and it's life supporting capacity.

Chapter 4
Methodologies

The scope of this research includes the first stage of incorporating sea-level rise in the future management of Lake Ellesmere/Te Waihora, in accordance with the development and implementation of a sea-level rise adaptation plan presented in Figure 2-3. In Russell and Griggs' 2012 framework for developing and implementing a sea-level rise adaptation plan, presented in chapter 2 of this thesis, the first step is referred to as the assessment stage, which involves conducting a sea-level rise risk and vulnerability assessment (Russell & Griggs, 2012).

This research adopts both a quantitative and a qualitative approach to assess the effects of sea-level rise on Lake Ellesmere/Te Waihora's opening regime and consequently on the lakeside communities and adjacent land use.

This chapter seeks to discuss the rationale for the choice of methods used to gather information to satisfy the aims and objective of this research, which are:

- to conduct a quantitative risk assessment to examine the effects of sea-level rise on the lake's opening regime, and
- to conduct a qualitative vulnerability assessment to examine the lakeside communities' (and professional experts') level of preparedness to cope with/manage these effects.

4.1 Measuring exposure

The land and communities surrounding Lake Ellesmere/Te Waihora rely on the current artificial opening regime to protect them from flooding. The operation of the lake's opening regime is dictated by nearby sea conditions and the continuation of this flood management practice is expected to be affected by future sea-level rise. There is a lack of information on the scale and nature of these anticipated effects. The aim of this chapter's quantitative analysis is to fill that void of information and provide some certainty in terms of what the "actual risk" of increasing lake water levels due to sea level rise are, who will be affected by it and when these effects are likely to take place. The quantitative analysis assesses the need and urgency of instigating the process of incorporating sea-level rise in the local (Selwyn District/Canterbury Region) flood hazard maps, regional/district plans and in the decision-making processes regarding the future management of the lake.

The relationship between Lake Ellesmere/Te Waihora and the sea is complex as previously discussed in Chapter 3. This relationship is driven by the interaction of multiple environmental processes. Sea-level rise is not the only impact of climate change that will affect the lake's water levels. Changes to wind intensity, local climate and the lake's hydrological cycle as well as changes in sediment deposition/supply (rate of erosion) are also expected to affect the lake's opening regime and the intensity of the anticipated effects of sea-level rise on the lake and adjacent land (Renwick et al., 2010). Moreover, land movement and changes in land elevation driven by tectonic activities such as earthquakes will also affect the nature of these effects (i.e. subsidence of adjacent land might mean that properties that didn't use to flood in the past might flood/become more sensitive to changes to the lake level in the future) (Hughes et al., 2015). The incorporation of these potential effects of these environmental processes and events in the quantitative risk assessment is not feasible due to the lack of local historical long-term records and the numerous uncertainties that exist around the science of climate change. Thus, the scenarios presented in the research are based solely on a hypothetically simplistic relationship between the sea and the lake that does not account for these environmental process and events.

The current predetermined winter opening trigger level is set at 1.13 m.a.m.s.l. This level currently provides a sufficient outflow gradient to enable successful artificial openings. As the sea-level rises, this hydraulic gradient will decrease. In order to maintain a sufficient gradient in relation to sea level rise, the current opening trigger level will need to increase potentially at the same rate that the sea level is rising.

The Ministry for the Environment (MfE) has prepared a guidance manual titled *Coastal Hazards and Climate Change: Guidance for Local Government* (Bell, Lawrence, Allan, Blackett, & Stephens, 2017)(hereafter referred to as the MfE manual) to provide direction for New Zealand's local government towards planning and management of future climate change-induced effects such as sea-level rise. The MfE manual has been adopted into this research to determine the necessary increase in the lake's opening trigger levels in response to future sea-level rise. The MfE manual was released in May 2008 and adopts global sea-level rise averages from the IPPC Fourth Assessment Report, which advocates and recommends the following sea-level rise values which are presented in Table 4.1 for planning and decision-making timeframes until 2099.

Table 4.1: MfE's baseline sea-level rise recommendations to guide the risk assessment processes for planning and decision making over the 21st century. (MfE, 2008)

Timeframe	**Base sea-level rise allowance** (m)	**Also consider the consequences of sea-level rise of at least:** (m)
2030–2039	0.15	0.20
2040–2049	0.20	0.27
2050–2059	0.25	0.36
2060–2069	0.31	0.45
2070–2079	0.37	0.55
2080–2089	0.44	0.66
2090–2099	0.50	0.80
Beyond 2100	10 mm/year	

There are over 35 sea-level measuring gauges around New Zealand managed by several agencies. These agencies include port companies, the National Institute of Water and Atmospheric Research (NIWA), regional councils and territorial authorities. The MfE manual adopts the global sea-level rise averages presented in the IPCC Fourth Assessment Report because they show similar trends to the oldest sea-level measuring gauge in New Zealand, placed at Waitemata Harbour, Auckland. The Waitemata Harbour gauge has been measuring sea level since 1889, while most of the other gauges have only been measuring sea level over the past 10 years, making it challenging to discern local variation in climate trends. Thus, it was deemed appropriate to adopt the global sea-level rise averages presented in the IPPC Fourth Assessment Report to plan for future sea-level rise in New

Zealand. The use of these averages presented in the IPPC Fourth Assessment Report will continue perhaps until the results gathered from Waitemata Harbour gauge start to differ from the global sea-level rise trends.

MfE's sea-level rise recommendations outlined above in Table 4.1 were used to estimate the potential short-term and long-term increase in Lake Ellesmere/Te Waihora's winter opening trigger levels, which are presented in Table 4.2 and Table 4.3 below. The short-term projections represent increases in the lake's water levels over the next 10, 20 and 30 years, while the long-term projections represent increases in the lake's water levels over the next 50 to 100 years.

Table 4.2: The change of Lake Ellesmere/Te Waihora's winter opening regime trigger level (providing that it remains at 1.15 m.a.m.s.l.) in the short-term future (over the next 10 to 30 years) in response to the anticipated future sea-level rise based on MfE's recommendations, summarised in Table 4.1 in this chapter.

Year(s)	Base sea-level rise allowance (m relative to 1980–1999 average)	Future lake's winter minimum (1.13 m) opening level (m above current mean sea level)	Also consider the consequences of sea-level rise of at least: (m)	Future lake's winter minimum (1.13 m) opening level (m above current mean sea level)
2025	0.10	1.23	0.15	1.28
2035	0.15	1.28	0.20	1.33
2045	0.20	1.33	0.27	1.4

Table 4.3: The change of Lake Ellesmere/Te Waihora's winter opening regime trigger level (providing that it remains at 1.15 m.a.m.s.l.) in the long-term future (over the next 50 and 100 years) in response to the anticipated future sea-level rise based on MfE's recommendations, summarised in Table 4.1 in this chapter.

Year(s)	Base sea-level rise allowance (m relative to 1980–1999 average)	Future lake's winter minimum (1.13 m) opening level (m above current mean sea level)	Also consider the consequences of sea-level rise of at least: (m)	Future Lake's winter minimum (1.13 m) opening level (m above current mean sea level)
2065	0.31	1.44	0.45	1.58
2115	0.71	1.84	1.09	2.22

The timeframe for the projections in this research was chosen to give effect to the following planning timeframes that New Zealand's local government is bound to under the RMA:

- commence review of a provision of a regional policy statement, a regional plan, or a district plan at least once every 10 years in accordance with Section 79(1); and

- give effect to Policy 24 of the New Zealand Coastal Policy Statement (NZCPS) 2010 by considering, managing and planning for the effects associated with climate change, sea-level rise and associated natural hazards over at least 100 years, through local plans and policy statements.

4.2 Projecting future lake levels

GIS Tools available in ArcMap (ESRI, 2015) were employed to create maps that project the results of the quantitative risk assessment presented in Table 4.2 and Table 4.3. The future anticipated increase in the lake's winter opening trigger level are presented via contour maps generated by ArcMap's spatial analyst tool using a light detection and ranging (LIDAR) digital elevation model with 8 metre resolution of the Lake Ellesmere/Te Waihora Catchment. These contour lines created were based on the Lyttelton 1937 NZDV2009k local mean sea level datum of 2.695 m.

Figure 4-1 and Figure 4-2 show the increase of the lake's winter opening trigger levels over the next 10, 20 and 30 years, and Figure 4-3 and Figure 4-4 show the increase over the next 50 to 100 years. The projections presented in Figure 4-1 and Figure 4-3 take into consideration a base value sea-level rise of 0.5 m while the projections presented in Figure 4-2 and Figure 4-4 take a base sea-level rise of 0.8 m from the MfE manual (MfE, 2008) into consideration.

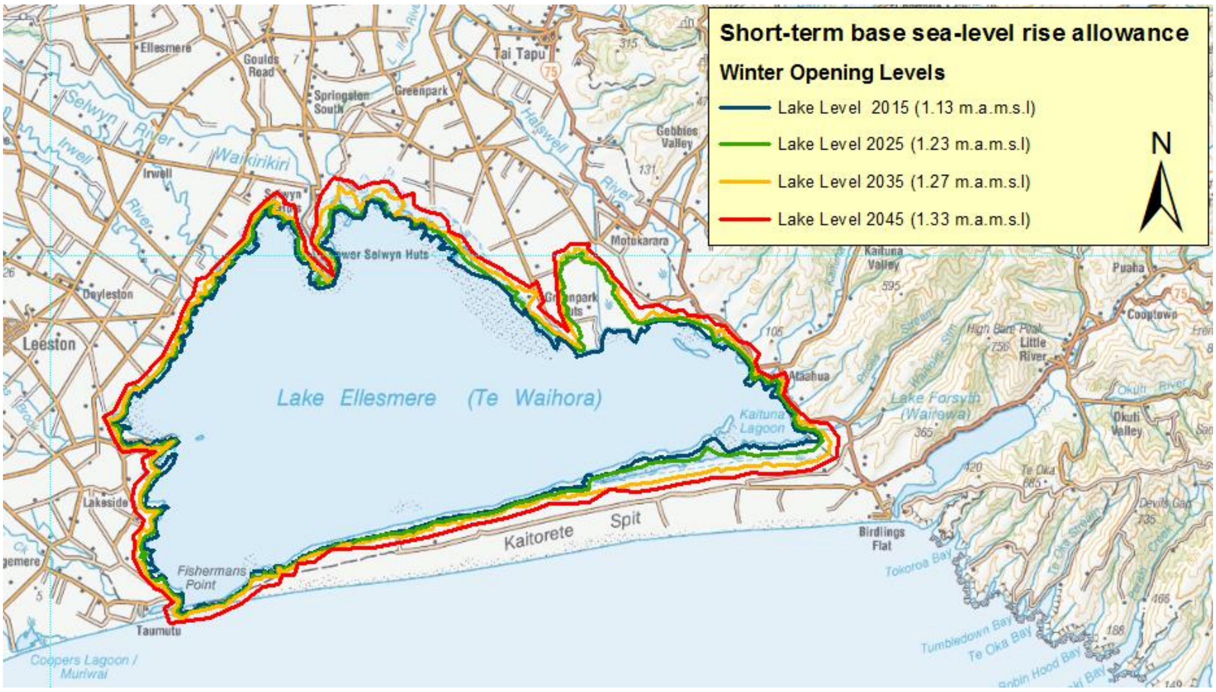

Figure 4-1: **Projected change of Lake Ellesmere/Te Waihora's winter opening regime trigger level (providing that it remains at 1.15 m.a.m.s.l.) in the short-term future (over the next 10 to 30 years) in response to the anticipated future sea-level rise based on MfE's base sea-level rise recommendations, summarised in Table 4.1 in this chapter.**

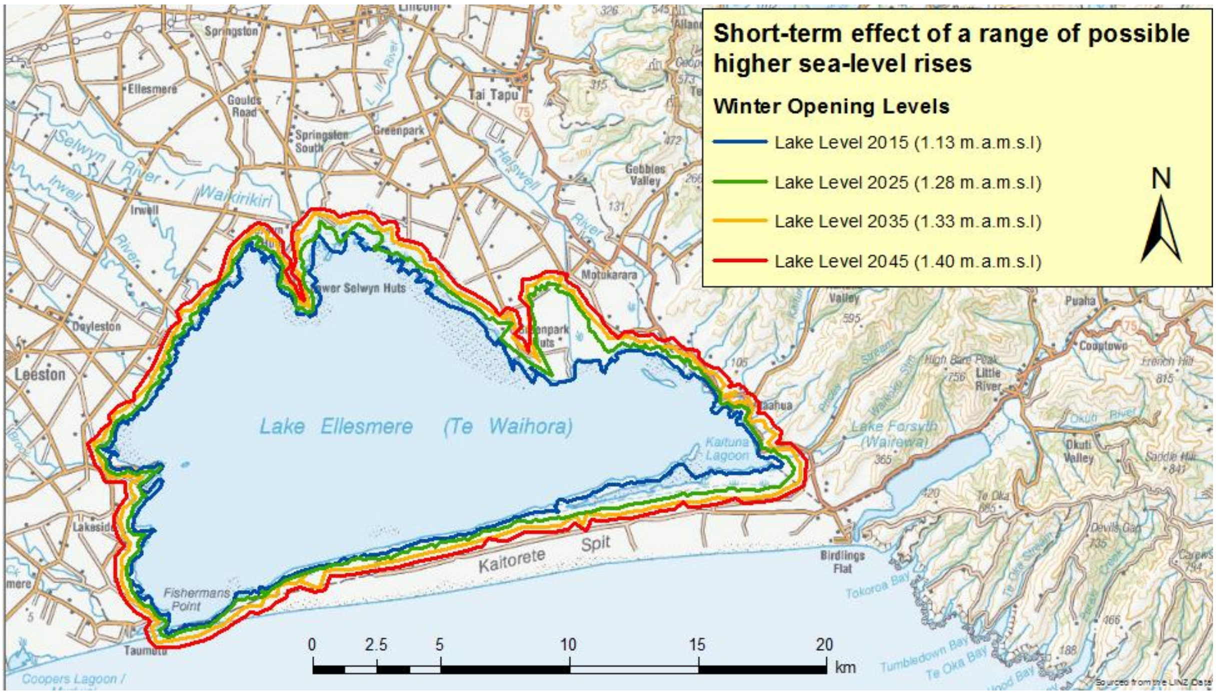

Figure 4-2: Projected change of Lake Ellesmere/Te Waihora's winter opening regime trigger level (providing that it remains at 1.15 m.a.m.s.l.) in the short-term future (over the next 10 to 30 years) in response to the anticipated future sea-level rise based on MfE's range of possible higher sea-level rise recommendations, summarised in Table 4.1 in this chapter.

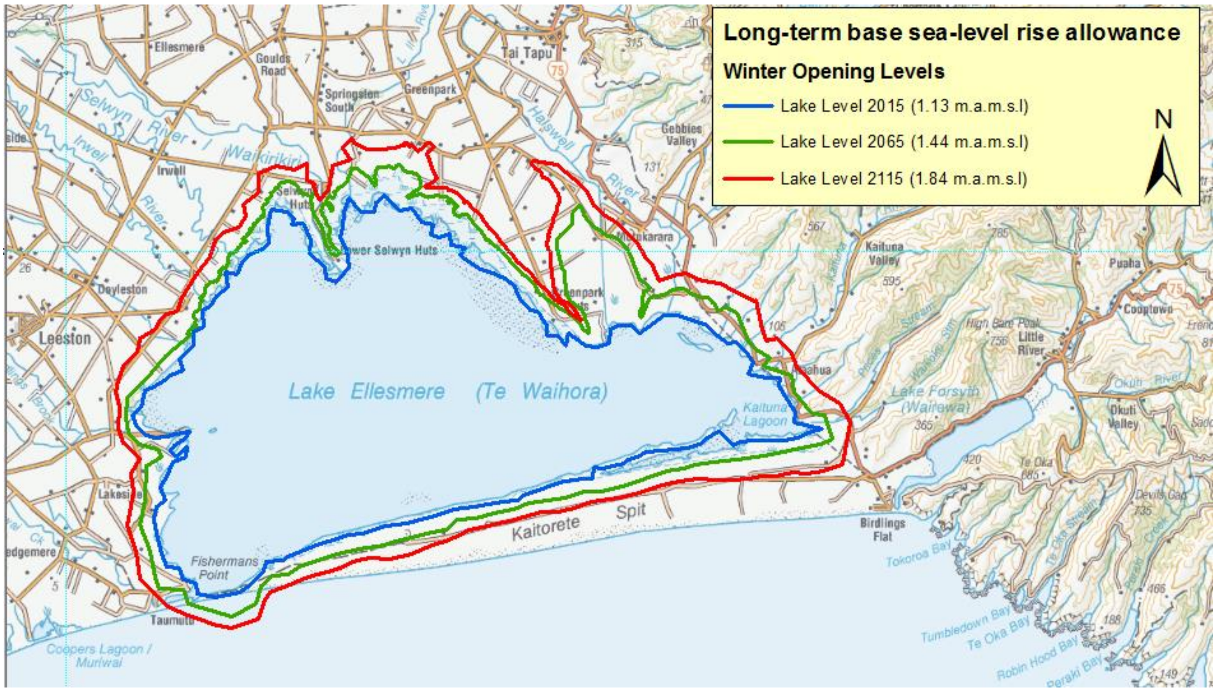

Figure 4-3: Projected change of Lake Ellesmere/Te Waihora's winter opening regime trigger level (providing that it remains at 1.15 m.a.m.s.l.) in the long-term future (over the next 50 to 100 years) in response to the anticipated future sea-level rise based on MfE's base sea-level rise recommendations, summarised in Table 4.1 in this chapter.

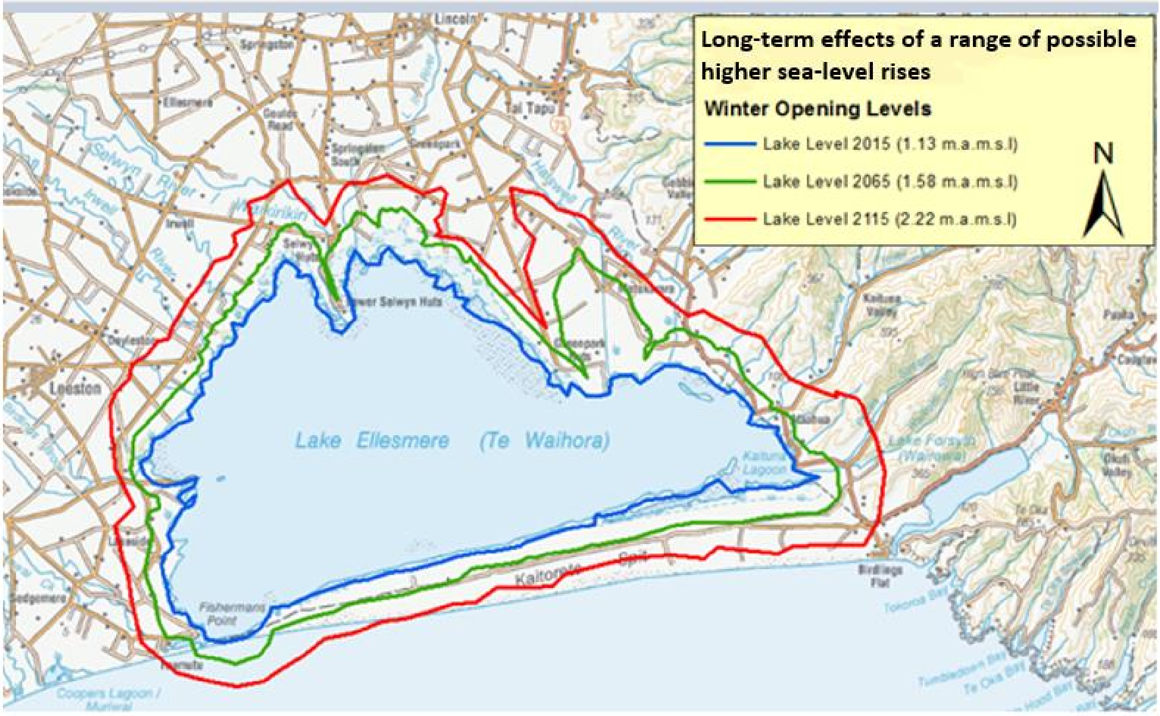

Figure 4-4: Projecting the change of Lake Ellesmere/Te Waihora's winter opening regime trigger level (providing that it remains at 1.15 m.a.m.s.l.) in the long-term future (over the next 50 to 100 years) in response to the anticipated future sea-level rise based on MfE's range of possible higher sea-level rise recommendations, summarised in Table 4.1 in this chapter.

In 2016, Land Information New Zealand (LINZ) established 13 local mean sea level datums based on the most updated records gathered from the sea-level measuring gauges around New Zealand. The new records allude to a higher mean sea level datum nationwide. The NZDV2016 is setting at 2.830 metres at the Lyttelton Harbour. This means the maps presented above have an inherent underestimation of the anticipated risk. However, given the scale of the maps and the small spatial variation they present in relation to the increase in the lake's water levels over time, it was deemed unnecessary to update the maps presented in this research, especially given that the estimated risk remains accurate. These maps were used to ease communication by spatially visualising water level rise during the interviews presented later in this chapter with those who have been identified to be at potential risk or involved in the current and potentially future management of the lake.

4.3 Qualitative vulnerability assessment – measuring preparedness

The aim of the qualitative vulnerability assessment is to capture the various levels of preparedness amongst the lakeside communities to the anticipated increase in the lake's water levels. The assessment intends to identify communities' opportunities and barriers to adaptation to sea-level rise to inform district and regional agencies and to spur community-level action in developing action plans for reducing vulnerability and strengthening resilience.

As discussed in Chapter 2, a communities' vulnerability to natural hazards is a function of exposure, sensitivity and adaptive capacity/resilience. Lake Ellesmere/Te Waihora's communities' level of exposure and risk has been identified earlier in this research through the quantitative risk assessment. The qualitative risk assessment focuses on assessing the sensitivity and the adaptive capacity of the communities that have been identified to be at risk (Turner et al., 2003).

4.3.1 Sensitivity and adaptive capacity

Given the wider purpose of this research, the qualitative vulnerability assessment employed in this thesis focuses on exploring the second-level sensitivity of Lake Ellesmere/Te Waihora's lakeside communities and on exploring the willingness of these communities at risk to adjust their behaviour to take into account the potential effects and impacts associated with the increase in the lake's water levels in response to sea-level rise.

Selecting indicators

There is an extensive list of possible social indicators for measuring and assessing sensitivity and adaptive capacity. The social indicators employed in this research have been drawn from indicator-based vulnerability assessment approaches presented in the climate change and natural hazards and disasters adaptation literature featured in Chapter 2 of this thesis. The indicators were selected from the DROP model (Cutter et al., 2008), Grothmann and Patt's (2003) socio-cognitive model of proactive private adaptation to climate change impacts, the vulnerability framework (Turner et al., 2003), and the local adaptive capacity framework (Africa Climate Change Resilience Alliance, 2010).

The following indicators were adapted to assess the sensitivity and adaptive capacity of Lake Ellesmere/Te Waihora's lakeside communities:

- **Awareness and knowledge:**

  This indicator was adapted in this research to investigate the level of knowledge and awareness amongst the lakeside communities and professional experts of the following matters:
  - climate change and sea-level rise;
  - potential effects of sea-level rise on the lake's artificial opening regime;
  - the risks associated with higher lake water levels; and
  - adaptation measures and options available.

- **Experienced exposure**

  This indicator has been adapted into this research to capture physical, economic and social drivers through lessons learned at the local government level and at an individual household level from the latest major flood event experienced in the area; the 2013 flood event, and other previous events.

- **Perceived risk/level of concern**

  This indicator has been adapted into this research to assess the lakeside communities' perception on the risk presented in the inundation maps created as part of this research and to assess the factors that may affect perception of risk. This indicator also assesses the factors that may affect a communities' motivation to take proactive action to prepare in order to minimise the effects of the anticipated flood events which are associated with the future increase in the lake's water levels.

  The information obtained on the communities' perception of risk was then communicated to the professional experts (i.e. Lake Opening Protocol Groups) to provide an insight on what challenges these results may translate to in terms of future management and to identify potential solutions.

- **Adaptation intention**

  This indicator has been adapted to enable the direct assessment of the research's participants' adaptation intention in relation to scenarios presented to them in the inundation maps (Figure 4-1, Figure 4-2, Figure 4-3 and Figure 4-4). Participants were presented with three adaptation options; retreat, accommodate or protect, and they were asked to choose their preferred option. This indicator has been adapted for completion purposes to capture how the previous indicators translate to the likelihood of individuals taking action in response to increasing lake water levels.

  In regard to the professional experts group, this indicator was used to assess the adaptation option that is likely to be promoted and supported by Lake Ellesmere's/Te Waihora's managers (government and non-government agencies). This was seen to be crucial as the government's financial support is likely to have an effect on the communities' choice of adaptation in the future.

4.4 Methods of data collection

Semi-structured interviews consisting of open-ended questions were deemed to be the most appropriate method of data collection to cater for this research's aims and objectives. Semi-structured interviews are best suited for explorative studies which revolve around obtaining the perceptions and opinions of respondents on multifaceted and sensitive topics (Barriball & While, 1994). In comparison with other qualitative data-collecting methods such as online questionnaires, focus groups and structured interviews, semi-structured interviews have a relatively open and flexible framework that enables purposeful and efficient two-way communication. These semi-structed interviews provide the respondents with the opportunity to provide profound and vivid answers that encompass creativity and emotions (Keller & Conradin, 2010). Most importantly, semi-structured interviews can allow both the researcher and the respondent to probe and clarify questions and responses (Kajornboon, 2005).

4.4.1 Construction of research questions

Open-ended questions were constructed using the indicators of adaptive and social sensitivity. The first set of questions aim to explore the knowledge and level of awareness amongst the professional experts group and Lake Ellesmere/Te Waihora's lakeside communities. The second set of questions aim to explore individuals past experiences with flood events and their perception of risk or level of control. The last set of questions aim to explore the adaptation intension and the level of willingness to adapt present in communities identified to be at risk of flooding.

4.4.2 Data collection and analysis

Interviews were carried out between September 2015 and February 2016, with 18 participants from the Lake Ellesmere/Te Waihroa's flood management zone (shown in Figure 3-2) and with professional experts from the following the Lake Opening Protocol Groups; SDC, ECan, Waihora Ellesmere Trust and Ngāi Tahu.

Land-use information within Lake Ellesmere/Te Waihroa's flood managed zone (Figure 3-2) (obtained from an AgriBase survey conducted by ECan and AsureQuality in April 2015). The data obtained are presented in Figure 4-5 below.

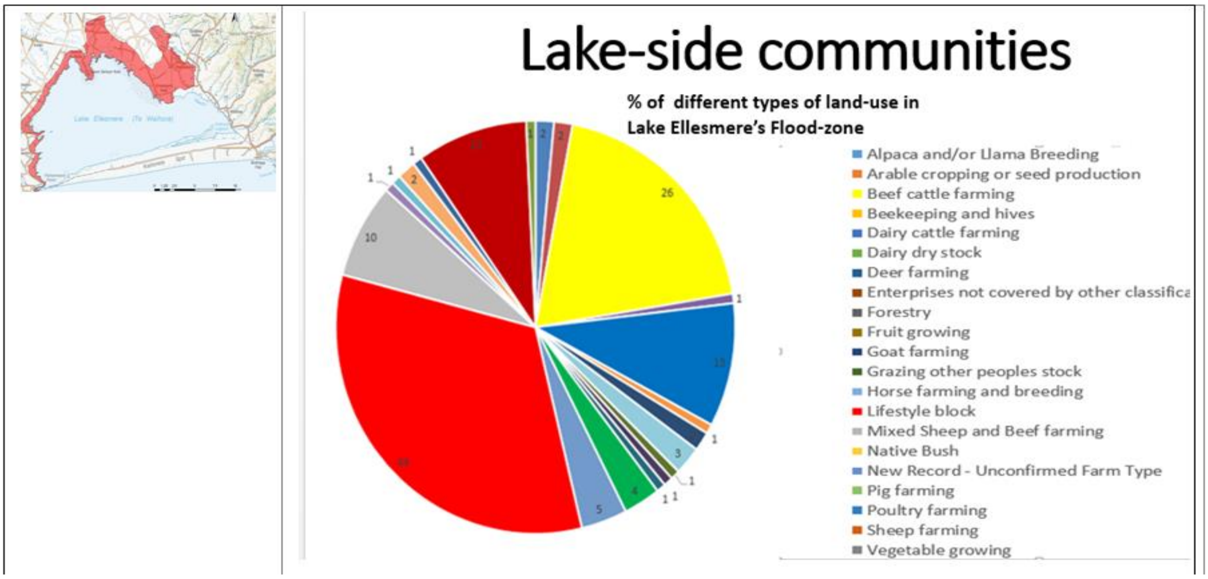

Figure 4-5: AgriBase 2015 survey dataset for properties intersecting the Lake Ellesmere/Te Waihora flood zone.

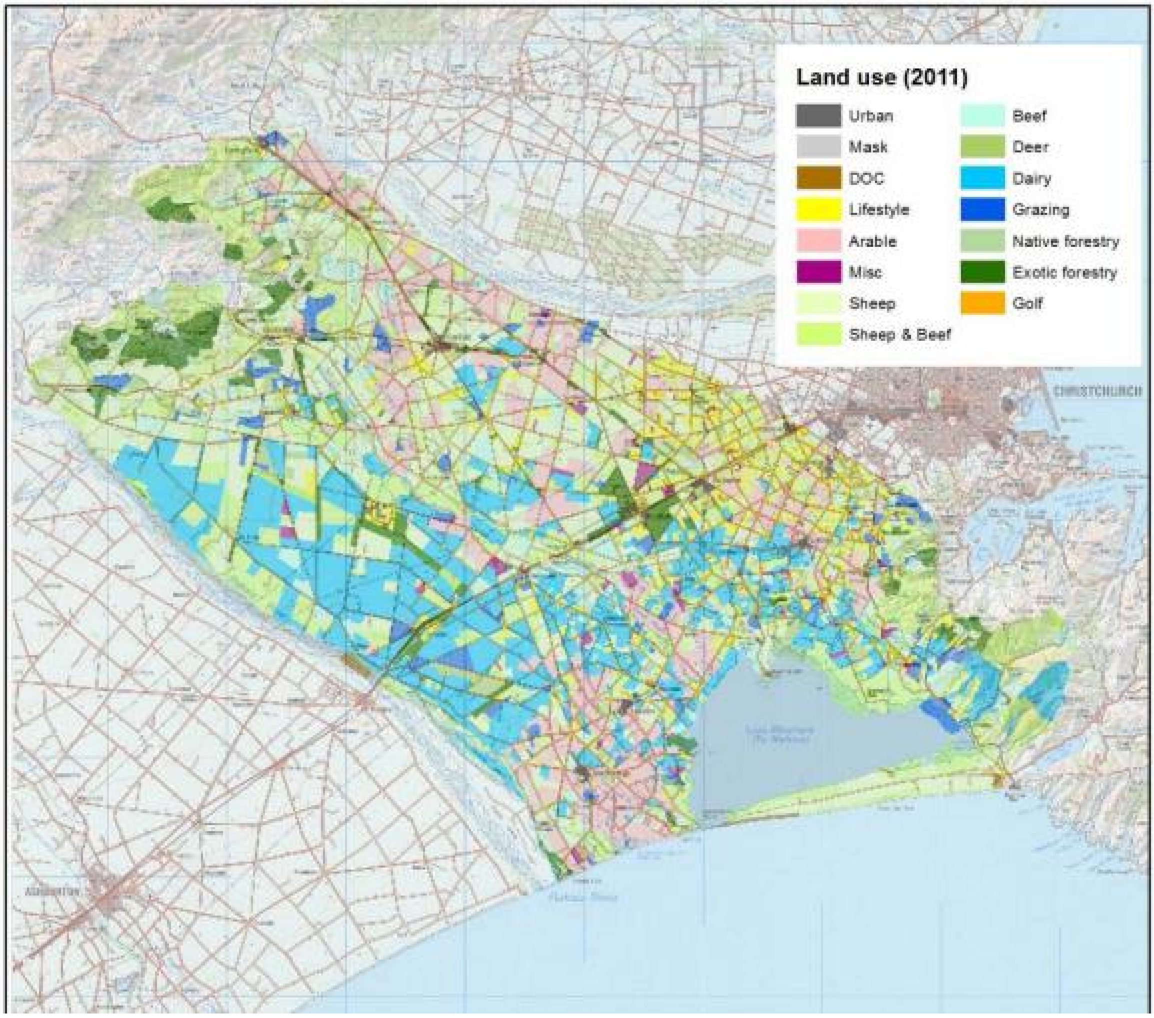

Figure 4-6: Land-use activities in the Lake Ellesmere/Te Waihora catchment. (McCallum-Clark, Maw, Painter, & Robson, 2014)

Based on the 2015 AgriBase survey, there are 134 properties situated within Lake Ellesmere/Te Waihora's flood zone and 21 different types of land use. A target sample set of 30 properties out of the 134 was initially deemed appropriate for the scope of this research. At the same time, it was deemed appropriate to cap the sample set size if a point of saturation is reached prior to reaching the target. A point of saturation occurs when no new themes emerge within six consecutive interviews or when the target cannot be reached within a reasonable timeframe (Saunders et al., 2017), which for this research is 3 months.

The concept of data saturation is used widely in qualitative research and it refers to the stage in research where no new themes are emerging. It sets the justification for discontinuing data collection (Saunders et al., 2017). Unlike quantitative studies, in qualitative research more data collected does not necessarily translate into more reliable information, as frequencies are not perceived as crucial (Al-Busaidi, 2008). Frequencies are not often significant in qualitative research, as a single occurrence of the data is potentially as valuable as the reoccurrence of many for obtaining insight on processes behind a topic (Manson, 2010). Qualitative data collection that revolves around studies of perception need to ensure that the sample is large enough to cover a range of potentially diverse opinions. However, large data can become repetitive and ultimately unessential (Manson, 2010).

The target sample was not reached within three months; however, a point of saturation was reached, bringing the completion of the interview phase after interview no. 18 as no new themes emerged within the last six consecutive interviews.

To ensure that the data collected is representative and reliable, the sample was chosen based on a stratified sampling approach. Stratified sampling is a method of probability sampling that involves the categorisation and division of the population of interest into different strata or subgroups, where a sample is selected via a simple random sampling method (Suresh, Thomas, & Suresh, 2011). Initially, the communities within Lake Ellesmere/Te Waihora's flood zone were divided into different strata based on the decade of the anticipated effect (i.e. year 10, year 20, year 30 etc.). However, this categorisation and divisional approach was abandoned as the inundation maps showed insignificant spatial variation between individuals to group them in relation to increasing lake water levels.

In this research, the lakeside communities were divided into groups based on the type of land use (i.e. dairy, sheep and beef, orchard, etc.) and the orientation of their property in relation to the lake (i.e. west, north, east, etc.).

The 2015 AgriBase survey did not include the Upper Selwyn Huts, the Lower Selwyn Huts or the Greenpark Huts settlements. To ensure that residents and property owners of the Huts are included in this research, door-to-door invitations were delivered.

All of the interviews conducted were audio recorded. The recorded responses were transcribed and categorised by the predetermined indicators of adaptive capacity and social sensitivity, outlined earlier in this chapter. The interviews conducted with members of the lakeside communities were undertaken confidentially, by assigning an identifying code to each participant and keeping a separate list in a separate and secure location that links the codes to the names of the participants. For the interviews conducted with the professional experts, consent was given by each participant to reveal their name and the organisation they were representing. Research information sheets (refer to Appendix C) and consent forms (refer to Appendix D) were sent out amongst the invitations delivered by mail, door-to-door delivery and emails. The consent forms consisted of a summary of the research as well as the research's aims and objectives and a brief outline of the reason for the invitation and the role that the potential participant would play in this research. A copy of these consent forms was taken to each of the interviews and discussed with the participants before commencing the interviews.

4.5 Summary

The quantitative risk assessment undertaken in this research consisted of estimating the increase in Lake Ellesmere/Te Waihora's current winter and summer opening trigger levels in response to future sea-level rise. The estimations are based on MfE's guide for assessing risk associated with sea-level rise for planning and decision-making purposes over the 21st century (MfE, 2008). ArcMap GIS software was used to visualise the anticipated risk. Adjacent land and communities at potential risk were identified through this assessment. A sample was selected from the lakeside communities that had been identified to be at risk and from the Lake Opening Protocol Group to assess their views and their level of preparedness to the projected risk of lake water level rise.

Chapter 5

Results

This chapter presents the key findings gathered during the interviews phase of this research carried out with professionals/decision-makers and members of the lakeside communities between December 2015 and February 2016. The key finding have been categorised into the indicators chosen in Chapter 4 of this thesis (i.e. awareness/knowledge, adaptation intentions, risk perception and experienced exposure) to explore adaptive capacity and level of preparedness at both the private property level and the local government level to the anticipated effects of sea-level rise on Lake Ellesmere/Te Waihora.

5.1 Lakeside communities

As stated in the previous chapter, interviews were carried out with 18 participants from the communities residing within Lake Ellesmere/Te Waihora's flood zone. The 18 participants included sheep and beef farmers (7 participants), dairy farmers (4 participants), beekeepers (1 participant), crop farmers (1 participant), lifestyle block property owners/residents (2 participants) and Huts residents (Greenpark Huts (1 participant), Lower Selwyn Huts (1 participant) and Upper Selwyn Huts (1 participant) from the north, north east, north west, west, east, south west and south east side of the lake. The interview questions that members of the lakeside communities were presented with are outlined in Appendix A.

5.1.1 Awareness

The first set of questions aim to explore the participants' general level of awareness of:

- the climate change induced sea-level rise;
- the operation of the lake's opening regime;
- the connection between the sea and the lake and how that relationship might change and affect them in the future; and
- general subtle changes of the local climate over the past decade or so.

Once the initial response of the participants was received, they were then presented with the maps created prior to the interviews as part of the quantitative risk assessment of this research and with ECan's map showing the lake's flood zone. The maps aimed to explore further what the participants' thoughts are on the situation at hand, in terms of whether they have thought about the potential of the lake receding landward over time as a result of sea-level rise prior to participating in this research.

Seventeen of the participants understand the operation of the lake-opening regime and are aware of the current opening level threshold. Moreover, they understand that the sea conditions do affect the ability to open the lake. Of those seventeen participants, one participant mentioned that they have been out during the opening process to observe. Sixteen of the eighteen of the participants mentioned that they receive emails from ECan informing them when the lake is opened and closed. Most of the participants mentioned that they can just tell whether the lake is open or closed by inspecting the drains on-site.

> *If they don't open the lake it affects us because it brings the water table quite high and again the water can only go so far. The water table here at the moment is about 800 mm to a metre below ground level, but when it's shut and they don't open it, it can be 300 mm. The water hasn't got up above ground level yet but it has been close. (Participant 1)*

In terms of subtle changes in local climate, Seventeen of the eighteen participants mentioned that they have been experiencing drier climate and more frequent "good winters" in comparison to the late 1990s and early 2000s.

None of the participants had seen ECan's Lake Ellesmere/Te Waihora flood-zone map prior to participating in this research, but all of the participants are aware that they are residing on flood-prone land that was at one point covered by water and part of the lake's bed.

> *We knew exactly what we were getting into when we bought the place. We knew exactly what we were doing when we moved here, and the plants we planted don't mind wet feet because they're hazelnuts and that was part of the reason why we came here because they don't mind having wet feet for a week. (Participant 8)*

Five out of the eighteen participants bought their property on the lake edge as a swamp and drained it in order to be able to farm on it, while nine participants had to build drains as soon as they bought their property to reduce the risk of flooding.

> *When I first came here I spent a lot of time digging out all the roads because all the pipes were collapsed and there was no water getting through. I also dug a big hole, a duck pond, and all the water goes down to that then through the drain and out to the lake. It certainly has made a huge difference to this place because it was extremely wet and now it's great because the water can now be drained. (Participant 9)*

Once the participants were presented with the maps showing the anticipated increase in the lake's water level over the next 10 to 100 years in response to sea-level rise, seventeen out of the eighteen participants stated that the information presented in front of them is not new to them and that they are fully aware of the possibly of the fact that it might get harder to open the lake. However, only one of the participants linked the increase in the lake's water level to future sea-level rise. Sixteen of the eighteen participants linked the increase in the lake's water level to storm events, earthquakes (subsidence of adjacent land), changes in local climate and change in the current lake management priorities (i.e. opening the lake at higher than the current level for the purpose of improving the lake's water quality) and funds (i.e. no government subsidies). Nevertheless, seventeen of the eighteen participants said that they understand the logic behind how sea-level rise might suggest increasing in the current lake opening level set under the WCO to maintain the current hydraulic gradient between the lake and sea required to achieve successful openings.

5.1.2 Experienced exposure

The second set of questions aimed to explore the participants' past experiences with flood events and the actions that were taken at the time to mitigate associated adverse effects on their property. The latest major flood event that the land adjacent to Lake Ellesmere/Te Waihora has experienced was back in 2013, where the flood levels reached 1.8 m.a.m.s.l. The participants were also asked specifically about the 2013 flood event.

Seventeen of the eighteen participants stated that they have experienced flood events in the past. Of those seventeen participants, three participants described some of those flood events to be major in nature. When asked specifically about the 2013 flood event, only one of the three participants considered it to be a major event. Participants from the north side of the lake stated that the 2013 flood event affected them more severely than it affected communities on the west and east sides of the lake due to a combination between land elevation and soil type. Nine of the eighteen participants mentioned that soil type varies significantly around the lake and it affects how fast the water is drained. Properties located further down west of the lake edge have better drainage due to highly permeable soil according to Participant 1, who said, "It's very porous here, it's gravely and not clay or anything like that." Participant 3 mentioned that "over the north side of the lake you can get up to half a metre to a metre depth of clay that affects the drainage in the area". The variation between the participants' responses also depended on what they considered to be a major flood. The severity of the flood event depended on previous experience and overall financial loss. The financial loss experienced by different participants from the same flood event depended on preparedness, in terms of having a management plan in place to reduce impacts of such major flood events, financial situation and occupation, and type of land use. A farmer who owns property on the west side of the lake said:

You see you're talking about the 2013 flood, but we really didn't get affected. I mean a lot of water came through for sure but nothing got damaged. We had quite a good river going through the place, but again everything just went through the duck pond then out through the orchard where I got bridges and water went straight out. (Participant 1)

Another farmer from the west side of the lake said, "No damage at all, I mean you take your stock away and you don't damage, you don't bog up the paddocks" (Participant 2). On the other hand, a beef and sheep farmer from the north east side of the lake was one of the few to describe the 2013 flood as a major flood event: "We lost about 30 to 40 hectares of productive land and we didn't have a place to relocate and lost some stock that year" (Participant 3). Two of the eighteen participants went through the Wahine storm in April 1968, including Participant 3, and thus subsequent flood events are not considered anywhere near major in comparison. Furthermore, seventeen of the eighteen participants commented on how they are experiencing less frequent and severe flood events due to "good winters" and very dry summers, and a much lower and drier Selwyn River. Some of the participants stated that the volume of water running through their drains has decreased significantly over the years. Box 5.1 below summarises a few quotes gathered from various participants regarding the subtle change in the local climate experienced over the past decade.

Box 5.1: Summary of quotes gathered during the interviews with members of the lakeside communities addressing changes to the nature of flood events and regional climate.

In the 80s and 90s we probably had more flood events in relation to the lake then we do now, mainly the water would come down the Selwyn. The water in the Selwyn is nothing like it was when we were kids. There used to be good swimming holes in there when we were kids. A lot of kids learned how to swim down there back in the sixties. (Participant 12)

Streams don't flow any more, especially the hammer drain. I mean it only flowed for less than a month this year. When we first came here it use to flow all year round and there used to be trout in it. Now it's lucky if it flows two months a year. (Participant 10)

I don't think we could do too much damage here really, I mean when you look at the floods they had in '45, most of this place was still above water. (Participant 13)

In the time, the 23 years that we have been here it's a lot dryer than when we first came here because Coe's Ford would be closed due to the flooding maybe three to four times a year, whereas I don't think it was closed once this year, maybe once at most last year when the water came *up. (Participant 15)*

This year and last year we didn't really have wet winters, we started in spring and were able to cultivate early, which I haven't been able to do for years, so it's hunky dory really … We dug and improved drains over the past two years, but they haven't had the chance to prove themselves yet as the past couple years have been quite dry. (Participant 18)

This is the first year that our ditches have been completely dry. We always had water in our ditches. Ditches were dry last year but not as early as this year … Before the bridge was there it would have happened quite few times every year didn't happen at all last year. (Participant 7)

Five of the eighteen participants stated that the financial loss from experiencing a flood event depends on the type of the land use that is being impacted. A beekeeper from the west side of the lake said, "Flooding of my land does not affect our honey harvest" (Participant 16), while crop farmers from the west and east sides of the lake stated that "with crops you can't really do much when the land is under water. Unlike stock farms, we cannot relocate the crops, so we expect to lose our entire yield if we were to flood" (Participant 17). Moreover, three of the farmers interviewed stated that farming is one of the many sources of income they have, so it balances out any financial losses they might experience. Four of the farmers stated that farming on the land at risk is their main source of income, and most of them don't have the option of relocating stock to higher ground when it is necessary. Six out of the seven sheep and beef and dairy farmers interviewed, stated they have reduced stock numbers on the properties at risk over the years to reduce financial losses during flood events and to ease the process of relocating the stock when necessary.

Participants from the Upper and Lower Selwyn Huts stated that the 2013 flood event affected them to a point where they did consider evacuation for the first time in five years:

During the 2013 flood event, I could see the groundwater seeping up from underground and it has flooded our backyard, nearly coming through into the backdoor into our bedroom. (Participant 5)

Another Huts resident said:

We live in the Huts for the lifestyle and because we don't have the financial means to live elsewhere, especially living on the pension. The majority of the Hut's permanent residents are over 65 years of age and relocation is not always easy, but we are a tight-knit community and we always help each other's out. (Participant 6)

5.1.3 Level of concern/perception of risk

The third set of questions aimed to explore the participants' perception of risk and level of concern. In general, the level of risk amongst the participants was perceived to be low, with fifteen of the eighteen participants stating that higher lake's water levels and alteration to the current opening level of the lake is not of any concern to them. Although none of the participants disputed the projections on the maps presented to them earlier in the interviews, the majority of the participants stated that they couldn't simply foresee change in the future when no major change has occurred over the past decade, and they believed that there are a variety of options available at the wider lake management level that haven't been totally exhausted or tried yet (i.e. some have suggested the construction of a permanent outlet).

> *The maps are showing that the lake is going back to its original level, that's not news to me. I can see it happening but it does not concern me because we can manage it. In the Netherlands they do, so I can't see a reason for us not to be able to do so. (Participant 11)*

Probing questions followed to explore the reason behind the general lack of concern and low perception of risk amongst the participants, and answers varied from aspects such as age and financial status to disbelief in the possibly of any major changes occurring over the next 20 years. The majority of the participants stated that they are not concerned or interested in effects beyond 20 years into the future as it's considered to be outside their lifetime.

> *I really don't think it's going to affect us in our lifetime. I don't think in 10 years' time we will be setting in anything different than what we're setting in now because it hasn't changed in the last 100 years, so why should it change in the next ten years? (Participant 13)*

Some of the participants stated that if any changes were to occur, they will be temporary in nature.

> *If it happens there is not much we can do about it, the whole world would change. You get good years and you get bad years. The last couple of winters have been the best winters we ever had mainly because it has been so dry and we can only hope that it stays that way. (Participant 11)*

Some of the participants even described the 2013 flood event to be rare in nature and thus wouldn't expect it to occur again in the near future.

> *It was the set of circumstances. The Selwyn, the rain and the lake pressure all come into it. All the ducks were in a row and that may never happen again for another 20, 30 years. (Participant 12)*

On the other hand, five of the eighteen participants stated that there is no point to be concerned because they have taken all the necessary precautions and have prepared and planned for such flood events from past experiences.

> *I'm not concerned because I have lived here all my life, I got hay for the next three years ahead and got shelter. I made my mind many years ago on how to handle it. (Participant 2)*

Seven of the eighteen participants said that they are not concerned about the effects of sea-level rise because they are more likely to experience the adverse effects of other natural disasters and hazards such as earthquakes and southerly storms before encountering the effects of sea-level rise. A few participants are simply not concerned as they don't believe that the lake's environmental value will be under threat, and that's what they care about the most.

> *I am not really concerned about it because if you're taking the history of the lake as from a Ngāi Tahu or Māori perspective, the lake was far bigger and it was drained through the settlement and so there was a lot of wetlands and scrublands lost and big change in the environment so I guess in the future, economically it's an issue but environmentally perhaps less so. (Participant 6)*

Five of the eighteen participants said they are concerned about how sea-level rise and lake-level increase is going to contribute to the decrease of their property value. Of those five participants, two participants said they are already struggling to sell their land. When asked about concerns they might have in regard to insurance and an increase in their current rates contribution going towards opening the lake more frequently than the current rate, only very few said that these aspects concerned them.

Five of the eighteen participants stated that they are concerned about the potential of flooding of properties that have subsided after the 2011 earthquake event and the potential increased frequency of flood events as a result of the Central Plains Water Enhancement Scheme.

> *I thought that it was meant to get wetter down here when the central plains irrigation scheme starts. There is an argument out there about the scheme that we will be getting back swamp lands and rushes around the lake edge. Things have been changed for our irrigation, which I understand, but if there is an awful lot of rain one year and they got a catchment that is overflowing and they let it go, what's going to happen down this end? I would say we possibly might be in trouble. Nothing has changed yet for us but it's always something at the back of your mind when they start developing things like that. (Participant 7)*

Some of the participants stated that they have noticed subsidence on their land after the 2011 earthquake: “It has changed since the earthquakes though. There are areas that didn’t use to flood that flood now. Nothing got pushed up, everything went down” (Participant 11).

When some of the farmers who are heavily involved in the Waihora Ellesmere Trust and drainage committees were asked about the potential reason behind the general lack of concern and low perception of risk amongst the lakeside communities, they have stated that the lack of concern could be due to not having a major flood event since 2013 and having “good winters”, which has made people feel more secure.

> *When you meet up with a wet winter, everybody shows up to drainage committee meetings. Apart from that they don’t really care. A good one was after the earthquakes, the major bank subsidence and the Halswell River flooded, people in Halswell had no idea about how the Halswell River works and things like that. The meeting we had after that because of the damage that happened after the earthquake to increase their rates to pay for river clean up and things like that, I think we had about 80 people turn up, where we usually would have around 13 at the meeting. This is the only reason people attend community meetings and become more aware. Until something majorly happens they really don’t care. (Participant 14)*

Moreover, the risk maps didn’t seem to have an effect on the level of concern amongst the lakeside communities, where the level of concern that the participants expressed at the start of the interviews did not change once the participants were presented with the risk maps. The only concern the participants had was the potential negative impact of publishing such maps on their property’s value.

5.1.4 Adaptation intentions and on-site management plans

The last set of interview questions aimed to explore the participants’ intentions to adapt and the current plans in place to manage the effects of potential future flood events on their properties in a manner that will reduce the impact of any potential adverse effects as much as practical. The participants were presented with three adaptation options – to retreat, to accommodate or to protect – which they were asked to choose from, in terms of which option appeals to them more.

Two of the eighteen participants chose the retreat option over the other two adaptation options. However, the term retreat in this research does not just refer to managed retreat but also reactive retreat. The term was left for the participants to interpret, and seventeen of the eighteen participants did interpret the option of retreating to be equivalent to taking no action (i.e. proactive retreat rather than planned and managed retreat).

I will stay here as long as I can. It all really depends on the cost of the defence structure and how much we would be contributing to it. At this stage in our lives and at my age, changing the current land use is not practical. I can only graze it, that's about all I can do without going to a great lot of trouble. I mean unless it got to be cost effective to grow rice or something like that. It's something I would consider but it's got to be cost effective. (Participant 4)

In terms of management plans and level of preparedness to the anticipated effects of sea-level rise on Lake Ellesmere/Te Waihora, participants were asked to rate their level of preparedness from 1 to 5 (1 = Not feeling prepared at all; 5 = Feeling very prepared), and they were asked about the plans they have currently in place for responding to flood events. Initially when the participants were asked about current and future management plans, Ten of the eighteen participants addressed the question at the catchment/lake scale rather than at their property scale, where some have suggested that the best option in the future would be to manage the lake in the same manner that the Ahuriri Lagoon is currently being managed – by constructing a permanent outlet and using pumps when necessary. A few of the participants mentioned a project carried out in the Netherlands of a very similar nature to Lake Ellesmere/Te Waihora and believe that we need to get experts from the Netherlands to try and implement the project here.

We need experts from overseas to go over to assess the cost of a permanent opening. It has been carried out successfully in the Netherlands and I don't see why we can't implement the same solution here. (Participant 11)

Probing questions followed to explore what management plans the participants had to protect their own properties from flood events.

Eleven of the eighteen participants gave a rating of 3 out of 5 for preparedness and the remaining 7 participants gave a rating of 4 out of 5. The majority of those who gave a rating of 4 out of 5 stated that being prepared comes down to the concept of "farming accordingly", having good drainage and knowing when to move the stock and where to place them.

Your farm is already under water. It's just what stock you got where and how you manage your stock when it does happen. When the Wahine storm went down, I noticed where all the ponding bits were and I got a map of the farm and marked them down. (Participant 18)

Most of the farmers stated that over the years they have reduced stock numbers on their property and consider further reduction in the future.

We did a SWOT [strengths, weaknesses, opportunities, and threats] analysis a year ago and the lake was the big threat because we can't control it. We have changed our management over time to do with the animals, and if we're still here then currently we're looking at the idea of downsizing and having a smaller farm. Going back 10 years ago we probably had around 200 cows during the winter. Now the farm is stock free from June to 3rd of July. (Participant 15)

5.2 Professional experts/decision makers

Ultimately the effective management/adaptation of the effects associated with the potential increase in the lake's water level as a result of sea-level rise will require collaboration between decision makers and members of the communities at risk. Thus, it was deemed necessary for the scope and purpose of this research to undertake interviews with planners, managers, engineers, scientists and iwi representatives from Ngāi Tahu, ECan and SDC who are either directly or indirectly involved/or have been involved in the decision-making process for managing the current operation of the lake's opening regime and/or the decisions around the general management of the lake as a whole. The decisions made at the local government level will influence actions taken at the private property level and vice versa. The interviews carried out with the professionals/decision makers aim to explore the general level of awareness and perspective on the future management of the lake (including the future operation of the lake's opening regime) at the local government level. Overall, five experts were interviewed. The interview questions these participants were presented with are outlined in Appendix B.

5.2.1 Level of awareness and risk perception

When the participants were presented with the future lake level maps, all eighteen participants stated that they were aware of the possibility of having to increase the current lake opening trigger level as a result of sea-level rise prior to participating in this research.

We know from experience, Mike Kit who has opened the lake for the past 25 years and from his on-ground experience that it's getting harder to open the lake. In the future we will need to open the lake at higher levels, which will obviously impact the lake margin and people that live around it. There is more chance in the future that there could be more flood events, it will happen slowly over time but it's definitely moving towards a higher operation level. (Leigh Griffins, ECan)

As the mean sea level increases, we will struggle with that gradient out of the lake. The opening level will probably have to increase over time as the mean sea-level rises otherwise we won't have the gradient to do it and in time we all will have to look at mitigation around the effects of high lake *levels. That might be that some of the farmers very close to the lake level will have wet feet more often than what they do now. (Murray Washington, SDC)*

Nine of the eighteen participants stated that there are numerous uncertainties around the science of climate change and sea-level rise, and in this case uncertainties exist around how the lake will respond to future sea-level rise.

> *The relationship between the sea and the lake and the potential effects of sea-level rise on the operation of the lake's opening is not as simple as it may seem. Aspects such as sediment transportation and a full analysis of the current hydrological cycle and future potential changes to that hydrological cycle due to both climate change and new policies and regulation coming into place in the Selwyn District such as the Central Plains Irrigation Scheme will be required. (Justine Cope, ECan)*

Some of the participants have stated these uncertainties have hindered and will continue to hinder proactive planning and management.

> *We are going through a district plan review at the moment which would take 3 to 7 years and I suspect that there will have to be consideration of flood levels in those, and we have to be very careful about that because as soon as we identify the lands that will be flooded under these extreme conditions, it goes on people's LINZ [property report] and unfortunately may affect the evaluation of their property so we've got to be careful with the information we're putting on that it's actually relatively accurate or as accurate as can be and that's the problem with sea-level rise. (Murray Washington, SDC)*

In terms of the future management of the lake and opening regime, sixteen of the eighteen participants agreed that a cost–benefit analysis is required to determine whether to promote managed retreat, alteration of the current land use, and/or the building of flood protection infrastructures (including constructing a permanent opening).

> *If there is going to be a future connection between sea level and lake level, any physical flood mitigation work is going to be at risk of becoming obsolete the higher the lake level goes. The structures will only have limited lifespans so the question's got to be asked – are the assets you're trying to protect worth protecting? (Justin Cope, ECan)*

However, most of the participants favoured managed retreat and alteration of the current land use over the building of flood protection infrastructure. Some of the participants have stated that the future management of the lake will not only depend on the results of the cost–benefit analysis, it will also depend on the range of values (social, cultural and environmental) of the lake and how the priorities of these values at both the communities level and the local government level change over time.

> *There has been a physiological change that has been occurring over the last decade, where the river engineers and the engineers that open the lake have shifted from a flood management perspective to certainly in the last five years a view that, right, we have reached the level now we need to have a conversation about if we open, what values would be enhanced and what values would be affected, and if we delay or not, would we get a better outcome. (David Perenara-O'Connell, Ngāi Tahu representative at ECan)*

Chapter 6

Discussion and Conclusion

The sea level is rising and it will continue to rise for at least this century. Some coastal communities around New Zealand have already been forced to retreat and take a reactive response to sea level rise. However, that does not have to be the case for the communities of Lake Ellesmere/Te Waihora. Unlike other natural hazards, sea-level rise is gradual and foreseeable, thus it is crucial to start planning for the future as soon as possible to reduce the impacts of the adverse effects associated with sea-level rise. Quantitative risk and qualitative vulnerability assessments are highly useful in their ability to gauge the effects of anticipated sea-level rise only on the central government and regional and city councils but also on individuals within the communities at risk (Hart, 2011; Russell & Griggs, 2012).

This chapter discusses the findings of the quantitative risk and qualitative vulnerability assessments.

6.1 Community displacement

The lowest existing floor level development around Lake Ellesmere/Te Waihora is the Lower Selwyn Hutt's floor level which is set at 1.5 metres above current mean sea level. This floor level marks the first trigger level in ECan's current flood management procedure for the Lake Ellesmere/Te Waihora area (Waihora Ellesmere Trust, 2013). Based on the results of the quantitative risk assessment and assuming there is no change to the current winter opening trigger level of 1.13 m.a.m.s.l., the minimum allowable artificial opening trigger level at which the lake can be opened during winter will be approximately 1.5 metres above current sea level by 2065. This marks the first point in time where a potential forced community displacement might occur. In the short-term future, the gradual increase of the lake's opening trigger level means high average lake water levels which are expected to increase the risk, duration and intensity of temporary flood events.

The results of the quantitative risk assessment confirm the need for local government to start integrating the potential effects of sea-level rise into their regional and district plans to manage activities in areas around Lake Ellesmere/Te Waihora identified to be at potential risk of flooding. However, given that no significant increase in the lake's opening trigger level is anticipated to occur until 2065, the current individuals within the lakeside communities that have been identified to be at potential risk of flooding might not need to consider the option of a proactive action in the form of a managed retreat as initially anticipated. Yet, preparing for more frequent and intense flood events in the short term might be necessary to minimise damage associated with these events.

Given that the estimated increase in the lake's opening trigger levels does not consider the current effects of wind or future climate change effects on the local climate (temperature, wind intensity, rainfall events) or on local coastal erosion, forced displacement of communities could occur much sooner than anticipated. Future assessment of the effects of climate change on the lake's hydrological cycle will be required to provide more precise estimates of future risk.

6.2 Willingness of communities to prepare for future sea-level rise

The impacts of future sea-level rise (i.e. increase in the lake's water levels) and associated natural disasters (i.e. more frequent and intense flood events) on the communities at risk can either be inhibited or catalysed by their level of preparedness. The communities' level of preparedness is fundamentally determined by the lessons learned that community has learned from past natural hazard events (i.e. floods). Although the land adjacent to Lake Ellesmere/Te Waihora is known to be a high-risk flood zone, the lakeside communities have not experienced a major flood event since 2013, and even then the flood event was not considered major to those who have resided in the area since the 1940s, 50s and 60s. This demonstrates a low level of preparedness amongst the lake-side communities. Overall, the Canterbury region has seen a gradual increase in temperature and a decrease in heavy rainfall events over at least the past decade. These local climate variations are represented by an increased risk of drought and an increased demand in water for irrigation as well as a decrease in surface water flows (including the flows of the tributaries discharging into Lake Ellesmere/Te Waihora) across the region.

The results of the qualitative vulnerability assessment indicate that amongst Lake Ellesmere/Te Waihora's lakeside communities, the level of awareness and knowledge is higher than the level of concern giving them a lower perception of risk. This relatively low perception of risk was reflected in the answers given by most of the participants when they were asked about their preferred adaptation option. Most of the participants chose managed retreat as their preferred adaptation option over protection and accommodation. However, it became clear during the interviews that managed retreat was chosen as it was seen to require less action and effort in relation to the other options, meaning this option was chosen out of apathy to adapt. It was noted that the managed retreat option was misinterpreted for "taking no action", where most of the participants clarified that they would only consider relocating only if they considered themselves forced to. This form of adaptation response is described in the socio-cognitive model (Grothmann & Patt, 2003) as a maladaptive response. Maladaptive responses are often chosen over adaptive response when risk perception is high, but perception of adaptive capacity is low. In this case, age, attachment to occupation, and experience gained from exposure to past events played a crucial role in influencing how the participants viewed their own adaptive capacity. The DROP model (Cutter et al., 2008) emphasises that past experiences play a fundamental role in motivating an individual to take proactive measures to prepare for future hazard events. The responses received during the interviews demonstrated otherwise because those interviewed who had resided near the lake for decades and experienced a range of flood events perceived themselves as having high adaptive capacity due to their past experience with damage associated with flood events. However, as the DROP model (Cutter et al., 2008) presented in Chapter 3 illustrates, preparedness enhancement is an ongoing process. If a community does not continue to enhance their level of preparedness, then their adaptive response will become outdated, decayed and inefficient for absorbing the shock of future events. Most of the responses indicated a low perception of potential harm as most of those who were interviewed could not envision the anticipated effect of sea level rise occurring within their lifespan.

The lack of concern amongst Lake Ellesmere/Te Waihora's communities becomes even more apparent through the responses received regarding their preferred adaptation option/pathways. Prior to the interviews taking place with the members of the lakeside communities, it has been assumed that participants who would choose accommodation and retreat over protection as an adaption option would be the ones who are likely to be more prepared and adapt better to the anticipated changes to their surrounding environment. However, this was proven not to be the case. The majority of the participants that chose managed retreat over the building of flood protection infrastructure have misinterpreted the option and chose it simply because they lacked interest, underestimated risk, did not believe in climate change. This was because managed retreat option presented itself as the option with the least effort and action to be taken. The majority of those who chose managed retreat stated that they don't think they will ever reach a stage within their lifetimes where they have to choose this option and that they are willing to take the risk and stay on their property for as long as they can rather than acting proactively. Those interviewed were willing to take the risk of being forced to retreat, with some stating that if they were ever to choose to migrate elsewhere it would be due to the financial burden involved with farming near water bodies in the region as they held concerns over the effects of agriculture on water quality at both the national and regional scale and not because of concerns over the potential impacts of sea-level rise and increasing lake water levels. This showed that those interviewed value environmental sustainability in the form of maintaining water quality though this concern only arose after the threat of financial loss became apparent.

The participants that chose protection over the other two options chose it mainly because they believe that the assets which they are trying to protect are worth protecting and they were willing to contribute financially towards the building of flood protection infrastructure. The findings indicated that these participants were not necessarily concerned about the anticipated effects of future sea-level rise, but they had strong attachment to their place and their occupations, and they planned on passing their land and occupations to their following generations. The participants who chose the protection option highly value the continuation of their farming culture to the point where they are willing to absorb the financial cost of flood protection infrastructure.

These findings indicate that the participants who chose accommodation over protection and managed retreat showed interest in the range of values that the lake holds and believed that opening the lake at higher levels could be beneficial for improving the water quality in the lake. These participants demonstrated improvisation and creativity and an overall willingness to adapt their lifestyles to increasing lake water levels in contrast to those participants who chose protection who were unwilling to change their lifestyles.

6.3 Future lake management

A hard engineering approach might be required to facilitate the continuation of artificially opening the Lake Ellesmere/Te Waihora to the sea at the current opening trigger levels. However, the promotion of this adaptation option over a proactive managed retreat option or the accommodation option might be hindered by the shift in environmental management and attitudes seen regionally and nationwide over the 20th and 21st century. As discussed in Chapter 3, the management of the lake's opening regime has evolved significantly since the significance of the lake's wildlife habitat was formally recognised internationally and nationally through the National Water Conservation (Te Waihora/Lake Ellesmere) Order 1990. In the meantime, New Zealand as a whole has seen a shift in environmental management and attitudes towards managing land-use intensification and improving water quality. Today, more than 1.14 million dollars has been spent on restoring the lake's wetland and swamps margins and improving the lake's water quality (Hughey , Taylor, & Ford, Te Waihora/Lake Ellesmere State of the Lake 2017, 2017). Whilst the local government has regulatory responsibilities to protect the adjacent lands of Lake Ellesmere/Te Waihora from flooding, it also has regulatory responsibilities to maintain and improve water quality throughout the region.

Lake Ellesmere/Te Waihora is co-governed and is valued by various groups for various reasons. The opening regime plays a fundamental role in serving these values. While the lake managers have attempted over the years to operate the opening regime in a manner that will provide and cater for all of these values, lower trigger opening levels seek to only provide for landowners of the land adjacent to the lake with protection from flooding. The professional experts interviewed indicated that a higher opening trigger level might be highly beneficial for the lake's ecological values. The experts' responses indicate that managed retreat might not only be the best option for the lake's health but also for adjacent landowners as the use of flood protection infrastructure might become less financially feasible. Financial loss experienced by the communities of Lake Ellesmere/Te Waihora will only get worse due to more frequent and intensive flood events. However, a thorough cost–benefit analysis should be undertaken in order to better understand this financial loss.

Lake Ellesmere/Te Waihora’s artificial opening regime plays a fundamental role in facilitating fish migration and maintaining water quality, the increase of the opening trigger levels will be beneficial to the lake’s ecological health. However, this increase of opening trigger levels would have detrimental effects on adjacent properties, drains, and infrastructure and land-use activities (Renwick et al., 2010).

The results of the interviews undertaken with the professional experts indicate that SDC and ECan are at the early stages of planning to provide for the effects of sea-level rise in their district and regional plans and accounting for the effects of sea-level rise in the lake’s flood-zone hazard maps shown in Figure 3-2. To date, the progress of publishing hazard maps and projecting future sea-level rise around the Lake Ellesmere/Te Waihora has been greatly hindered by the uncertainty around the science of climate change and sea-level rise and how the lake’s natural processes will respond to these changes. Due to this perceived uncertainty, the experts are reluctant to request changes to district and regional plans and local flood maps from these scientific observations due to their knowledge that these changes would result in a decrease in housing values around Lake Ellesmere/Te Waihora’s area, resulting in a backlash from existing landowners in these communities.

The management of Lake Ellesmere/Te Waihora and land-use activities across the catchment has changed significantly over the 20th and 21st century. Firstly, the significance of the lake’s wildlife habitat was recognised internationally and nationally with the passing of the National Water Conservation (Te Waihora/Lake Ellesmere) Order 1990. Since then, multiple values were acknowledged, which triggered the need to amend the WCO in 2011 to reflect them. These values included ecological and cultural values. With the increasing recognition of Lake Ellesmere/Te Waihora’s ecological and cultural significance, the maintenance of low lake water levels might not be supported by the local government or the local iwi, given that the lowered water level do not enhance these values any form. The timings of lake openings and the artificial opening trigger levels at which they occur has been a source of conflict as different segments of the community are affected differently and have different needs and values for the lake.

In relation to the future management of Lake Ellesmere/Te Waihora and management of land-use activities within the catchment, the lake managers’ responses reflect the shift in the management approach and environmental attitudes towards the lake documented in current literature. The lake managers indicated that gains from improving the lake's water quality and restoring adjacent swampland and wetlands might outweigh the gains from preventing adjacent land from flooding.

The publication of natural hazard maps can have an unnecessarily detrimental effect on property values. SDC and ECan face challenges in terms of uncertainty around the signs of climate change and the effects it might have on property valuation which was stated by Mr Washington from SDC and Mr Cope and Ms Shearer from ECan during their interviews. Although primarily the artificial lake openings of Lake Ellesmere/Te Waihora are driven by the need to protect adjacent land use and communities from inundation, there has been a significant shift in the management of the lake where there has been an increased focus on the lake's water quality. The experts interviewed stated that it is already difficult to align the opening regime with the range of values that the lake holds and expect it to become more challenging in the future, as higher lake levels might be beneficial for the lake's water quality but not for the current adjacent land use. This shows awareness amongst the experts currently involved in managing the lake around the effects of sea level rise on artificial opening and what the challenges these effects might pose on the current management of the lake's water quality.

6.4 Conclusions and recommendations

The original goals for this research were to determine the effects of sea-level rise on Lake Ellesmere/Te Waihora's opening regime and consequently adjacent land use and lakeside communities, and to assess the lakeside communities' level of preparedness to cope with the anticipated increase in lake's water levels.

The quantitative risk assessment undertaken in this research indicated that forced community displacement might not occur until 2065, and thus will not impact the current generation of lakeside communities of Lake Ellesmere/Te Waihora. However, more frequent flood events are anticipated in the short term that might affect their livelihood and the viability of their current use of land. While there is generally a high perception of risk amongst the lakeside communities, there is a lack of concern and motivation towards taking proactive actions driven by lack of recent experience with flood events and a high adaptive capacity perception.

Whilst the anticipated increase in the lake's water level is not expected to displace the current communities around Lake Ellesmere/Te Waihora, it is expected to have significant effects on future development in the area, which the local authorities and decision makers are aware of.

The findings of this research suggest that future researchers will find it useful to explore the effects of climate change on the catchment's local climate and coastal erosion and the lake's hydrological cycle to gain a more precise estimate of objective risk. In addition, it will be useful for the local government and decision makers to undertake a cost–benefit analysis to assess whether the worth of the assets that are currently being protected by the artificial opening regime outweigh the benefits of increasing the opening trigger levels for enhancing water quality and the lake's life-supporting habitat.

Overall, the findings suggest that the indirect, cascading effects of slow-impact sea-level rise will need careful attention by disaster planners and may require a substantial effort to create an understanding of the potential consequences for those people who are likely to suffer from such effects.

Appendix A
Interview Guide – Professional Experts (Lake Opening Protocol Group)

1. What role does your organisation/iwi play in the operation of the lake opening? And how long have you been involved with operating the lake openings?
2. From your experience since you have been involved in the operation of the lake openings, what were the major obstacles faced? And how did you respond and cope with them?
3. What is your general opinion on the current opening regime? Do you think it's practical or does it require improvement? And do you have any suggestions in mind?
4. In your opinion, what would be some of the major obstacles that the operation of the lake opening might face 10 years into the future from now?
5. What is your perspective on climate change and sea-level rise? Do you consider sea-level rise to be one of the major obstacles to face the operation of the lake opening in the future? And do you have any management plans for the future in place or are you planning to create one in the near future to address climate change and sea-level rise impacts on the lake?
6. What changes are expected to be experienced in regard to the nature of future flood events (clarify to the participant that by nature I mean frequency and duration) as a result of sea-level rise increasing the level of the lake?
7. In your opinion do you think sea-level rise poses a great threat to the current adjacent land use and the lakeside communities (lake settlers)? (If they do then ask) And would you be more inclined towards advising them about and recommending to those who are affected or could potentially be affected in the future various management options? Which might these be? Would you see building dikes and using water pumps as reasonable options? Or would you be more inclined towards advising them to seek an alternative land use? Or do you think they will just have to leave their land? Whichever options, have you made any plans or strategies to facilitate that process?
8. Do the maps showing the flood zones in the Selwyn District Council Plan take sea-level rise into account? (If they don't know, ask them who I could see about it.) (If they do know the answer and it's a no, then ask) Do you think they should take sea-level rise into account? And do you think future potential lake expansion due to sea-level rise as part of the flooding hazard should be included in the plan maps? (If they do then ask) Is there a plan in the near future to improve those maps by taking sea-level rise future projections into consideration? (This question is for ECan and SDC participants only.)

Appendix B
Interview Guide – Lakeside Communities

1. Since you have been farming/residing here, roughly how many flood events have you experienced and how did you cope with them?
2. What is your understanding of the operation of the current opening regime of the lake and its effects on you?
3. What is your perspective on climate change and sea-level rise?
4. Do you have any concerns about the potential impacts of sea-level rise on your home and/or business? And have you got a management plan in place or are you planning to create one in the near future?
5. Have you thought about options of alternative land use for the future? If you did what are they? If not (then ask) what is your opinion on options such as fish farming, coastal wetland or any other alternative land use? (Not valid for Lower, Upper and Greenpark Hut residents.)

(Participants will be presented with the maps and it will be explained to them what the maps are showing and how they were created, then the following questions will be asked.)

6. What do you think of the map(s) and what they are showing? Were you aware that the effect of sea-level rise might be experienced as soon as 10 years from now? And does it change your perspective on the issue and/or affect any decisions you may take in the future in regard to your current land use?

Appendix C
Research Information Sheet

Lincoln University Faculty of Environment Society and Design, Waterways Centre Research Information Sheet

You are invited to take part in a research project entitled "The effects of sea-level rise due to climate change on the current opening regime of Lake Ellesmere/Te Waihora". As the sea level rises, the lake levels will rise, which will increase the risk of flooding for the lakeside communities and poses a threat to the viability of the current adjacent land use. The aim of my research is to examine the effects the change in the lake's opening regime due to sea-level rise will have on adjacent land use and lakeside communities and their preparedness for coping with these effects.

The aim of the interviews is to enable the researchers to design a questionnaire to collect data to further understand this topic.

The focus group will comprise of lake settlers, members representing Te Taumutu Rūnanga, Christchurch City Council (CCC), Selwyn District Council (SDC), Environment Canterbury (ECan), Ngāi Tahu, Waihora Ellesmere Trust (WET), Department of Conservation (DOC), Fish and Game (F&G) and commercial fishers. It is anticipated that the pilot study will take an hour of your time.

Participation in this study is voluntary. You may withdraw at any time, or decline to be involved in any part of the discussion or research. You may ask to view any notes compiled by the researcher during the focus group/pilot study. Any such notes will be destroyed after the questionnaire/research instrument has been finalised.

I am undertaking this research as part of my studies towards a Master in Water Resource Management. My supervisors for this research are Hamish Rennie and Magdy Mohssen. My supervisors and I will address any questions you might have regarding this research. Our contact details are as follows:

Dalia Zarour (student researcher) – mobile: 021 250 8828, email: dalia.zarour@lincoluni.ac.nz

Hamish Rennie (supervisor) – Telephone: +64 3 423 0437, email: Hamish.Rennie@lincoln.ac.nz

Magdy Mohssen (co-supervisor) – Telephone: +64 3 423 0433, email: Magdey.Mohssen@lincoln.ac.nz

Thank you for your valued assistance.

Kindest regards,
Dalia Zarour

Appendix D
Proforma Consent Form

Lincoln University Policies and Procedures

This pilot study discusses sea-level rise effects on the current opening regime of Lake Ellesmere/Te Waihora. Latest reports indicate that the sea level is going to rise up to 30 cm by 2050 across New Zealand, threatening low-lying lands. As the sea level increases so would the lake level, threatening the livelihood of the lakeside communities and the viability of the current land use. Thus, it is crucial to have a management plan in place to reduce vulnerability and increase resilience to such changes. The aim of this research project is to examine the effects that changes to the lake's opening regime due to sea-level rise will have on adjacent land use and lakeside communities and their preparedness for coping with these effects.

I have read and understood the description of the above-named pilot study. On this basis, I agree to participate in the pilot study and consent to the information that I provide being used to develop a research questionnaire. I will respect the privacy of information given to me by others participating in the pilot study and not discuss the information they have provided with others outside of the pilot study.

Name: **Dalia Zarour**

Signed: ___________________________________ Date:______________

Bibliography

2017 Central Plains Water Limited . (2017). *Scheme Development*. Retrieved from Central Plains: https://www.cpwl.co.nz/scheme-development-2/stage-1

Adejuwon, J., Azar, C., Baethgen, W., Hope, C., Moss, R., Leary, N., Walker, B. (2001). *Working Group II: Impacts, Adaptation and Vulnerability.* Cambridge: IPCC.

Adger, W. N. (2006). Vulnerability. *Global Environmental Change*, 268-281.

Africa Climate Change Resilience Alliance. (2010). *The ACCRA Local Adaptive Capacity framework.* Retrieved 1 10, 2016, from Africa Climate Change Resilience Alliance: http://community.eldis.org/.59d669a7/ACCRA%20Local_Adaptive%20Policy_new.pdf

Al-Busaidi, Z. Q. (2008). Sultan Qaboos University Medical Journal. *Qualitative Research and its Uses in Health Care*, 11-19.

Anthony, A., Atwood, J., August , P., Byron, C., Cobb, S., Foster , C., . . . Vinhateiro , N. (2009). Coastal Lagoons and Climate Change: Ecological and Social Ramifications in U.S. Atlantic and Gulf Coast Ecosystems. *Ecology and Society*.

Asian Disaster Reduction Center . (2005). *Total Disaster Risk Management - Good Practices .* Asian Disaster Reduction Center .

Barriball, K. L., & While, A. (1994). Collecting data using a semi-structured interview: a discussion paper. *Journal of Advanced Nursing*, 328-335.

Bell, R., Lawrence, J., Allan, S., Blackett, P., & Stephens, S. (2017). *Coastal Hazards and Climate Change: Guidance for Local Government.* Wellington: Ministry for the Environment.

Bolter, K. P. (2014). *PERCEIVED RISK VERSUS ACTUAL RISK TO SEA-LEVEL RISE:A CASE STUDY IN BROWARD COUNTY, FLORIDA.* Florida: Florida Atlantic University.

Brand, B., McMullin-Messier, P., & Schlegel, M. (2015, December 7). *Unit 1: Hazards, vulnerability and risk*. Retrieved Agust 11, 2016, from InTeGrate: http://serc.carleton.edu/integrate/teaching_materials/map_hazards/unit1.html

Brody, S., Zahran, S., Vedlitz, A., & Grrover, H. (2008). *Examining the Relationship Between Physical Vulnerability and Public Perceptions of Global Climate Change in the United States.* Sage Publications.

Brooks, N., Adger, N., Barnett, J., Woodward, A., & Lim, B. (2004). *Assessing and Enhancing Adaptive Capacity .* Research Gate .

Canterbury Maps. (2015). *Canterbury Maps*. Retrieved March 1, 2015, from Canterbury Maps: https://canterburymaps.govt.nz/explore/?district=Selwyn

Cardona, O. D., van Aalst, M. K., Birkmann, J., Fordham, M., McGregor, G., Perez, R., . . . Sinh, B. T. (2012). Determinants of risk: exposure and vulnerability. In C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Eb, . . . P. M. Midgley, *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (pp. 65-108). Cambridge(UK) and New York (US): Cambridge University Press.

Care . (2001). *Adaptive Capacity* . Retrieved May 12, 2016, from Toolkit for Integrating Climate Change Adaptation into Development Projects: http://www.careclimatechange.org/tk/integration/en/key_concepts/adaptive_capacity.html

Care Climate Change. (2016). *Community-Based Adaptation Toolkit*. Retrieved March 3, 2016, from Climate Change information Centre: http://www.careclimatechange.org/tk/cba/en/cba_basics/key_concepts.html

Carter, J., Gavan, G., Connelly, A., Guy, S., Handley, J., & Kazmierczak, A. (2015). *Climate change and the city: Building capacity for urban adaptation.* Manchester: University of Manchester.

Cenacchi, N. (2008). *Adaptation to Climate Change in Coastal Areas of the ECA Region.* Washington DC: World Bank .

Chin, K. (2015, May 1). *Ellesmere, Lake – Night Fishing Lake Ellesmere River Tributaries*. Retrieved July 30, 2018, from Fishingmag: https://fishingmag.co.nz/south-island/canterbury-places-to-fish/canterbury-river-fishing-destinations/ellesmere-lake-night-fishing-lake-ellesmere-river-tributaries

Chiras, D. D. (2012). *Environemtnal Science* . Burlington, Massachusetts: Jones & Bartlett Publishers.

Ciurean, R. L., Schröter, D., & Glade, T. (2013). *Conceptual Frameworks of Vulnerability Assessments for Natural Disasters Reduction.* Laxenburg: IntechOpen Limited.

Conde, D., Vitancurt , J., Gallego , L., Alava , D., Nerrastro , N., Chreties , C., Panario , D. (2015). Coastal lagoons and Sandbar Dynamics. In J. Baztan , O. Chouinard, B. Jorgensen , P. Tett, J. Vanderlinden, & L. Vasseur , *Coastal Zones: Solutions for the 21st Century* (pp. 218- 224). Elsevier .

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. *Elsevier* , 598–606.

Dang, H. L., Li, E., Nuberg, I., & Bruwer, J. (2014). Understanding farmers' adaptation intention to climate change: A structural equation modelling study in the Mekong Delta, Vietnam. *Environmental Science and Policy*, 11-22.

Davies, J. D., Galloway, L., & Nutt, A. H. (1994). *Lake Ellesmere Past Present Future .* Lincoln: J D G Davies, L Galloway and A H C Nutt.

Department of Conservtion . (2011, July). *New Zealand Coastal Policy Statement 2010 - National implementation plan*. Retrieved July 30, 2018, from Department of Conservtion : https://www.doc.govt.nz/about-us/science-publications/conservation-publications/marine-and-coastal/new-zealand-coastal-policy-statement/national-implementation-plan/

Dronkers, J., Gilbert, J. T., Butler, L., Carey, J., Campbell, J., James, E., von Dadelszen, J. (1990). *Strategies for Adaption to Sea Level Rise.* Geneva: Intergovernmental Panel on Climate Change.

Environment Canterbury . (2017). *Managed Te Waihora/Lake Ellesmere Openings* . Retrieved April 8, 2018, from Environment Canterbury Regional Council : http://www.crc.govt.nz/services/environmental-planning/pages/te-waihora-openings.aspx

Environment Canterbury . (2018). *Opening Te Waihora/Lake Ellesmere*. Retrieved March 28 , 2018 , from Environment Canterbury Regional Council : https://www.ecan.govt.nz/your-region/your-environment/river-and-drain-management/opening-te-waihoralake-ellesmere/

Gallopín, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *ELSEVIER*, 293–303.

Golder Associates. (2011). *Te Waihora/Lake Ellesmere Catchment Flow review; Ecological Values and Flow Requirements.* Christchurch: Environment Canterbury.

Grothmann, T., & Patt, A. (2003). *ADAPTIVE CAPACITY AND HUMAN COGNITION.* Potsdam: Potsdam Institute for Climate Impact Research .

Haines , P. E. (2007). *ANTICIPATED RESPONSE OF COASTAL LAGOONS TO SEA LEVEL RISE.* NSW: BMT WBM Pty Ltd.

Haines, P. E., & Thom, B. G. (2007). Climate Change Impacts on Entrance Processes of Intermittently Open/Closed Coastal Lagoons in New South Wales, Australia . *Journal of Coastal Research* , 242 - 246 .

Handoko, R. a. (2016). Vurnerability Assessment of Climate Change on Agriculture Sector in the South Sumatra Province, Indonesia. *Science Alert*, 31-42.

Harding, S. (2007 , January 8). *The long road to enlightenment*. Retrieved November 23, 2015, from The Guardian : https://www.theguardian.com/environment/2007/jan/08/climatechange.climatechangeenvironment

Hart, G. (2011). *Vulnerability and adaptation to sea-level rise in Auckland, New Zealand.* Wellington: The New Zealand Climate Change Research Institute .

Hughes, M. W., Quigley, M. C., Ballegooy, ,. S., Deam, B. L., Bradley, B. A., Hart, D. E., & Measures, R. (2015). The sinking city: Earthquakes increase flood hazard in Christchurch, New Zealand. *GSA Today*, 4-10.

Hughey , K. F., Taylor, K. J., & Ford, D. E. (2017). *Te Waihora/Lake Ellesmere State of the Lake 2017.* Christchurch: Waihora Ellesmere Trust.

Hughey, K. (2010). *Te Waihora Ellesmere- the 2009 Living Lake Symposium: a summary of the key findings and conclusions.* Christchurch: Lincoln University .

Hughey, K. F., Johnston, K. A., Lomax, A. J., & Taylor, K. J. (2013). *Te Waihora/Lake Ellesmere State of the Lake 2013.* Christchurch : WET .

ICF International. (2009, July 24). *Literature Review: Climate Change Vulnerability Assessment, Risk Assessment, and Adaptation Approaches.* Retrieved August 10, 2016, from Federal Highway Administration: https://www.fhwa.dot.gov/environment/climate_change/adaptation/publications/vulnerability_assessment/#Toc236233839

IPCC. (2007). *IPCC*. Retrieved May 12, 2016, from Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability: https://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch17s17-3.html

James, B. (1991). *A BICULTURAL PARTNERSHIP FOR TE WAIHORA (LAKE ELLESMERE): A CASE STUDY IN MANAGEMENT PLANNING .* Wellington: Department of Conservation.

James, B. (1991). *A BICULTURAL PARTNERSHIP FOR TE WAIHORA (LAKE ELLESMERE): A CASE STUDY IN MANAGEMENT PLANNING .* Wellington: Department of Conservation.

Jones, L., Ludi, E., & Levine, S. (2010). *Towards a characterisation of adaptive capacity: a framework for analysing adaptive capacity at the local level.* Overseas Development Insitute .

Kajornboon, A. B. (2005). Using interviews as research instruments . *E-Journal for Researching Teachers*, 1-8 .

Keller, S., & Conradin, K. (2010). *Semi-Structured Interviews*. Retrieved January 10 , 2016 , from Sustainable Sanitation and Water Management: https://webcache.googleusercontent.com/search?q=cache:TG8vxchnT14J:https://www.sswm.info/content/semi-structured-interviews+&cd=1&hl=en&ct=clnk&gl=nz

Kitto, S. (2010). *The Environmental History of Te Waihora – Lake Ellesmere.* Christchurch: University of Canterbury .

Kjerfve, B. (1994). Coastal Lagoon Processes. *Elsevier Oceanography Series*.

Landscape Institute . (2016). *Medmerry Managed Realignment Scheme*. Retrieved March 27, 2016, from Landscape Institute : http://www.landscapeinstitute.org/casestudies/casestudy.php?id=431

Lettink, M., Cree, A., Norbury, G., & Seddon, P. J. (2008). *Monitoring and restoration options for lizards on Kaitorete Spit, Canterbury.* Wellington: Department of Conservation.

Lockwood, M., Raymond, C., Oczkowski, E., & Morrison, M. (2015). *Measuring the dimensions of adaptive capacity: a psychometric approach.* Resilience Alliance.

Lomax, A. J., Johnston, K. A., Hughey, K. F., & Taylor, K. J. (2015). *Te Waihora/Lake Ellesmere State of the Lake 2015.* Christchurch: WET.

Ludena, C., & Yoon, S. (2015). *Local Vulnerability Indicators and Adaptation to Climate Change.* uncclearn.

Manson, M. (2010). Sample Size and Saturation in PhD Studies Using Qualitative Interviews. *Forum Qualitative Sozialforschung* .

Marshall, N., Marshall, P., Tamelander, J., Obura, D., Malleret-King, D., & Cinner, J. (2010). *A Framework for Social Adaptation to Climate Change.* Gland : IUCN.

Marshall, N., Marshall, P., Tamelander, J., Obura, D., Malleret-King, D., & Cinner, J. (2010). *A Framework for Social Adaptation to Climate Change.* Gland: IUCN Publications Services.

McCallum-Clark, M., Maw, P., Painter, D., & Robson, M. (2014). *Variation 1 to the Proposed Land and Water Regional Plan Section 42A Report.* Christchurch : Environment Canterbury .

McGinnis, M. D., & Ostrom, E. (2014). Social-ecological system framework: initial changes and continuing challenges. *Ecology and Society*, 19-30.

McGinnis, M. D., & Ostrom, E. (2014). Social-ecological system framework: initial changes and continuing challenges. *Ecology and Society* , 19-30.

McGuire, C. J. (2015 , December 4). *UMASS.* Retrieved May 1, 2016, from Perception of Risk in Promoting Social Policies for Resilience : https://www.umassd.edu/media/umassdartmouth/smast/labpdffiles/Perception_of_Risk_in_Promoting_Social_Policies_for_Resilience.pdf

McSweeney, S. L., Kennedy, D. M., & Rutherfurd, I. D. (2014). *Classification of Intermittently Closed and Open Coastal Lakes and Lagoons in Victoria, Australia.* Townsville: The University of Melbourne.

MfE. (2014, 8 29). *Making the Lake Ellesmere Water Conservation Order* . Retrieved from Ministry for the Environment : http://www.mfe.govt.nz/fresh-water/reform-programme/water-conservation-orders/existing-water-conservation-orders/te-0

Mills, M., Mutafoglu, K., Adams, V. M., Archibald, C., Bell, J., & Leon, J. X. (2016). Perceived and projected flood risk and adaptation in coastal Southeast Queensland, Australia. *Climate Change* , pp 523–537.

Ministry for the Environment . (2016, February 11). *About water conservation orders*. Retrieved May 25, 2018, from Ministry for the Environment : http://www.mfe.govt.nz/fresh-water/water-conservation-orders/about-water-conservation-orders

Ministry for the Environment. (2008, May). *Risk Assessment*. Retrieved August 20, 2016, from Ministry for the Environment: http://www.mfe.govt.nz/publications/climate-change/climate-change-effects-and-impacts-assessment-guidance-manual-local-9

National Water and Soil Conservation Authority. (1990). *Application for a Water Conservation Order on Lake Ellesmere: Report of the committe of the National Water and Soil Conservation Authority.* National Water and Soil Conservation Authority.

nzfishing. (2018). *Lake Ellesmere Map*. Retrieved July 30, 2018, from nzfishing.com: https://www.nzfishing.com/fishingwaters/northcanterbury/NCMaps/EllesmereMap.htm

Obura, D., Malleret-King, D., Cinner, J. E., Marshall, N. A., Marshall, P. A., & Tamelander, J. (2010). *A Framework for Social Adaptation to Climate Change.* Gland: IUCN.

O'Donnel, C. F. (1985). *Lake Ellesmere: A Wildlife Habitat of International Importance .* Christchurch: N.Z. Wildlife Service Department of Internal Affairs.

ODPM. (2013). *Vulnerability and Risk*. Retrieved August 11, 2016, from Government of the Republic of Trinidad and Tobago: http://www.odpm.gov.tt/node/162

Preparing New Zealand for rising seas: certainty and uncertainty . (2015 , November 19). Retrieved June 23 , 2016, from Parliamentary Commissioner for the Environment : http://www.pce.parliament.nz/publications/preparing-new-zealand-for-rising-seas-certainty-and-uncertainty

Renwick , J., Horrell, G., McKerchar, A., Verburg, P., Hicks , M., & Hreinsson, E. (2010). *Climate change impacts on Lake Ellesmere(Te Waihora).* Wellington : NIWA .

Rohrmann, B. (2008). *RISK PERCEPTION, RISK ATTITUDE, RISK COMMUNICATION, RISK MANAGEMENT: A CONCEPTUAL APPRAISAL.* Melbourne : University of Melbourne .

Russell, N., & Griggs, G. (2012). *Adapting to Sea Level Rise:A Guide for California's Coastal Communities.* Santa Cruz: University of California.

Russell, N., & Griggs, G. (2012). *Adapting to Sea Level Rise:A Guide for California's Coastal Communities.* California: University of California, Santa Cruz.

Sadat-Noori, M., Santos, I. R., Tait, D. R., McMahon, A., Kadel, S., & Maher, D. T. (2016). Intermittently Closed and Open Lakes and/or Lagoons (ICOLLs) as groundwater-dominated coastal systems: Evidence from seasonal radon observations. *Journal of Hydrology*, 612–624.

Samad, S. S. (2007). AN ANALYSIS OF THE IMPACT OF SEA LEVEL RISE ON LAKE ELLESMERE – TE WAIHORA AND THE L2 DRAINAGE NETWORK, NEW ZEALAND. Christchurch, Canterbury, New Zealand.

Saunders, B., Sim, J., Kingstone, T., Baker, S., Waterfield, J., Bartlam, B., . . . Jinks, C. (2017). Saturation in qualitative research: exploring its conceptualization and operationalization. *Quality and Quantity*, 1-15.

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *ELSEVIER*, 282–292.

Smith, N. (2010, December 20). *First step taken to recognise additional outstanding values for Lake Ellesmere (Te Waihora)*. Retrieved July 30, 2018, from Beehive.govt.nz: https://www.beehive.govt.nz/release/first-step-taken-recognise-additional-outstanding-values-lake-ellesmere-te-waihora

Song, X., Zhang, J., Zhan, C., Xuan, Y., Yee, M., & Xu, C. (2014). Global sensitivity analysis in hydrological modeling: Review of concepts, methods, theoretical framework, and applications. *Journal of Hydrology*, 739-757.

STREAMsim. (2006). *What is History Matching?* Retrieved July 30, 2018, from STREAMsim: https://www.streamsim.com/technology/history-matching

Suresh, K., Thomas, S. V., & Suresh, G. (2011). Design, data analysis and sampling techniques for clinical research. *Annals of Indian Academy of Neurology*, 287–290.

Te Rūnanga o Ngāi Tahu. (2014, July 28). *Understanding the Te Waihora lake opening process*. Retrieved July 30, 2018, from Te Rūnanga o Ngāi Tahu: http://ngaitahu.iwi.nz/our_stories/understanding-te-waihora-lake-opening-process/

Teng, J., Jackeman, A., Vaze, J., Croke, B., Dutta, D., & Kim, S. (2017). Flood inundation modelling: A review of methods, recent advances and uncertainty analysis. *Environmental Modelling and Software*, 1-15.

The Greenmarket oracle. (2016, Ocotber 13). *The Greenmarket oracle*. Retrieved July 2018 , 2018, from Adapting to sea level rise : http://www.thegreenmarketoracle.com/2016/10/adapting-to-sea-level-rise.html

The Institution of Civil Engineers. (2016). *Managed realignment at Medmerry, Sussex*. Retrieved March 28, 2016, from The Institution of Civil Engineers: https://www.ice.org.uk/disciplines-and-resources/case-studies/managed-realignment-at-medmerry-sussex

The Ramsar Convention. (2014). *WETLANDS & AGRICULTURE:PARTNERS FOR GROWTH.* Rasmar : The Ramsar Convention.

The University of Auckland. (2016). *About thematic analysis*. Retrieved 3 13, 2016, from The University of Auckland: https://www.psych.auckland.ac.nz/en/about/our-research/research-groups/thematic-analysis/about-thematic-analysis.html

Threat Analysis Group. (2016). *Threat, vulnerability, risk – commonly mixed up terms*. Retrieved August 11, 2016, from Threat Analysis Group: http://www.threatanalysis.com/2010/05/03/threat-vulnerability-risk-commonly-mixed-up-terms/

Turbott, C., & Stewart, A. (2006). *Managed Retreat from Coastal Hazards : Options for Implementation.* Hamilton: Environment Waikato.

Turner II, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., . . . Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *PNAS*, 8074–8079.

Varona, G. S. (2012). *Community Environmental Attitudes: A Ellesmere-Te Waihora Community Study of the Changing Attitudes in the Lake in the Twentieth Century* . Christchurch: Lincoln University. Retrieved from https://researcharchive.lincoln.ac.nz/bitstream/handle/10182/5320/varona_phd.pdf?sequence=3

Varona, G. S. (2012). *Community Environmental Attitudes: A Study of the Changing Attitudes in the Lake Ellesmere-Te Waihora Community in the Twentieth Century.* Christchurch: Lincoln University.

Verhoeven, J. T., & Setter, T. L. (2010). Agricultural use of wetlands: opportunities and limitations. *Oxford University Press*, 155–163.

Waihora Ellesmere Trust . (2013 , June 27). Retrieved March 28, 2015 , from Waihora Ellesmere Trust : http://www.wet.org.nz/about-the-lake/lake-level-2/

Waihora Ellesmere Trust . (2015). *About the Lake*. Retrieved May 5, 2016, from Waihora Ellesmere Trust : http://www.wet.org.nz/about-the-lake/

Weis, S., Agostini, V., Roth, L., Glimer, B., Schill, S., Knowles, J., & Blyther, R. (2016). Assessing vulnerability: an integrated approach for mapping adaptive capacity, sensitivity, and exposure. *Climatic change* , 615-629.

WET. (2015). *Application to amend the Water Conservation Orde*. Retrieved July 30, 2018, from Waihora Ellemere : https://www.wet.org.nz/news/application-to-amend-the-water-conservation-order/

WET. (2015). *Te Waihora Lake Ellesmere*. Retrieved June 26, 2016, from Waihora Ellesmere Trust: http://www.wet.org.nz/

Yunus, A. P., Avtar, R., Kraines, S., Yamamuro, M., Lindberg, F., & Grimmond, C. (2016). Uncertainties in Tidally Adjusted Estimates of Sea Level Rise Flooding (Bathtub Model) for the Greater London. *Remote Sensing*, 1-23.

Zarafshani, K., Sharafi, L., Azadi, H., & Passel, S. V. (2016). Vulnerability Assessment Models to Drought: Toward a Conceptual Framework. *Sustainability* , 588.