The impacts of climate change in Canterbury: a summary of the literature

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Executive summary

Climate change presents significant challenges, risks and opportunities to Canterbury. These are caused by both the changing climate and the transition to a low-emissions future as NZ contributes to the global effort to keep the global average temperature below 2°C above pre-industrial levels.

The projected changes in climate for Canterbury are well known. However there has been no synthesis of the wide-ranging effects on the environment and society from the changing climate. Building an understanding of the direct and indirect impacts will grow our capacity to manage these climate change risks and opportunities to ensure environmental, social, cultural and economic wellbeing in Canterbury.

We simplified an existing conceptual framework to summarise the direct and indirect impacts from climate change and transition change for Canterbury from existing literature. These were grouped into the impacts on environmental, economic, social, cultural and governance wellbeing.

Climate-driven changes in Canterbury include increasing temperature, hot days (over 25°C), extreme rainfall, sea level rise and storm surges, and decreasing frosts and snow days. These will cause increasing hazards in certain areas such as river flooding, low flow timing, erosion and drought.

Transition-driven changes will include changing laws, policies, regulations, innovation and investment. These will likely cause land-use to change, such as conversion of sheep and beef farms to forestry, and changes in transport such as conversion to electric vehicles.

Environmental impacts will include land damage and loss, spatial and seasonal changes in freshwater supply and quantity, sub-optimal health of organisms, changing species distribution including pest and disease species and changing food webs. In terms of the built environment, coastal defences, buildings, infrastructure and public amenities are all exposed to sea level rise and storm surges, increasing drought and extreme rainfall.

Much of the existing literature covering **economic impacts** of climate change focus on agriculture, describing the impacts of changing growing seasons, crop cycles, water availability and biosecurity on yields, farm operations and profits.

Social impacts of climate change in New Zealand which are applicable to Canterbury include various health-related impacts, increasing social disruption, changing land values and increasing cost of living.

Cultural impacts of climate change include changes in the functioning of Te Waihora Lake, inundation of wāhi tapu sites and other culturally significant sites, and potential changes to taonga species and mahinga kai practices.

Governance impacts include changing roles and responsibilities, funding stressors, legal liability and legal challenges, managing community expectations about levels of service, compensation demands and livelihood, and adapting planning approaches to consider design-life of land use.

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1 How to use this guide

Climate change presents significant challenges, risks and opportunities to Canterbury. The Council's role is to support the region and its communities to better understand and proactively respond to the challenges, risks and opportunities presented by climate change. This document summarises available literature on climate change impacts for Canterbury.

This document is intended to be used as a guide and initial reference list. While the robustness of the research is considered, it is up to the reader to decide on the applicability of the results to their own work area or project. See sections 2 and 6 for methodology and limitations.

Use this guide to:

- find out how the Canterbury climate could change in the future (Section 3),
- find out how we might transition to a low-emissions economy (Section 4)
- identify potential cascading impacts across environmental, economic, social and cultural domains relevant to your work area (Section 5)

2 Methodology

2.1 Literature search

A two-step methodology was used to undertake this review. The first step involved Environment Canterbury staff who reviewed and filtered the literature based on the following criteria:

- climate change-related risk, impact
- geographic area (Canterbury-specific findings and New Zealand-wide findings which could be extrapolated to Canterbury)
- peer-reviewed and grey literature (CRIs, reports prepared for government departments, academic research)

The results from this first step were then supplemented and cross-referenced by researchers from Manaaki Whenua - Landcare Research (MWLR). The aim of this second step was to identify any additional literature in academic and scientific databases, also drawing on researchers' own knowledge and experience in adaptation and familiarity with the Canterbury region (e.g. Cradock-Henry et al., 2018, 2019a, 2019b; Kirk et al., 2017; Simon et al., 2019) to address knowledge gaps and include additional relevant literature. This second step included reviewing all literature for any statements about certainty/uncertainty and the level of anticipated impact caused by climate change.

The second step used a 'systematic review' process (see Ford et al., 2011). Systematic reviews are increasingly used in climate change research to review and synthesise existing knowledge in a structured fashion (Pearce et al., 2018). A document search was performed in the Scopus database using the following search terms: 'climate change', 'impacts', 'Canterbury', 'New Zealand' in the title, keywords, and abstract fields. A similar search was performed using the Web of Science database as well. Scopus was selected due to its availability as one of the most current, powerful, comprehensive and widely used search engines for peer-reviewed literature. The search did not specify a date range.

To ensure inclusion of grey literature (e.g. research reports, summary and technical reports) a manual search of the Climate Cloud database (www.climatecloud.co.nz) was also undertaken. Finally, the MWLR researchers consulted with colleagues to ensure inclusion of any other additional publications, and to assess completeness of searches.

The various searches retrieved 471 references. Of these, 89 met the criteria outlined in step one above. These 89 references were cross-referenced with the original search results obtained from ECan, resulting in 68 additional original references. Abstracts were reviewed and then each reference was evaluated according to the following criteria and either:

- included in the report if they identified relevant climate change impacts for Canterbury, or New Zealand that could be extrapolated to Canterbury
- excluded if they detailed old/superseded information or summarised information in other sources already included.

All references were reviewed for statements about levels of certainty/uncertainty and the scale of anticipated impacts caused by climate change. Communicating certainty/uncertainty and the scale of anticipated impacts from climate change is difficult because of the complexity of the global climate system, the cascading nature of impacts, and the unknown future responses by human societies (Wilby and Dessai, 2010). Consistent with best practice, MWLR researchers used guidance for Contributing Authors provided by the IPCC Fifth Assessment (AR5, 2013) and Sixth Assessment (AR6, 2021) based on Mastrandrea et al., (2010) to communicate certainty/uncertainty in terms of confidence. High agreement by experts and robust evidence (including type, amount, quality and consistency) would indicate high confidence/certainty. For this report if a reference mentioned certainty/uncertainty we categorised this using three qualifiers – 'high', 'medium' and 'low'. 'High' indicates robust evidence and agreement by experts. 'Medium' indicates some evidence and some agreement by experts. 'Low' indicates little evidence and limited agreement by experts. If a reference mentioned scale we categorised this by 'national', 'regional' and 'local', and then 'major', 'minor' or 'contingent' (meaning it depends on future choices). These categorisations were made based on the statements and evidence provided in each reference.

To ensure the report remains concise MWLR researchers have not provided statements around certainty/uncertainty and scale of impacts for every single reference. Rather, references have been aggregated and general summaries of certainty/uncertainty and scale are provided. Because of the complexity associated with evaluating and communicating certainty/uncertainty and scale, readers are encouraged to review identified references and make their own judgements if further information is required.

2.2 Climate change impacts: Concepts and terminology

Climate change impacts are driven by both the physical change in climate and extreme weather and the socioeconomic processes related to adaptation and mitigation actions. The risk of these impacts occurring is a function of (Fig 2.1):

- **hazards** – a potentially damaging event which may cause loss of life or injury, property damage, social and economic disruption or environmental degradation (MCDEM, 2019)
- **vulnerability** – predisposition to be adversely affected. Includes sensitivity to harm or damage and lack of coping capacity and adaptive capacity (IPCC, 2018)
- **exposure** – presence of people, livelihoods, species, ecosystems, infrastructure, or assets in places that could be adversely affected (IPCC, 2018)

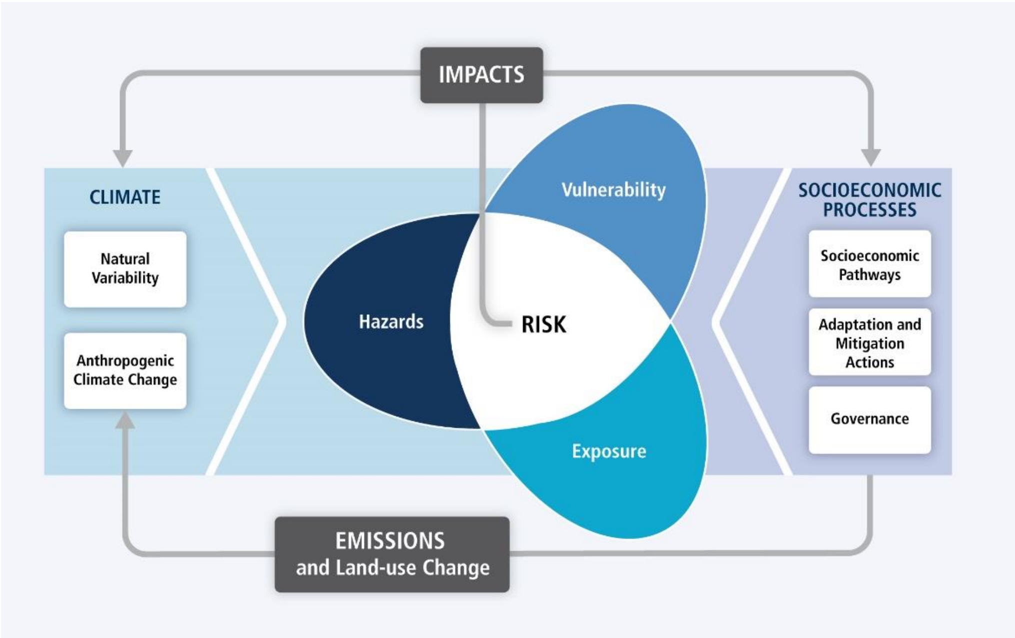

Figure 2.1 Relationship between climate change, impacts and risk (IPCC, 2014).

While it is important to understand the hazards caused by climate change, it is also important to understand the direct and indirect impacts of climate change. These indirect impacts can propagate as cascades across environmental, social, economic, cultural and governance systems (Lawrence, Blackett, Cradock-Henry, & Nistor, 2018; Rocha, Peterson, Bodin, & Levin, 2018). Thus, impacts in this summary are grouped into the four wellbeing's – environmental, economic, social and cultural, drawn from section 3 of the Local Government Act, and governance wellbeing.

Because the terms 'hazard', 'impact' and 'risk' are used inconsistently in the literature we developed a simplified conceptual framework to ensure consistent framing of these terms and to distinguish direct from indirect (cascading) impacts (Fig 2.2). Definitions of the terms used are detailed in Table 2.1.

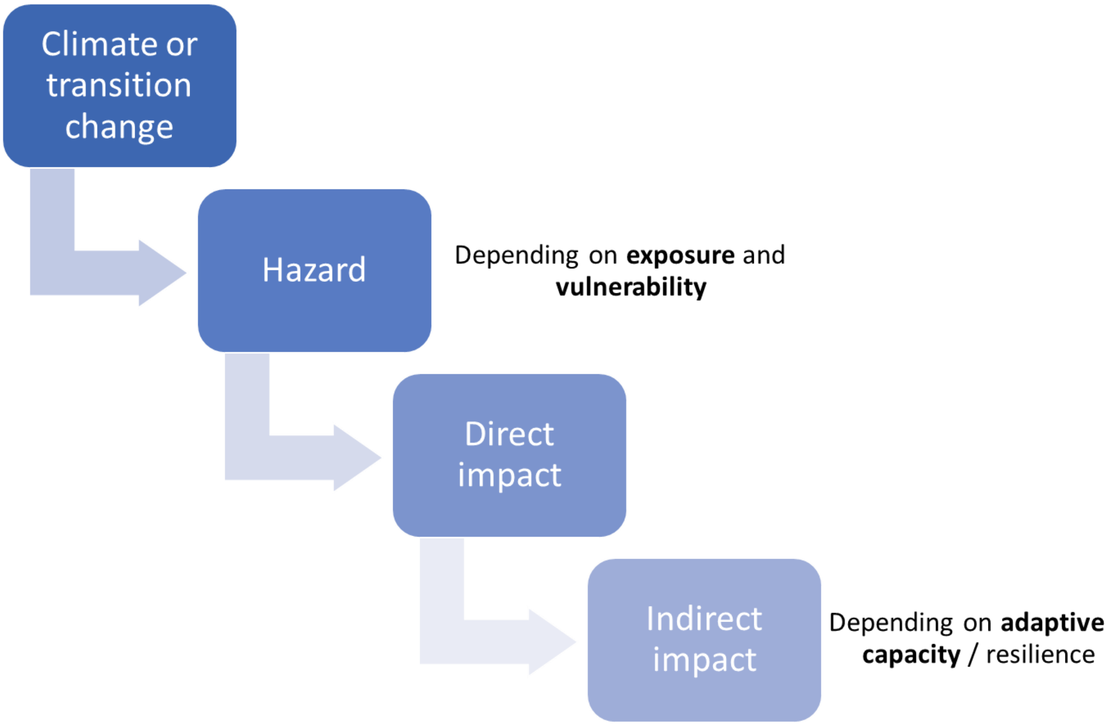

Figure 2.2 Simplified conceptual framework defining the relationships between climate changes, transition changes, direct impacts and indirect impacts (adapted from adapted from Keating et al. (2014)).

Table 2.1 Definitions of terms used in the conceptual framework.

Term	Definition
Climate changes	Changes in climate variable(s) such as temperature or rainfall.
Transition changes	The process of changing from one state or condition to another in a given period of time, in this case transitioning to a low-emissions future (adapted from IPCC (2018)).
Direct impact	The outcome (of an event or transition), expressed qualitatively in terms of the level of impact. Consequences can be measured in terms of economic, social, environmental or other impacts (adapted from MfE, 2008).
Indirect impact	Indirect impacts are the consequences that flow from the direct impacts (adapted from Keating et al. (2014)).
Adaptive capacity/ resilience	The ability of people, institutions, organisations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in the short to medium term (IPCC, 2018).

3 Climate-driven changes

This section sets out a brief overview of well-documented changes expected in Canterbury. The primary sources of regional climate change-related information for Canterbury are Mullan et al (2016), Ministry for the Environment (2018a)[1], Carey-Smith et al. (2018) and Pearce et al. (2017).

Literature relating to Canterbury specific climate-driven changes take the approach whereby climate model data from the IPCC Fifth Assessment (IPCC, 2013) has been used to update climate change scenarios for New Zealand, through both a regional climate model (dynamical) and statistical downscaling process. The dynamical and statistical downscaling processes are described in detail in climate guidance material prepared for the Ministry for the Environment (Ministry for the Environment, 2018a; Mullan et al., 2016).

Climate projections are modelled representations of the future climate for use in exploring the potential impacts and implications of climate change. They are useful for characterising changes in key climatic variables (such as temperature and precipitation), and as inputs to other models (such as biophysical or crop models) to determine implications on productivity or yield. The models typically indicate expected trends in climate variables (e.g. air and sea temperatures, rainfall, sea-level rise) under various emissions scenarios, and the quantum of change over different time periods.

In selecting model parameters it is necessary to consider emissions scenarios known as Representative Concentration Pathways (RCPs). The reports consider the consequences for the future New Zealand climate of four concentration pathways from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment (IPCC, 2013) which range from low- to high. The pathways are abbreviated as RCP2.6, RCP4.5, RP6.0, and RCP8.5, in order of increasing radiative forcing by greenhouse gases.

The Ministry for the Environment website (2018) presents a summary of Canterbury projections based on (Table 3.1). The projected changes are calculated for 2031–2050 (referred to as 2040) and 2081–2100 (2090) compared to the climate of 1986–2005 (1995), across the four RCP scenarios.

NIWA's Our Future Climate New Zealand website (2019) presents national maps and local charts for Christchurch of several climate variables using each RCP scenario.

3.1 Changes to temperature

The magnitude of the temperature change projections for Canterbury varies with the RCP and climate models used.

Future temperature scenarios for 2040 (2031-2050 relative to 1986-2005) show that annual average temperatures across Canterbury are projected to increase by between 0.7°C (RCP 2.6) and 1.0°C (RCP 8.5). By 2090 (2081-2100 relative to 1986-2005) annual average temperatures are projected to increase by between 0.7°C (RCP 2.6) and 2.8°C-3.0°C (RCP 8.5). The greatest warming is projected for summer or autumn (depending on the RCP) and the least warming is projected for spring. A slight acceleration in warming is projected for the second half of the 21st century compared to the first 50 years under the higher emission scenarios. Warming is not spatially consistent across Canterbury – inland high elevation areas tend to warm more than lowland and coastal areas (Pearce et al., 2017).

[1] NOTE: This 2018 "2nd Edition" is the same as an original 2016 report (Mullan et al 2016), except for incorporation of results from a 2018 report on very extreme rainfall – the "HIRDS" report (Carey-Smith et al., 2018)

3.1.1 Hot days

Hot days are defined as reaching temperatures greater than 25°C. Projections of the number of hot days varies across Canterbury depending on the RCP, although overall the number of days increase. Under a lower emission scenario (RCP 2.6) at 2040, the Canterbury Plains and inland areas of Canterbury are projected to experience up to 10-15 more hot days per year. Under RCP 8.5 at 2040, the projection for hot day increases is spatially similar to RCP 2.6, except that inland and higher elevation locations are projected to experience up to 20 more hot days per year than the historical period. By 2090 under RCP 2.6, slightly more hot days per year are projected than in 2040 under the same scenario, with up to 20 more hot days projected for inland areas. However, under RCP 8.5 at 2090 there is a significant increase in the number of hot days projected across much of Canterbury, with most areas projecting an increase of at least 20 more hot days per year (Ministry for the Environment, 2018a; Pearce et al., 2017).

3.1.2 Cold nights

Cold nights are defined as nights where temperatures drop below 0°C. Spatial variations also exist for cold nights (i.e. frost) projections, with small decreases in frost frequency projected around the coast and lowland areas (up to 10 fewer frosts per year for these areas at 2040 under RCP 2.6 and 8.5, and 2090 under RCP 2.6). Under RCP 8.5 at 2090 frost frequency declines by ~20 per year for most coastal areas. For colder inland areas, declining frost frequency is much more marked (Ministry for the Environment, 2018a; Pearce et al., 2017).

3.2 Changes to precipitation

Precipitation projections for Canterbury show more spatial and seasonal variation than the temperature projections and the magnitude of the projected change will scale up or down with the different RCPs and differs between different climate models (Pearce et al. 2017).

The range of variations in rainfall across the range of RCP scenarios and through the seasons, can be seen in Table 3.1. For nuanced regional and seasonal precipitation changes there are detailed regional maps and tables in Ministry for the Environment (2018a) and Pearce et al. (2017).

3.2.1 Snow

The number of snow days per year essentially reduces everywhere in Canterbury with the largest reduction in the coldest areas where there are a large number of snow days under present climatic conditions (Pearce et al., 2017). In the Canterbury high country and inland basins, a reduction in the snow season of 30 days is possible by the end of the century under the high emission (RCP 8.5) scenario.

3.2.2 Extreme Rainfall

Projections for New Zealand (Ministry for the Environment, 2018a) indicate that moderate and extreme rainfall events are likely to increase across the country, including Canterbury. However, Pearce et al. (2017) indicate that there may be a decrease in extreme rainfall events in eastern areas of Canterbury, particularly for coastal south Canterbury.

MfE (2018a) present regional maps of changes in precipitation during high rainfall events per degree of warming. However, they note that Carey-Smith et al (Carey-Smith et al., 2018) found that the large regional variability between climate model simulations does not provide enough confidence in these regional patterns and recommended that until further information suggests otherwise, climate change rainfall augmentation factors should be assumed to be uniform over New Zealand. These national augmentation factors are presented in Table 13 of MfE (2018a) and present estimates in the increase of rainfall for each degree of warming for each event duration and return period.

3.3 Wind

Extreme daily winds are likely to increase by up to 10% by the end of the century in the high RCP8.5 emissions scenario. This will be especially noticeable east of the Southern Alps due to the increased westerly pressure gradient in winter and spring (Pearce et al., 2017). Extreme winds are predicted to be more frequent in winter but will decrease in summer (Mullan et al., 2011).

3.4 Storms

3.4.1 Tropical and ex-tropical cyclones

Canterbury is rarely affected in an adverse way by cyclones of tropical origin. These storms are usually weakened by the time they travel south towards Canterbury, but they can retain characteristics which have the potential to cause flooding, wind damage and higher-than-normal wave heights and coastal storm surges. IPCC (2013) projections for tropical cyclones in the future are that tropical storms making landfall will be stronger but overall, there is significant uncertainty surrounding projections of tropical cyclones into the future (Pearce et al., 2017). The frequency with which ex-tropical cyclones and other storms of tropical origin may reach Canterbury in the future is therefore uncertain.

3.4.2 Extra-tropical/mid latitude storms

There is little regional specific information on mid-latitude low pressure weather systems. IPCC (2013) say that extratropical storm tracks (such as the low-pressure southerly weather systems experienced in Canterbury every few days) will tend to shift poleward by several degrees but the reduction in storm frequency will only be a few per cent. The current consensus is that future changes in storms are likely to be small compared to natural inter-annual variability (IPCC, 2013; Ministry for the Environment, 2017b).

3.5 Mean sea level pressure

Mean sea level pressure (MSLP) is projected to increase in summer, resulting in more north-easterly flow and anticyclonic ("high" pressure) conditions. MSLP is projected to decrease in winter resulting in stronger westerlies (Ministry for the Environment, 2018a; Mullan et al., 2016; Pearce et al., 2017).

3.6 Solar radiation

Solar radiation is predicted to decrease in coastal Canterbury during summer (consistent with increased rainfall) and increase during winter (consistent with decreased rainfall) (Ministry for the Environment, 2018a; Mullan et al., 2016; Pearce et al., 2017).

Table 3.1 A summary of climatic and extreme weather changes for Canterbury across a range of emissions scenarios (MfE, 2018).

Climate

Average annual temperatures increase

- Annually 0.7 - 1˚C by 2040, 0.7 - 3˚C by 2090
- Spring 0.6°C - 2.6°C
- Summer 0.6°C - 3.0°C
- Autumn 0.7°C - 3.0°C
- Winter 0.7°C - 3.3°C

Rainfall will vary within the region and seasonally

Spring

- 0-2% increase in Christchurch
- 1-2% increase in Hanmer
- 6-13% increase in Tekapo

Summer

- 1-8% increase in Christchurch
- 0-9% increase in Hanmer
- 2-5% increase in Tekapo

Autumn

- 0-8% increase in Christchurch
- 0-2% increase in Hanmer
- 2% decrease to 3% increase in Tekapo

Winter

- 12% decrease to 1% increase in Christchurch
- 10% decrease to 1% increase in Hanmer
- 6-28% increase in Tekapo

Snowfall & snowy days will significantly decrease (30 days less per year by 2090)

Duration of snow cover decreases (particularly at lower elevations)

Westerly winds increase (particularly in winter & spring)

NZ sea level rise will be 0.18 - 0.27m by 2040, 0.42 - 0.90m by 2090

Extreme weather

Hot days increase (max temp exceeds 25˚C) by 6-35 extra days per year
Frost days decrease 13-38 less days per year
Extremely windy days increase 2-10% by 2090
Extreme rainfall events increase. (greater than 2-year average recurrence interval)
Drought frequency and severity increases
Extreme wind speed strength increases

3.7 Hydrological Changes

Several hydrological reports have been prepared for the Ministry for Primary Industry (MPI) and Ministry for the Environment on hydrological modelling of multi-model climate forecasts for agricultural applications, and the effect of climate change on agricultural water resources and flooding (Collins & Zammit, 2016a, 2016b). Although these reports have a national focus some regional analyses are provided, including for Canterbury. The Canterbury specific analyses in Collins and Zammit (2016a, 2016b), have been summarised by Pearce et al., (2017).

Collins et al. (Collins & Zammit, 2016b) present an analysis of potential effects of climate change on hydrological conditions at 20 river mouths around New Zealand. The Rakaia River is the only Canterbury river included in this study and was shown to exhibit an increase in all mean flow and extreme flow variables under climate change scenarios. Collins et al. (2012) outline projected changes in river flows for Ashley River, Waimakariri River and Heathcote Stream in Canterbury, noting an increase in variability for all three streams due to climate change.

3.7.1 River Flooding

Pearce et al. (Pearce et al., 2017) present a brief synopsis of changes to mean annual flood (MAF) and Q5 discharge (flow threshold exceeded 5% of the time). MAF is projected to either increase or remain about the same across the Canterbury region. There is a tendency for increases to be larger for more extreme emission scenarios, particularly under RCP 8.5 which sees widespread and substantial increases in MAF (Pearce et al., 2017).

Canterbury tends to exhibit a west-east pattern in change in Q5 discharge, with slight increases towards the very west, decreases across much of inland Canterbury from north to south as well as Banks Peninsula, and increases along much but not all of coastal and near-coastal Canterbury. Where there are increases, they tend to be larger with the higher emission scenario; the same trend is not apparent for the decreases (Pearce et al., 2017).

3.7.2 Mean Discharge

Models show variability in mean discharge throughout Canterbury depending on the time period and emission scenario. Southern coastal Canterbury tends to become wetter, particularly for the higher emission scenario and late-century, and inland Canterbury often becomes drier, but otherwise there is no pronounced pattern in the changes (Pearce et al., 2017).

3.7.3 Mean Annual Low Flow (MALF)

Canterbury exhibits a mix of increases and decreases in MALF under climate change. The increases tend to be isolated to southern Canterbury and inland portions of mid-Canterbury, although these decline in extent late-century (Pearce et al., 2017).

3.7.4 Low Flow Timing

Low flow conditions tend to be reached sooner after winter across Canterbury except for high alpine areas in the west and areas across Canterbury Plains and Banks Peninsula. Changes in the major alps-fed rivers tend to reflect changes in their source areas, which can differ from the surrounding rivers across the Plains. The Rangitata, for example, reaches low flow conditions later while the Waimakariri reaches them earlier. There is no strong dependency on emission scenarios or time period (Pearce et al., 2017).

3.8 Erosion

Hill country erosion is a significant issue for higher-elevation parts of Canterbury, particularly those areas used for primary industries such as agriculture, horticulture and forestry. Hill country erosion has downstream effects including river sedimentation which can affect water quality and aquatic habitats (Pearce et al., 2017). Climate and erosion are linked through water movement into and through the soil. Projected increases in extreme rainfalls in some areas of Canterbury will play a critical role in determining the effect of climate change on erosion processes. Hillslope erosion processes (e.g. shallow landslides, earthflows, gully, and sheet erosion) are likely to be influenced by climate change (Pearce et al., 2017).

Basher et al. (2012) studied the effect of climate change on erosion, using projections from the IPCC's Fourth Assessment Report. They found that mountain and hill country areas of Canterbury, including parts of Banks Peninsula are most susceptible to increased landslides, gully erosion and sheet erosion.

Areas most susceptible to wind erosion are the Canterbury alluvial plains, loess-mantled areas of Canterbury where vegetation has been depleted by grazing, hill country with shallow soils and areas that have low soil moistures (Pearce et al., 2017).

A related issue to erosion is greater risk of rock avalanches and landslides as a result of melting ice retreat from glaciers. However, to date research has not been able to distinguish the effect of ice retreat from climate change and other influences such as tectonic shifts or general erosion (Allen et al., 2011).

3.9 Drought

An increase in climatic drought frequency is projected for Canterbury (Pearce et al., 2017). Drought risk is expected to increase during this century in all areas that are currently drought prone. For the Canterbury Plains, even very mild future climate changes are expected to shift this area towards a more drought prone setting.

Under the most likely mid-range emissions scenario the projected increase in percentage of time spent in drought for Canterbury from 1980-99 levels is about 7-10% for 2030-2050 and 10% for 2070-2090 (Pearce et al., 2017).

3.10 Sea level rise

The most recent national information and guidance on sea level rise (Ministry for the Environment, 2017a) takes global forecasts (IPCC, 2014) and applies them to the New Zealand national context. There is a close comparison between global and New Zealand average historic rates of sea level rise which means that projections of future sea-level rise by the IPCC which are generated as global means, can generally be adopted for overall use in New Zealand.

Small local adjustments for significant local vertical land movement may be needed (Ministry for the Environment, 2017a). For example, historic sea level data from Lyttelton shows that historic sea level rise over the past 100 years is 2.12mm/yr compared to the NZ long-term average across 10 tide gauge sites of 1.76mm/yr. The difference is relatively small and in the absence of any more nuanced regional information, any national guidance can be applied to the Canterbury context.

According to the IPCC Fifth Assessment Report (IPCC, 2013), global sea-level rise will likely be in the range 0.28-0.98 m by 2100 (lower bound for RCP 2.6, upper bound for RCP 8.5). However, onset of the collapse of the polar ice sheets could cause global mean sea level to rise substantially above the likely range during this century. Recent observations reveal a rapid thinning of glacier regions in Antarctica, which can be attributed partly to warming oceans. These findings have raised concerns of an accelerated ice loss of the West Antarctic ice sheet and potential contributions to global sea level rise. Ice loss can occur in the form of melt-induced (liquid) freshwater discharge into the ocean, or through (solid) iceberg calving (Schloesser et al., 2019).

MfE (2017a) guidance has been developed on the principle that no one particular or ‘most likely’ climate future can be determined, due to uncertainty around future global emissions pathway and the emergence of polar ice sheet instabilities. Therefore, the guidance states that planning for coastal areas needs to consider several scenarios to cover the range of possible futures.

Four scenarios have been developed for New Zealand to cover a range of possible sea-level futures (Ministry for the Environment, 2017a):

1. a low to eventual net-zero emission scenario (RCP2.6)
2. an intermediate-low scenario based on the RCP4.5 median projections
3. a scenario with continuing high emissions, based on the RCP8.5 median projections
4. a higher H+ scenario, considering possible instabilities in polar ice sheets, based on the RCP8.5 (83rd percentile) projections from research carried out after the release of the IPCC 5th assessment report.

The MfE (2017a) guidance presents useful summary tables of decadal increments for projections of sea-level rise for New Zealand (MfE (2017a), Table 10) and bracketed timeframes to reach a specific increment of sea-level rise, from the earliest to latest time across the RCP2.6, RCP4.5, RCP8.5 and H+ scenarios (MfE (2017a), Table 11).

3.11 Oceanic Changes

Literature around oceanic changes under climate change is more general than region-specific. Law et al., (2016) presents climate change impacts and implications for New Zealand’s Exclusive Economic Zone with detail regarding likely changes to New Zealand’s marine environment to 2100, including forecast changes to ocean acidification, sea surface temperatures and changes to nutrients and the impact on fisheries (see also Office of the Chief Science Advisor, 2013).

3.12 Certainty and uncertainty

The majority of research cited in Section 3 draws on the most up to date IPCC global climate models and RCPs. All the references acknowledge climatic and non-climatic variables, where relevant, that may affect the certainty of projections and impacts. For example, the Ministry for the Environment (2017b) notes projections are inherently uncertain due to model uncertainty, New Zealand’s maritime climate and non-climatic socio-economic changes which will influence emissions pathways, such as changing commodity prices. To manage uncertainty the global climate models and RCPs build in different possibilities to predict a range of plausible future scenarios. While they incorporate uncertainties, they represent the highest source of robust data to date with general international agreement. When downscaling these projections to regional and local contexts, further uncertainties are introduced. For example, the Allen et al. (2011) and Basher et al. (2011) both acknowledge difficulties projecting landslide changes under climate change due to uncertainty on how increased rainfall could affect erosion, thus we classify their research findings as having 'medium' certainty. Carey-Smith et al. (2018) used resampling methods to estimate uncertainty in their rainfall models. Given this, we also classify this research as having 'medium' certainty. Mullan et al. (2016) used the 'Linked empirical Modelled and Observed Distribution (LeMOD)' correction method for bias correction on their regional climate model. This method helps reduce uncertainties in model projections and given this we classify the model projections as having 'medium' certainty. Despite these categorisations, to date this research represents the most robust data sources on the direct impacts of climate change.

For further discussion and insight into uncertainty and climate change impacts and implications for New Zealand, the reader is referred to Flood and Lawrence (2016).

4 Transition-driven change

Nationally and internationally there is a push to transition to a low-emissions future. Under the Paris Agreement (ratified in 2016) NZ has committed to having an emissions reduction target, contributing to the global effort to keep the global average temperature below 2°C above pre-industrial levels. This has driven the development of the Zero Carbon Bill, now the Climate Change Response Amendment Bill. The Bill sets targets for NZ for greenhouse gas emissions reductions by 2050.

Transitioning to a low-emissions future will require changes to the economy and society. The NZ government has committed to making the process a 'just transition' to a low-emissions future – one that is fair, equitable and inclusive. The NZ Productivity Commission (2018) identified the following drivers to achieve this change:

- Emissions pricing – this may include changes to structure and coverage of the Emissions Trading Scheme
- Laws and institutions – including new climate policy
- Regulations and policies – including pricing mechanisms, e.g. rebates to encourage uptake of electric vehicles, increasing waste disposal levy
- Innovation and investment – including increasing R&D funding for mitigation.

These drivers may cause changes to land-use, transport, electricity, waste and the built environment (New Zealand Productivity Commission, 2018).

Land-use change may be driven by transition changes, including the emissions price (New Zealand Productivity Commission, 2018) and societal preferences and worldviews changing demand for agricultural goods and services (Rutledge et al., 2011). Key interdependencies of land-use change include future population increase, technological development, skills shortages, risk aversion, need for new supply chains and infrastructure. Land-use change in Canterbury could manifest in the following ways:

  - Forestry – predicted to significantly increase in Canterbury as modelled in a case study of the Hurunui. Conversion from sheep and beef and scrubland (Parliamentary Commissioner for the Environment, 2019)

- Bioenergy production - increasing demand for potential bioenergy sources, such as plantation forestry, perennial grasses, canola, maize and sugar beet, could drive conversion of unmanaged lands, some existing forestry land, and marginal, hill country pasture (Rutledge et al., 2011)
- Crop production – increasing demand for more localised food production could displace pastoral production by crops on remaining suitable soils near urban areas that remain available for production (Rutledge et al., 2011)
- Horticulture – increasing overseas demand in short term could trigger increase, most likely via transfers from pastoral uses in areas with existing infrastructure to support expansion (Rutledge et al., 2011)
- Sheep & beef production – competition for land from bioenergy, horticulture, and forestry may cause sheep & beef to decline over long term (Parliamentary Commissioner for the Environment, 2019; Rutledge et al., 2011)
- Dairy – decrease predicted, likely conversion to horticulture (Parliamentary Commissioner for the Environment, 2019).

In terms of **urban** land use, the Productivity Commission (2019) notes that there is not a strong case to use urban planning policies to reduce emissions. This is because advances in low-emissions transport options may occur more quickly than the significant increase in density needed from urban planning policies.

In the **transport** sector a shift to electric vehicles is seen as the most significant opportunity to reduce emissions. However, a shift to public transport, cycling and walking will also reduce emissions while having health co-benefits (New Zealand Productivity Commission, 2018). There are also opportunities to use biofuels for aviation, shipping and heavy vehicles.

There may be increasing costs of **electricity** production and reduced security of supply with a push to increase renewable energy sources (New Zealand Productivity Commission, 2018). New technological options are expected over time, such as tidal, carbon capture and storage, which have their own co-benefits and trade-offs.

Reducing emissions from solid **waste** may be achieved through various policy drivers. These include extending the waste disposal levy and regulating farm dumps through the RMA and Waste Management Act (New Zealand Productivity Commission, 2018).

The references that outline potential impacts of transition driven change in Section 4 do not use statistical probabilities of certainty such as those used in assessments of direct impacts projected by global climate models. Rather, they tend to use behavioural, economic and optimisation modelling to identify strategies (including regulatory, incentives, behaviour change etc.) to achieve specified outcomes. Consequently assigning ‘certainty’ to transitional activities is difficult as they are contingent on future social, cultural, political and economic decisions. Nevertheless, these references identify and summarise key issues using robust scientific, economic and social science knowledge to evaluate the benefits and costs of different decisions. Therefore they are useful for evaluating different decisions related to climate change.

5 Cascading impacts

5.1 Environmental

This section details how climate change may affect both the natural (land, water, biological and ecological) and built environment. The focus is primarily on the cascading indirect effects of climate change. For biological effects on species used in the agriculture sector, see Economic impacts section.

5.1.1 Land

Land damage around NZ will include long-lasting salt damage to flooded pastures from seawater inundation (Ministry of Civil Defence and Emergency Management, 2010), siltation of pasture and crop land and deposition of gravel, rock and remnants of vegetation (Basher et al., 2012) as flood management and protection measures are overtopped (Bell, 2001). Soil loss could increase due to coastal and river erosion and increased landslides, mudslides and general erosion (Basher et al., 2012). Quilter et al. (2015) note that sea-level rise may lead to more saturated soils beneath the water table, thereby increasing susceptibility to liquefaction during an earthquake. Coastal margins in Christchurch may be more vulnerable to liquefaction risk due to the combined effects of sea-level rise and ground motion due to earthquakes.

Land loss in Canterbury due to sea level rise includes the following Department of Conservation ecosystem management units:

- Brooklands
- Horseshoe Lagoon
- Opihi River mouth
- Te Waihora
- Wainono (Tait, 2019).

5.1.2 Water (freshwater, estuarine, marine)

Water supply will be directly affected by climate change via decreasing rainfall and indirectly via decreasing groundwater recharge and drainage from irrigated and un-irrigated land (Bright et al., 2011). Where surface water is used for irrigation it substantially mitigates the effects of climate change on groundwater recharge. The lack of a sufficiently reliable source of surface water for irrigation will limit the size of both the groundwater supplied irrigation area and the surface water supplied area, to a total area well short of the potentially irrigable area on the Canterbury Plains (Bright et al., 2011).

Water quality will be affected by changes in climate and extreme weather both directly and indirectly. Changes in river flow and water temperature are expected to cause declining water quality in receiving water bodies (Collins et al., 2012) due to stratification limiting the mixing of oxygen and nutrients through the water column (McGlone & Walker, 2011). For example, Trolle et al. (2011) found that increasing air temperature, especially in summer would lead to eutrophication in Lake Ellsemere. Bores near the coast will have an increased risk of saltwater intrusion (Kouvelis et al., 2010). Areas with increased frequency and durations of very low river/stream flows may contribute to increased variability of dissolved oxygen and pH regimes (Kouvelis et al., 2010). This will cause negative impacts on instream ecology which could be compounded by increased temperatures leading to a higher risk of nuisance algae blooms, pest fish or other unwanted organisms (Kouvelis et al., 2010).

Lake levels of Te Waihora could decrease, leading to reduced frequency and duration of lake openings (Renwick et al., 2010). It is assumed that the beach barrier height above mean level of the sea will rise as sea level rises. Projected rising sea levels suggest that the threshold rules for lake opening will need to be re-assessed in future (Renwick et al., 2010).

Coastal water quality in terms of nutrient levels could be reduced due to a reduction in vertical mixing/upwelling, coupled with increased freshwater from melting glaciers and increased precipitation (Office of the Chief Science Advisor, 2013).

The references outlined in sections 5.1.1 and 5.2.2 generally draw on IPCC climate scenarios which are then downscaled for New Zealand. They therefore use what is considered 'high' certainty data to inform the projected impacts. The scale of the impacts is difficult to categorise though, as these will often depend on future human choices. For instance, future nutrient concentrations in river outflows and whether increased freshwater will actually reach the coast is partly contingent on how much water will be used for irrigation due to increasing frequency of drought. Similarly, the transition to a low-emissions future and the subsequent land use conversion to forestry could result in decreasing water flows, changing river flow regimes and increasing water quality due to decreasing sediment loading and nutrient leaching (Parliamentary Commissioner for the Environment, 2019).

5.1.3 Biological

Environmental change may cause sub-optimal health in some coastal and freshwater species. For example:

- changes in sediment movement and coastal upwelling of cooler nutrient-rich ocean waters could have an impact on phytoplankton productivity (Bell, Hume, & Hicks, 2001)
- ocean acidification could weaken shells of marine organisms and affect the auto-regulatory systems such as absorption of oxygen and salt balance (Willis et al., 2007)
- salmon and trout are sensitive to effects on dissolved oxygen and nitrate concentrations (Collins et al., 2012)
- sea-level rise could increase water levels in wetlands thereby decreasing light levels and negatively effecting vegetation (Willis et al., 2007)
- increased sediment loads to estuaries could impact ecosystems (Bell et al., 2001)
- lake stratification causing crowding in the lower layers, where there is less oxygen, resulting in increased competition for food, and greater susceptibility to disease transmission (McGlone & Walker, 2011)
- weather extremes (drought and flooding) may cause changes in population profiles for threatened native species, such as the Kowaro (Canterbury mudfish) (Meijer et al., 2019).

A key interdependency for coastal species is the influence of freshwater inflows to the coastal ecosystem, and for freshwater species, is changes in ingress of seawater (Bell et al., 2001).

Other biological impacts of climate change include altering pollinator foraging periods and behaviour (Howlett, Butler, Nelson, & Donovan, 2013).

Impacts to physiological functioning of organisms will drive changes in **species' distributions**. For example, terrestrial species' distributions would move further south, and higher into the mountains to remain within the same general temperature ranges. Tree species with a wide tolerance to climate fluctuations, good dispersal capacity, and short generation times could widen their distribution (Mcfadgen, 2001). However, species populations could also be threatened where there is little potential for dispersal of suitable species e.g. where sites are geographically isolated from a native seed source (Mcfadgen, 2001).

Changes in **pest and disease species** will have flow-on impacts on predator-prey interactions and biodiversity. For example, an increase in climate suitability (increasing temperatures, decreasing frosts) could cause increases in:

- Mediterranean fruit fly, particularly in South Canterbury (Kean et al., 2015)
- Pine processionary moth (*Thaumetopoea pityocampa*) (Watt et al., 2011)
- invasive sub-tropical grass species, particularly on dry, northern slopes in North Canterbury (Ministry of Agriculture and Forestry, 2010a)
- banana passionfruit (Ministry of Agriculture and Forestry, 2010a)
- Argentine ants (Ministry of Agriculture and Forestry, 2010a)
- fungal diseases affecting *P. radiata* in New Zealand such as *Dothistroma* needle blight and *Cyclaneusma* needle cast (Watt et al., 2012)
- parasitic diseases like *fasciola hepatica* affecting sheep, which are predicted to rise by 186% in Canterbury by 2090 (Haydock et al., 2016).

5.1.4 Ecological

Biological and ecological climate-induced impacts are likely to cause numerous complex changes throughout food webs (Office of the Chief Science Advisor, 2013). Coastal areas where freshwater inflows influence the structure or functioning of the coastal ecosystem could be affected, including significant species and fisheries in these areas (Bell et al., 2001).

Positive impacts on ecosystems could be driven by adaptation planning and an increasing focus on ecosystem-based management, valuation and measurement of ecosystem services and ecosystem-based adaptation measures (Rutledge et al., 2011). For example:

- enhancing coastal foredunes which provide natural and cost-effective protection from coastal erosion, flooding and sea level rise, while maintaining and enhancing the natural, cultural and amenity values of our beaches (Dahm, Jenks, & Bergin, 2005)
- using native species and habitats in positive ways to build resilience into rural landscapes (Green, 2014)
- Creating riparian zones using native plants along waterways to reduce nutrient runoff, reduced in-stream temperatures for native invertebrates, build resilience to flooding (Green, 2014)
- Restoring wetlands on farmlands to regulate waterflows in times of flood or retaining it during droughts (Green, 2014).

Provisioning ecosystem services e.g. food, raw materials, and energy are included in the Economic impacts section.

There are typically 'high' levels of certainty for the references cited in Sections 5.1.3 and 5.1.4, which describe likely interactions and impacts of one-two variables (for example, temperature increase and pest spread). The level of certainty around impact decreases where two or more interacting variables are taken into account, especially when modelling future changes. For example, changing biosecurity practices may reduce the impact of new climate pests, or the transition to a low-emissions future and increasing conversion to forestry may cause an increase in weeds such as wilding pines, but lead to increased freshwater quality and native habitat (Parliamentary Commissioner for the Environment, 2019). Results should be interpreted accordingly.

5.1.5 Built

Coastal defences, such as coastal barriers (gravel or dune systems) or seawalls, could be damaged or breached with ponding of seawater which can be exacerbated by backwater effects or closure of stormwater flap gates from high storm-tide levels (Ministry of Civil Defence and Emergency Management, 2010).

Buildings could be damaged by river flooding, coastal inundation and salt damage (Ministry of Civil Defence and Emergency Management, 2010). For example, flooding of the Avon River in Christchurch (Harris Consulting & Christchurch City Council, 2003) and Gleniti in Timaru (Opus International Consultants Ltd & Timaru District Council, 2003). In Canterbury, $570m of Council buildings and facilities are exposed to 3m of sea level rise (LGNZ, 2019).

Transport infrastructure (road, rail, ports) will be affected. For example, in Banks Peninsula erosion and/or failure of the coastal protection structures will have an impact on the transport corridor as there is little opportunity for re-location of coastal road networks (Todd, Jupp, & de Vries, 2008). Stronger winds will have an impact on roads and ports in eastern coastal areas of the North and South Islands, and on the Canterbury Plains in the lee of the Southern Alps (Gardiner et al., 2008). Rail infrastructure could be affected by heat stress (Gardiner et al., 2009). In Canterbury, 664km of roading infrastructure is exposed to 3m of sea level rise (LGNZ, 2019).

Water supply infrastructure in terms of pipes and storage schemes will be affected by changes in climate and extreme weather, increased erosion and soil runoff, and changes in pH. It is estimated this will lead to higher maintenance costs and effects on pipeline stability for scheme infrastructure due to clogging of screens and increased corrosion (Kouvelis et al., 2010). Mechanical devices, such as pumps, gates and valves, may be affected by changes in sediment-induced damage or changes in the frequency of use, leading to altered lifespans and increased operation and maintenance costs (Bell, 2001). Increased sediment and nutrient inputs to storages may also increase the risk of nuisance algae blooms or weeds (Kouvelis et al., 2010). While these impacts are predicted for both pipe and canal storage schemes, the costs are expected to be higher for canal based schemes as they are more exposed (Collins et al., 2012).

Stormwater and wastewater infrastructure will be affected by changes in sea level rise, drought and extreme rainfall. In Canterbury, $630m of Council water infrastructure is exposed to 1m of sea level rise (LGNZ, 2019).

Sea level rise will:

- prevent wastewater and stormwater discharging into tidal areas
- increase groundwater infiltration into wastewater pipes reducing the overall capacity, resulting in sewerage overflows
- increase saltwater intrusion, corroding pipes and machinery and disrupting the biological processes in wastewater treatment ponds
- inundate low lying wastewater treatment plants with sea water during storm surges (White et al., 2017).

Extreme rainfall will:

- overwhelm both wastewater and stormwater systems and may restrict maintenance access routes (e.g. manhole covers and tunnels) needed to restore service (White et al., 2017).

Drought will:

- disrupt gravity-fed wastewater systems by slowing overall flow and allowing solids to accumulate at pipe joints, leading to blocked pipes and subsequent breaches
- raise concentrations of ammonia and other contaminants such as hydrogen sulphide to the point where they interfere with biological treatment processes, creating safety issues for maintenance crews (White et al., 2017).

Failure of stormwater systems can have cascading impacts on other systems (Lawrence et al., 2018). For example, flooding of major sections of transport infrastructure can result in significant disruptions to social and economic activity. In extreme cases, flooding may also cut off evacuation routes (White et al., 2017). While there is limited research into the economic effects of flooding in New Zealand due to a lack of data, NZEIR (2004) note that climate change will increase the likelihood of flood costs for both public and privately owned assets.

Wastewater failures can have significant economic impacts in locations where commercial activity is directly dependent on healthy waterways and beaches, particularly if extreme weather events coincide with peak demand or key tourism seasons/events (White et al., 2017).

Public amenities can be damaged, such as shoreline structures and facilities in low-lying coastal areas particularly around the Avon-Heathcote Estuary and Brookland Lagoon areas (Ministry of Civil Defence and Emergency Management, 2010).

The references used to inform the findings in Section 5.1.5 provide broad economic estimates or summaries of impacts on key built infrastructure. Economic estimates are generally based on current IPCC projections for New Zealand and in some cases downscaled national- and regional- climate model outputs. Models project possible impacts of climate change for built infrastructure. A range of uncertainties are acknowledged in the findings due to incomplete and missing input data used to parameterise models (e.g. historic costs of flooding, the age and condition of wastewater, stormwater and water infrastructure in different regions). Missing information makes detailed economic modelling and quantifying certainty likely effects more difficult. Hence, the references generally suggest consideration of these issues in current and future planning and decision making, rather than predicting detailed costs of impacts of climate change in specific regions.

5.2 Economic

This section details operational and economic impacts across various industry sectors, including investment, supply chains and Māori business. For sector-specific land use changes see the 'Changes caused by transition to a low emissions future' section.

A transition to a low emissions economy could result in a renewed focus on local production, local economy and local jobs (Christchurch City Council, 2010), thereby altering **supply chains**. However, there is a gap in literature on the flow-on impacts through supply chains from climate change.

Greater **investment** in, and access to, "green" solutions and technologies are expected to decrease emissions and increase the productivity of various sectors (Christchurch City

Council, 2010)(New Zealand Productivity Commission, 2018)(Ministry for the Environment, 2018c). In particular, the Low Emissions Accelerator Fund (LEAF) may de-risk climate-aligned investment for private investors (Hall & Lindsay, 2018). However, much of this work is speculative and depends on the specific arrangement and uptake of incentives and decisions made going forward.

5.2.1 Agriculture

The impacts of climate change on agriculture have been extensively studied, primarily driven by the Ministry for Primary Industries. Impacts on dairy, horticulture, grains, and sheep and beef sectors are detailed below.

While many negative impacts have been identified (see below), some studies suggest that farmers and farm systems are resilient to negative climate change impacts. In one study, a cross-section of farms surveyed were found to be financially resilient to disruptions through low debt levels (Greig, Nuthall, & Old, 2017). While not specifically related to climate change and the associated interdependencies, the results suggest these farmers may be relatively resilient to future financial shocks resulting from climate change (Greig et al., 2017).

Across agriculture generally the efficiency of irrigation schemes is likely to decline as rates of evaporation increase. More water would need to be abstracted to compensate for the losses during the storage and delivery of water to crops (Collins et al., 2012).

Technological innovation such as biogas systems which capture methane by collecting and managing animal waste may require changes in farm management to maximize waste collection (Stewart & Trangmar, 2008).

Domestically, continued expansion of livestock production (respecting environmental limits) is predicted to drive an increase in the demand for forage and feed grain. Higher grain prices in the global market intensify competition between grain and forage/feed production. This, together with higher prices of imported alternatives, will increase prices for all crop types (E Teixeira & Brown, 2012).

Dairy

Operating profit of dairy farms could be affected by decreases in milk solid production driven by decreases in mean pasture production (Lee et al., 2012; Renwick et al., 2012). This may require the introduction of new pasture species (Lee et al., 2012). In addition, competitiveness issues could have an impact on this trade-exposed emissions-intensive industry (Ministry for the Environment, 2018c). However, existing approaches such as improved **farm practices** and land use changes, including reduced livestock numbers, could reduce both nutrient loss and greenhouse gas emissions by a meaningful amount without necessarily affecting profitability (Ministry for the Environment, 2018b).

Horticulture

Yields of many vegetable crops around the country will probably increase due to an extended **growing season** and increased biomass through carbon fertilisation via increased concentrations of carbon dioxide (CO_2) in the atmosphere (Clothier, Hall, & Green, 2012). Similarly, grape yields, vine canopies and grape flavour and aroma will be affected by warmer temperatures and CO_2 fertilisation (Ministry of Agriculture and Forestry, 2010b). Grape cultivars could be affected by changing climate with the suitable growing area for sauvignon blanc shifting southwards from Marlborough to central and north Canterbury (Ministry of Agriculture and Forestry, 2010b).

A shortened **crop cycle** due to high temperatures offsets the potential benefits from CO_2 fertilisation and reduced cold stress. Potato yield will decrease due to a shortened crop cycle (EI Teixeira et al., 2012). Because Canterbury is the largest potato-producing area there will be flow-on impacts for French-fry production as the majority of potato crops are used for this (EI Teixeira et al., 2012). However, there is an opportunity for growing 'break' crops such as forages between main crops (EI Teixeira et al., 2012).

Water availability due to decreases in rainfall patterns, and increased plant water use due to higher temperatures, could affect vegetable yield despite an extended growing season mentioned above. The availability of irrigation water will be critical in determining the ongoing viability for crops within particular regions, and on certain soils within particular regions (Clothier et al., 2012).

Water logged soils due to increased storm frequency are likely to increase problems with waterlogging, flooding, and soil erosion. Waterlogged soils can significantly delay crop planting in spring, reduce plant strike following planting, or cause considerable crop damage later in the season, in some years in some regions (Clothier et al., 2012).

Pest and disease incidence could increase throughout New Zealand, either through increased survival of pest insects during winter, or through decreased insect generation times during the growing season (Gerard et al., 2010). However, in eastern regions, decreased rainfall and humidity may reduce certain fungal disease pressures (Clothier et al., 2012). Examples of pests and diseases that could increase include:

- Grapevine downy mildew (Beresford & McKay, 2012)
- Grapevine leafroll virus, which is carried by mealybugs (Ministry of Agriculture and Forestry, 2010b)
- Secondary pests such as the Argentine ant that feeds on honeydew-producing insects such as mealybug, scale insect, leaf hopper and aphid (Ministry of Agriculture and Forestry, 2010b)
- Late season botrytis on grapes (Ministry of Agriculture and Forestry, 2010b).

Biocontrol is a key component in integrated pest management programmes in some of New Zealand's largest export crops, such as pip fruit. Biocontrol, the use of 'natural enemies' to control pests through predation, parasitism, herbivory etc, reduces the need to use pesticides and provides cheap, long-term, self-sustaining control of pests. Some cropping systems may have to move southward, i.e. to Canterbury or out of Canterbury, and the biocontrol systems will be able to move with them with little change in composition and impact (Gerard et al., 2010).

Evidence also suggests that as winters become warmer, vertebrate pest control will become more difficult. There are two reasons: i) warmer winters will affect the seasonal availability of natural foods which will affect bait acceptance; and ii) the efficacy of some toxins is temperature dependent and enhanced by colder conditions (Latham et al. 2015). Thus, efforts to control pests such as rabbits and brushtail possums will be affected by warmer winters.

Arable farming (including grains)

Wheat and barley **yield** could increase, when water and soil nutrients are not limiting. Interdependencies include improvement in irrigation availability and its efficiency; development and/or use of new species/varieties to match the changed environment; and adjusting sowing dates, timing of fertiliser applications and pest control management (El Teixeira et al., 2012).

Gross margins on the crops indicated that there is potential to make more money from tropical and late-maturing maize hybrids sown early in the spring, in combination with a winter forage. Assuming that maize silage remains the most profitable forage, then higher income per hectare can be expected (Trolove et al., 2008).

Due to increased wet periods, some harvested crops may require drying facilities and additional machinery. Different types of machinery (such as tractors or tyres) may also be required to manage water logged soils and reduce compaction (Ministry of Agriculture and Fisheries, 2010).

Pasture

Significant changes in **seasonality** of pasture growth are projected, generally with increases in winter (temperature rise) and decreases in summer (reduced soil moisture) (Renwick et al., 2012). Pasture **yield** will generally increase through higher carbon dioxide levels in the atmosphere and an extended growing season. This will also however increase weeds and pasture management costs (Newton et al., 2011). A key interdependency however, is higher fertiliser inputs and availability of water for irrigation, particularly in Canterbury, where there will be increased drought risk (Kenny, 2001). Increasing drought may have an impact on pasture quality leading to changes in pasture **composition** (Renwick et al., 2012).

Sheep & beef

The increase in droughts will negatively affect sheep and beef **production** due to, for example, heat stress and drought (Renwick et al., 2012; Stroombergen et al., 2008). Heat stress and temperature changes may also affect animal health through increased diseases like facial eczema, and internal parasites (Ministry of Agriculture and Fisheries, 2010). Droughts will also have an impact on **farm operations** due to the need for supplementary feed, extra labour, discounted prices when selling stock (Kenny, 2005).

The references outlined in Section 5.2.1 summarise key climate impacts, generally using IPCC and downscaled climate modelling to predict potential effects on significant aspects of agricultural systems. In some instances, climate data is used as an input into other biophysical models (e.g. APSIM). While the models are considered robust, when climate data is applied to complex ecosystems and social systems, certainty around the likelihood and scale of impact is reduced. In dealing with this complexity, Rutledge et al. (2017) provide a useful assessment of potential climate effects on the sheep and beef sector and wider community and ecosystems in the Upper Waitaki Catchment. They describe a range of interacting biophysical, social and economic factors that will affect sheep and beef production in the Canterbury high-country over the remainder of the century.

5.2.2 Transport

Climate-induced extreme weather, damaging transport infrastructure could cause increasing disruption to operations (Climate Change Adaptation Technical Working Group, 2017).The transition from fossil fuels to electricity and other low-emissions fuels across the economy could mean a rapid and comprehensive switch of the light vehicle fleet to electric vehicles (EVs) and other very low-emissions vehicles if New Zealand intends to meet the targets of the Climate Change Response (Zero Carbon) Amendment Bill 2019 by 2050 (New Zealand Productivity Commission, 2018).

5.2.3 Forestry

Changes in temperature and rainfall could have both positive and negative effects on *Pinus radiata* **productivity**. For instance, when the enhanced fertilisation effect of increased atmospheric CO_2 is accounted for, productivity is projected to increase 30 to 40% on average (Renwick et al., 2012). Kanuka/manuka productivity will also increase (Watt et al., 2012). However, expected losses in soil carbon, mainly due to the increase in temperature, which is expected to stimulate organic matter decomposition may lower productivity (Kirschbaum et al., 2010). Increased **damage** to forestry stocks could also adversely affect productivity due to increased fire (Watt et al., 2012), insects, new diseases and weeds (Dunningham, Kirschbaum, Payn, & Meason, 2012). For example, Pearce et al. (2011) predict fire risks to increase across New Zealand, with some regional variability due to increased drought, longer fires seasons, drier and windier conditions and greater difficulty suppressing fires once they start. Scion (2012) developed a decision making tool that summarises these changes and identifies risks for specific regions to help landowners. While the climate change data (temperature, rainfall, etc.) used in impacts models for forestry is consistent with other modelling, the interaction between climate and complex ecological and biological processes adds additional uncertainty with respect to projected impacts and implications for productivity.

See Section 4 for information on the potential for land-use conversion to forestry driven by the transition to a low-emissions future.

5.2.4 Tourism

Recreational freshwater species such as salmon and trout may be negatively affected due to changes in dissolved oxygen and nitrate concentrations in rivers (Collins et al., 2012).

Damage may occur to Department of Conservation (DOC) assets such as visitor structures, roads, tracks, buildings, camp sites, historic sites from climate-induced extreme weather events (Mcfadgen, 2001). In Canterbury, Wainono Lagoon and the Little River Rail Trail were found to be most exposed to sea level rise (Tait, 2019).

Recreational activities in hill- and high-country environments such as skiing will also be affected by a changing climate. Days with snow depths equal to or exceeding ski industry standards shift from a current figure of 125 days to 99-126 days in the 2040s and 52-110 days in the 2090s across all of New Zealand (Hendrikx et al., 2013). The number of hours in which ski-fields will be able to make snow will be reduced by 82-53% by the 2040s, and by 59-17% by the 2090s, when compared with 1990s figures (Hendrikx and Hreinsson, 2012).

These references draw on relatively ‘high’ certainty climate modelling data to predict impacts on tourism activities. As noted above in relation to transport though, what is more difficult to predict with certainty are the effects of extreme weather events on tourism more generally, particularly long haul international tourism to New Zealand (Becken, 2013).

5.2.5 Aquaculture

Ocean acidification could have an impact on yields due to weaker shells of marine organisms used in aquaculture (Willis et al., 2007). In localised restricted areas it may be theoretically possible to deploy chemical measures to temporarily increase pH levels (to combat acidification), however such geo-engineering solutions only offer short-term solutions and may have unintended consequences at a wider ecosystem level (Office of the Chief Science Advisor, 2013).

5.2.6 Insurance

Insurers are now typically more risk aware and sensitive to climate risk signals from the reinsurance industry (Lawrence et al., 2016). **Insurance retreat** from coastal locations could increase the unfunded fiscal risk faced by the Crown and decrease house prices as mortgages become unavailable (or more costly). Insurers may be more willing to continue to provide insurance to high risk areas if they decide to discriminate between these areas and lower-risk ones in the policies they offer (in premium prices, in excess, or in the policy wording). **Policy discrimination** in New Zealand has historically taken the form of higher excesses instead of higher premiums, but this is changing (Storey et al., 2017).

5.2.7 Banking

New Zealand’s financial system is primarily exposed to climate risks through the sectors that it lends to and insures (Reserve Bank of New Zealand, 2018). There may be regional risks due to climate-related and transition-related impacts to the agriculture sector. It is important that banks’ lending decisions account for farm-specific exposures to these climate risks (Reserve Bank of New Zealand, 2018).

The financial system is also exposed to the effects of climate change on property (Reserve Bank of New Zealand, 2018). Property insurance penetration is high in New Zealand, so these risks may crystallise in the insurance sector. An increase in the cost of insurance or a reduction in its availability may reduce the value of affected assets. This represents a cost to the owners of the assets and can translate into higher risks for lenders if the value of loan collateral falls or underinsured borrowers suffer losses (Reserve Bank of New Zealand, 2018).

Climate change could increase home loan defaults because of the maturity mismatches between residential insurance and mortgages. Bankers expect that in the future they may lend to owners of coastal property less often, or require more equity or higher interest rates (Storey et al., 2017).

The impact of these financial and insurance changes could be significant in certain regions. However, it is difficult to evaluate certainty as the effects will be highly contingent on future insurance policies and regulatory decisions.

5.2.8 Energy

New Zealand’s HEP energy generation is sensitive to climate change through changes in seasonal river flows and snow melt and increased rain in the headwaters of Canterbury rivers and hydro-lake catchments (Christchurch City Council, 2010). For instance, Caruso et al. (2017) modelled the effects of climate change on runoff and inflows into Lakes Pukaki, Tekapo and Ohau. They found that lake inflows will increase under all climate scenarios, but with greater seasonal variability, leading to electricity demands in Summer and Autumn and more spill required in Winter and Spring, with potential downstream effects. Jenkins (2018) outlines some of these potential downstream effects in terms of flood and water infrastructure. This work draws on relatively high certainty data to predict the impact of a changing climate on rainfall in relation to electricity generation.

Energy demand is also likely to shift with changes in climate. The increase in mean temperatures could have a positive impact in terms of projected energy demand, levelling off the winter peak requirements as a result of reduced heating requirements (although conversely summer demand will expect to increase with more use of air conditioning) (Office of the Chief Science Advisor, 2013). Industrial electricity use is expected to increase due to the transition to low-emissions energy sources (New Zealand Productivity Commission, 2018). This work provides less certainty as the impacts will be contingent upon changing consumer and sector behaviour.

5.2.9 Manufacturing

A switch away from fossil fuels in providing process heat, energy primarily used for warming spaces and industrial processes, for industry, particularly for low- and medium-temperature heat users could have an impact on the manufacturing industry (New Zealand Productivity Commission, 2018). For the year ended March 2018, manufacturing was the most important sector in terms of Canterbury's GDP, but there is a gap in climate change impacts information for this sector and certainty around effects is low given there are a range of potential future scenarios (Statistics NZ, 2019).

5.3 Social

5.3.1 Health and loss of life

Direct impacts on human health from changes in climate extremes are likely to be relatively moderate (Teixeira et al., 2012). Milder winters may result in fewer winter deaths and less air pollution (Christchurch City Council, 2010). But increases in **heat-related deaths and illness**, particularly for those with chronic disease, and those aged over 65 years are likely to outnumber any fewer winter deaths by 2050 (New Zealand College of Public Health, 2018). However, there is uncertainty about the role of seasonal factors (such as infectious diseases) versus temperature in winter-related deaths (New Zealand College of Public Health, 2018). In addition, there may be increases in heat stress and occupational health concerns for outdoor workers (New Zealand College of Public Health, 2018).

Recovery of the stratospheric ozone layer may be delayed by climate change, and this will lead to continued adverse effects from ultraviolet radiation, such as **skin cancers**. Increased or decreased outdoor time may also affect exposure to solar ultraviolent radiation (UVR) – with possible impacts on rates of skin cancer and eye disease, and vitamin D levels (New Zealand College of Public Health, 2018).The cascading and interacting impacts of climate change are predicted to have major indirect effects on human health. There is the potential for bush/forest fire air pollution to impact on people with **cardiorespiratory disease** (New Zealand College of Public Health, 2018). Climate change will also lead to the establishment of new pests and diseases (Christchurch City Council, 2010), other **vector-borne diseases** (e.g. tick-borne), non-vector-borne zoonotic diseases and **food and water-borne disease** affecting human health (New Zealand College of Public Health, 2018). For example, Tompkins et al. (2011) modelled the spread of six key indicator diseases in New Zealand under three future climate scenarios, including: campylobacteriosis, cryptosporidiosis, meningococcal disease, influenza, and Ross River and Dengue Fevers. Their research showed increases in the spread and incidence of these diseases due to climate change. Weather extremes will also lead to disease due to drinking water contamination. For instance, heavy rainfall events can transport faecal contaminants into waterways. People can subsequently be exposed to pathogens through drinking water and recreation (e.g. swimming, contaminated shellfish). More frequent dry conditions may affect continuity of household water supplies, affecting diseases influenced by hygiene (e.g. enteric infection) (Woodward et al., 2001) There may be a possible increase in incidence of leptospirosis through contact with flood contaminated surface water. Increased temperature, and both high and low rainfall, may have impacts on parasitic diseases (e.g. cryptosporidiosis, giardiasis) particularly in the context of agricultural intensification in NZ. McBride et al. (2014) projected in a high emissions scenario that rates of campylobacteriosis infection would rise by 20% while rates of cryptosporidiosis infection would rise by 36% in New Zealand.

Climate change may also indirectly affect people through building effects, such as the healthiness of indoor environments through overheating of buildings, changed concentration of indoor air pollutants, increasing flood damage, and an increase in indoor moisture (New Zealand College of Public Health, 2018).

Injury and illness from extreme weather events may increase, particularly wind related injuries (New Zealand College of Public Health, 2018). Increasing safety issues may arise due to substantial volumes of wave splash and wind-driven saltwater spray caused by sea level rise (Ministry of Civil Defence and Emergency Management, 2010).

Stress and mental health could increase due to:

- loss of livelihood (e.g. farmers with drought, or tourist operators) (New Zealand College of Public Health, 2018).
- disruption from extreme weather events and forced migration (New Zealand College of Public Health, 2018).
- young people suffering anxieties about potential catastrophic climate change, not unlike those experienced by children growing up with the fear of nuclear war (New Zealand College of Public Health, 2018).
- house prices dropping and the risk of future flooding that add to the **stress** of the situation (Ministry of Civil Defence and Emergency Management, 2010)
- degradation of the local environment, alterations of natural ecosystems, and loss of valued structures and places that lead to the erosion of long established bonds between people and place (Stephenson et al., 2018).

The research on the health effects of climate change tends to draw on climate model data to then investigate the likely impacts and implications. Much of this work extrapolates existing trends, based on current understanding of disease response and transmission, and physiological responses to climate extremes to describe potential future effects. As such, other than the modelling of disease spread, these references do not generally ascribe certainty or predict the scale of impact, but rather highlight generalised impacts.

Mitigation measures may cause some positive effects for people including improved air quality as a major co-benefit (Metz et al, 2007). Air quality is relatively good in New Zealand, so while it is still relevant in the New Zealand context (particularly in eliminating coal use), the dominant health benefits are more likely to come from increasing exercise, reducing accidents and improving the quality of housing stock (Ministry for the Environment, 2018b).

5.3.2 Socio-economic

Land values could be affected by coastal flooding, eroding shorelines and changes in zoning measures (Harris Consulting & Christchurch City Council, 2003). This could have flow-on impacts on lending and insurance for residential property.

Slower rates of growth in **household incomes** could occur (Ministry for the Environment, 2018c). Where emissions-reduction policies generate significant shocks (e.g., the loss of a major employer) the response should be targeted toward re-training opportunities for those who will have the most difficulty gaining new employment (New Zealand Productivity Commission, 2018).

5.3.3 Food and water security

The extent of the demand for food crops to produce biofuels (1st generation technology), has the potential to foster competition for land, water and other production resources - contributing to increasing world food prices. Climate change also contributes to food price increase, depending on its suppression of crop yields (E Teixeira & Brown, 2012).

Increased global food prices may exacerbate food insecurity and therefore compromise nutrition for some groups (New Zealand College of Public Health, 2018). Both urban demand and demand from changes in land use could significantly increase water demand for the same resource in areas such as Canterbury (Christchurch City Council, 2010) (Lawrence et al., 2016).

Water supply reliability for irrigation will also be affected by changing climatic conditions. It is projected that under current water allocation policies, by 2040 the land able to be irrigated would be reduced by 10%, and existing irrigators would in theory face reduction of allocations of up to 10% in Canterbury (Aqualinc, 2011).

5.3.4 Disruption

Various references suggest climate change will disrupt societies and ecosystems. For example social and economic disruption caused by natural hazards, extreme weather, and rising fossil fuel prices (Christchurch City Council, 2010). Coastal inundation may result in people losing their possessions or having to fix saltwater damage (Ministry of Civil Defence and Emergency Management, 2010). However, disruption may also come from changing social practices and industries which are harder to predict with certainty, such as an increase in electric vehicles, technological innovations, or synthetic proteins. While electric vehicles are seen as fundamental to mitigating transport emissions, they will not necessarily reduce congestion or accidents, nor will they encourage people to get exercise as part of their daily commute (Ministry for the Environment, 2018b). Rather, active and public transport can reduce both congestion and lower emissions, while also improving public health. The way future societies will respond to disruptions is very difficult to predict.

5.3.5 Community

Changes in climate could have a negative impact on **public amenities** such as drought affecting our ‘garden city’ (Christchurch City Council, 2010) and increased algal growth affecting the use of river swimming holes. However, potential positive impacts include renewed interest in building stronger communities and enhancing support networks in light of climate change-induced extreme weather (Christchurch City Council, 2010).

The transition to a low-emissions future and the subsequent land use conversion to forestry could have an impact on rural employment resulting in rural depopulation, decreasing social cohesion and sense of community (Parliamentary Commissioner for the Environment, 2019).

5.3.6 Migration

Climate change and changes in the global economy may indirectly cause an increase in migration to Canterbury. For example, displaced people from low lying and drought prone nations (particularly in the Pacific) wanting to live in Christchurch (Christchurch City Council, 2010; Nottage et al., 2010). This may cause flow-on impacts on social services and infrastructure (Christchurch City Council, 2010) and new health and social pressures such as household overcrowding and incidence of some infectious diseases (e.g. tuberculosis) (New Zealand College of Public Health, 2018).

However, while some of these climate refugees may be more vulnerable to impacts from climate change related events due to language and socioeconomic barriers,, they may also be more resilient due to coping mechanisms learnt from experiences of survival, and from strong community networks (Stephenson et al., 2018).

5.4 Cultural

Impacts on culturally valued places and practices (e.g. wāhi tapu, mahinga kai, historic places) will affect the people and communities for whom these are an important part of identity and heritage. Some Māori communities may be disproportionately vulnerable because of their socio-economic characteristics, and heavily exposed because of their reliance on coastal mahinga kai, and the proximity of housing and community infrastructure to active coastal processes such as erosion (Stephenson et al., 2018).

Erosion and inundation of low-lying coastal areas particularly around the Avon-Heathcote Estuary and Brookland Lagoon areas will have an impact on heritage and cultural sites (Christchurch City Council, 2010).

In addition, some of the environmental impacts mentioned in section 5.1 will have an impact on mahinga kai and taonga species.

5.5 Governance

Climate change may have an impact on governance and the ability to achieve environmental, social, cultural and economic wellbeing, especially as impacts cascade (Lawrence et al., 2016, 2018). Previous work by O'Donnell (2007) identified climate impacts and potential policy responses in relation to Canterbury. While more research is needed on the implications for governance, key issues relevant to Canterbury include:

- changing roles and responsibilities of local government
- increasing resources needed to work with communities to manage change
- funding stressors
- liability and legal challenges
- managing demands for compensation to damaged assets
- adopting a community development approach to climate change adaptation
- managing community expectations about levels of service
- adapting planning approaches to consider design-life of land use
- adjusting planning rules and building legislation to factor in climate change effects
- 'climate proofing' key infrastructure such as stormwater, wastewater and water
- reviewing the adequacy of institutional arrangements (Lawrence et al., 2018; Simon et al., 2019).

NIWA et al. (2012) have produced a tool box that focuses on governance and decision making for climate change in urban contexts. This tool box outlines anticipated and cascading effects in urban environments, and suggests approaches to managing these.

6 Gaps and future work

This document is intended to be used as a guide and initial reference list that summarises key impacts of climate change on environmental, economic, social, cultural and governance wellbeing in Canterbury and New Zealand. It is anticipated that this document function as an evolving resource to which new literature can be added.

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