



Applying adaptation pathways

Climate change adaptation planning for Hawke's Bay primary industries

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Summary

Project and client

This report address the priority topic ‘A “deep dive” into key regions affected by climate change’ for the Ministry for Primary Industries, through the Impacts and Adaptation theme of the Sustainable Land Management and Climate Change (SLMACC) programme. The report describes the development and application of pathways planning to support climate change adaptation planning for primary industries in Hawke’s Bay, New Zealand.

Background

Climate change is expected to adversely affect primary industries, compounding existing vulnerabilities, creating new ones, and confounding traditional decision-making. Although our understanding of potential impacts has improved, the capacity to identify, evaluate and compare adaptation options remains limited by poor integration of social and economic studies with biophysical impact assessments and an emphasis on individuals’ adaptive strategies. Working with land managers and other primary industry stakeholders, including local and regional government, the research developed applied adaptation pathways to support decision-making and adaptation planning for Hawke’s Bay primary industries.

Methods

The research used mixed methods – including downscaled climate projections, participatory workshops, expert interviews, biophysical and crop modelling, and systems dynamics – to develop insights into the likely impacts and implications of climate change for primary industries at the catchment and regional scale. Adaptation options are identified using these methods, supplemented by desktop analysis of the relevant literature. Outputs include completed pathways for four key decision areas identified by stakeholders, and an emerging multi-sectoral regional pathway.

Comparative case study analysis in two catchments with differing socio-economic and environmental characteristics provided the basis for the identification of priorities for decision-making:

- freshwater management
- community resilience and well-being – infrastructure
- primary industries’ adaptive capacity.

Inputs from local case studies are synthesised and combined with additional data, including iteration in regional stakeholder workshops, as shown in Figure S1.

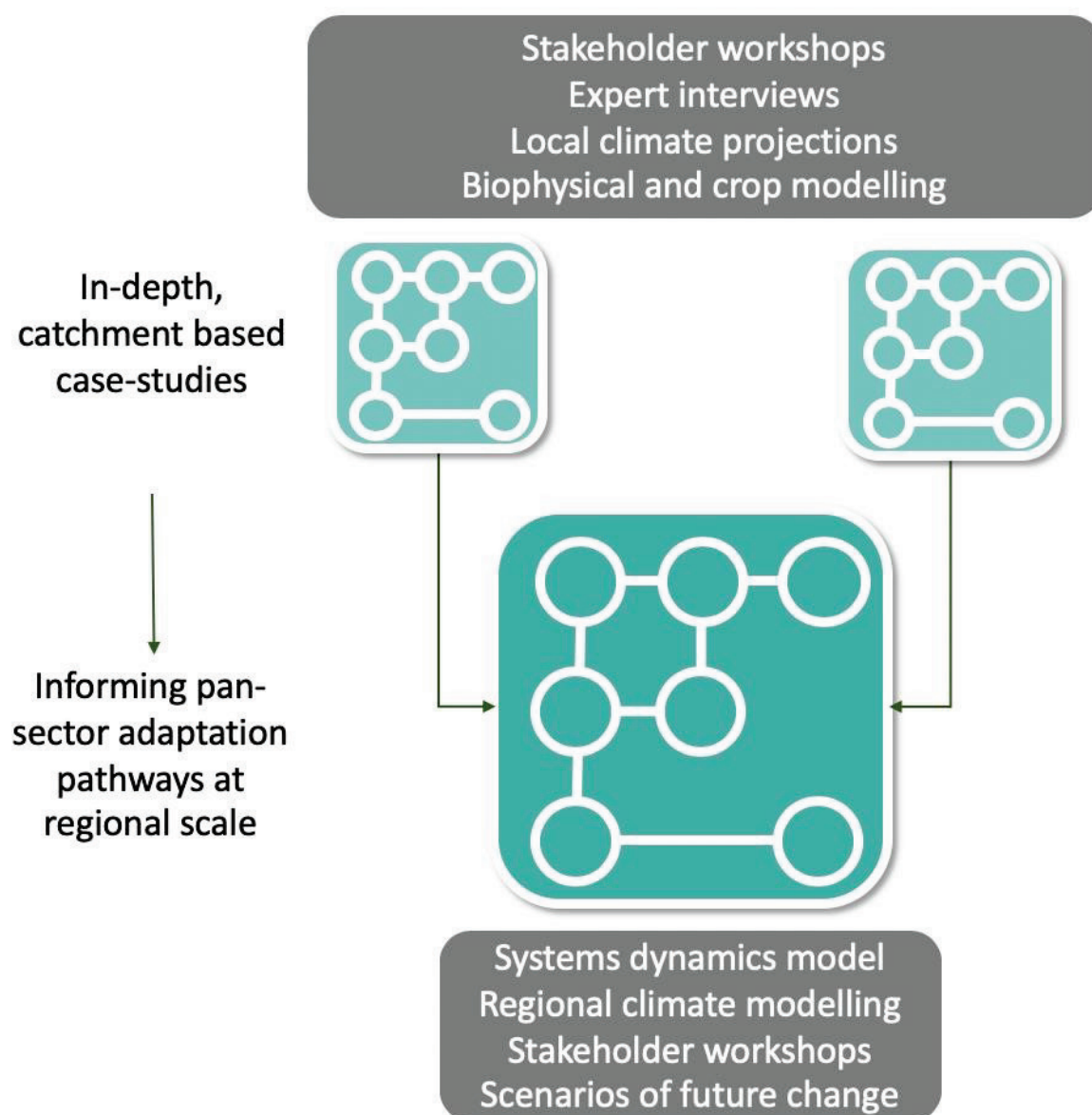


Figure S1: Local to regional pathways development, incorporating multiple methods.

Results

The results show the ways in which climate change will affect primary industries in Hawke's Bay and the extent to which adaptation will require closer consideration of enabling conditions. Vulnerability is context-dependent, and adaptation planning should closely consider the significance of non-climatic stressors in relation to climate change.

Completed pathways for water, community, infrastructure and primary industries highlight stakeholders' concerns, which extend beyond direct impacts and the implications of climate change to incorporate social and environmental well-being, the capacity of infrastructure to support regional value chains, the potential for realising efficiencies in production, and the possibility of transformational change.

The regional pathway provides insight into how decisions taken in one domain or sector can have an impact on others, and how the region as a whole prioritises action. An emerging multi-sector regional pathway draws out some of the interactions among sectors in terms of timing and regional needs.

Over the coming decade (short term), best practice will probably contribute to adaptation through incremental change to maintain current production systems under a variable climate. The two

highest priority planning actions that could assist with cross-sectoral adaptation are the development of sector-specific adaptation plans, and investment in education, outreach, and extension to enhance learning opportunities.

In the medium to long term (10 to 30 years), preparatory work should be undertaken to explore the potential for transition to low-water-use activities and land-use change, including research and development for crops that are more resilient to climate extremes and water variability.

Applied adaptation pathways provide a useful framework for strategic planning for primary industries, but they are not without their limitations. Adaptation for primary industries, particularly at the regional scale, involves multiple stakeholders, stressors, and potential options for adaptation. There is unlikely to be a single suitable option, rather in most instances a suite of actions will be required to achieve desired outcomes. The need to consider multiple actions and the absence of a single, mandated authority responsible for implementation complicates planning. While adaptation pathways are used elsewhere in New Zealand for addressing coastal hazards, pathways planning for primary industries is complex due to the multiple impacts and levels of governance and decision-making, and this kind of planning benefits from the use of additional tools and processes, including systems modelling.

The results also demonstrate the benefits of involving affected stakeholders and decision makers in adaptation planning processes. Workshops in case study catchments and at the regional level provide an opportunity for stakeholders to explore possible futures and identify adaptation options. The process of iterating and producing pathways diagrams provides a practical output, the results of which can be used to inform sector-specific pathways, provide the basis for prioritising regional adaptation actions, and enhance capability and capacity through engagement, learning, and socialising new processes, techniques and knowledge with diverse audiences. Working across sectors also provides opportunities to identify synergies and potential trade-offs for adaptation options.

The results provide a novel application of the pathways planning methodology to primary industries, and can serve as a template for further applications by local and regional authorities, and for sector-specific pathways development.

Conclusions

The development and application of pathways planning with and for primary industries in Hawke's Bay:

- provided a useful and versatile framework for engaging with diverse stakeholders on adaptation issues – the process is scalable and can be applied to individual land managers, across local and regional scales, or to generate sector-specific insights
- generated additional insight into the complexities of adaptation planning for primary industries
- demonstrated the growing interest in adaptation knowledge, which advances practical application and moves beyond continued debates and discussions regarding impacts and implications to more closely consider decisions and actions
- helped to facilitate cross-sector collaboration and knowledge sharing.

Recommendations and observations

Adaptation to climate change is emerging as a priority in the primary sector and across New Zealand society more generally. The insights gained through this research have informed the following recommendations and observations, which we believe provide a foundation for further application and development of adaptation pathways and research to support adaptation planning more widely with primary industries.

- Local, regional and multi-sectoral approaches should be informed by sector-specific understanding.
- Systems modelling, expert advice and local understanding of climate impacts and adaptation options can reveal the complexities of adaptation planning for primary industries.
- Participatory approaches are essential to enhancing adaptive capacity, facilitating learning and enhancing adaptive capacity.
- Pathways diagrams provide a practical output, which can be used to inform outcomes across multiple domains.
- The pathways process is inherently flexible and can be scaled up or down according to resource availability, including data.

- Transformational change will require greater coordination across sectors and scales, and preparatory work should begin now to consider how governance arrangements affect the functioning and performance of innovation in the primary sector.
- Stakeholders should be empowered to carry out adaptation planning by providing them with additional tools to explore possible futures and implement adaptation actions.
- Research to support adaptation planning should be prioritised in response to growing demand for knowledge regarding adaptation options, beyond impacts and implications to consider adaptation decisions and actions.
- Tools and processes for documenting adaptation experiences by sectors and regions need to be developed to help make successes reproducible. Monitoring and evaluating adaptation can provide an empirical basis for understanding and tracking progress towards outcomes, improve the ability to design effective policy interventions and demonstrate the impact of adaptation science, supporting the transition towards climate-resilient primary industries.
- Multi-sector and regional coordination are required to identify synergies and trade-offs, realise opportunities, and avoid maladaptation.

Glossary

Adaptation	Taking action to avoid, withstand or benefit from current and projected climate changes and impacts.
Adaptation pathways	An approach to adaptation planning that enables the consideration of a range of possible adaptation options, how they will be affected by climate change through time, and whether any options have an 'expiry date' (i.e. a point in time when they are no longer viable). A key aspect of this approach is the identification of a preferred pathway that identifies those options to be progressed based on currently available information, including stakeholder input/preferences at the time of preparing the pathway. The preferred pathway does not preclude continuing with current actions that contribute to future adaptation, and the pathway should be reviewed at least every 5 years, at which time new information may suggest that it should be amended.
Adaptive capacity	The ability to adjust to climate change impacts (including climate variability and extremes), moderate potential damages, take advantage of opportunities, or cope with consequences. In determining adaptive capacity, consideration is given to the extent to which a feature or its function in its current form, with current management practices or funding, is able to continue to function, cope or adjust to the expected climate conditions.
Climate	Climate summarises the average, range and variability of weather elements, such as precipitation, wind speed, air temperature, humidity, and sunshine hours (solar radiation), observed over many years (typically over 30 years) at a location or across an area.
Climate change	Any change in climate over time, whether due to natural variability or as a result of human activity.
Climate variables	The different climate factors, such as rainfall and temperature, that determine the climate. Changes in these are projected to occur as a result of climate change, including declining rainfall, increasing rainfall intensity, increasing average temperature, increasing frequency and intensity of heatwaves, and increasing drought risk.
Dynamic Adaptive Policy Pathways (DAPP)	Dynamic Adaptive Policy Pathways (DAPP) is a pathways planning approach to support the development of an adaptive plan capable of dealing with conditions with deep uncertainties. The approach combines dynamic adaptive management with adaptation pathways. The exploration of adaptation pathways is one of the main ingredients of an adaptive plan. The DAPP approach specifies a sequence of actions over time. Alternative actions are included in order to maintain flexibility to adapt to a range of future conditions. A monitoring system collects information to get early warning signals (triggers) for the implementation of actions or for a reassessment of the plan. Originally developed in the Netherlands, Dynamic Adaptive Policy Pathways have been applied in New Zealand for assessing coastal hazards and risks associated with sea-level rise, and they are featured in the Ministry for the Environment's <i>Coastal Hazards and Climate Change: Guidance for Local Government</i> (2017).

Exposure	The likelihood of a feature or its function being subjected to change in a particular climate variable. For example, low-lying land is more exposed to inundation from flooding; and much of eastern New Zealand is exposed to higher temperatures and declining rainfall, and is more exposed to drought risk.
Maladaptation	Occurs when an attempt to adapt produces unintended negative consequences.
Mitigation	In the context of climate change, taking action to reduce or prevent the emission of greenhouse gases.
Resilience	The ability of a social or ecological system to absorb disturbances while retaining: the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress or environmental change.
Sensitivity	The degree to which a feature or its functions are affected by change to a particular climate variable. For example, non-irrigated open space is sensitive to reduced rainfall, and low-input, pasture-based dairying farms may be more sensitive to drought due to their dependence on grass growth.
Transformation	Widespread, systemic change to existing decision-making processes and patterns. Transformation is often understood as radical change requiring innovation and testing of new approaches. In relation to climate change adaptation, for example, a distinction is made between incremental adaptation, where the central aim is to maintain the essence and integrity of a system or process at a given scale, and transformational adaptation, involving changes to fundamental attributes of a system in response to climate and its effects.
Vulnerability	The degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change. Vulnerability to the impacts of climate change is a function of exposure to climate conditions, sensitivity to those conditions, and the capacity to adapt to the changes.

1 Introduction

1.1 Climate change adaptation and the primary industries

New Zealand's productive sector is currently operating in an environment of increasing risk and uncertainty. Primary enterprises will have to contend with more frequent climate crises (e.g. drought and flood), ecosystem services degradation (e.g. eroding soils, water pollution and loss of biodiversity), biosecurity incursions, changing social and market demands (e.g. the demand for sustainable products), and subsequently new industry- and public policy affecting terms of production and trade. Some of these risks act as persistent pressure on enterprises, while others are short, sharp shocks. Collectively they can have a significant impact on the sector and New Zealand's environment and economy.

Many of the non-climate-related risks will be compounded by the impacts of climate change, which is expected to lead to warmer temperatures, decreased precipitation, increased likelihood of extremes such as high-intensity rainfall and wind events, and sea-level rise in low-lying areas that compounds with river flooding.

The increased frequency of such events is extremely relevant to New Zealand. They will challenge management systems in the primary sector, with implications across the New Zealand economy and society. The primary sector contributes 7% of GDP and accounts for 79% of export earnings (Statistics New Zealand 2018). Approximately half the land base is in productive pasture and arable

cropping, including 1.8 million hectares of productive forest plantation. Nationally the primary sector is a significant economic driver, employing 350,000 people, and it is fundamentally important to many local and regional economies.

Climate events such as the El Niño–Southern Oscillation (ENSO) have demonstrated their impacts on the economy, and there is increasing evidence of human influence on recent climate extremes affecting New Zealand (Harrington et al. 2014). Primary sector economic activities such as pastoral farming, horticulture, viticulture and cropping are acutely vulnerable to climate change (Cradock-Henry et al. 2019). The shift towards more intensive production and high-input systems has exposed the sector, and there is further potential to create new risks and increase uncertainty for producers. Overall, as much as 79% of New Zealand’s economic activity is considered vulnerable to future climate change (Fitzharris 2007).

Successful adaptation to climate change in rural environments and enterprises is vital to securing New Zealand’s economic resilience. At the most general level, climate adaptation is what people do to avoid and recover from unusual or extreme climate events (Table 1). Adaptation in the primary industries encompasses diverse strategies that can be used by individual farmers and land managers, sectors, industries and regions to adequately respond to climate change. It involves adjusting practices, processes, and capital in response to the actuality or threat of climate change, as well as responses in the decision environment, such as changes in social and institutional structures or altered technical options that can affect the potential or capacity for these actions to be realised. In a nutshell, adaptation is ‘positive response to the prospect of climate change’ (Clark & Nottage 2012).

To support adaptation actions, decision-makers must understand the nature of the sector’s vulnerability in terms of who is vulnerable, the nature of the vulnerability, the nature of the stresses, and the capacity to adapt to ongoing changing risk where uncertainties prevail (Moss et al. 2013).

Table 1: Definitions of adaptation

Source	Definition
Intergovernmental Panel on Climate Change (IPCC)	Adaptation is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC 2014).
United Nations Framework Convention on Climate Change (UNFCCC)	Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change (UNFCCC website).
United Nations Development Program (UNDP)	Adaptation is a process by which strategies to moderate, cope with and take advantage of the consequences of climatic events are enhanced, developed, or implemented (UNDP 2005).

United Kingdom Climate Impacts Program (UKCIP)	Adaptation is the process or outcome of a process that leads to a reduction in harm or risk of harm, or realisation of benefits, associated with climate variability and climate change (UKCIP 2003).
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Scenarios of future climate change indicate likely changes in temperature, rainfall and the distribution and frequency of climate extremes (Harrington et al. 2014; IPCC 2014). With growing concern that the target of limiting change to within 2°C is unlikely to be met, researchers and policy makers are planning for future climate conditions more than 4°C higher than the long-term global average (Moss et al. 2010; Stafford-Smith et al. 2011; Rahmstorf et al. 2012; Herring et al. 2014). For climate-sensitive, resource-dependent industries and sectors, this will require significant changes in management, enhanced adaptive capacity, and a commitment to the monitoring and evaluation of long-term trends in order to minimise risk, and enhance resilience to a range of shocks and stressors (Howden et al. 2007; Fleming & Vandy 2010; Kenny 2011; Marshall 2011).

The ability of socio-ecological systems to cope with the predicted changes is shaped by complex, interactive and non-linear dynamic processes (Folke 2006; Westley et al. 2013). Thresholds, amplifying feedbacks and time-lag effects are widespread and make the impacts of global change hard to predict, difficult to control once they begin, and slow and expensive to reverse once they have occurred (Berardi et al. 2011; Dakos et al. 2015). Global change shifts the sustainability challenge from preserving natural resources for future generations, to strengthening resilience and adaptive capacity in socio-ecological systems (Benson & Garmestani 2011; Fischer et al. 2015). Decision makers and concerned citizens urgently demand reliable, scientifically based information to help them respond to climate change impacts and opportunities for adaptation (Fazey et al. 2007; Ford & Pearce 2010; Measham et al. 2011; Kristjanson et al. 2014).

This is of particular importance for New Zealand, a peripheral economy in the global context, largely dependent on primary production. Nearly half of the land is in productive pasture and arable cropping. Dairy farming is fundamental to the rural economy, accounting for almost half (47.6%) of agricultural earnings. Horticulture is also growing in importance, predominantly due to niche production of high-value wine and kiwifruit (NZ Winegrowers 2018).

Climate variability, including extremes, has a marked effect on primary industries (Clark et al. 2012; Cradock-Henry & Mortimer 2013; Manning et al. 2015). The adaptation of primary sector enterprises to a changing climate is therefore of fundamental importance in supporting a sustainable primary sector and maintaining a strong economic future for New Zealand. Climate change is likely to make organisations and institutions more vulnerable to external shocks that can affect business operations. Climate change-induced shocks include anticipated changes in the frequency of extreme events such as fire and drought, as well as the incremental impacts arising from changes in climate, such as disease and loss of biological productivity. Significant knowledge gaps remain in our understanding of potential impacts and implications for New Zealand, in particular for the country's primary sector (Hennessy et al. 2007; Kenny 2011; IPCC 2014; Reisinger et al. 2014; Cradock-Henry et al. 2019).

Because climate change is expected to have a profound impact on natural resources, and thus on the primary sector (agriculture, forestry and fisheries), it is imperative to understand the projected areas at risk and how to be informed on the appropriate adaptation responses (Park et al. 2012; Rickards & Howden 2012). The sustainability of the primary sector, which contributes to fundamental aspects

such as food security, social benefits and economic growth, is highly vulnerable to future climate changes and variability (Fitzharris 2007; IPCC 2014; Manning et al. 2015; Marshall et al. 2014).

Given the complexity and associated uncertainty, identifying and prioritising adaptation actions presents challenges to primary industry stakeholders and decision makers. There is unlikely to be a single suitable adaptation, and in most instances a suite of actions will need to be implemented to achieve the desired outcomes. Over time, different adaptation actions will be required, or preferred, depending on how the climate (and other non-climate parameters such as population and social values) change through time.

1.2 Research aims and objectives

Given this complexity, working out what to do now to adapt to climate change can seem daunting. This can be compounded by uncertainty, or the range of possible futures for which planning must allow. Experience shows that where people perceive there is uncertainty and complexity, they find decision-making hard and may put it off altogether.

Primary industries and other weather- and climate-sensitive sectors therefore require practical and accessible concepts and tools to assess and communicate the implications of climate change for land management decision-making. Within New Zealand there is a growing demand from concerned stakeholders, who increasingly pose questions about whether current management practices are able to cope with climate change and increased climate variability, or whether alternative strategies are needed.

The aim of this research is to develop and empirically apply an *adaptation pathways* approach to support decision-making at the local and regional scale. Identifying and prioritising options is at the centre of adaptation pathways planning. The basic process identifies potential adaptation options and considers how robust these might be across the potential future scenarios developed in the previous phases, as well as their flexibility. Then possible turning points, tipping points and trigger points are identified. The aim is to identify options that could achieve management objectives. The process draws on outputs from the current situation as well as future analyses.

Pathways development can allow primary industry stakeholders and decision-makers to justify, prioritise and implement actions that take into account climate change and associated changes in ecosystems, values and knowledge, as well as socio-political and economic conditions.

Although the focus here is on Hawke's Bay, the process described has the potential to be applied elsewhere. In the following report we identify:

- the potential impacts of climate change on key sectors and adaptation options
- areas of decision-making that need to consider climate change the most – adaptation pathways
- priorities for adaptation action.

The research has three objectives:

- 1 to collate and overlay existing knowledge and data sets to determine the potential impacts of climate change for Hawke's Bay
- 2 to develop in-depth, multi-scale, multi-stakeholder assessment of the primary sector's vulnerability to the potential impacts
- 3 to articulate a multi-scale, multi-sector analysis of future options (adaptation pathways) and identify key opportunities and drivers that will help guide regional pathways in a direction that is profitable and environmentally sustainable.

1.3 Research questions

The research was guided by the following questions:

- What are the likely impacts of climate change for primary production systems in Hawke's Bay?
- How vulnerable are primary producers to these impacts, and what, where and when are systemcritical decision-points likely to occur?
- How can the concept of applied adaptation pathways be used to help translate uncertainty regarding the extent of climate impacts into a decision-support tool to enable stakeholders to

more easily identify the time range over which specific impacts are likely to occur, and which can be used to take adaptive action?

1.4 Research design and method

To meet these objectives, the project was structured around three research stages, to take it from engagement, review and synthesis, to design and application of the adaptation pathways. The study relied on detailed investigation, and collaboration and participation by stakeholders and experts, to develop empirical evidence to inform decision-making at the regional scale. The results provide a template for further assessments.

The research answered these questions using an interdisciplinary and mixed-methods approach, drawing insights from diverse fields of climate change adaptation studies, vulnerability and resilience, farm-systems science, and farm management.

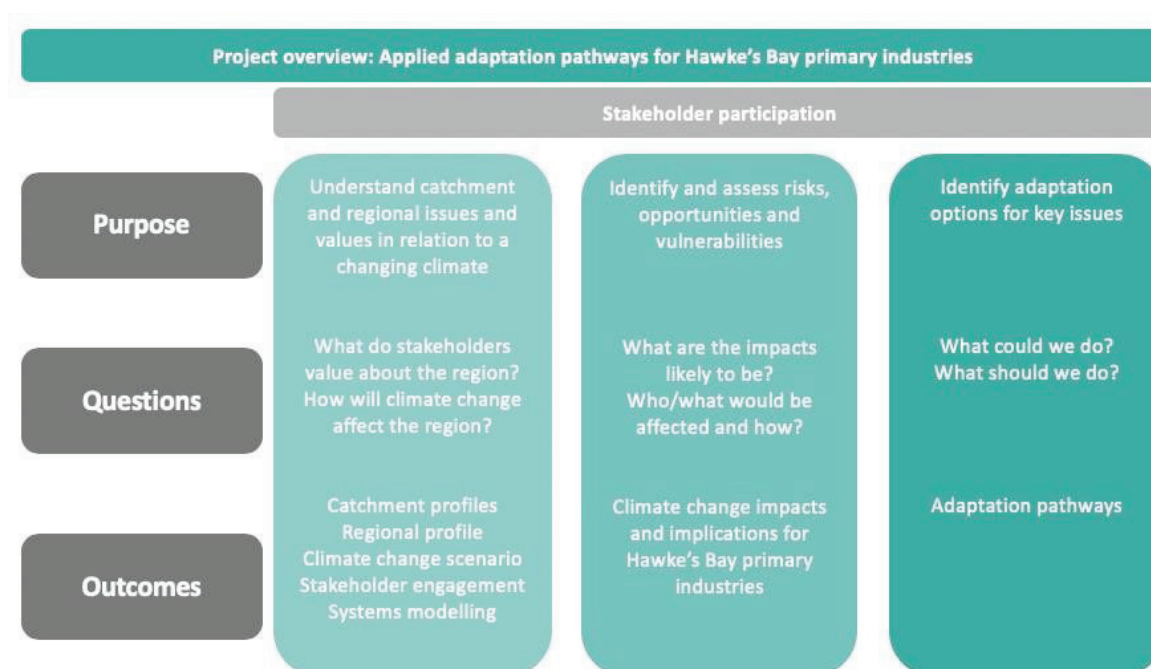


Figure 1: Applied adaptation pathways project overview

In the first stage of the research, stakeholder workshops in Wairoa and Central Hawke's Bay were used to develop a shared understanding of the context for adaptation, including stakeholders' vision and aspirations for the primary industries in their local area.

Second, the risks and opportunities associated with climate change for Hawke's Bay primary industries were identified using a combination of downscaled climate modelling, expert interviews, desktop analysis, and stakeholder consultation.

In the final stage of the research, adaptation options were identified and assessed. Adaptation pathways for four key issues were developed, and the results were used to inform a regional pathway incorporating priority action to support the primary industries.

The research team has experience and interest in collaborative approaches and the co-production of knowledge. An overarching aim of the project was to build adaptation capability and capacity in the primary sector by developing shared understanding. Because of this we sought to work closely with policy makers, practitioners, primary producers, and affected stakeholders to identify values, the significance of likely impacts, and preferred adaptation options (see Appendix A).

Delivery of these stages has generated a series of outputs relating to different aspects of climate change adaptation in Hawke's Bay, including:

- **values workshops** – a series of workshops undertaken in stage one to identify regional values in each of the two sub-regional case studies that were used in subsequent stages of the project (see Appendix B)
- **adaptation options** – a series of interviews with researchers and primary industry sector leaders to identify the potential impacts and adaptation options for different activities (see Appendix C)
- ***Climate Change Projections for Hawke's Bay*** – a report that describes the current and potential future climate in the region (see Appendix D)
- ***Systems Dynamics Modelling*** – a report on the development of a systems dynamics model for Hawke's Bay primary industries, which was used to explore potential implications and qualitatively assess adaptation options (see Appendix E).

1.5 Report structure

There is no single, ideal blueprint for primary industries' adaptation to climate change. Adaptation needs to be both strategic and focused on outcomes, while remaining agile in the face of change.

This report contributes to addressing that challenge. It is a key output of a collaborative process, bringing together researchers, policy makers and practitioners, and primary industry stakeholders and end-users. The report can be read in several ways.

First, it is a technical report, summarising the results of the research, its application and recommendations for further development. The document is also intended to provide sufficient detail for others interested in applying pathways concepts. Finally, it is intended to inform the development of appropriate regional and sectoral adaptation strategies for Hawke's Bay and elsewhere, and to support the development of specific programmes and projects.

- **Section 1 (this section)** introduces **key concepts and scope** of the report.
- **Section 2** reviews the **literature** on decision-making in the face of uncertainty, and introduces pathways concepts and their application.
- **Section 3** outlines details of the **research methodology**.
- **Section 4** describes **future climate change** for Hawke's Bay, against which options can be evaluated. This section contains a synthesis of climate drivers, climate change, and impacts on priority areas for decision-making identified by stakeholders.
- **Section 5** discusses **identifying and prioritising** adaptation options. It provides detail on the sorts of options available and the means of assessing them to build pathways towards achieving long-term objectives.
- **Section 6** presents **adaptation pathways** for key areas of decision-making.
- **Section 7** presents an and an emerging, **multi-sectoral regional pathway**. It also provides a basis for the development of an adaptation strategy for the region, sensitive to stakeholders' priorities.
- **Section 8** concludes with **recommendations** for implementation, including options for setting up monitoring and evaluation to underpin ongoing learning and adaptive management, governance, and next steps.

Communication and engagement have been central to the success of this project, and stakeholder participation was embedded in each stage of the research. This reflects the research team's experience and interest in collaborative approaches and the emphasis placed on the co-production of knowledge. We sought to work closely with policy makers, practitioners, primary producers, and affected stakeholders to identify values, the significance of likely impacts, and preferred adaptation options. The co-production approach was motivated by our desire to build capability and capacity for adaptation planning, and to enhance scientific impact.

It is a reflection of the project's methodological position – supported by previous research and practice – that people matter. Values, decisions and behaviour are central to climate change adaptation, and the active involvement of those who will be required to adapt is essential to support meaningful action, and the development and implementation of practical adaptation options.

The project has actively sought stakeholder involvement to shape its outcomes – from the preparation of the original proposal, through the various stages of research, to the final pathways. We have followed a deliberate strategy to both generate ownership of the project by those with a stake in its implementation and effectiveness, and to engender a robustness and practicality in the adaptation actions and recommendations. This strategy also supports the project's objective of increasing understanding of climate change risks, vulnerability, and adaptation responses in Hawke's Bay.

Stakeholders participated throughout the life of the project, representing a diverse range of organisations and interests across case study catchments and the wider Hawke's Bay region, including local and regional government, research, community interests, financial services, natural resource management, and representatives from the primary industries in the region. This participation directly influenced key outputs and shaped the direction of key stages of the research. Figure 2 summarises how stakeholders participated in this process.

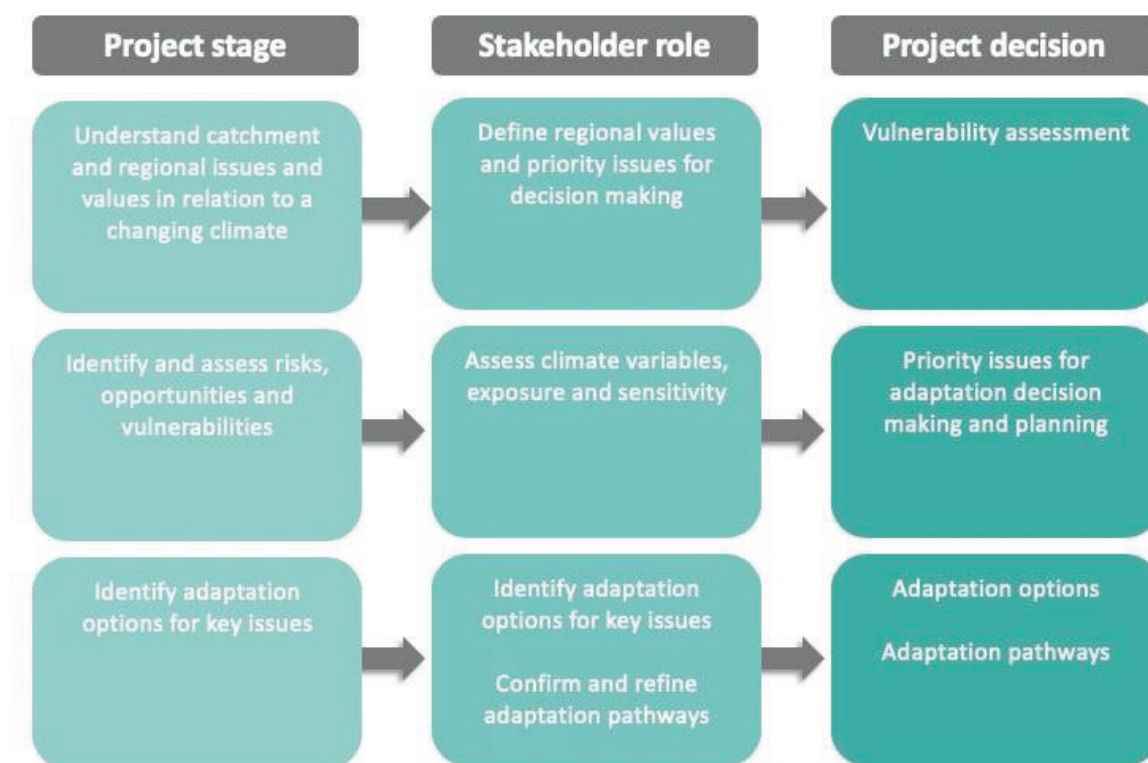


Figure 2: Applying adaptation pathways project overview.

2 Adaptation planning and primary industries

There is a growing appreciation of the need to acknowledge the context in which primary industries must make adaptation decisions. Adaptation planning – at the regional level, for sectors and industries, and for individual land managers – is characterised by change and uncertainty. While the overall trends in future climate are clear, there is still some irreducible uncertainty in downscaled climate projections, particularly at the local level, which is further compounded when assessing the likely impacts on biophysical systems. Furthermore, changes in social and economic conditions – including trading relations, policy, social norms and values – add additional complexity, complicating decision-making.

To support decision-making in the face of uncertainty, new conceptual and methodological tools have been developed that allow for greater flexibility to accommodate uncertainty and change. 'Adaptation pathways' is an approach to planning that is receiving increased attention as a means of undertaking planning and implementation that allows for uncertainty and change (Haasnoot et al. 2013; Barnett et al. 2014; Cradock-Henry, Frame et al. 2018). It does this by encouraging consideration of multiple possible futures and the robustness and flexibility of options across these futures. The robustness derives from testing the options against plausible futures, and the approach is flexible because a diverse array of options are considered and evaluated to avoid 'lock-in' and to inform future decisionmaking (Hallegatte 2009). Consequently, the approach has the potential to enable primary industries to develop an array of options that work reasonably well across a wide range of circumstances, both now and in the future, and provide options that are flexible in response to inevitable changes in those circumstances (Abel et al. 2016; Bosomworth et al. 2017).

The following section briefly reviews the literature on decision-making and uncertainty, before proceeding to a more detailed discussion of adaptation pathways and their application internationally and in New Zealand.

2.1 Decision-making in the face of uncertainty

Adapting to climate change poses challenges to primary industries that need to decide *now* whether and how to adapt activities, systems and sectors, at all geographical scales, to a changing climate (Howden et al. 2007; Meinke et al. 2009; Panda 2018).

Uncertainty is not exclusive to climate change and adaptation: many other scientific and policy fields are confronted with a wide range of uncertainties in their work. Uncertainty is a complex concept that can be described in multiple ways, and the way it is understood in decision-making has evolved over time. Following are two relevant descriptions of uncertainty.

A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g. a probability density function) or by qualitative statements (e.g. reflecting the judgment of a team of experts). (IPCC 2014:17)

The degree of confidence that a decision-maker has about possible outcomes of specific decisions and/or probabilities of these outcomes. Reasons behind this lack of confidence might include a judgement of the information as incomplete, blurred, inaccurate, unreliable, inconclusive, or potentially false. (Refsgaard et al. 2007:1546)

Uncertainty, therefore, presents particular challenges where there are long lead-times or lifetimes of projects, and in these cases uncertainty regarding the timing, location, and magnitude of impacts can present barriers. A body of international literature has emerged over the last decade developing principles, tools, and processes to support decision-making despite uncertainty (Watkiss et al. 2015; Kwakkel et al. 2016; Dittrich et al. 2017; Allen et al. 2018; Lawrence et al. 2019). The basic principles of decision-making in situations where there is uncertainty have been characterised by Hallegatte (2009) as requiring flexibility, reversibility, generating win-wins in the current time periods, avoiding lock-in and path dependency, and, where possible, adopting 'soft' rather than 'hard' strategies (preferring behavioural and management changes rather than investment in solid, engineering structures as much as possible).

These principles are designed to achieve 'robustness' against a range of plausible futures rather than optimising for one scenario that may turn out to be wrong. Instead, optimisation is obtained across scenarios: robust approaches do not assume a single climate change projection, but integrate a wide range of climate scenarios through different mechanisms to capture as much of the uncertainty on future climates as possible.

These principles of robustness are developed further in a range of approaches, sometimes known collectively as 'decision-making under uncertainty'. Robustness is achieved in different ways:

- by finding the least vulnerable strategy across scenarios (e.g. robust decision making), or
- by defining flexible, adjustable strategies (dynamic adaptation pathways and real options analysis for investment appraisal), or
- by diversifying adaptation options to reduce overall risk (portfolio analysis).

Approaches differ in their methodological origins (some developing from financial theory, mathematics, or engineering, while others build on principles of adaptive management), and the type of decision they are supporting (see Dittrich et al. 2017, who demonstrate an approach to selecting appropriate methods for the livestock sector). It is important to recognise that the range of approaches is developed specifically for different types of decisions and processes and is not universally transferable. Therefore, before choosing a decision-making approach, it is necessary to define the objectives, understand the context and issues, and identify options.

A considerable body of the literature on decision-making under uncertainty develops approaches for economic appraisal, with three dominant approaches currently applied internationally:

- real options analysis – portfolio analysis
- robust decision-making.

Real options analysis originates from option trading in financial economics (Black & Scholes 1973; Dixit & Pindyck 1994) and develops flexible strategies that can be adjusted when additional climate information becomes available. It is most appropriate for large, irreversible investment decisions. Applications to climate adaptation are growing quickly, most addressing infrastructure investment (Gersonius et al. 2013), but studies in land-use decisions are also emerging Sanderson et al. 2016; (Dittrich et al. 2019).

Portfolio analysis combines several adaptation options in a portfolio to reduce risk by diversification, and robust decision-making identifies how different strategies perform under many climate outcomes, trading off optimality for resilience (Lempert 2013). More detail on the relative merits of each approach is provided in Dittrich et al. 2016 and Watkiss et al. 2015.

However, even some of these more robust options still require an assessment of probability – an ‘agreeing on’ assumptions – which can lead to challenges in application (Kalra et al. 2014), although formalised expert judgement can improve the characterisation of uncertainty (Kunreuther et al. 2014).

Other approaches to decision-making under uncertainty have built on the principles of adaptive planning, using a monitoring, research, evaluation and learning process (cycle) to improve future management strategies, and develop iterative risk management and dynamic adaptive pathways (Haasnoot et al. 2013). Adaptive planning has a long history in environmental management (Holling 1978; McLain & Lee 1996).

Robust, flexible planning for climate change also has a well-documented history in the decision and policy sciences. For example, Lempert et al. (1996, p236) argues that ‘a simple adaptive strategy, designed to be robust across many plausible futures, performs better on average than policies optimized for particular best-estimates of the future, unless we are virtually certain that one best estimate is correct.’ In an adaptation context, this idea has been most explicitly addressed in the adaptation pathways approach (Haasnoot et al. 2013; Barnett et al. 2014; Wise et al. 2014). Adaptation pathways are the focus of this study, and the following section discusses pathways planning in more detail.

2.2 Planning in an uncertain world

Contemporary planning frameworks for natural resource management are largely predicated on the assumption that environmental conditions will be relatively static. Consequently, planning objectives and policies have tended to be designed to maintain existing states (Barnett et al. 2014; Urruty et al. 2016). However, climate change has already altered – and will continue to alter – the biosphere, creating significant uncertainties about the timing, scale and nature of future changes (Dovers & Handmer 1992; Walker et al. 2003). These include uncertainties around how ecosystems will respond to climatic changes, the spread and emergence of new diseases and pests, the extent of sea-level rise after 2050, and how these changes will interact (Leichenko & O’Brien 2008; Moss et al. 2013; Cutter et al. 2015; Challinor et al. 2018;). Because of this cascading uncertainty, climate adaptation plans using a single ‘preferred’ pathway or a ‘most-likely’ scenario are likely to fail (Walker et al. 2003).

Planning therefore needs more flexible models for decision-making that can accommodate high uncertainty and consider a range of potential conditions, while juggling competing social values and emerging new information (Bosomworth et al. 2017). Adaptation pathways is an analytical approach to planning that is receiving increased attention as a means of undertaking planning and implementation that allows for uncertainty and change. It does this by encouraging consideration of multiple possible futures and the robustness and flexibility of options across these futures. Robustness is achieved because options are tested against plausible futures, and flexibility is achieved because a diverse array of options have been considered and evaluated to avoid ‘lock-in’ and to inform future decision-making. Consequently, adaptation pathways approaches have the potential to enable primary industries to develop an array of options that work reasonably well across a wide range of circumstances, both now and in the future (Wise et al. 2014; Abel et al. 2016), and that provide for inevitable changes in those circumstances.

Adaptation pathways are characterised by a sequence of linked and manageable steps over time, which are triggered by a change in environmental or social conditions and provide low regrets, thereby preserving options for future generations when new information emerges or when environmental conditions change (Haasnoot et al. 2012, 2013). An adaptation pathways approach recognises that there are often many possible ways to respond to climate change, and that a combination of actions – some of which are taken now and some in the future – could present the best way to respond. By breaking down adaptation into steps it is easier to take the first step with confidence.

Part of the attractiveness of adaptation pathways is the ability to present pathways on a diagram (see Figure 3). The diagram illustrates the range of adaptation options and how they can be sequenced through time. For example, Figure 3 shows a simplified pathways diagram for adaptation in the dairy industry in response to climate change (x-axis). The diagram shows current practice (dark green line) and actions that can be taken in the future (light green line) but which require some preparation. Decisions (circles) represent points at which practices change or action is taken. Most pathways diagrams allow for several potential preferred pathways (yellow line) to be selected by stakeholders. As a general approach, adaptation pathways can be applied to almost any type of adaptation project.

Pathways planning draws on multiple sources of information. It provides a flexible framework that can be adapted to suit different problem contexts, and inputs can be scaled up or down according to the availability of resources and scope. Adaptation pathways generally rely on scenarios that provide descriptions (rather than predictions) of plausible futures that reflect different perspectives on development (Butler et al. 2016).

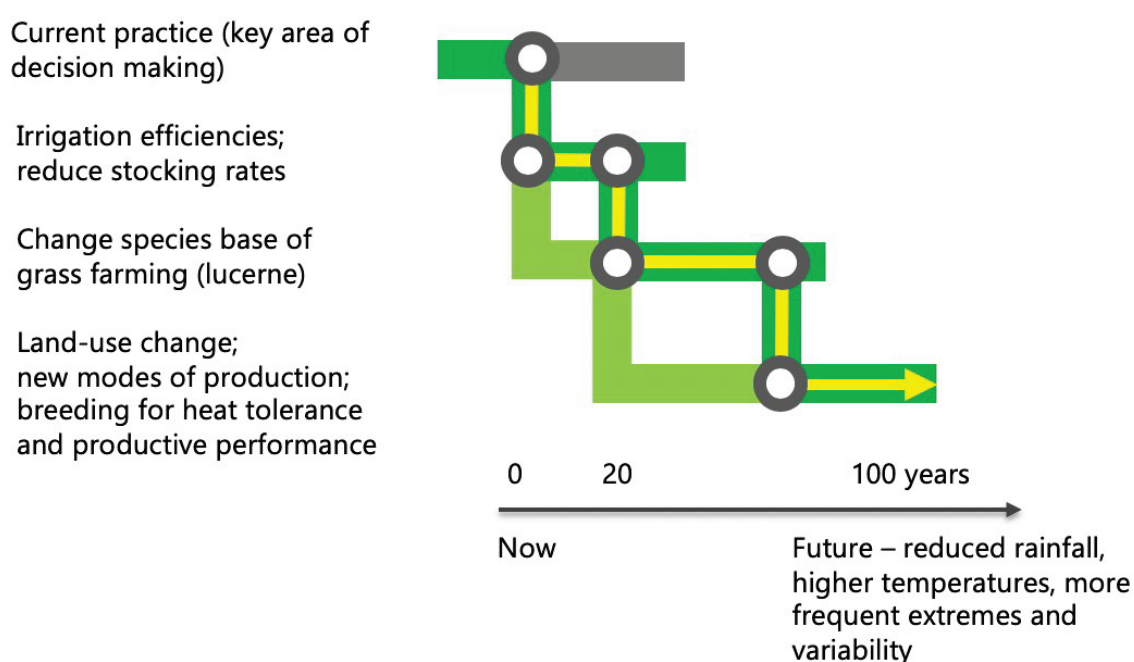


Figure 3: A simple adaptation pathway¹

The main features of a pathways approach is that it can take into account multiple possible futures (pathways) and foresee adjustments to plans as conditions change and new information is gathered. Advocates argue that adaptation pathways encourage people to explore and contrast the robustness of multiple options, while identifying tipping and trigger points across them to signal when a change is needed (Haasnoot et al. 2012, 2013; Kwakkel et al. 2015, 2016).

Triggers and adaptation signals are crucial for adaptation pathways. A trigger signals the point in time that current management strategies no longer meet objectives and new actions are needed (Stephens et al. 2018; Raso et al. 2019). These triggers might be biophysical (such as temperature change, or the appearance of a new pest species), or they might be socio-economic (such as loss of insurance,

¹ For more information on how to read the pathways diagram, please refer to section 6.1 and see also Figure 9.

or the inability of people to deal with increasing stress), or a combination of both (Haasnoot et al. 2013).

2.3 Pathways planning in the international literature

While there is an increasing number of examples of adaptation pathways in the literature, their use in real-world decision-making is still relatively limited (see Table 2 for an overview²).

Table 2: Applications of adaptation pathways approaches

Context/sector	Location	Reference
Water and flood management	New York	Yohe & Leichenko 2010; Rosenzweig et al. 2011
	Rhine-Meuse Delta (The Netherlands)	Delta Programme Commissioner 2011; Haasnoot et al. 2012
	New Zealand	Lawrence & Manning 2012; Lawrence et al. 2013
	Thames river and estuary (United Kingdom)	McGahey & Sayers 2008; Lowe et al. 2009; Wilby & Keenan 2012; Ranger et al. 2013
Coastal hazards (sea-level rise and storm surges)	Australia	Barnett et al. 2014
	New York	Rosenzweig & Solecki 2014
Resource management (agriculture, cropping, forestry)	Australia	Maru et al. 2014; Bosomworth et al. 2017; Prober et al. 2017
Livelihood strategies	Romania	Câmpeanu & Fazey 2014
	Indonesia	Butler et al. 2016
Urban heat risk	London	Kingsborough et al. 2017
Ecosystem management (urban lake/wetland)	Australia	Nanda et al. 2018

The two most well-known examples of applying pathways approaches to decision-making are for large infrastructure projects and managing floods, droughts and sea-level rise in the Rhine-Meuse Delta and Thames estuary river catchments (Haasnoot et al. 2012; Ranger et al. 2013). In the Rhine-Meuse Delta example in The Netherlands, having the right amount of water in the right place at the right time, at a socially acceptable cost, was the agreed objective. Four water-related scenarios were initially developed for The Netherlands that covered two representations of future climate for the extent of sea-level rise, rainfall, flooding, water-table changes, saltwater intrusion, and temperature change. These biophysical scenarios were then used to inform socio-economic scenarios relating to population growth/decline and associated impacts on water use and demand for water in various sectors (agriculture, industry, drinking water, environmental).

Following this, a range of actions (pathways) were identified that included things like raising the level of dykes, increasing the capacity of pumps, changing the distribution of water in the system, and moving to drought- and salt-resistant crops to reduce agricultural water demand. These actions (pathways) were then evaluated for effectiveness, cost, and the point in time at which they would no longer meet the objective (their 'sell-by date'). The final steps involved considering the various actions to identify a series of preferred pathways, and developing relevant triggers and a monitoring plan (Haasnoot et al. 2012).

The Rhine-Meuse Delta and Thames estuary examples are both at national scales, with high levels of political support and access to significant resources for the modelling and comparison of different

² Not all of the examples listed in Table 2 applied pathways approaches to real-world decisionmaking. Some are desk-based case studies/analysis using pathways for modelling purposes and do not involve engagement with affected stakeholders to agree on objectives, decide actions, and confirm triggers.

pathways. There is debate in the literature as to whether pathways approaches are applicable at other scales, institutional settings, cultures and resource-scarce areas (Bosomworth et al. 2017). Given the concept's newness, there are also no longitudinal studies demonstrating what is required to actually implement adaptation pathways over time, with some suggesting that the more transformational pathways will be the hardest to implement (Butler et al. 2016).

Finally, there have been few studies that apply pathways to livelihood planning or the primary sector. A recent exception is Prober et al. (2017), who used adaptation pathways and a 'values-rulesknowledge' (VRK) framework to develop biophysical pathways for agriculture in south-eastern Australia. Their adaptation options included shifts from cropping grazing to rangeland grazing or biomass enterprises, and planting natives and other exotic trees to maximise ecosystem services. They used VRK to identify the social, institutional (rules) and knowledge barriers to implementing these pathways, and found that concerns around farm viability, environmental legislation, and conflicting values about exotic plants would need to be addressed to implement the adaptation pathways.

2.4 Dynamic Adaptive Policy Pathways and coastal hazards in New Zealand

Adaptation pathways have received some attention in New Zealand in recent years, particularly in relation to coastal hazards. Dynamic Adaptive Policy Pathways (DAPP) is a pathways planning framework to support decision-making in the face of deep uncertainty. The DAPP process has been primarily used to help communities plan for flooding and coastal hazards associated with sea-level rise (Haasnoot et al. 2019). It begins with the identification of objectives and problem definition, and then uses scenarios to assess options across multiple futures.

A version of DAPP has been applied in the context of coastal hazards in New Zealand, including Hawke's Bay (Lawrence et al. 2019). In New Zealand, district and regional councils have a statutory responsibility under the Resource Management Act 1991 (RMA) for integrated planning and resource management, as well as a general requirement to avoid, remedy or mitigate natural hazards as a matter of national importance. The New Zealand Coastal Policy Statement (NZCPS) is the only national statutory directive for local decision makers that includes specific direction for climate change adaptation at the coast for sea-level rise and associated storm surges. A requirement of the NZCPS is that district and regional plans must give effect to the NZCPS's objectives and policies.

In addition to these statutory requirements, there is also a range of non-statutory national guidance on coastal hazards and climate change for implementing the NZCPS (see Ministry for the Environment, 2017a, 2017b). While these provisions technically empower councils to plan for and manage the effects of climate change at the coast, in practice this has not really occurred, especially for decisions that have long lifetimes (e.g. subdivisions, buildings, infrastructure and existing uses) (Lawrence et al. 2018). There are a number of reasons for this: the contested and long-term timeframes of climate change, development pressures in coastal areas, short-term political cycles, inadequate use of statutory instruments and methods for public engagement, and un-coordinated governance (Weber 2010; Lawrence et al. 2018).

In response to the increasing adverse effects of sea-level rise on coastal parts of Hawke's Bay and the NZCPS requirements, three councils (Hawke's Bay Regional Council, Napier City Council and Hastings District Council) formed a non-statutory committee to develop a 100-year Coastal Hazards Strategy. The strategy development was enabled through the participation of researchers from the 'Living at the Edge' programme, part of the Resilience to Nature's Challenges National Science Challenge, who worked with local communities, technical advisors, elected councillors and iwi/hapū to develop and apply a DAPP process (Figure 4) (Kench et al. 2018; Lawrence et al. 2019).

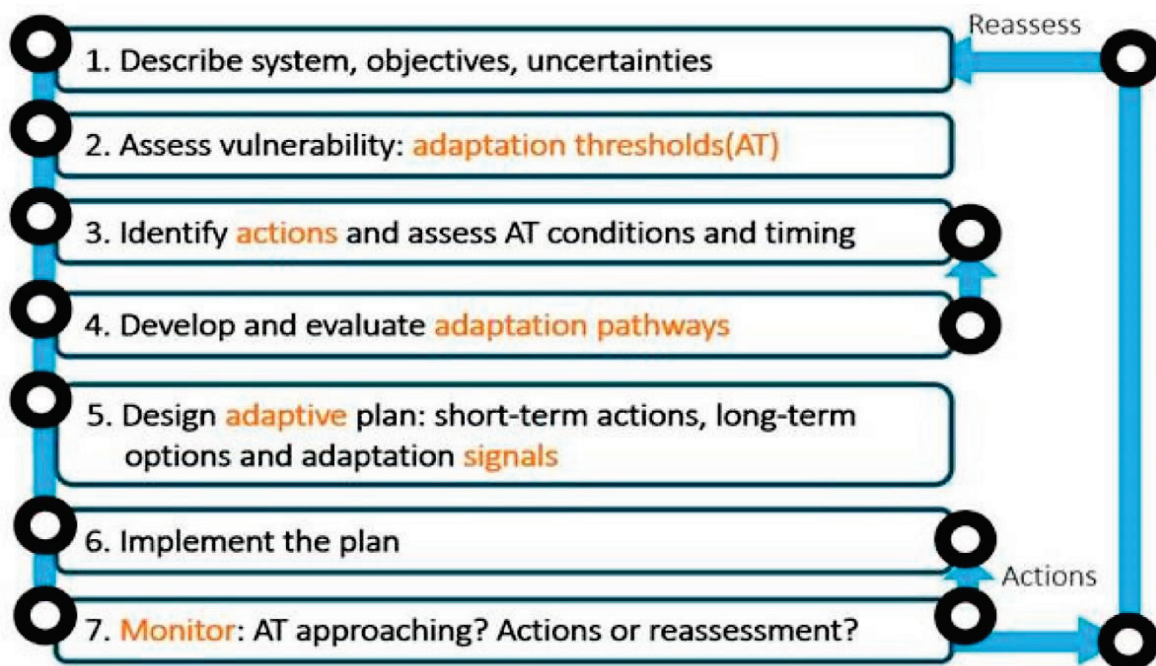


Figure 4: The Dynamic Adaptive Policy Pathways process applied to coastal hazards management in Hawke’s Bay. (Source: Lawrence et al. 2019)

Eighteen possible adaptation actions were identified, including no change, seawalls, beach nourishment, engineering options, and managed retreat. These actions were then evaluated to create a shortlist that was used to develop up to six pathway sequences for each coastal area on the basis of technical feasibility, practicality to implement, and ability to adapt over at least a 100-year period without locking in dependencies. Real options analysis and multiple-criteria decision analysis were used to evaluate the relative costs of the potential pathways to help inform the committee and the wider community.

This is the only example of local councils in New Zealand using the DAPP process to develop a framework for decision-making. Lawrence et al. (2019) note that the process enabled people to understand that a greater range of options was available, rather than the traditional either/or approach to future planning. However, they also identified a range of ways the process could have been improved. They conclude by suggesting that although DAPP is resource intensive, the costs of doing nothing and responding reactively to climate hazards will be much higher and result in worse outcomes for coastal communities.

2.5 Pathways planning and primary industries

As discussed above in relation to coastal hazards, most adaptation pathways approaches have focused on narrowly defined issues for a single sector or primary stressor (e.g. sea-level rise). There are few examples of pathways being applied to interacting and cascading effects, such as the interaction of flooding, drought, temperature changes, pest and biosecurity incursions, and volatile global markets for primary industries (Kwakkel et al. 2015; Cradock-Henry, Frame et al. 2018). While existing examples of adaptation pathways provide useful guidance on how best to approach decisionmaking in uncertain conditions, the first adaptation pathways principle is that climate change and societal responses cannot be considered in isolation, but are components of dynamic, multi-scale social-ecological systems. For rural regions and primary industries, therefore, climate change adaptation is best considered in the light of contemporary and long-term issues that influence rural communities and their livelihoods (Butler et al. 2016; Cradock-Henry, Fountain et al. 2018).

Climate change adaptation research for New Zealand primary industries has largely focused on characterising the direct impacts of changes in climatic variables and implications for management (Cradock-Henry et al. 2019). Consequently, there is currently limited understanding about potential adaptation options for the primary sector, the effectiveness of these options, and how and when to make decisions about them. Cradock-Henry et al. (2019) note the following specific gaps:

- the ability of pastoral farming to adapt to the increase in range across climate impacts and compounding hazards such as earthquakes (Stevenson et al. 2017; Cradock-Henry, Fountain et al. 2018; Cradock-Henry & Fountain 2019)
- the effect of heat stress on animal health
- the effects of climate change on biosecurity and primary industries (Kenny 2011)
- adaptation options for arable cropping, horticulture and viticulture – for some crops, warmer temperatures may result in higher yields, but this may be offset by increased water demands and competition, changes in frosts and loss of winter chilling (Cradock-Henry, Frame et al. 2018; Tait et al. 2017), and an increase in pests and disease (e.g. apple black spot) (Beresford & McKay 2012) or pollination (Howlett et al. 2013)
- adaptation options for high-value horticulture (to date research has focused on kiwifruit production) (Cradock-Henry 2017).

Successful adaptation will require in-depth understanding of the links between different industries due to complex interdependencies such as reliance on irrigation and land-use restrictions. To support adaptation planning, industry-specific information, regionally based options and pathways that reflects specific geographical and social contexts are needed (Cradock-Henry et al. 2019). Adaptation pathways provide a useful method by using integrated socio-economic, policy, and climate change scenarios to engage people in thinking about multiple futures and make decisions despite uncertainty.

It is important to acknowledge the limitations of pathways planning, particularly in relation to the complex socio-political dynamics that shape adaptation decisions (Bosomworth et al. 2017; Cradock-Henry, Frame et al. 2018). Authentic and in-depth engagement with affected communities, stakeholders, scientists and indigenous knowledge holders is central to pathways planning. Such engagement is essentially a political process (Bosomworth et al. 2017), and the ability to reach some kind of consensus at each stage needs to be transparent at different regional and temporal scales (Bloemen et al. 2018).

The socio-political challenges to reaching consensus are under-explained in most pathways literature, which tends to imply that goals are agreed and the actions to achieve them are largely technical and uncontested (Bosomworth et al. 2017). These authors note that there has been little to guide decision makers when engaging with contested goals and values, or knowledge uncertainties. Similarly, Câmpeanu and Fazey (2014) suggest that there has been less emphasis on the human dimensions (practices, beliefs, and decision-making processes) that shape adaptation pathways.

Finally, in most pathways there will need to be a transition from incremental to transformational actions, but there is not much evidence on how to do this in practice (Bloemen et al. 2018). Notwithstanding these critiques, the empirical evidence – and our experience – supports the value of using pathways approaches to build capability and capacity, enhance learning, and develop a shared understanding of climate change adaptation issues with diverse stakeholders (Gidley et al. 2009; Chaudhury et al. 2012; Johnson et al. 2012).

3 Research methodology

To develop regional adaptation pathways, an integrated mixed-methods approach was used to provide a multi-pronged perspective on climate change adaptation. The research combined stakeholders' perceptions of climate risk, climate and biophysical modelling, and systems dynamics. There were five key activities (see Figure 5):

- define the objectives and desired outcomes
- understand the current situation
- analyse possible futures
- develop adaptation pathways
- implementation, monitoring and evaluation.

Given the purpose of this project, we only provide limited comment on implementation, monitoring and evaluation of the preferred pathways.



Figure 5: The process for developing adaptation pathways in Hawke's Bay.

The research focused first on gaining insight into the local context, including values, drivers of change, and potential climate change impacts, before aggregating the findings to the regional scale. Two catchments were selected in consultation with Hawke's Bay Regional Council to provide contrasting comparative studies: Wairoa, in northern Hawke's Bay, and Karamu, in central Hawke's Bay. The catchments present different soil and landscape characteristics (from steep, afforested, and erosion-

prone hill country to diverse lowland pastoral, arable and horticultural production), with differing socio-economic characteristics.

Comparative case studies involve the analysis and synthesis of the similarities, differences and patterns across two or more cases that share a common focus or goal in a way that produces knowledge that helps to answer causal questions such as how and why particular programmes or policies work or fail to work (Yin 2009; Augerot & Smith 2010; Matarrita-Cascante & Trejos 2013). They may be selected as an appropriate impact evaluation design when it is not feasible to undertake an experimental design, and/or when there is a need to explain how the context influences the success of programme or policy initiatives. Comparative case studies usually utilise both qualitative and quantitative methods, and are particularly useful for understanding how the context influences the success of an intervention and how best to tailor the intervention to the specific context to achieve the intended outcomes (Yin 2009).

The research combined top-down modelling of climate change and future impacts with a participatory bottom-up process of working with affected communities and other stakeholders to identify relevant impacts, options for adaptation, and preferences for the future. The bottom-up approach encourages communities to assess and identify their own vulnerability and coping capacities in order to produce recommendations grounded in the communities' reality. Füssel and Klein (2006) argue that this move reflects a change in informational needs, because the purpose of assessing vulnerability shifts from an impact assessment approach to one that focuses more directly on developing adaptation strategies. The latter emphasis, they state, is far more grounded in the social determinants of vulnerability, and has a stronger emphasis on stakeholder involvement.

This reasoning explicitly identifies that what makes one community vulnerable may have no bearing on the vulnerability of another, requiring locally grounded, flexible and responsive adaptation policy development (Ford & Smit 2004; Brooks et al. 2005; van Aalst et al. 2008). A number of studies of community vulnerability have adopted this format, which is able to incorporate stakeholders' knowledge and resource-use patterns, and is flexible enough to look beyond vulnerability to inherent coping capacity within the societies, drawing on historical experiences (Campbell & Beckford 2009; Bizikova et al. 2012; Hammond et al. 2013; Borquez et al. 2017;).

Closely related to this is a growing trend towards working more closely with stakeholders to assess and develop solutions for a range of land- and resource-management issues, and assessments are increasingly made at the local and regional scale (van Aalst et al. 2008; Bartels et al. 2012). Stakeholder input ensures that stressors or vulnerabilities that only stakeholders know about are identified, and that the community buy-in needed to implement any resulting adaptation strategies or policy changes is achieved (Malone & Engle 2011). Stakeholder involvement can be used in conjunction with other methods (case studies, indicators, etc.) (Barnett et al. 2014; Ross et al. 2015; Kench et al. 2018).

Downing and Patwardhan (2010) for example, suggest a grassroots, participatory approach in which stakeholders self-assess vulnerabilities and resilience. Similar bottom-up, place-based and community-specific approaches have been advocated elsewhere (Westerhoff & Smit 2009; Odemerho 2014; Wise et al. 2014; Cradock-Henry & Fountain 2019).

To complement insights derived from stakeholders and community members, the research contracted additional modelling to derive downscaled climate change information for the study area. Biophysical and crop modelling for selected primary industries in central Hawke's Bay was supplemented by the development of scenarios of future change and expert elicitation of likely impacts. A systems model was also developed, drawing on the results from stakeholder workshops, to formally articulate the stocks and flows of goods, services and capital between systems and sub-systems that form the basis of regional primary industries in Hawke's Bay.

The research proceeded stepwise, beginning with the definition of climate-ready objectives, using an adaptive management cycle with a pathways focus. An overview of the methodology is as follows.

- 1 To define the objectives and identify desired outcomes, we held workshops in the two case study catchments. The aim of these workshops was to develop a shared understanding of climate-ready objectives for local primary industries, and document stakeholders' desired outcomes with respect to future conditions.
- 2 To understand the current situation, workshop participants produced a series of 'rich pictures' illustrating their understanding of activities in the catchment and how these might be affected by climate change. The illustrations and workshop results are available in Appendix B. To gain

additional insight into the current situation and the ways in which primary industries would be affected by climate change, we synthesised workshop findings to develop a systems dynamics model for Hawke's Bay.

- 3 To develop and analyse possible futures, downscaled climate projections for Hawke's Bay were produced. The climate projections were used to inform two scenarios of future change, using a medium- and high-emissions scenario. Structured interviews with experts from arable cropping, horticulture, forestry and pastoral farming were conducted to elicit knowledge on potential impacts for key characteristics of different primary industries. Through close collaboration with a Deep South/Our Land and Water and Deep South National Science Challenges funded project on land-use change, we also produced modelled findings for selected crops, including maize, kiwifruit and wine production. The modelling results, interview data and workshop findings were analysed to identify four priority areas for decision-making. These were then used in workshops with stakeholders to identify adaptation options.
- 4 Preliminary adaptation pathways were developed in a workshop with stakeholders. Additional adaptation options were identified based on literature review, the results of expert interviews, and previous work by members of the research team, and then incorporated into the second-order drafts. These draft pathways were presented in a workshop setting, and the adaptation options were assessed and refined. The resulting data were recorded, and preferred pathways were identified indicating potential priority areas for decision makers' attention.
- 5 The implementation of the preferred pathways will require coordination from sector, local and regional government, and other stakeholders. We provide some guidance in the concluding section of this report to help facilitate monitoring and evaluation, and to enhance opportunities for further learning.

In summary, the following methods were used in combination to conduct the research:

- participatory workshops with stakeholders and end-users in two case study catchments and wider, regional-level workshops ($n = 5$) – downscaled climate modelling for Hawke's Bay
- desktop analysis and review to identify relevant adaptation options for the primary sector
- expert interviews with researchers and primary industry stakeholders to assess the potential for adaptation, barriers and enablers, and drivers of change in their respective industries
- biophysical modelling for selected cropping and horticultural systems in the Karamu catchment to assess changes in production and yield under future climatic conditions, and to identify potential adaptation options
- systems dynamics modelling to further explore the interaction between primary industries in Hawke's Bay.

Figure 6 summarises the application of the research methodology.

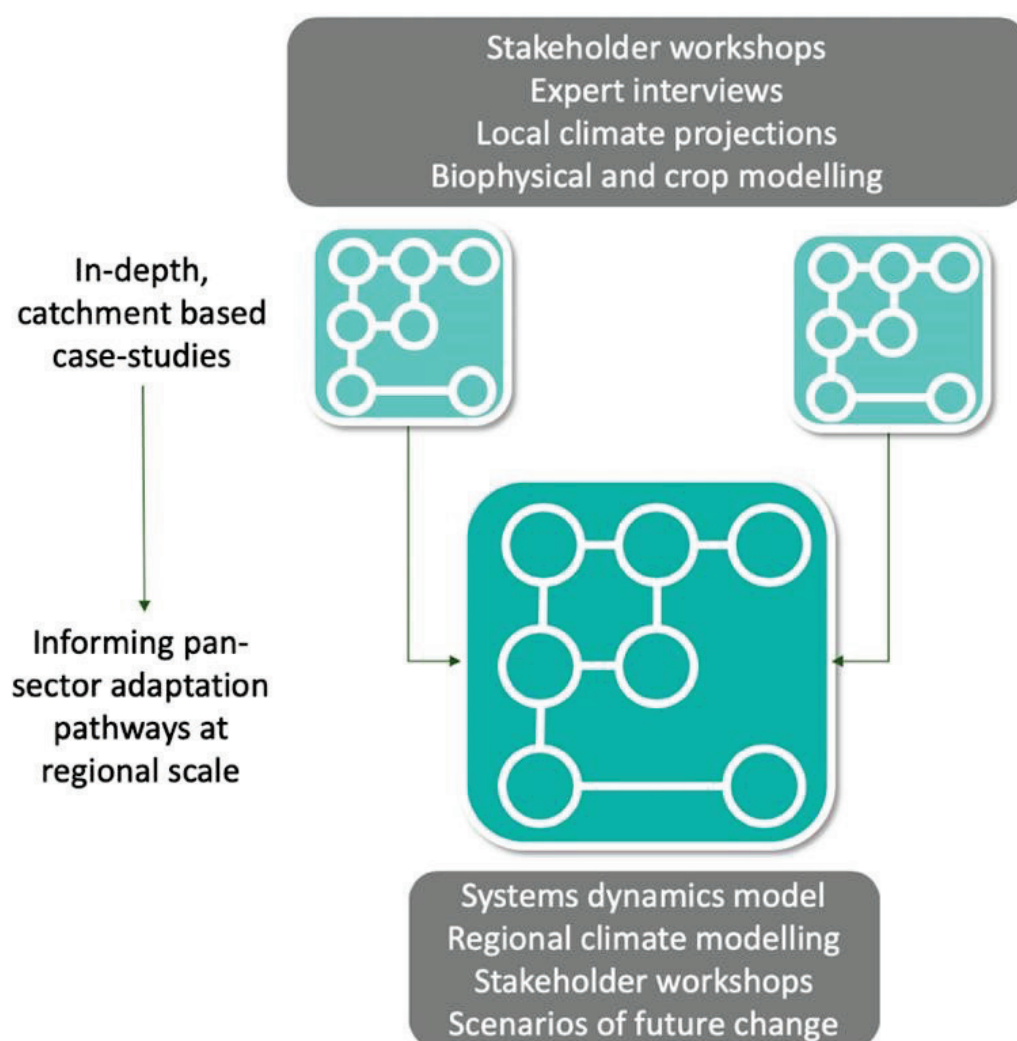


Figure 6: The research methodology.

The relevance and use of each of these tools and methods are briefly described here. We begin by first discussing the case study setting, including an overview of Hawke's Bay and the two catchments that were the initial focus of the research.

3.1 Regional context for adaptation planning

Hawke's Bay covers 14,200 square kilometres and includes parts of the central North Island mountain ranges to the north and west, 350 kilometres of diverse coastline, productive plains and hill country, and native forest. There are seven major rivers that flow through the region; from north to south: Wairoa, Mōhaka, Esk, Ngaruroro, Tūtaekurī, Tukituki, and Waipawa. The region is one of the most seismically active parts of New Zealand because it sits close to the intersection of the Australian and Pacific tectonic plates (Pollock 2015). Approximately 80% of the region is hill country or mountainous terrain, and 12% is flat to gently rolling land built up from sedimentary material deposited by rivers and ocean processes. The largest flat areas form the Ruataniwha and Heretaunga plains just south of Napier (Hawke's Bay Regional Council, N.D.). There is one regional council (Hawke's Bay Regional Council) and four local councils (Wairoa District, Hastings District, Central Hawke's Bay District, and Napier City) (Pollock 2015).

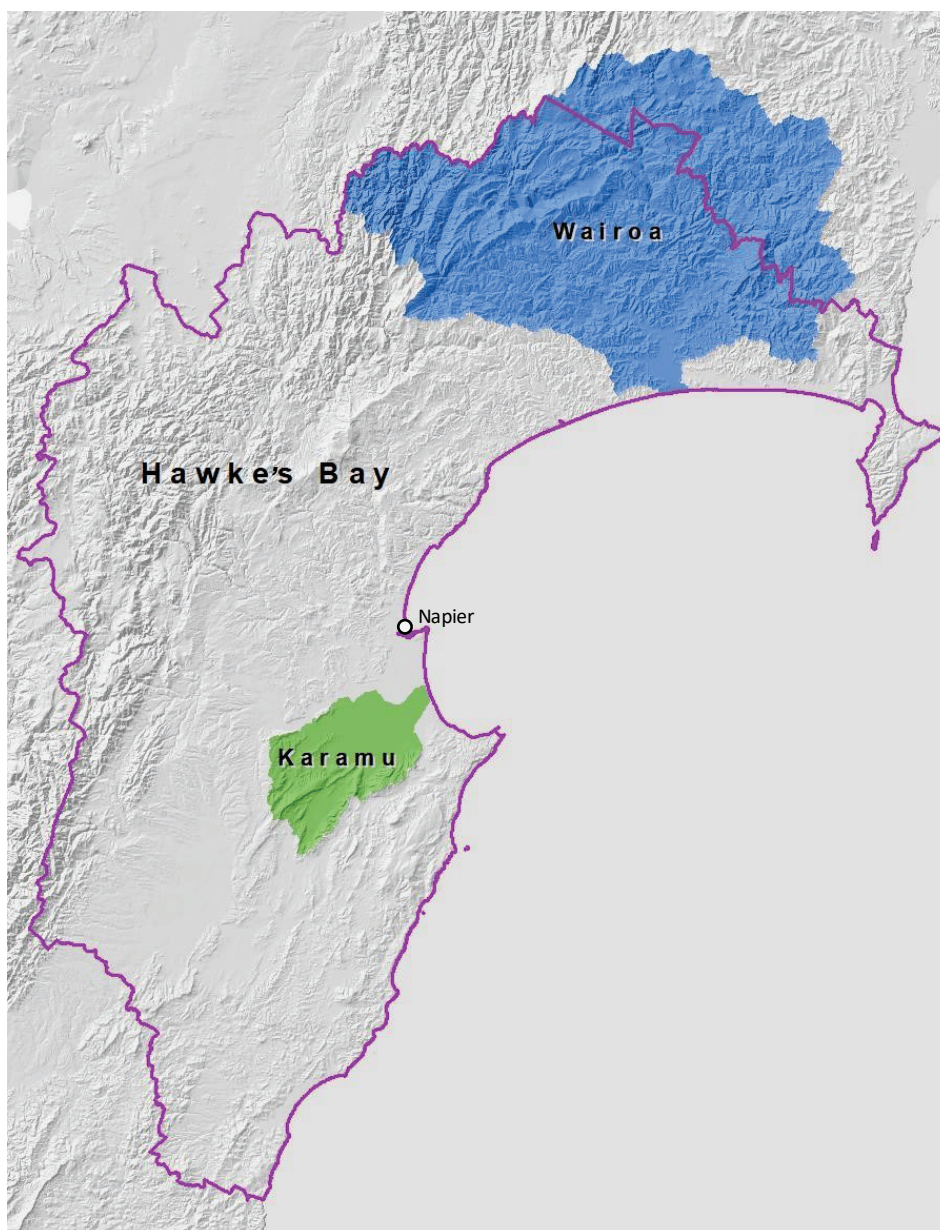


Figure 7: Case study region, Hawke's Bay and focus catchments.

Hawke's Bay has a mild, Mediterranean-type climate (dry and warm). Summer is generally sunnier and hotter than New Zealand averages, with temperatures higher in the eastern lowland plains and cooler in the western hill country and mountain ranges. The ranges shelter Hawke's Bay from prevailing westerly winds resulting in a relatively low mean annual rainfall (~1000 mm) and one of the lowest number of rain days in the North Island (Fowler et al. 2013). While winters are usually mild, frosts and occasional snow do happen. The region tends to experience long, dry periods and regular droughts, with average precipitation highest in winter and December. Table 3 provides a snapshot of average climatic conditions for Napier³. Localised rainfall patterns are closely related to elevation and exposure to predominant air flows, with the inland hill country and mountains getting the most intense and frequent rainfall and the central plains receiving the least. Areas with high annual rainfall (over 2,000 mm per year) include the Ruahine, Kaweka and Huiarau ranges, while the Heretaunga and Takapau Plains receive less than 800 mm of rain per year on average. Because of the high variability in rainfall patterns, flooding is a regular issue, especially for the lowland Ruataniwha and Heretaunga river plain catchments, which have a range of flood control measures in place (Pollock 2015). The

³ These averages for Napier do not apply to other parts of the region due to significant differences in topography and climatic conditions.

western ranges create relatively sheltered and calm conditions for most of the region, although there is a tendency for wind to be funnelled through river valleys. In central and southern Hawke's Bay the predominant wind directions are from the west or southwest along the Heretaunga and Takapau Plains. Extreme weather events do occur relatively frequently in Hawke's Bay and include ex-tropical cyclones and thunderstorms (Chappell N.D.).

Table 3: Napier climate (averages)

Month	Precipitation (mm)	Average temperature	Sunlight hours
January	45.8	23	8.03
February	60.2	23	7.17
March	87.6	21	6.36
April	67.5	19	5.26
May	64.1	16	4.38
June	90.2	14	4.48
July	84	13	4.30
August	78.6	14	5.13
September	66.4	16	6.22
October	51.6	18	6.44
November	47.3	20	7.22
December	66.4	22	7.56

Source: ClimaTemps. N.D.

In terms of soil moisture, the high evapotranspiration and lower rainfall in summer mean that irrigation or watering is usually necessary for plant growth from late spring to early autumn. The need for irrigation is most pronounced on the Heretaunga Plains, which on average have about 95 days between November and April when there is insufficient soil moisture to maintain plant growth without irrigation. Further north in Wairoa this reduces to approximately 43 days when irrigation is usually needed for plant growth (Chappell N.D.).

The most recent 2013 Census data put the population of Hawke's Bay at 151,179, with approximately 81% of people living in the Napier–Hastings conurbation. The remainder of the region, particularly the northern and western areas of Wairoa, is sparsely populated. The region has a long history of Māori settlement, with Ngāti Kahungunu being the oldest and largest iwi in the area. Consequently, Hawke's Bay has a high proportion of people who identify as Māori (24.2%) compared to the New Zealand average (14.9%), and there are a significant number of marae and Māori settlements (Pollock 2015). While there is wealth in the region, this is unevenly distributed, with vineyard owners, food producers and traditional farming families earning significantly more than the rest of the population, who, on average, earn less than the national median income. This inequality is particularly pronounced in certain areas, such as parts of urban Napier–Hastings and Wairoa. The effects of this inequality play out in a range of socio-economic indicators. For instance, a 2008 study found that the health of Hawke's Bay residents was generally poorer when compared to other parts of New Zealand (Pollock 2015).

The Hawke's Bay economy has relied primarily on land and primary production since the colonisation of New Zealand by Pākehā. Historically, pastoral farming (sheep and beef) and horticulture have been the major industries. The relatively accessible and fertile river plains of the region initially attracted farmers, who significantly modified the landscape, clearing native forest and draining wetlands before modifying the hill country. Most of the remaining native forest in the region is found on the western mountains surrounding Lake Waikaremoana, located in Te Urewera. Socio-economic changes since the 1980s have seen an extension of red wine- and chardonnay-producing vineyards, and the region is now the second-largest wine-growing area in New Zealand after Marlborough.

3.2 Case study catchments

Two case study catchments were selected in consultation with Hawke's Bay Regional Council staff. The two catchments – Wairoa and Karamu – are broadly representative of the issues facing rural communities in Hawke's Bay, and are exemplars for other regions dependent on primary industries. The regions are a study in contrast and diversity with respect to land management and primary industries. Both face a number of inter-related challenges, including climate change adaptation, soil erosion, drought, water availability, and social and economic vulnerability. One (Wairoa) is a remote, hilly, and erosion-prone region; the other (Karamu) is flat, with diverse land uses focused on high-value horticultural and viticultural production.

3.2.1 Central Hawke's Bay (Karamu, Heretaunga Plains)

The Karamu catchment comprises 51,462 hectares, extending south from Awatoto to Havelock North and west to the Raukawa Range (Figure 7). The Karamu Stream and its tributaries drain the Poukawa Basin, the Kohinurākau, Kaokaoroa and Raukawa Ranges, and a large part of the Heretaunga Plains. The Heretaunga Plains are a 320-square-kilometre alluvial plain in the central south of Hawke's Bay that contains the major conurbation of Napier, Hastings and Havelock North. The plains consist of approximately 300 m-deep sediment deposited by the Tūtaekīurī, Ngaruroro and Tukituki rivers and from coastal marine deposits as sea levels rose and retreated. The sediment is composed of permeable layers of gravel, sand and silt, and there are extensive aquifers and artesian groundwater that provide approximately 85% of the requirements for public water supply and irrigation and industrial use for the area. The Plains soils are fertile, and the relatively dry and protected climate and underground water supply are ideal for horticulture and agriculture, including vineyards. Consequently, the area is the most intensively farmed part of Hawke's Bay and contains the majority of the region's crops, orchards, and vineyards (Land Air Water Aotearoa N.D.). The southwestern half of the Karamu catchment primarily supports dryland sheep and beef, with the exception of the Poukawa Basin, which is a significant cropping area (Hawke's Bay Regional Council N.D.).

As of 2013 approximately 73,245 people lived on the Heretaunga Plains, which is the most heavily populated part of the region. The median personal income was \$26,500, which is slightly higher than the wider Hawke's Bay median but lower than the New Zealand median (Statistics New Zealand 2013). Over the last 20 years there has been much debate about how best to protect the valuable fertile soils while enabling urban expansion, particularly around Hastings. Similar to pressures surrounding land use, there has also been increasing pressure and debate about how to manage the Heretaunga aquifer, which is the largest groundwater resource in Hawke's Bay. As noted above, the Heretaunga Plains are the hottest and driest parts of Hawke's Bay, and approximately 55% of the water taken from the aquifer is used for irrigation while about 22.5% is used for municipal supplies. Many crops grown on the Heretaunga Plains are dependent on irrigation water, and the prevalence of droughts has significant effects on the viability of these crops. For example, the 2013 droughts saw many growers facing restrictions and crop loss.

One focus has therefore been on improving irrigation practices to make better use of limited water (Hawke's Bay Regional Council N.D.). Hawke's Bay Regional Council manages consents for water take, and while it is not known what constitutes a sustainable take from the Heretaunga aquifer, there has been a slow decline in aquifer levels and a gentle increase in the amplitude of seasonal fluctuations over the last 45 years (Land Air Water Aotearoa N.D.). Consequently, there has been substantial public debate about how best to ensure the health of the aquifer, the amount of water that can be taken, and the kinds of land use most appropriate on the plains to manage both the aquifer and streams and rivers. For instance, the water quality and ecology in the Karamu Stream system around Hastings is generally poor, with high levels of nitrogen, nitrate-nitrogen, and phosphorus, and high levels of *Escherichia coli* (Hawke's Bay Regional Council N.D.2). Many argue that horticulture remains one of the best land-use options for the Heretaunga Plains because it is an efficient use of water (particularly tree and vine crops) as opposed to the more water-intensive meat and milk farming.

3.2.2 Northern Hawke's Bay (Wairoa)

Wairoa District is the northern-most part of Hawke's Bay, covering an area of 4,120 square kilometres, and it is the largest catchment in Hawke's Bay (Figure 7). The district is characterised by low-lying coastal land to the east and mountainous hill country to the west, with what was formerly known as Te Urewera National Park in the north-western corner. The Wairoa catchment is characterised by fine, soft, sedimentary geology. The soils have relatively low infiltration rates, which, combined with

localised extreme rainfall (particularly in the hills), can create a 'peaky' hydrological regime with relatively low base flows but high-magnitude floods. The land use is split between native forests in the northwest (approximately 45% of the total area), plantation forestry (9%), and agricultural grassland (42%) towards the southeast, with some orchards and cropping to the east near the coast (<1%) (Hawke's Bay Regional Council 2016).

An estimated 7,890 people live in the Wairoa District, although the population has been declining since 2006. The median personal income is the lowest in Hawke's Bay (\$21,973) and the population has a higher than average number of children, young people and older people compared to national averages, with a very high proportion of people who identify as Māori (approximately 4,689, or 62.9% of the population). Like other rural areas of New Zealand, the district was hit hard by restructuring in the 1980s and has had persistent low employment and education indicators compared to national averages since the 1990s. However, as Smith (2019) notes, there is also a strong informal economy, with significant volunteering and community connectedness in the district that helps support local livelihoods.

Notwithstanding these community strengths, there has been ongoing debate in the district about the need for more employment opportunities, particularly for younger people. While agriculture, forestry and fishing are the key employers in the district (employing 22.7% of the population), there has been local debate about the relative merits and over-reliance on these industries – especially plantation forestry. For instance, while the majority of the agricultural grassland in the district is used for sheep and beef (98%), over the last 30 years the number of individual farms has decreased (from 454 in 1990 to 330 in 2017) as farms have become larger, and stock numbers have decreased. Since the 1990s there has been an increase in forestry plantation, partly in response to market changes and the profitability of pastoral farming, and concerns around the erosion of land. However, because there is no wood processing or manufacturing in the district and local roads and infrastructure are limited, some argue that the forestry sector is not able to provide the stable, well-paid local jobs that farming once did and is contributing to a 'hollowing out' of the community. Consequently, there has been an emphasis at the local level on growing business and employment opportunities that are not solely reliant on the agricultural sector. These desires to diversify the economy have evolved alongside increasing concerns about an over-reliance on primary production and volatile markets, the implications of climate change on agriculture, and increasing concerns about environmental degradation, particularly of freshwater (Smith 2019).

The dominant land uses in the Hawke's Bay region and focus case study catchments are shown in Figure 8. Pastoral is a key land use in both case study catchments, representing 38% to 62% of the available land area. The Karamu catchment has a more diverse mix of land-use options, including approximately 16% as perennial horticulture and 12% short rotation cropland. The Wairoa catchment includes approximately 8% as exotic forestry.

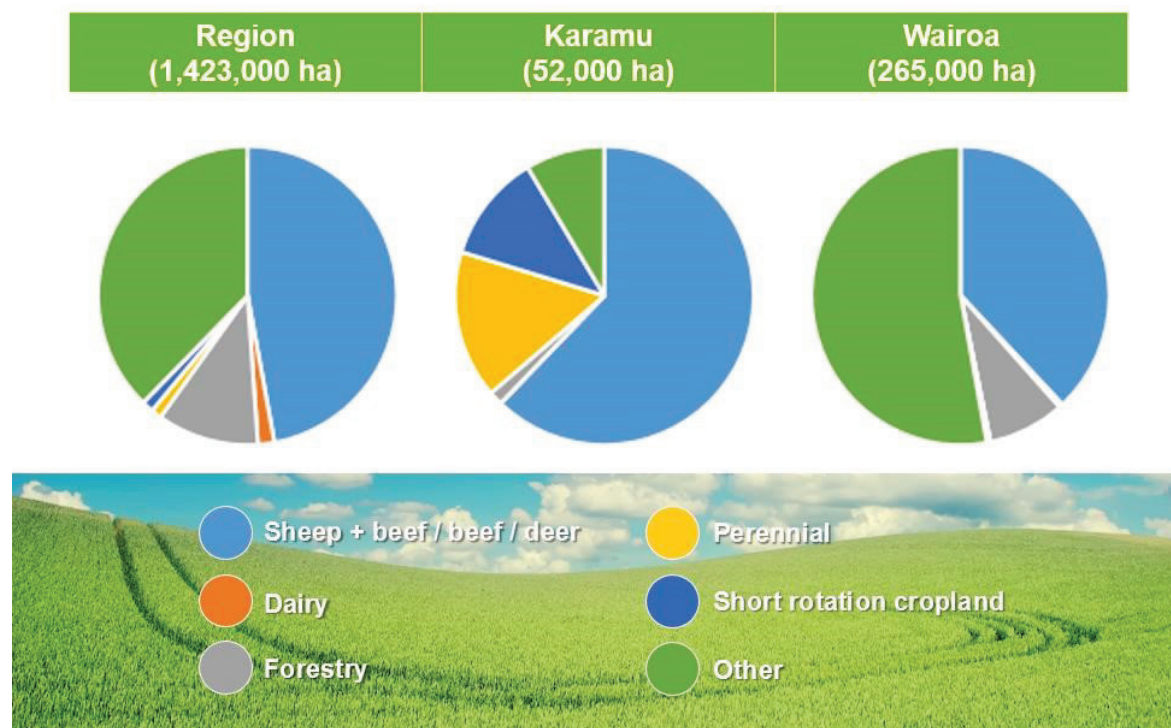


Figure 8: Land-use estimates for Hawke’s Bay and the case study catchments (Karamu and Wairoa). Other land uses include all land in the catchment not considered in either the sheep + beef/beef/deer, dairy, forestry, perennial or short rotation cropland categories (e.g. built-up areas, lakes, indigenous forest) (Hawke’s Bay Regional Council 2016)

The distribution of land uses across the region reflects soil types, topography and growing conditions. The Ruataniwha and Heretaunga plains are intensively farmed, with fruit orchards and vineyards where water and climatic conditions are most ideal, while in the central and southern parts of the region open paddocks and pastoral farms dominate (Pollock 2015).

Hawke’s Bay has generally had strong economic growth over the last decade (Hawke’s Bay Regional Council 2016), but experienced significant socio-economic changes during the late 1980s and early 1990s. The removal of agricultural subsidies in the 1980s significantly affected many sectors and jobs, particularly outside the major urban centres. For example, the closure of the Whakatū and Tōmoana freezing works in 1986 and 1994 resulted in the loss of thousands of jobs (Pollock 2015). In terms of key industries today, agriculture and manufacturing employ the largest numbers of people. Horticulture (particularly fruit growing) is the single largest agricultural employer, followed by sheep and beef farming. Meat processing is the largest employer in the manufacturing sector, followed by fruit and vegetable processing. The Heinz-Wattie’s manufacturing and processing factories have a long history in Hawke’s Bay and continue to be a key employer. While dairy farming is significant in parts of the region, this tends to be relatively localised, and the region has not experienced the level of conversions other parts of New Zealand have seen (such as Canterbury). There is some exotic forestry, but most plantation owners are large overseas companies or farmers with small farm forests.

3.3 Stakeholder workshops

Two workshops in each of the case study catchments, and a regional workshop to synthesise findings and assess the pathways, were conducted. Additional information about the workshops is available in Appendix B. The following provides a brief overview of the objectives and methodology of each of the workshops.

Workshops 1 and 2 were used to introduce the aims and objectives of the research project, and to develop a shared understanding of local values and the way in which stakeholders perceived these to be affected by climate change. Following a brief introduction about the project, participants were invited to work in groups to develop a ‘rich picture’ of the local environment, with an emphasis on how

they perceived the function of primary industries. When developing their illustration, participants were asked to reflect on the resources (including ecosystem services, human capital and infrastructure) required; the current challenges to production; and the inputs at various points along the value chain, from farm to market.

The second part of the workshop was used for a structured conversation and further refinement of the drawings to understand how the system would be affected by climate change. A short presentation on future climate for Hawke's Bay was delivered, along with results from biophysical modelling.

Participants were then asked to consider how the productive sector might be affected, the implications for their respective region(s)/sector(s), and key challenges and opportunities.

Workshops 3 and 4 were used to develop draft pathways diagrams. The workshops began with a review of the systems diagrams from Workshops 1 and 2, followed by a more detailed discussion of climate change impacts and implications. We then undertook a facilitated brainstorm discussion with participants to identify adaptation options for key challenges and opportunities. Participants were encouraged to 'think big', beyond incremental or short-term changes, to consider potential transformational adaptations and long-term strategic options. Following the brainstorming, the options were clustered, and then sequenced over time. We used broad temporal categories at this stage to organise adaptation actions by timing: which options could be implemented 'now' (present time and roughly ten years into the future), 'later' (30 years, nominally mid-century and which includes the next few cycles of council Long Term Plans, and planning time frame for local government infrastructure strategies) and or 'much later' (30-50 years, late-century, in line with requirements for planning and assessing risk for long-lived or major new/upgraded infrastructure and approaching planning timeframes that councils must give effect to in assessing coastal risks in district and regional plans, regional policy statements and resource consents under the NZ Coastal Policy Statement (2010). Preliminary pathways were sketched out as a group for further iteration by the research team.

3.4 Climate modelling

Downscaled climate data for Hawke's Bay region were generated to inform stakeholder workshops, assess anticipated changes in key climate variables, and provide a basis for identifying and assessing suitable adaptation options.

Global climate model output based on two representative concentration pathways (RCPs) was downscaled to produce future projections for temperature, precipitation, evaporation and wind for the Hawke's Bay Region. RCP 4.5 is a low to mid-range emissions scenario, which is also called a 'stabilisation' scenario, where radiative forcing stabilises by 2100. RCP 8.5 is a scenario with very high greenhouse gas emissions, and radiative forcing continues to increase beyond 2100. Each RCP provides spatially resolved data sets of land-use change and sector-based emissions of air pollutants, and it specifies annual greenhouse gas concentrations and anthropogenic emissions up to 2500, although only changes to 2100 were considered. RCPs are based on a combination of integrated assessment models, simple climate models, atmospheric chemistry, and global carbon cycle models.

The climate change scenarios were generated by NIWA, who used climate model data from the IPCC Fifth Assessment (IPCC 2013) to update climate change scenarios for New Zealand, through a regional climate model (dynamical) process. The dynamical downscaling processes are described in detail in an updated climate guidance manual prepared for the Ministry for the Environment (Mullan et al. 2016), and are briefly discussed below.

All climate projections start as simulations by global climate models, which have coarse spatial resolution. Dynamical downscaling means using a higher-resolution climate model or weather prediction model to get finer-scale detail (5 km resolution in this report). Several different models are used to simulate future climate (six for dynamical downscaling). The projections from each of the models are averaged together, creating an ensemble average.

The results of the modelling describe climate changes that may occur over the coming century for Hawke's Bay. The results do not address the issue of mitigation (reducing greenhouse gas emissions, or increasing 'sinks', such as areas of growing forest).

Data for climate factors provided and discussed include temperature, precipitation, wind, and evaporation. The climate data (also available as GIS data files) provide an indication of what could occur within the region, how it might be affected, and how adaptation might occur. The complete report on downscaled regional climate is provided in Appendix D.

3.5 Desktop analysis of adaptation options

To supplement the adaptation options identified by stakeholders and workshop participants in stage 2, we drew on the results of parallel projects (Cradock-Henry, Blackett et al. 2018, Cradock-Henry et al. 2019). The desktop analysis identified relevant SLMACC project reports and literature focused on Hawke's Bay, and relevant primary industries (e.g. horticulture, viticulture, dairy). Desktop analysis and review were undertaken to identify additional adaptation options not identified in the workshops. The results were input into an XLS table and cross-referenced with workshop findings.

3.6 Expert interviews

To gain additional insight into local conditions, two scenarios were developed based on low- and high-emissions pathways, representing moderate and extreme changes in key climate variables (Table 4). Industry experts (farmers, growers and consultants) were provided with scenarios in advance, and phone interviews were conducted. Thirteen interviews, each interview lasting between 35 and 60 minutes, were conducted. The aim of the interviews was to gain expert insight into the significance of changes and the potential for sectors to adapt. The results of the interviews provided additional understanding of local issues and helped determine the selection of adaptation options for pathways.

Table 4: Focus of expert interviews

Focus catchments	
Climate change indicators	
Wairoa catchment: sheep + beef, beef, forestry •	Warmer – mostly summer and autumn
Karamu catchment: sheep + beef, beef, deer, short rotation cropping, perennial crops •	More hot days
	Fewer cold nights
	• Less rainfall, mostly in spring
	• More extreme rainfall
	• Flood risk
	• Potential evapotranspiration deficit (PED) storms
Issues of interest	
	• Productivity change estimate
	• Quality change estimate
	• Scheduling of operations • Cost of production
	• Risk of production failure
	• Land-use options

3.7 Biophysical and crop modelling

Downscaled climate projections for Hawke's Bay were supplemented with biophysical and crop modelling for selected activities. There is no single model for the different agricultural systems represented in the Hawke's Bay and existing models available are time-consuming to run and are still being actively developed by the research community. Therefore, a tiered-approach was used to generate insight into impacts for production using a suite of simple to complex models.

Key climate attributes (for both changes in average seasonal patterns and drought) that may affect production and impacts on the receiving environment in selected crops and variables were identified, drawing on information from climate projections, expert interviews, and stakeholder consultation.

Models generated information about the impacts of climate change on a selection of production systems and crops at the regional scale, as well as implications for selected environmental variables. The Agricultural Production Systems Simulator (APSIM; Holzworth et al. 2014) model was used to simulate both pasture and crops under future climatic conditions. For the horticultural sector, regional

trends were informed by bioclimatic indices at a national scale owing to resource and model limitations.

Results from the modelling were supported, in part, through an in-kind contribution from the project 'Climate Change Impacts on Land Use Suitability', funded by the Our Land & Water and Deep South National Science Challenges. Generalised findings from various model runs were used to develop scenarios for discussions with stakeholders, and for assessing the suitability of adaptation options during the final stages of the project.

3.8 Systems dynamics modelling

Climate change is expected to adversely affect primary industries, compounding existing vulnerabilities, creating new ones, and confounding decision-making. Although our understanding of potential impacts has improved, the capacity for identifying, evaluating and comparing adaptation options remains limited by poor integration of social and economic studies with biophysical impact assessments and an emphasis on individuals' adaptive strategies.

Systems thinking methodologies were identified as an approach that could bring together a range of insights sourced across various stakeholder workshops, and present them in an accessible and relevant manner. Systems thinking or 'systems dynamics' seeks to articulate and understand how systems function: what the crucial factors of a system are, their relationship with each other, and how the factors interact, interconnect, and function as a whole. The value of using systems thinking is that system boundaries are flexible and can be set at a scale that is appropriate to the question of interest. In this case, boundaries were drawn to include factors that influenced the function of primary industries in Hawke's Bay, broadly defined in terms of inputs and outputs.

Drawing on the stakeholder systems' diagrams and rich pictures from Workshops 1 and 2, we developed a systems model to represent the primary industries in Hawke's Bay (Figure 9). The model is an 'archetypical' system in that it accounts for core influences and tensions shared across both Wairoa and Central Hawke's Bay. The aim was to formalise stakeholders' tacit knowledge, perceptions of key drivers of change, and relationships between various components of primary industries' activities at the local and regional scales. The diagram represents all types of infrastructure for all the climate impacts considered. The systems map is also known as a causal loop diagram, since it shows dependencies and interdependencies.

The summary map shown in Figure 9 (overleaf) is broadly representative of the core influences and tensions shared Wairoa and Central Hawke's Bay. The relationships (arrows) link to various capital stocks. We chose to use capitals outlined in the Living Standards Framework (LSF) (NZ Treasury, 2018) to align the systems mapping with other initiatives.

The system map is focused on primary production, and depicts activities occurring in Hawke's Bay as primarily seeking a return on investment from a particular type of land-use. This productive land-use occurs within the natural capital constraints of the region. At the same time this land-use spurs investment in – and is constrained by the levels of – financial and physical, human and social capital.

Climate change is shown as shown as a stressor which will impact capitals directly through higher temperatures, climate variability and extremes; and indirectly through relationships with other parts of the system. These impacts are mediated through adaptive capacity, and adjustments made to moderate potential damages, take advantage of opportunities, or cope with consequences.

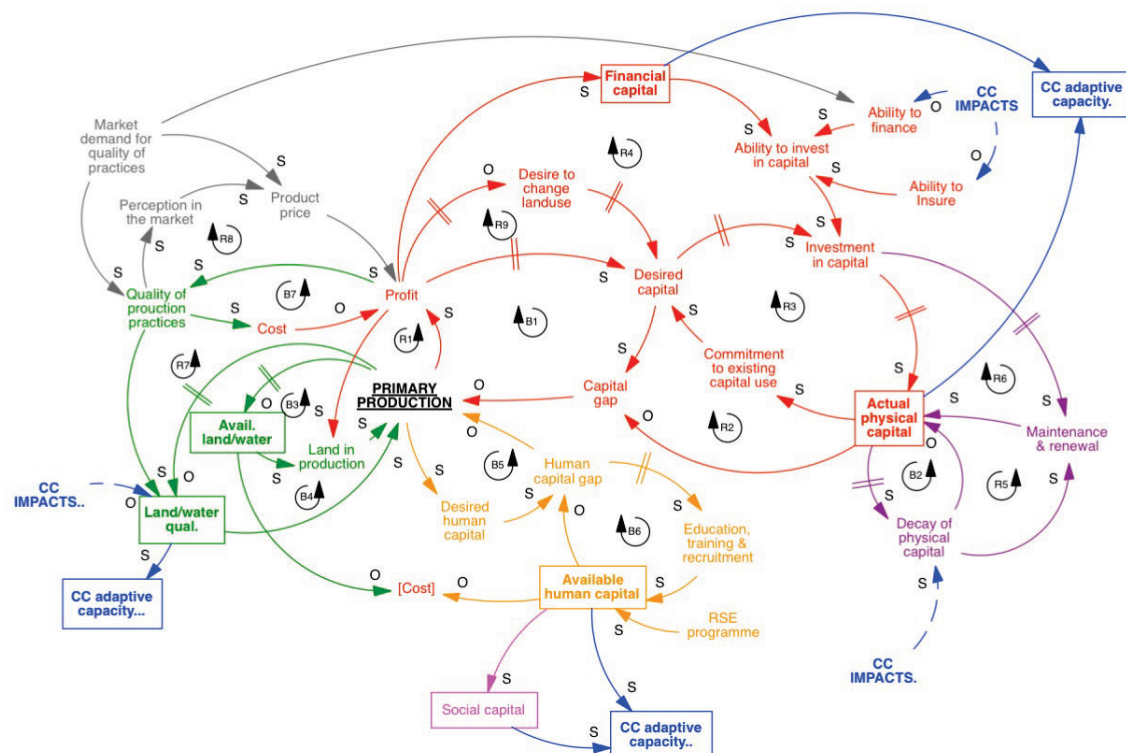


Figure 9: System map: climate change and Hawke's Bay primary industries.

Figure 9 is made up of the following. Financial and physical capital (including built infrastructure) is shown in RED. The arrows articulate relationships between primary production and profit fuelling more productive land and the increased desire for capital and subsequent investment in capital that this encourages. Natural capital including land and soil, water, plants, animals (NZ Treasury, 2018) is shown in GREEN, and represents available land and water and available water. Human capital is the other critical supporting capital shown in YELLOW. Human capital is best articulated as the things that enable them as an individual to participate fully in society. This is their skills, their knowledge and their mental and physical health (NZ Treasury, 2018). The human capital that was considered most relevant to primary production is predominantly the skills and knowledge required to work in an industry. While not fully explored in this system map, social capital (LIGHT BLUE) is also shown, representing the norms and values that underpin society (e.g. law, government, etc) (NZ Treasury, 2018).

The map also illustrates where climate change (DARK BLUE) is expected to impact primary production, affecting the quantity and quality of physical capital through increased storm events for example. Natural capital is also likely to be affected. Direct impacts on land (e.g. increased rates of soil erosion) or water may be experienced along with declining quality of natural capital. Climate change will also affect financial capital, in particular producer's ability to finance and ability to insure.

The final addition to the summary system map is adaptive capacity, also shown in DARK BLUE. Adaptive capacity is depicted as a function of the four major capitals: Financial and physical capital; natural capital; human capital; and social capital.

A full report on the development of the systems mapping is provided in Appendix E along with more detailed discussion of individual system components.

4 Climate change and Hawke's Bay primary industries

A climate projection model is:

a plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. (IPCC 2007, 78).

Such scenarios have been used as the basis for comparison and analysis in other studies of future vulnerability to climate change, often in conjunction with insights from stakeholders (Gidley et al. 2009; Chaudhury et al. 2012; Allington et al. 2018). In these studies, researchers have drawn on national climate scenarios and empirically derived data drawn from a community or district to identify problematic, future climate-related conditions. 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.

Using climate modelling in adaptation planning requires selecting a climate projection model to describe different climate variables in the future. Factors considered in selecting a projection model include the model's:

- emissions scenario (e.g. low, medium or high)
- climate model output (e.g. median or 90th percentile results) – year of the projection (e.g. 2030, 2070 or 2100).

For this project, we used high and medium emissions scenarios, to describe key climate variables for Hawke's Bay in the future.

This understanding of the future climate in Hawke's Bay was used, along with other information, to determine adaptation properties that form the basis of the adaptation pathways.

The following section describes the future climate of Hawke's Bay in relation to the climate variables considered throughout development of the research project. In summary, the projected changes are expected to include:

- warming temperatures
- more frequent and intense heatwaves
- increased rainfall intensity
- decreased annual rainfall
- decreased number of frost days
- increased number of days of extreme fire danger – rising sea levels
- increased evaporation.

4.1 Regional climate change

Climate projections for Hawke's Bay indicate warmer temperatures, consistent with those predicted for much of eastern New Zealand, and hotter, drier conditions (Ministry for the Environment 2018). Hawke's Bay warms by an average of approximately 0.50°C by 2040, and by about 1.00°C by the 2090s under a mid-range emissions scenario, and by 1.25°C to 1.75°C under a high emissions scenario. There is, however, widespread variation in the predicted temperatures, which is a limitation of current global and downscaled models of future climate (Moss et al. 2010). There are marked changes in rainfall predicted (Mullan et al. 2008; Salinger et al. 2019). Precipitation in New Zealand is strongly influenced by El-Nino Southern Oscillation/Interdecadal Pacific Oscillation (Harrington et al. 2014), including variability and extremes (Salinger et al. 2019). Changes in precipitation will be superimposed on existing inter-annual and inter-decadal variability. There is also significant variation in precipitation within the regional council region and the study area. The following summary is drawn from the technical report prepared by NIWA as part of this project (Appendix D).

Mean temperature change

Projected future warming in the Hawke's Bay Region at 2040 under the RCP 4.5 scenario is between 0.5°C and 1°C. Warming is most pronounced in autumn and least pronounced in winter. By 2090 the

magnitude of warming is larger, and most pronounced in autumn and summer, with temperature increasing between 1.25°C and 1.75°C.

Under a high emissions scenario (RCP 8.5), by 2040 warming of >0.5 °C is observed everywhere. The region is projected to warm by up to 0.75°C–1.25°C in autumn. By 2090 under RCP 8.5 significant warming is observed over the entire Hawke's Bay Region, with winter observing the least amount of warming and autumn the most. At an annual scale, a minimum warming of 2.25°C is projected for the region.

Frosts and hot days projections

For Hawke's Bay, as seasonal mean temperature increases, changes in temperature extremes are also likely. In general, an increase in high temperature extremes and a decrease in low temperature extremes are expected. High temperature extremes (i.e. 'hot days') are defined as the number of days per year with a maximum temperature of 25°C or above, and low temperature extremes (i.e. 'cold nights', or frosts) are the number of nights per year of 0°C or below.

By 2040, Hawke's Bay's ranges (Huiarau, Kaweka and Ruahine) are projected to experience increases in hot days by no more than 10 days per year for RCP 4.5 and RCP 8.5. Central Hawke's Bay, Hastings and Napier districts are projected to see an increase of up to 15 hot days per year for RCP 4.5 and up to 20 hot days per year for RCP 8.5. Wairoa district is projected to see up to 20 more hot days per year under both RCP 4.5 and 8.5, with isolated parts of the district projected to experience up to 30 hot days per year for RCP 8.5

Towards the end of the century, increases in hot days by up to 20 days per year for RCP 4.5 and RCP 8.5 are expected for the ranges, while the remaining majority of the region is projected to experience up to 30 more hot days per year for RCP 4.5 and up to 60 more hot days per year for RCP 8.5. Under a high emissions scenario, 60-70 more hot days per year are projected for parts of Wairoa district relative to 1986–2005.

There is a projected decrease in the number of cold nights (i.e. frosts) per year regardless of RCP. The decrease is greatest in the ranges (up to 40 fewer cold nights under RCP 8.5), with decreases of up to 10 cold days per year elsewhere. Some coastal regions will very rarely experience frosts in the future.

Changes to precipitation and extreme rainfall events

Changes in rainfall are likely for Hawke's Bay. In general, rainfall is projected to decrease across the region, with seasonal differences. Under a mid-range (RCP 4.5) scenario, decreases in annual rainfall of up to 5% are projected for most of the region, with slight increases for coastal areas. Seasonally, spring exhibits a drying signal across the region, with a spring rainfall decrease of up to 15% in parts of Hastings district. Winter shows the largest increase in projected rainfall, with up to 10% more rainfall for parts of the Hastings district. The drying signal is more pronounced by 2090, with seasonal rainfall declines in the spring of up to 15% in parts of the region. Similar patterns are seen for RCP 8.5 at 2040 and 2090, but these patterns are amplified.

A warmer atmosphere can hold more moisture (about 8% more for every 1°C increase in temperature), so there is potential for heavier extreme rainfall with global increases in temperatures under climate change. In its Fifth Assessment Report, the IPCC concluded that the frequency of heavy precipitation events is 'very likely' to increase over most mid-latitude land areas (this includes New Zealand) (IPCC 2013, Table SPM.1). Given the mountainous nature of New Zealand, spatial patterns of changes in rainfall extremes are expected to depend on changes in atmospheric circulation and storm tracks.

Most areas expect a 5% increase in extreme daily precipitation, with some small parts of the region experiencing up to a 10% and 15% increase in extreme daily precipitation by 2040 under RCP 4.5 and up to 15% more extreme precipitation in Wairoa and some coastal parts of Hastings and Central Hawke's Bay by 2090. The expected increases are similar under RCP 8.5 to 2040, but by 2090 most areas are likely to see at least a 5–10% increase in extreme daily precipitation, with some coastal areas projected to receive up to 20% more extreme precipitation.

Changes to evaporation and drought

The increase in the frequency and intensity of climatic droughts in a changing climate is of deep concern for New Zealand's society and economy, not least for stakeholders in the primary sector.

Drought intensity is affected by increasing temperature, which in turn increases moisture loss through higher evapotranspiration rates, and also by the lack of sufficient moderate-intensity precipitation required to recharge aquifers and replenish soil moisture.

Potential evapotranspiration deficit (PED) is the cumulative difference between potential evapotranspiration (PET) and rainfall. PED, in units of mm, can be thought of as the amount of rainfall needed in order to keep pastures growing at optimal levels. An increase in PED of 30 mm or more corresponds to an extra week of reduced grass growth.

Projected PED varies across Hawke's Bay, with smaller increases in PED for the highest elevations of the Huiarau, Kaweka and Ruahine Ranges, and larger increases in PED for parts of Hastings district. By 2090, under RCP 8.5, increases in PED of over 160 mm/year are projected for parts of the Wairoa and Hastings districts. This indicates that these areas are likely to become more drought prone in the future.

Previous research (Clark et al. 2011) identified distinct regional differences across New Zealand in changes to climatic drought vulnerability projected under future climate change, with an increase in climatic drought on the east coast of the North and South Islands being the most plausible and consistent outcome. This is consistent with previous studies on climate change impacts on climatic drought in a New Zealand context (e.g. Mullan et al. 2005). The study concluded that climatic drought risk is expected to increase during this century in all areas that are currently drought prone, under both the 'low-medium' and 'medium-high' scenarios. During this century, evidence for increases in time spent in climatic drought is apparent for Canterbury, Hawke's Bay, Gisborne, and Northland (Clark et al. 2011).

Under the most likely mid-range emissions scenario, the projected increase in percentage of time spent in drought from 1980–99 levels is at least 5% for 2030–2050 and at least 10% for the whole region for 2070–2090 (NIWA 2017).

4.2 Climate change implications for Hawke's Bay

The above projected climate change impacts for each case study catchment were summarised and presented to industry experts and used in workshop discussions. The results were drawn from the NIWA technical report (NIWA 2017) prepared for the project and are presented for each case study catchment in Table 5. This table was presented to industry-specific experts with whom a semistructured interview was conducted to collect information on expected production impacts and adaptations for the dominant sector in each case study catchment. The projected impacts were used in workshops with stakeholders to inform the identification of challenges in their region, along with potential adaptation options.

Table 5: Summary of climatic impacts, by case study catchment, that were presented to industry experts. Adapted from downscaled projections produced by NIWA for the project (NIWA 2017)

	Climate scenarios Case study	Moderate	Extreme
Karamu	0.75°C warmer, mostly in summer/autumn 15 additional ‘hot days’ per year 5 fewer ‘cold nights’ per year (i.e. frosts) 5% less rainfall annually, mostly in spring 5% more extreme rainfall 120 mm increase in PED deficit (drought proneness) + increase in extreme winds and storms is uncertain	2.5°C warmer, mostly in autumn 60 additional ‘hot days’ per year 10 fewer ‘cold nights’ per year (i.e. frosts) 10% less rainfall annually, mostly in spring 10% more extreme rainfall 160 mm increase in PED deficit (drought proneness) ++ increase in extreme winds and storms is uncertain	
Wairoa	0.75°C warmer, mostly in summer/autumn	2.75°C warmer, mostly in autumn	

30 additional 'hot days' per year	60 additional 'hot days' per year
5 fewer 'cold nights' per year (i.e. frosts)	5 fewer 'cold nights' per year (i.e. frosts)
5% less rainfall annually, mostly in spring	5% less rainfall annually, mostly in spring
5% more extreme rainfall	15% more extreme rainfall
100 mm increase in PED deficit (drought proneness)	140 mm increase in PED deficit (drought proneness)
+ increase in extreme winds and storms is uncertain	++ increase in extreme winds and storms is uncertain

Definitions: **hot days**: the number of days per year with maximum temperature >25°C; **cold nights/frosts**: the number of nights per year with minimum temperature <0°C; **extreme rainfall**: 1% top highest rainfall events; **Potential Evapotranspiration Deficit (PED)**: the cumulative difference between potential evapotranspiration (PET) and rainfall from 1 July of a calendar year to 30 June of the next year, for days of soil moisture under half of available water capacity (AWC), using an AWC of 150 mm for silty-loamy soils; **+**, **++**: (very) positive change

Results from semi-structured interviews identified the climate change implications perceived as most important by industry experts in the region. Across case study catchments these included:

- an increase in the intensity and frequency of extreme events, including:
 - more rainfall/storm/floods (low yields, infrastructure damage)
 - greater heat stress (low yields, low animal performance, effects on workers' health)
 - greater pest damage (overpowers effectiveness of chemical controls, resistance)
 - abrupt production loss (e.g. cyclones happening when trees are fully loaded) – increased risk of forest fires
- increased production costs from new infrastructure needed to adapt to climate risks
- increased water cost (unfavourable supply/demand) and limited access to water resources
- greater risk of environmental impacts from agriculture, compromising social licence to operate
- reduction in land-use options for strategically diversifying activities
- stacking of multiple stresses in hot spots where primary production may become unprofitable.

5 Understanding vulnerability and key areas for adaptation action

A key objective of the research is to identify adaptation actions that reduce or address key vulnerabilities that are presented by climate change, or build on areas of resilience and take advantage of opportunities.

5.1 Vulnerability assessment for adaptation action

To identify areas for focusing adaptation action in Hawke's Bay, multiple sources of evidence were collected, synthesised and analysed. An integrated vulnerability assessment was undertaken. This assessment considered the risks, opportunities and vulnerabilities of various aspects of primary industries in Hawke's Bay, which were drawn directly from the regional values developed from stakeholder input collected in the first stages of the project. The assessment considered indicators that related to aspects or features valued by stakeholders in the two case study catchments to understand how they might be vulnerable to climate change. The indicators related to aspects or features of Hawke's Bay that were considered to contribute to the following values identified in the first stage of the project:

- sustainable management of freshwater resources
- community engagement, education and participation
- community connection and inclusion
- health, well-being and safety
- governance
- infrastructure and built environment – economic activity and vibrancy – cultural health (mātauranga Māori).

We considered both the potential impact of climate change (exposure and sensitivity) and adaptive capacity (see Table 6 for definitions). Vulnerability assessment enables aspects or features that are valued by the stakeholders in Hawke's Bay that may be more vulnerable to the impacts of climate change to be determined. This then allows areas of focus to be identified for adaptation planning.

Table 6: Definition of key terms

Term	Definition
Exposure	The likelihood of a feature or its function being subjected to change in relation to a particular climate variable. For example, much of Hawke's Bay is exposed to higher temperatures and low precipitation, resulting in increased drought frequency. Given the uncertainties associated with assessing climate-related risks, exposure relates to qualitatively-based assessment of changes over the next 50 years, based on information derived from climate scenarios and comprehensive understanding of primary industries in the region.
Sensitivity	The degree to which a feature or its function is affected by change to a particular climate variable. For example, non-irrigated land is sensitive to reduced rainfall.
Adaptive capacity (to cope with and adapt to conditions in 2070)	The ability or potential of a feature or its function to adjust to climate change impacts (including climate variability and extremes). It enables systems to moderate potential damages, take advantage of opportunities, or cope with consequences and maintain the valued characteristics of that feature or its function. Consideration is given to the extent to which a feature or its function in its current form, with current management practices or funding, is able to continue to function, cope or adjust to the expected climate conditions. For example, irrigation systems can support continued production in response to reduced rainfall and/or higher evaporation. If no irrigation is in place now, then the adaptive capacity would be considered less than if irrigation was currently in place.

The vulnerability assessment identified a series of priorities for stakeholders, from which decision areas of focus for adaptation were derived (Table 7).

Table 7: Values and priorities to inform key decision areas

Domain	Values and priorities
Community resilience and well-being	Vibrant regional economy Safe communities Sustainable, engaged community, with diverse vibrant population Community can affect policy outcomes Affordable living Desirable lifestyle
Agriculture	Diverse and profitable primary industries Local employment/entrepreneurial opportunities Natural capital maintained (or improved) Confidence in biosecurity measures Access to labour
Infrastructure	Connections to regional and national systems/assets Safe location of critical assets Secure, reliable and resilient services

Water	Protected healthy freshwater systems (rivers, lakes and aquifers)
	Enough water for everyone
	Efficient use
	Fair and equitable access

An important step in the development of the pathways (section 6) is to frame the areas of focus identified by the vulnerability assessment as ‘key areas of decision-making’. Key areas of decisionmaking comprise questions that the pathways and associated adaptation actions are looking to respond to, and they are made up of three elements:

- the *objective* Hawke’s Bay primary industry stakeholders (including the communities) seek to achieve in relation to an aspect or feature that is valued; for example, to provide, protect and manage [the aspect or feature]
- the *valued feature or aspect* that is being focused on; for example, the well-being of vulnerable members of the community, or the sustainability of freshwater resources
- the *reason* why the action needs to be taken; e.g. in response to a particular climate impact or driver of change, such as increased frequency and severity of drought, or more frequent extreme rainfall events.

For Hawke’s Bay primary industries, the four key areas of decision-making – community, infrastructure, agriculture, and water – are directly linked back to the vulnerability assessment and data collected through the workshop, interview, modelling and systems analysis.

5.2 Adaptation planning for key decision areas

We used adaptation pathways analysis to inform adaptation planning for key decision areas. Rather than being limited to identifying the best single set of adaptation options for a limited set of climate change scenarios, the pathways approach enables decision makers to consider a range of possible adaptation options, how they will be affected by climate change over time, and whether any options have a ‘use-by date’ (i.e. a point in time at which they are no longer viable).

Pathways planning also enables decision makers to explore what combination of options (referred to as ‘pathways’) is most suitable for adapting to future climate change, and how this can be sequenced over time (i.e. what should be done now, versus what can be done later).

An initial step of the pathways approach is to frame key questions in the form of key areas of decisionmaking in relation to which adaptation options are then identified. This step brings together the priorities indicators identified by the vulnerability assessment with relevant climate change projections.

Four key areas of decision-making were identified for Hawke’s Bay primary industries, and a pathway has been prepared for each. Importantly, these key areas of decision-making and their associated pathways have been developed in close collaboration with stakeholders and end-users. Stakeholder involvement has been fundamental to the project.

The following key areas of decision-making are addressed by the adaptation pathways in the following section (see section 6):

Community resilience and well-being: How can community resilience and well-being be enhanced or maintained in the face of growing environmental change, socio-economic inequality and urbanisation?

Water resource management: How does Hawke’s Bay maintain security of supply for agriculture given future possible reduction in supply, either as a consequence of climate-change-induced rainfall decline or reduced availability of groundwater?

Infrastructure (production, processing and distribution): How can production, processing, and distribution infrastructure be managed to provide the greatest resilience when exposed to frequent storms, sea-level rise, and possible disruption?

Primary industries: How and when can primary industries transition to more viable agricultural practices (including land use) in the face of warmer and drier conditions?

6 Adaptation options and pathways for key decision areas

This section presents the adaptation pathways for each of the key decision areas identified by the project. In developing the pathways for each key decision area, a range of information generated by the project has been drawn on, specifically the outputs and processes shown in Table 8. **Table 8: Summary of information and sources for key decision areas**

Information provided for key decision area	Information sources
Discussion regarding why a focus on the key decision area is important for Hawke's Bay	Values workshops Case study catchment profiles
Overview of how climate change will affect the key decision area	Climate change modelling for Hawke's Bay Impact scenarios and targeted one-on-one conversations with experts where additional insight and expertise were required Systems dynamics model for Hawke's Bay primary industries Desktop analysis and literature review
Discussion on preferred options for progressing adaptation action in relation to the key decision area	Adaptation planning workshops with stakeholder representatives from primary industries, local and regional government and other interest groups Impact scenarios and targeted one-on-one conversations with experts where additional insight and expertise were required
Barriers and enablers to implementing adaptation actions	Adaptation planning workshops with stakeholder representatives from primary industries, local and regional government, and other interest groups
Adaptation pathways	Adaptation planning workshops with stakeholder representatives from primary industries, local and regional government, and other interest groups Impacts scenarios and targeted one-on-one conversations with experts where additional insight and expertise were required Systems dynamics model for Hawke's Bay primary industries Desktop analysis and literature review

6.1 Understanding adaptation pathways

The pathways in sections 6.2 to 6.5 set out both the range of adaptation options considered for each key decision area and the preferred adaptation pathway, made up of the preferred options. The timing for each option and its relationship with other preferred options are also shown on the pathways. Each pathway should be read in conjunction with the description of the relevant key decision area. The adaptation pathways diagram for the community priority is given below in order to explain the colours and symbols used in all the pathways.

Issue
Community resilience and well-being

Key decision
How can community resilience and well-being be enhanced or maintained in the face of growing environmental change, socio-economic inequality and urbanisation?

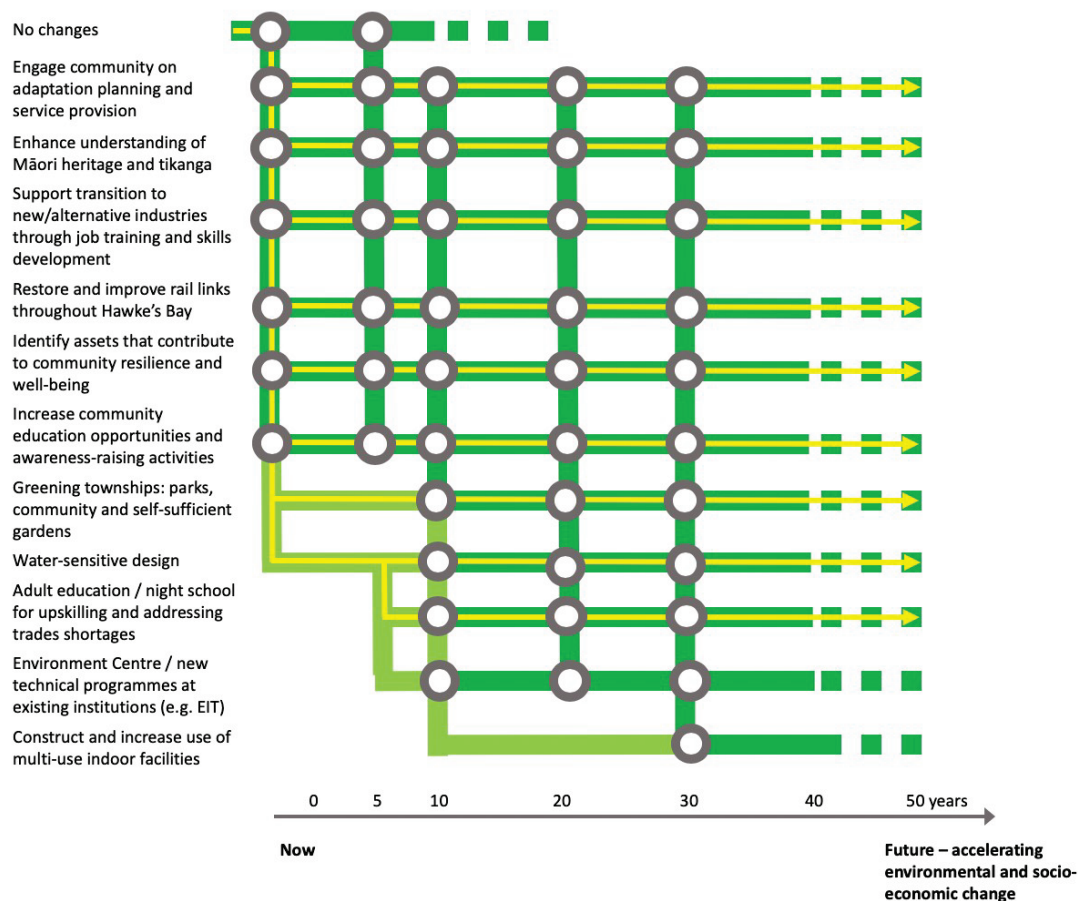


Figure 10: How to read the adaptation pathways diagrams.

The horizontal axis of the pathway, at the bottom, shows both a timescale and expected changes to the climate that are relevant to the key decision area. The range of adaptation options considered for the decision area are listed down the left-hand side of the pathway. Each option on the left relates to a pathway to the right, which is a combination of lines and circles that indicates:

- the contribution of the option to the relevant key decision – whether it fully or partly addresses the decision
- the favourability of the option
- the time period over which the option is effective
- the time period before an option is implemented, during which preparatory work is required – decision points where decision makers need to choose between options – the preferred pathway through the options listed.

A vertical line through a ‘decision point’ circle identifies a point in time at which a decision needs to be made between different options. The timing of the decision is indicative only, relative to the x-axis timeline. This is based on the premise that as the climate changes, some options will become less suitable as adaptation measures and new ones may be required.

For each pathway, ‘no changes’ is the first listed option. This relates to all aspects of the current approach being taken to the decision area (e.g. management, and maintenance regimes). The length of the adjacent line shows how long the current approach with no changes can be expected to effectively address the area of decision-making.

The preferred pathway (yellow line/s) identifies which options should be progressed now and into the future, based on currently available information, including information provided by relevant experts and affected stakeholders. The preferred pathway does not preclude current actions that contribute to future adaptation from continuing. Pathways should be reviewed at least every 5 years, at which time new information may suggest that the preferred pathway should take a different course through potential options.

It should be noted that although there was significant stakeholder involvement in the preparation of the pathways, further assessment of options by relevant individual sectors may still be required. In particular, we acknowledge that further engagement is required with iwi, community, and environmental sectors. Cultural values were identified as an important and valued part of the community, but the research team did not have sufficient expertise to develop a mātauranga Māori pathway, although it would be desirable.

6.2 Community

Key area of decision-making

How can community resilience and well-being be enhanced or maintained in the face of growing environmental change, socio-economic inequality and urbanisation?

6.2.1 Why are community resilience and well-being important?

While the focus of adaptation pathways is on primary industries, adaptation and transformation are also enabled and supported by social systems, including regional economic activity, political and institutional arrangements, and other forms of human and social capital. As such, local communities in Hawke’s Bay have an important role to play in building capacity for adaptation to enable primary industries to respond to the challenges and opportunities associated with climate change. Vibrant, thriving communities will be better situated to cope with ongoing change.

Vibrant, thriving communities also play an important role in the maintenance and enhancement of the natural environment. In order to achieve the adaptation objectives identified by stakeholders and within this report, it will be important to continue to foster a strong regional identity and connection with the environment. An important part of adaptation and transformation is making the connection between historical actions and present-day environmental issues. Programmes focused on cultural heritage, culturally sustainable development, and mātauranga Māori will play a key role in regional adaptation, improving partnerships and outcomes for communities within the region.

There is already a strong community commitment to improve natural resource outcomes across the region, as demonstrated by the work of the TANK Collaborative Stakeholder Group for freshwater⁴, although more can be done to raise awareness and to support a transition towards a community that

⁴ The TANK Group – named after the Tūtaekuri, Ahuriri, Ngaruroro and Karamū catchments – was convened by Hawke’s Bay Regional Council in 2012 to address specific water allocation and water quality issues as part of regional planning process.

is more fully connected with the environment. There is also an opportunity to increase understanding of the role of ecosystem processes and the social and financial importance of functioning ecosystems. Increasing uptake in partnership projects, and participation at community forums and field days, will contribute to this. However, the long-term goal is to develop programmes and processes that allow not just for the involvement of communities, but for true collaboration and empowerment of communities. Through adaptive governance, building resilience, and allowing and encouraging social learning, primary industry stakeholders – including local and regional government, sector bodies, community groups, and MPI – can play a leading role in the adaptation and transformation of the region.

6.2.2 How will climate change affect community resilience and well-being?

Local communities may be on the frontline of the impacts of climate change in Hawke's Bay. Many small communities are economically reliant on climate-sensitive primary industries, and residents and local organisations are intimately connected to local places, and familiar with the locality's particular social, historical and political contexts (Adger et al. 2009; Moser 2010; Sheppard et al. 2011; Bennett et al. 2016).

The results of the climate modelling indicate that the region is likely to become hotter and drier over coming decades. Storms and rainfall may intensify. Climate extremes place added pressure on already constrained resources, while extreme weather events such as floods endanger biodiversity, damage infrastructure, and threaten lives and livelihoods, especially of the vulnerable (Roiko et al. 2012).

Communities will experience the direct effects of hotter temperatures and increased climate variability and extremes. These will have implications for local economies dependent on primary industries, as well as for infrastructure connectivity. Road and rail closures, for example, may become more frequent, disrupting daily activities. Extreme events may also result in greater demands on emergency response personnel, and volunteer and community groups (particularly those caring for older people and other vulnerable populations).

The increased frequency and severity of drought may lead to more intense fires, endangering people and the built and natural environments. Drought also has implications for psycho-social well-being. Economic activity declines during drought nationally, as well as having local and regional economic implications, and can lead to psychological and financial stress among rural households (AdenijiOloukoi et al. 2013; Udmale et al. 2014; Tanner et al. 2015).

6.2.3 How can community resilience and well-being be enhanced or maintained in the face of growing environmental change, socio-economic inequality, and urbanisation?

The development of an adaptation pathway for community resilience and well-being is required to acknowledge and actively counter any detrimental impacts of a changing climate. It is focused on supporting community involvement and engagement in adaptation decision-making, enhancing local environments through additional green space, and investments in education, partnerships, and collaboration. This pathway forms the foundation for achieving enhanced outcomes for communities across Hawke's Bay.

There is an urgent need to support community involvement in adaptation planning. Knowledge about the potential impacts and implications of climate change is often too broad to provide a strong basis for local adaptation planning (Scott & Weston 2011), and is frequently fragmented. The impacts of climate change on our local areas and communities are complex, intersecting and compounding, and require an integrated approach involving communities and all levels of government, especially local government.

Communities need to be able to interpret the impacts of climate change in ways that have local meaning, and since they and succeeding generations are directly affected, they deserve a leading role in designing actions. This requires appropriate 'learning spaces' (Tschakert & Dietrich 2010). However, the politicisation of climate change in the primary industries – where it has been conflated with mitigation and perceived punitive measures (Reisinger et al. 2011) – has worked against productive community discussion to collectively address the issue. Effective collective adaptation to climate change requires a shared understanding of the potential impacts and risks, gained by informed discussion with other participants. In this context, effective and inclusive participatory

processes can build the empathy necessary to overcome divisions that exist around climate change and adaptation, and help communities to build the knowledge base and collective action needed to move forward.

6.2.4 Summary of key findings

To support community resilience and well-being, the immediate priorities for adaptation are educating and raising awareness of climate change impacts, and the implications, options and actions for Hawke's Bay. Participatory processes in local communities can be used to enhance adaptive capacity, and to explore needs and options, including realising educational opportunities.

The reopening of the railroad is seen as an important factor in enhancing resilience by improving connectivity and creating new opportunities for economic development. This was identified by stakeholders in Wairoa as an urgent priority for the region. The railway was officially reopened in June 2019. Other investments in infrastructure and the built environment may be required in the future, and a shift towards water-sensitive urban design and enhancement of green spaces is desired. Long-term opportunities to be explored include the development of new technical programmes and multi-purpose facilities for the amenity, vibrancy and well-being of communities.

Issue
Community resilience and well-being

Key decision
How can community resilience and well-being be enhanced or maintained in the face of growing environmental change, socio-economic inequality and urbanisation?

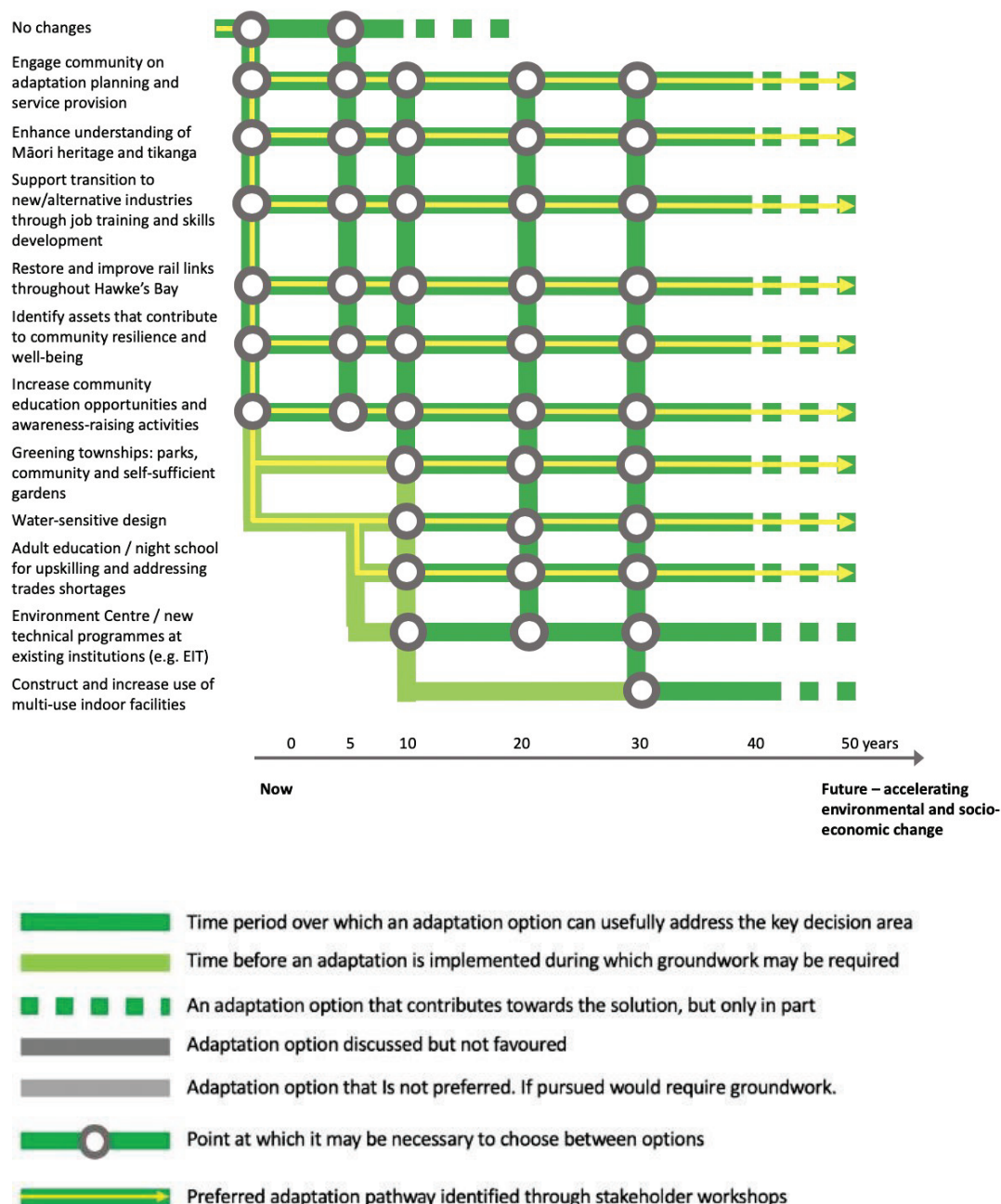


Figure 11: Community resilience and well-being pathway

6.3 Infrastructure

Key area of decision-making

How can transportation, processing and distribution infrastructure be managed to provide the greatest resilience to more frequent storms, sea-level rise, and possible disruption?

6.3.1 Why is resilient infrastructure important?

Hawke's Bay primary industries depend on production, processing, and distribution infrastructure at multiple levels. Securing the long-term viability and sustainability of energy, transport logistics and

processing capacity is essential to ensure the viability of the productive sector, primarily because of the need to move agricultural products – including dairy, fruit and vegetables, and livestock – through to processing, storage, and distribution facilities. Road and rail networks also play an important role for emergency services and social connections.

Disturbance to infrastructure can have considerable impacts for primary producers. Road and rail closures affect the in- and out-bound movement of key products. Disruption to the supply of supplemental feed during a drought, for example, or the inability to move fruit and vegetables to processing facilities during harvest have implications throughout the regional supply chains.

The long-term sustainability of primary production will also depend on improving efficiencies in energy supply and reducing waste, in alignment with other emerging legislation.

6.3.2 How will climate change affect production, processing and distribution infrastructure for primary industries in Hawke's Bay?

Critical production, processing and distribution infrastructure include roads and bridges, telecommunications, water supply, and electricity. Climate change may result in more frequent extreme weather events. Extreme heat, snow and ice storms, sea-level rise, flood events and erosion may disrupt networks.

More-frequent storms and inundation of roads will result in additional closures and delays. In some cases, transportation networks will require relocation due to permanent inundation or irreparable damage. Rail networks may also be affected by slips and erosion hazards. Higher temperatures may lead to deterioration of the road surface.

The demand for energy from the primary industries may increase in parallel with changes in land use to realise new opportunities. Additional cool storage capacity may be established to provide additional buffering to continue to service markets in the event of supply chain disruption, but this will require additional energy.

6.3.3 How can transportation, processing and distribution infrastructure be managed to provide the greatest resilience to more frequent storms, sea-level rise, and possible disruption?

To enhance the resilience of infrastructure, a fundamental shift in thinking is required. Adaptation options could include improvements to distributed infrastructure, enhancing emergency preparedness, and exploring the feasibility of a long-term shift in energy supply, including the incorporation of alternative energy sources.

Adaptation options that can be implemented immediately include:

- strategic planning and greater public engagement in decision-making for long infrastructure investment
- assessing the existing vulnerability of distribution networks and critical lifelines across regional value chains, to consider risks from farm to port – vulnerability assessment could prioritise asset management by factors such as regional economic importance
- diversifying transport options to reduce reliance on roads through improved rail infrastructure
- exploring the potential for new forms of economic development, including a circular economy, to reduce waste and realise new opportunities and encourage a shift towards renewable energy.

In the longer-term, preparatory work will be required to determine future energy demands and properly scope the continuity of supply of essential services, protection options and the suitability of alternatives such as renewables.

6.3.4 Summary of key findings

In the immediate short term, adaptation needs to focus on risk assessment, education, and engagement that considers current and future vulnerability of critical infrastructure and lifelines. This adaptation option has been identified as a high priority by key stakeholders in the region. In the longer term, accelerating the transition towards a circular economy and infrastructure investment to support new opportunities from the primary sector may be required.

Issue
Infrastructure

Key decision

How can transportation, processing and distribution infrastructure be managed to provide the greatest resilience in the face of more frequent storms, sea-level rise and possible disruption?

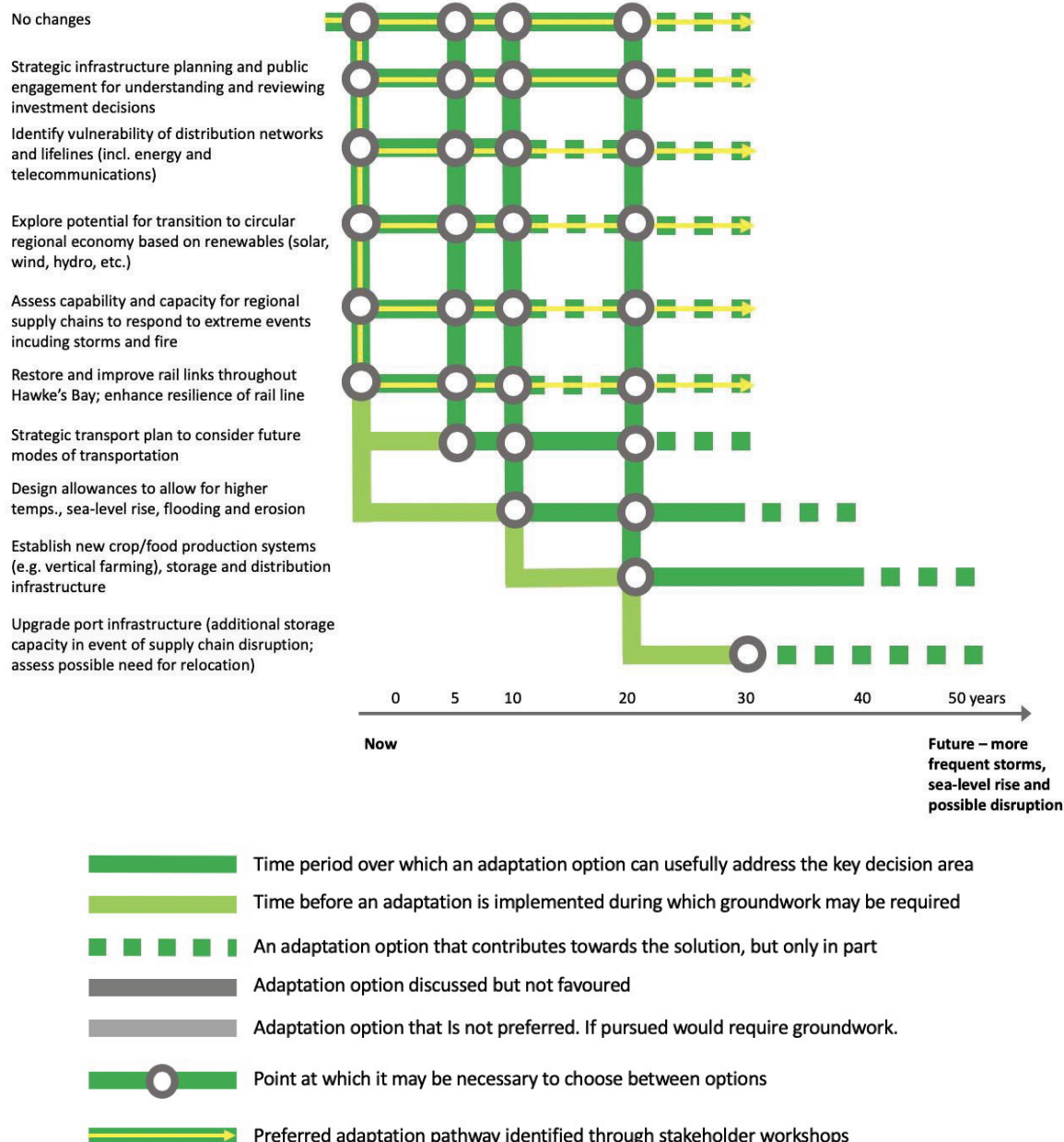


Figure 12: Infrastructure pathway.

6.4 Water

Key area of decision-making

How does Hawke's Bay maintain security of supply for agriculture given a future possible reduction in supply, either as a consequence of climate-change-induced rainfall decline or reduced availability from groundwater?

6.4.1 Why is security of supply and sustainable management of freshwater resources important?

The quality and quantity of water are of critical importance to Hawke's Bay from environmental, economic, cultural, and social perspectives. Throughout the region, watercourses have been highly

modified from their natural state, having been deepened and widened, and their course altered, as a result of catchment development and increased catchment runoff.

Groundwater is used across Hawke's Bay for a variety of purposes, including processing and for the irrigation of horticulture, viticulture, pasture and arable. The enhancement of water security using managed aquifer recharge schemes is also very important.

6.4.2 How will climate change affect water resources in Hawke's Bay?

Water resources in Hawke's Bay, including surface- and groundwater, are used extensively for potable, irrigation, and stock and domestic supplies. The majority of water comes from groundwater sources. Higher temperatures and declining rainfall may reduce water availability, while demand for water is likely to increase.

6.4.3 How does Hawke's Bay maintain security of supply for agriculture given future possible reduction in supply, either as a consequence of climate-change-induced rainfall decline or reduced availability from groundwater?

There is a need to address the security of water supply for Hawke's Bay primary industries, particularly with the withdrawal of the Ruataniwha Dam proposal. Irrigation has been widely promoted as a means to enhance productivity, ensure water security, and promote regional economic development. In the face of climate change, long-term access to groundwater or large-scale water storage is seen as essential to ensuring the long-term viability of the productive sector. However, access can act as a maladaptation where it allows unsustainable farming intensification in areas threatened by lower rainfall, drought, and other climate disruptions.

Large water storage schemes have come under increased public scrutiny, precipitating debates about water rights, use, and allocations (Joy 2015). Costs to access such schemes are high, and the security afforded may be short term (e.g. the Ruataniwha Dam proposal to provide farmers with more secure water supplies in central Hawke's Bay was widely contested and finally turned down by the Supreme Court). Such debates over irrigation highlight the deeply held social, cultural and environmental values held by many New Zealanders about their natural environment, in particular, who should have access to water and for what purpose. Concerns are compounded by delays in addressing the lock-in of unsustainable intensification pathways, leading to over-use, and compounding nutrient runoff, leaching and degradation of water quality (Hughey et al. 2016). Conversely, irrigation is seen as an adaptation option for landowners facing an increasing probability of drought. Where irrigation already occurs, there is an economic imperative to realise a return on the substantial costs of the investment, which encourages further intensification, creating deep divisions across society (Srinivasan et al. 2017).

Realising efficiencies in freshwater management in the primary sector is an essential part of adaptation, and of matching water use and availability. This will enable best use of the water resource overall, while avoiding the allocation of water unsustainably. The planning process needs to avoid creating incentives for water-intensive land uses in areas that are, or will become, water stressed. Importantly, the potential limits (lifespan) of water efficiency strategies, in some areas, should be noted.

A number of opportunities for enhancing outreach, knowledge transfer and education to improve management outcomes for freshwater were identified by stakeholders. These include promoting awareness of best practices to realise efficiencies, improve soil and crop cover practices, and exploring opportunities to incentivise water use away from water-intensive agriculture and towards horticulture. This might include:

- increasing soil-water retention and soil protection through land management techniques that reduce evaporative and erosive forces, which could include wind breaks, the use of cover crops and retaining stubble
- allocating land-use options according to soil type and water availability, such as favouring the use of less-water-demanding systems such as dryland farming with deeper-rooted and wintergrowth species (e.g. perennial legumes) in drier areas with low-water-capacity soils
- adjusting management (e.g. sowing dates and genotype selection) to better match crop water demand with changes in the seasonality of water supply.

- enhancing the efficiency of irrigation water use through monitoring and controlling techniques (e.g. precision irrigation)
- strategic investment in environmentally and economically sustainable water storage.

Investment in new irrigation infrastructure was discussed by stakeholders, but it was not a preferred option due to the possibility of changing limits, which may result in stranded assets or sunk costs. Efficiency gains were the most common adaptation strategy and aligned with stakeholders' values. Stakeholders struggled to conceive of a situation where water would need to be obtained via alternative sources (e.g. desalination or fog machines) – even when pushed by the research team.

6.4.4 Summary of key findings

The need to sustainably manage freshwater resources was recognised as an essential part of climate change adaptation for Hawke's Bay primary industries. A number of options – focusing on realising efficiencies, education and extension to ensure best practice throughout the region – were identified and should be prioritised. The emphasis was on effective management of known resources rather than accessing or developing additional resources.

Issue Water

Key decision

How does Hawke's Bay maintain security of supply for agriculture given future possible reduction in supply, either as a consequence of climate change induced rainfall decline or reduced availability from groundwater?

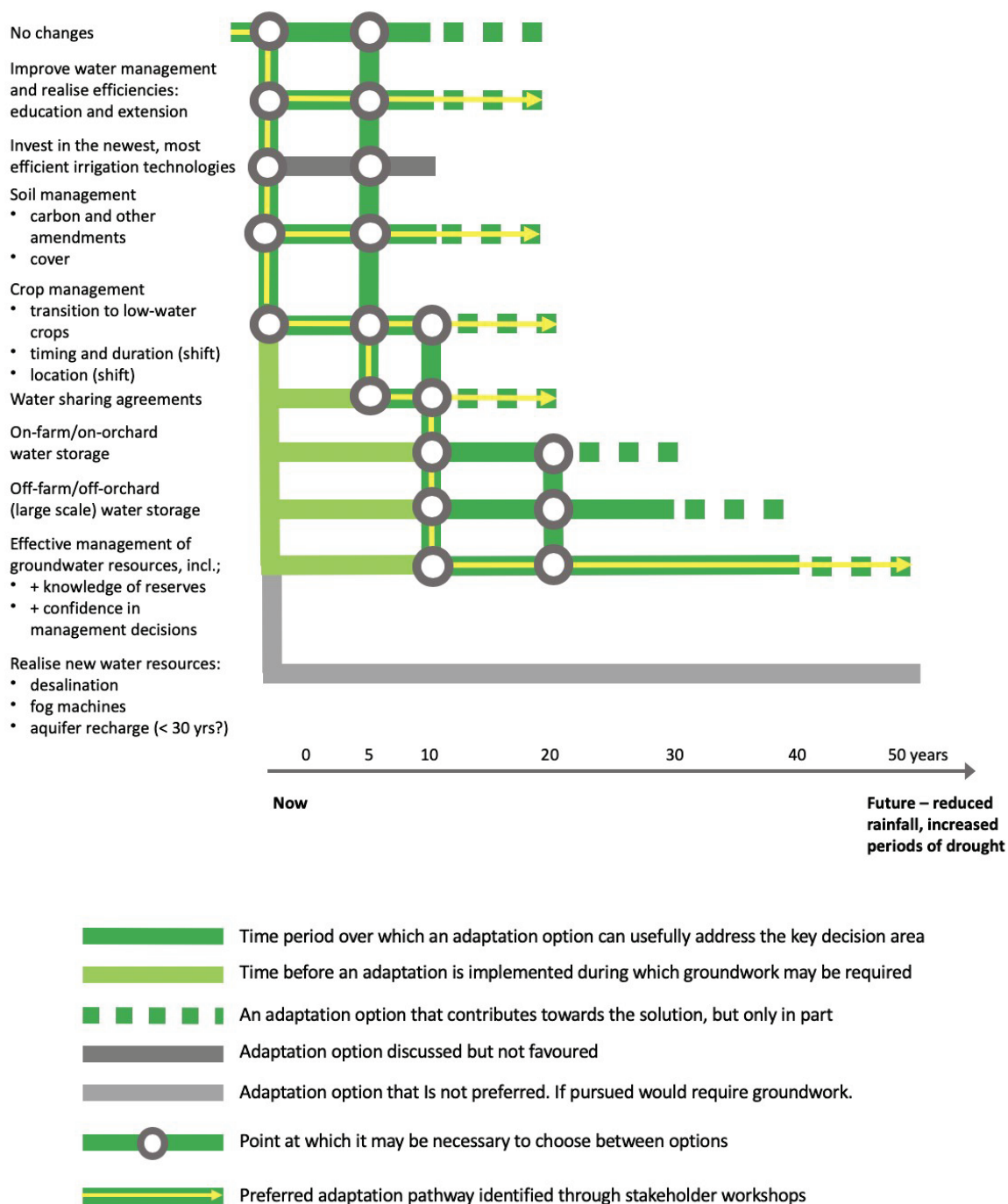


Figure 13: Freshwater management pathway.

6.5 Primary industries

Key area of decision-making

How and when can primary industries transition to more viable agricultural practices (including land use) in the face of warmer and drier conditions?

6.5.1 Why is it important for primary industries in Hawke's Bay to adapt to climate change?

The diversity of primary industries in Hawke's Bay serves an important social and economic function, contributing to the well-being of communities throughout the region, as well as playing a role in managing the natural environment. Climate-sensitive primary industries – including dairy, arable, livestock, horticulture, and viticulture – face unique and acute pressures from climate change, many of which will increase with higher temperatures.

6.5.2 How will climate change affect primary industries in Hawke's Bay?

The potential impacts of climate change for Hawke's Bay primary industries include increased frequency and severity of drought; changes in crop yields, pasture growth, animal health, carrying capacity and soil condition; and changing risk profiles for pests and diseases.

Future drought risk is of primary concern for farmers, as are the ways in which higher temperatures, declining rainfall, and increased demands on freshwater resources may influence production and yield. An understanding of how dry years affect yield and farm production has been developed using models like Biome-BGC and APSIM (Agricultural Production Systems sIMulator). The Biome-BGC model, for example, predicts increased pasture yield in Hawke's Bay under climate change due to favourable climate conditions and the modelled CO₂ fertilisation effect. However, there is a seasonal shift, with warmer temperatures allowing more production in winter and spring throughout the region, and less precipitation in late spring and summer, leading to a corresponding reduction in yield in summer.

For pastoral farming, despite any increase in yield, the risk of dry summer conditions is the most significant concern, coupled with the trend towards increasing water limitation, especially in spring and summer. This could have implications for irrigation and water demand in a region that is already prone to drought.

Arable crops such as maize and wheat, as well as horticulture are also sensitive to climate variability. Higher temperatures and decreased precipitation will result in higher water demand for these sectors.

6.5.3 How and when can primary industries transition to more viable agricultural practices (including land use) in the face of warmer and drier conditions?

Identifying suitable adaptation options for Hawke's Bay primary industries is of paramount importance. Based on the results of key stakeholder workshops, expert interviews and recent studies, climate change adaptation strategies for the region could include:

- changing existing management practices to optimise land use, reduce exposure and realise opportunities – adaptation options that were identified include shifting the timing of key activities in response to changes in climate, and adjusting stocking rates to better reflect the likelihood of adverse events
- agricultural business management to maintain high equity and hence greater capacity to weather the negative financial impacts of a more inclement climate
- increased diversification of farm enterprises, such as incorporating livestock into dairy units, the addition of small-scale horticulture or agri-farm tourism, so that susceptible land uses can be augmented in high-risk years with more stable sources
- new crop varieties from traditional breeding programmes that develop traits better suited to changing local conditions and improved water-use efficiency, heat and disease tolerance, and nutrient usage
- transformational change – gaining insight into the capacity for widespread changes in land use, and the potential relocation of key activities, processing and distribution should be explored; such transformations are likely to require significant lead times and resources.

Without successful adaptation actions, agricultural producers will face increasingly challenging conditions. Key questions for regional primary industries include the scope for widespread land-use change, including the extent to which large-scale transformational adaptation options might be required compared with incremental changes.

6.5.4 Summary of key findings

Various agricultural practices that are considered leading edge will provide some measure of adaptation in the coming 10–20 years. However, long-term adaptation may require more transformational responses, such as the adoption of advanced breeding techniques, and earlier planning is needed for these options. Transformational adaptation should be considered, and assessing regional and sectoral capacity for widespread, systemic change should be explored now. Understanding the drivers of transformational adaptation, barriers and enablers is a critical issue.

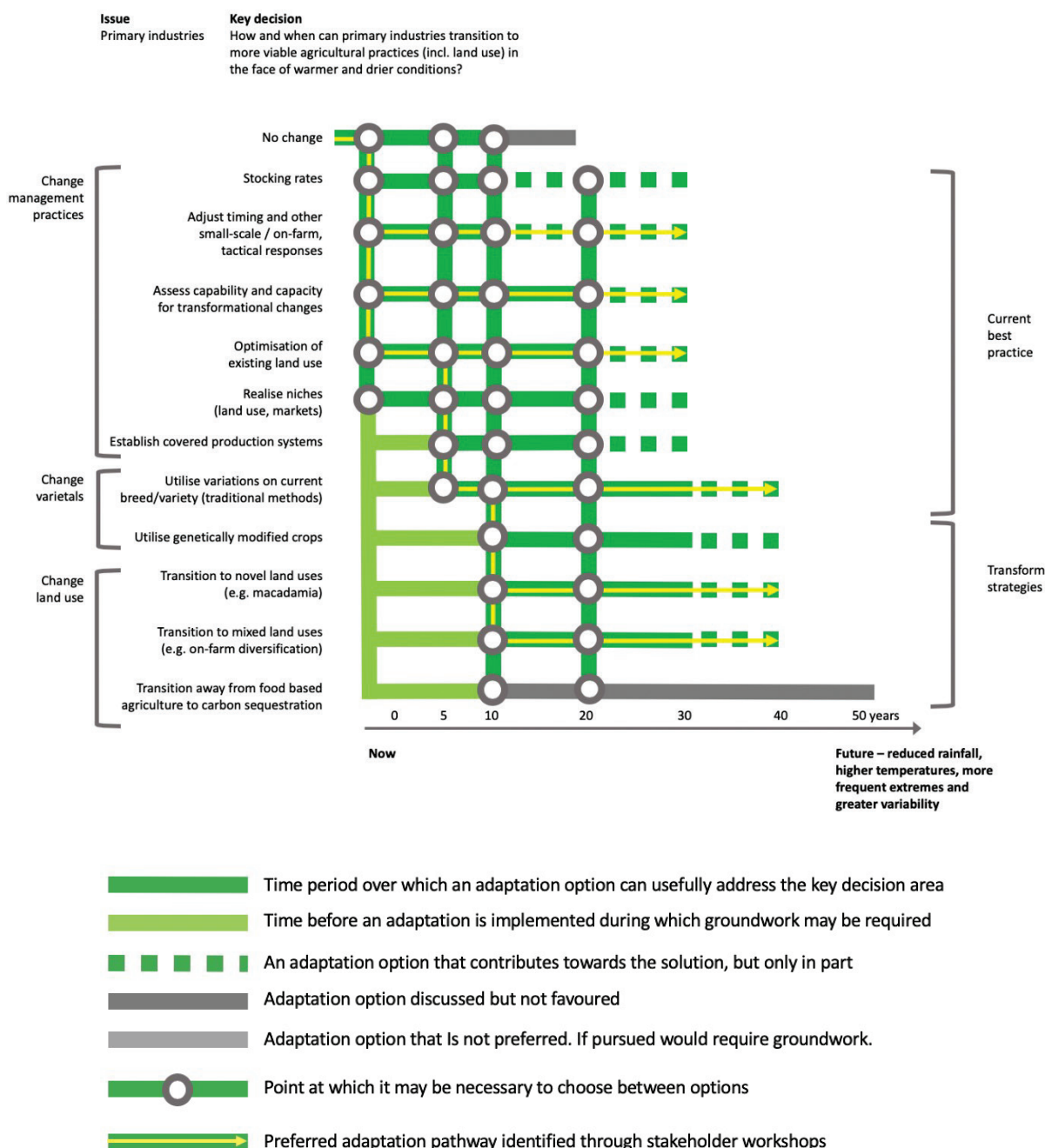


Figure 14: Primary industries pathway.

7 Regional adaptation pathway

The adaptation pathways presented in section 6 identify a wide range of options relevant to the four different key areas of decision making. To assist with adaptation planning for Hawke's Bay primary industries and with identifying adaptation priorities for regional implementation, the preferred adaptation options were further reviewed by the research team and then iterated within a workshop setting to determine those that:

- are of regional scale or relevance
- are common to more than one key decision area (i.e. are cross-sectoral)
- will deliver multiple benefits
- would benefit from a coordinated, regional response across key regional stakeholders, including sector bodies, community interests, tangata whenua and government.

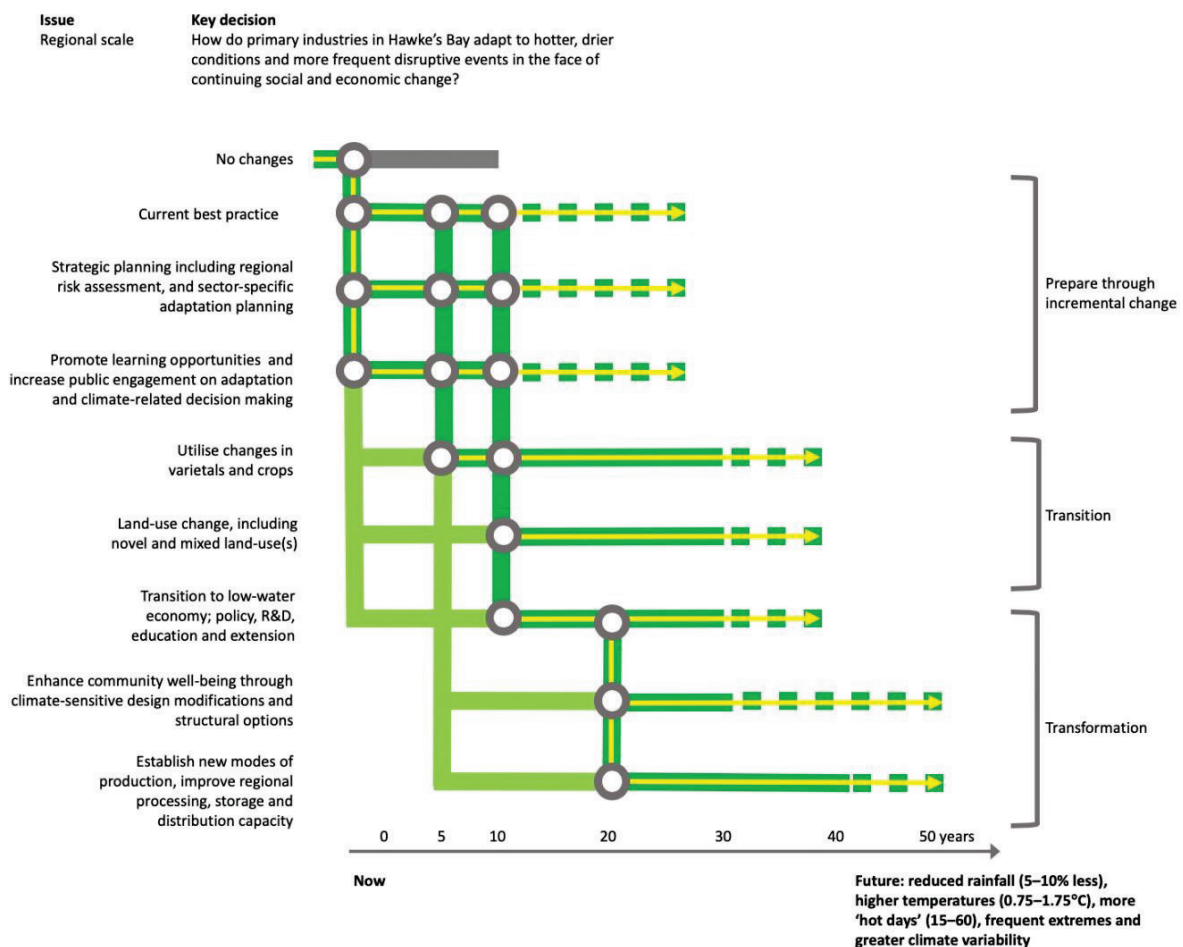
This review process resulted in the identification of eight adaptation priorities (see Figure 15).

A number of these priority adaptation options accelerate current practice and are recommended for immediate implementation, while others should be delivered within 5 years to build resilience for specific key decision areas/sectors. Options for delivery over a longer timeframe (e.g. in 10 to 30 years' time) are aimed at supporting the transition to lower water use, and establishing a basis for transformational changes to realise opportunities.

These will not be the only adaptation actions required, nor will these options be immediately transferable to other regions. The pathway, instead, is intended to provide a basis for further development to focus initial regional, cross-sectoral action. The remaining preferred options identified for each of the four key decision areas are still considered critical to ensuring the resilience of primary industries, to enable the region to adapt and thrive in the face of the climate change challenge.

7.1 Emerging regional adaptation pathway

The pathways analysis presented here is focused on four key areas of decision-making identified through stakeholder engagement. Regional adaptation planning, however, requires consideration of how decisions taken in one domain or sector can have an impact on others and how the region as a whole prioritises action. Drawing on the pathways presented in Figures 11, 12, 13 and 14, a crossregional emerging pathway map has been developed (Figure 15). This simplified regional pathway draws out some of the interactions among sectors in terms of timing and regional needs.



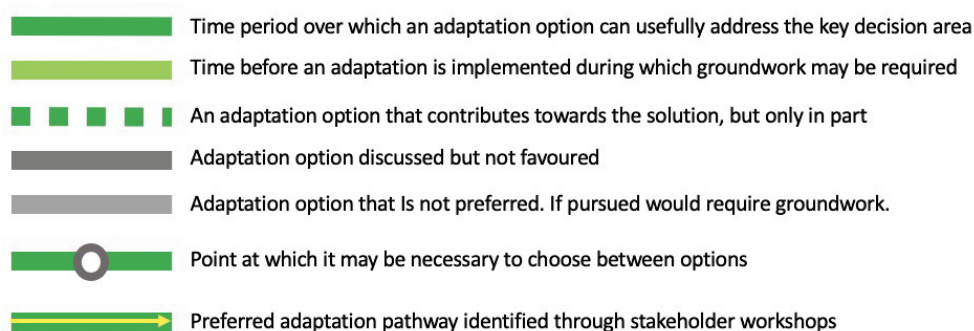


Figure 15: Emerging regional pathway.

In the short term, many of the adaptation actions identified are likely to continue with current best practices that will help to prepare for climate change through incremental change. Such actions could include risk assessment across regional value chains, promoting awareness of climate change adaptation, risks and opportunities, support for research on the potential for transformational changes, and selective breeding for agriculture.

The two highest-priority planning actions that could assist with cross-sectoral adaptation are the development of sector-specific adaptation plans, and investment in education, outreach and extension to enhance learning opportunities.

Adaptation planning for Hawke's Bay primary industries will be assisted by continued strategic planning within and across sectors. Recent research has highlighted the need for industry-specific, regionally based options and pathways. Successful adaptation requires contextually sensitive, industry-specific, regional or local solutions. It is unlikely that many universal solutions can be identified as farming and growing practices, social norms and values, aspirations, access to resources, and infrastructure all vary throughout New Zealand.

There is no such thing as a 'one size fits all' capacity to adapt. The determinants of adaptive capacity vary 'from system to system, sector to sector and region to region' (Yohe & Tol 2002). Instead, adaptive capacity is best reflected by a broad 'coping range', which is location-specific, group-specific, and time-specific (Smit & Pilifosova 2003; Berman et al. 2012; Raso et al. 2019). System characteristics that reflect on adaptive capacity are resilience, stability, robustness, and flexibility (Smit & Pilifosova 2003; Urruty et al. 2016; Fernandez et al. 2017).

Although adaptation is local and potentially a sector-specific endeavour, it will require industry (e.g. sector bodies) and institutional support (e.g. local and central government) at different scales to be efficient and effective. Regional (and sometimes national) adaptation strategies must be developed in concert with other industries (see Cradock-Henry, Fountain et al. 2018) to avoid maladaptation, realise synergies, and optimise cross-sectoral adaptive capacity. Narrowly focused actions may not create an adaptive sector (if they do not account for opportunities, challenges, and preferred adaptations elsewhere).

For example, water-use adaptation at the farm scale will be underpinned by sound regional policy and strategies, which in turn are enabled by national guidance and policy. Without this co-ordination across governance scales and over time, individuals, industries and regions could compete for scarce resources in a detrimental way.

Sector-specific adaptation strategies, such as those being developed by the dairy and wine industries, should therefore be prioritised. The identification of preferred adaptation options can lead to the identification and evaluation of potential synergies and trade-offs.

There is also a significant opportunity to enhance adaptive capacity through participatory engagement with primary industry stakeholders and communities, to enhance learning. Across the four key decision areas, greater participation and involvement of stakeholders and enhancing opportunities for learning were identified as preferred priorities for adaptation action. These learning opportunities might involve a renewed focus on climate change adaptation through farm extension programmes to share best practices on adaptation-related topics, including water and irrigation efficiencies and crop and soil management. It might also involve the development and promotion of new methods of

engagement to promote active learning, such as through the use of novel technologies or ‘serious games.’

Over the coming decades, greater attention will need to be given to infrastructure initiatives to consider the impacts of climate change. Ensuring the resilience of transportation infrastructure and processing capacity (including storage and distribution facilities) will be crucial, particularly if there are widespread changes in land use. Upgrades may be required to road and rail, along with emergency preparedness to minimise disruptions and restore functionality as quickly as possible following major disturbances.

Within two to three decades more of the region’s adaptation actions will need to focus on maintaining and enhancing critical value chains, protecting assets, and undertaking preparatory actions for transformational change. Major emerging actions could be large-scale land-use change or the establishment of novel or genetically modified crops. In the long term, adaptation may require the relocation of some activities and further transformation within key areas of decision-making. Notably, planning work for many of these medium- and long-term actions needs to commence now.

Importantly, there is a need to consider interactions between major adaptation actions, especially when they are occurring at the same time. Greater cross-regional input will also be required when an adaptation action could affect multiple sectors (e.g. responding to declining water resources availability).

7.2 Principles for cross-sector adaptation planning

The activities in this project outline adaptation priorities identified by stakeholders from Hawke’s Bay with interests in ensuring the long-term sustainability of primary industries in the region. In the future, further adaptation planning will be required by individual sectors and should be guided by the following principles.

- **Build economic resilience:** adaptation planning should proceed on the basis that individuals and organisations are best able to adapt when they are profitable and sustainable. Economic resilience to climate change is therefore important to achieving social and environmental adaptation.
- **Prepare not repair** investment decisions across sectors in the region need to focus on investing in adaptation and mitigation actions rather than repairing damage once the impacts of climate change are experienced.
- **Take joint responsibility:** while sectors are individually responsible for their own adaptation planning, they are jointly responsible for regional-scale, cross-sectoral adaptation planning and implementation.
- **Identify long-lifetime decisions:** sectoral planning needs to ensure that decisions made today that have long lifetimes, such as major infrastructure initiatives and land-use planning, consider long-term climate change impacts in their design.
- **Seek out and avoid cross-sectoral maladaptation:** future adaptation needs to consider the interactions between different sectors and how these affect the individual and collective response of the region. In some instances, an adaptation action in one sector could have negative consequences for another, leading to maladaptation.

7.3 Enabling cross-sector adaptation

Much of the focus of adaptation planning is on priority impacts and adaptation options. Yet various enabling conditions need to exist for adaptation to occur. For example, proposed actions need to align with community values, and need to be achievable within regional policies and governance arrangements. Cross-sectoral adaptation in the region requires consideration of the following enabling conditions:

- a regional governance approach that provides for continuation of a collaborative approach to adaptation planning across the region
- further development of the business case for regional action on climate change
- improved awareness of climate change issues within sectors, undertaken by sector leaders, with the support of Hawke’s Bay Regional Council, sector and industry bodies, and MPI, such as through annual summits focused on information networking

- improved engagement with tangata whenua – this needs to be considered as part of broader efforts to involve iwi in adaptation planning
- the development of a vision for a vibrant and diverse regional economy that considers the impact of climate change on key sectors and plans for a 'low carbon, low water' future
- funding to address knowledge gaps for primary sector, enhance and maintain recent progress on adaptation research to enable adaptive planning
- training the next generation of industry and community leaders to participate in adaptation planning processes, and enhancing adaptation research capability and capacity in the science system.

7.4 Monitoring and evaluation

This report presents adaptation options based on information available at the time of its preparation, and the local knowledge and preferences of those stakeholders who were involved in its development. Consistent with an adaptive management approach, the pathways presented here should be reviewed as new information becomes available, as climatic conditions change, or as adaptive capacity grows within sectors or at the regional level.

Adaptation depends on learning and responding effectively to lessons learnt, as well as experience, changing circumstance and new knowledge. There is therefore a need for robust monitoring and evaluation for adaptation. Monitoring of key indicators of systems change (e.g. tipping, turning and trigger points) underpins decision-making about adjustments to strategies, operational plans and implementation practices. This includes monitoring the biophysical, social, economic and political systems.

Adaptation indicators can be used to determine whether or adaptation activities are leading to desired outcomes (Arnott et al. 2016). Evaluation can support the ongoing management of adaptation interventions by assessing progress and pointing out needs for adjustments and provide accountability by demonstrating and reporting on results.

Documenting adaptation lessons and experience can also help make successes reproducible, and makes the strengths and weaknesses of different forms of activity, intervention, and investment explicit. Formal lessons about what did and did not work through implementation can be shared through case studies, field days, and sector networks. This information can also be linked back to higher-level strategies and policies through good governance across local, regional and national scales, as well as providing necessary information for provisions of the global agreements.

8 Conclusions and recommendations

The research presented in this report was guided by three complementary objectives:

- 1 Collate and overlay existing knowledge and data sets to determine the potential impacts of climate change for Hawke's Bay.
- 2 Develop an in-depth, multi-scale, multi-stakeholder assessment of the primary sector's vulnerability to the potential impacts.
- 3 Articulate a multi-scale, multi-sector analysis of future options (adaption pathways) and identify key opportunities and drivers that will help guide regional pathways in a direction that is profitable and environmentally sustainable.

To meet these objectives, this study developed and applied a pathways approach to adaptation planning at the regional scale. Working with diverse primary industries in Hawke's Bay, the research used an adaptive management cycle with a pathways focus to assess climate-related risks and vulnerabilities, and to identify and then sequence adaptation options for four key decision areas. This involved participatory workshops with stakeholders to identify values and current and future exposuresensitivities to climate stress.

Downscaled climate projections for Hawke's Bay, expert elicitation and biophysical and crop modelling were used to generate regional scenarios to explore adaptative strategies employed to deal with them and being considered for the future. Insights regarding the climate and non-climate factors that influence exposure-sensitivity and adaptation were incorporated into the analysis using a systems model.

Adaptation options identified were used as the basis for four pathways diagrams for each of the key decision areas, which were iterated with stakeholder input. Results from two case study catchments were then used to inform the development of a regional pathway to support decision-making for climate resilience.

The following section summarises the key research findings and suggests future research directions for supporting adaptation decision-making and action for New Zealand's primary industries.

8.1 Key findings

- **The trend towards hotter and drier conditions in Hawke's Bay is of significant concern to stakeholders.** The work that has been completed and our own research provide detailed insight into the stakeholders' concerns and priorities. Hotter and drier conditions for Hawke's Bay is perceived by stakeholders to be the most significant driver of future exposure and sensitivity. Higher PED will result in more frequent drought, requiring changes in current land management practices. Climate change will put additional pressure on available water resources. The socioeconomic pressures, including psychosocial well-being and financial stress, should be considered alongside biological or physical impacts and implications.
- **Impacts will be felt across multiple domains, requiring a linked-up and coordinated approach to adaptation.** The results show the ways in which climate change will affect primary industries in Hawke's Bay and the extent to which adaptation will require closer consideration of enabling conditions including regional governance solutions, education and raising awareness of climate change issues and improved engagement with tangata whenua.

Vulnerability is context-dependent, and adaptation planning should closely consider the significance of non-climatic stressors relative to climate change.

Completed pathways for water, community, infrastructure and primary industries highlight stakeholders' concerns, which extend beyond the direct impacts and implications of climate change to incorporate social and environmental well-being, the capacity of infrastructure to support regional value chains, the potential for realising efficiencies in production, and the possibility of transformational change.

The regional pathway provides insight into how decisions taken in one domain or sector can have an impact on others, and how the region as a whole prioritises action. An emerging multi-sector regional pathway draws out some of the interactions among sectors in terms of timing and regional needs.

- **Best practice is likely to contribute to adaptation through incremental change.** The two highest-priority planning actions that could assist with cross-sectoral adaptation are the development of sector-specific adaptation plans, and investment in education, outreach and extension to enhance learning opportunities.
- **Best practice alone is insufficient, and transformational adaptation may be required.** Preparatory work should begin. In the medium to long term (10 to 30 years) preparatory work should be undertaken to explore the potential for transitioning to low-water-use activities and land use change. Furthermore, transformational adaptation will require coordination across the primary industries to identify emerging needs and to realise opportunities. For example, developing markets for new agricultural products may take decades.
- **Transformation will require multi-agent negotiation and collaboration.** To realise opportunities and reduce risks associated with climate change in Hawke's Bay, transformational adaptation may be required. Collective action can facilitate widespread change by leveraging existing multi-stakeholder platforms to address context specificity and facilitate engagement, provide pathways for interactions with diverse partners, and build social capital.
- **Adaptation planning is enabled and enhanced by the participation of affected stakeholders.** Planning processes are strongest when they are participatory and inclusive. Wide consultation with stakeholders can, and should, inform the pathways planning process.

The results also demonstrate the benefits of involving affected stakeholders and decision makers in adaptation planning processes. Workshops in case study catchments and at the regional level provide an opportunity for stakeholders to explore possible futures and identify adaptation options. The process of iterating and producing pathways diagrams provides a practical output, the results of which can be used to inform sector-specific pathways, provide the basis for prioritising regional adaptation actions, and enhance capability and capacity through engagement/learning/socialising new processes, techniques, and knowledge with diverse audiences. Working across sectors also provides opportunities to identify synergies and potential trade-offs with respect to adaptation options.

- **Stakeholders increasingly demand information to support adaptation decision-making and action.** The positive reception and productivity of the five workshops demonstrates there is considerable interest in climate change adaptation. Primary industries and other weather- and climate-sensitive sectors require practical and accessible tools and processes to support adaptation planning. Within New Zealand there is a growing demand from concerned stakeholders, who increasingly pose questions about whether current management practices are able to cope with climate change and increased climate variability, or whether alternative strategies are needed, and if so, when.
- **Understanding the context of adaptation decision-making is essential.** All decision-making processes sit within a broader context. Understanding this context and ensuring appropriate conditions are in place to enable adaptation action is as important as identifying the adaptation options themselves.
- **Applied adaptation pathways provide a useful framework for strategic planning for primary industries, but it is not without its limitations.** Adaptation for primary industries, particularly at the regional scale, involves multiple stakeholders, stressors, and potential options for adaptation. The absence of a single mandated authority responsible for implementation further complicates planning. While adaptation pathways are used elsewhere in New Zealand to address coastal hazards, pathways planning for primary industries is complex, and benefits from the use of additional tools and processes, including systems modelling.

The results provide a novel application of pathways planning methodologies to the primary industries, and can serve as a template for further applications by local and regional authorities, and for sector-specific pathways development.

In summary, the development and application of pathways planning with and for primary industries in Hawke's Bay:

- provides a useful and versatile framework for engaging with diverse stakeholders on adaptation issues – the process is scalable and can be applied to individual land managers, across local and regional scales, or to generate sector-specific insights
- generates additional insight into the complexities of adaptation planning for primary industries

- demonstrates the growing interest in adaptation knowledge, which advances practical application and moves beyond continued debates and discussions on impacts and implications, to more closely consider decisions and actions
- helps to facilitate cross-sector collaboration and knowledge sharing.

8.2 Recommendations and observations

The results provide a novel application of pathways planning methodology to the primary industries, and can serve as a template for further applications by local and regional authorities and for sectorspecific pathways development.

Adaptation to climate change is emerging as a priority in the primary sector and across New Zealand society more generally. The insights gained through this research have informed the following recommendations and observations, which we believe provide a foundation for further application and development of pathways processes and research to support adaptation planning more widely with primary industries. The recommendations include:

- Local, regional and multi-sectoral approaches should be informed by sector-specific understanding.
- Systems modelling, expert advice and local understanding of climate impacts and adaptation options can reveal the complexities of adaptation planning for primary industries.
- Participatory approaches are essential to enhancing adaptive capacity, facilitating learning and enhancing adaptive capacity.
- Pathways diagrams provide a practical output, which can be used to inform outcomes across multiple domains.
- The pathways process is inherently flexible and can be scaled up or down according to resource availability, including data.
- Transformational change will require greater coordination across sectors and scales, and preparatory work should begin now to consider how governance arrangements affect the functioning and performance of innovation in the primary sector.
- Stakeholders should be empowered to carry out adaptation planning by providing them with additional tools to explore possible futures and implement adaptation actions.
- Research to support adaptation planning should be prioritised in response to growing demand for knowledge regarding adaptation options, beyond impacts and implications to consider adaptation decisions and actions.
- Tools and processes for documenting adaptation experiences by sectors and regions need to be developed to help make successes reproducible. Monitoring and evaluating adaptation can provide an empirical basis for understanding and tracking progress towards outcomes, improve the ability to design effective policy interventions and demonstrate the impact of adaptation science, supporting the transition towards climate-resilient primary industries.
- Multi-sector and regional coordination are required to identify synergies and trade-offs, realise opportunities, and avoid maladaptation.

This document has recorded the facilitated deliberations of stakeholders in Hawke's Bay at a point in time, but such deliberations are always incomplete and conditions will continue to change. Therefore, a final action is to review this plan periodically, such as every 2–3 years, in a spirit of adaptive management. Not only will such reviews be able to take account of how conditions are changing, but participants will also be able to build on this work. Future reviews should look closely at where profound transformative change may in fact be needed in complex issues such as freshwater management and land-use change, as well as other areas mentioned here.

8.3 Conclusion

Adaptation to climate change is emerging as a priority scientific need in the primary industries and across New Zealand society more generally. A single project cannot achieve major steps forward, especially in a short time frame, but it can be part of the momentum to connect and empower primary industries to capacities towards meaningful roles in climate adaptation. The principles and procedures outlined in this research support using a participatory, qualitatively-based pathways approach to enhance social learning for understanding, planning options, and motivating action towards climate change adaptation.

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Appendix A – Organisations/sectors that participated in the pathways process

ANZ

Beef + Lamb

Dairy sector (private farmers)

Department of Conservation

EcoVillage

Farmlands

Federated Farmers

FMG

Foundation for Arable Research

Gimblett Gravel Winegrowers

Grape and wine (private growers/wine makers) Hastings

District Council

Hawke's Bay Fruitgrowers' Association

Hawke's Bay Regional Council

Hawke's Bay Vegetable Growers

Hawke's Bay Winegrowers

Foundation for Arable Research

Gimlet Gravels Growers

Heinz-Watties (NZ)

Lincoln University

Maori land development (private)

Maori land trustees (private)

NIWA

NZ Apples & Pears

Plant & Food Research

Te Taiwhenua o Heretaunga

Twyford Irrigators Group

Wairoa District Council

Wairoa Economic Development Trust

Appendix B – Workshop report - Values

The following describes the process of engagement, data collection and preliminary analysis as part of the SLMACC-funded project "Applied Adaptation Pathways: Supporting Robust Regional DecisionMaking: An Application in Hawke's Bay".

Through engagement and collaboration with end-users, farmers/growers from representative systems, and with the support of key stakeholders, including Hawke's Bay Regional Council (HBRC) our research has begun to synthesize and prioritize climate change impacts for the region, identify management and production thresholds, triggers, and critical decision points.

The process we are undertaking has five stages (Figure 1). The purpose of this section of the report is to provide an update of recent research activity, in particular the catchment based workshops in

Wairoa and Heretaunga which fulfils the first two stages. An overview of the methods and results from the workshops is presented and indicative plans to fulfil remaining stages is outlined.

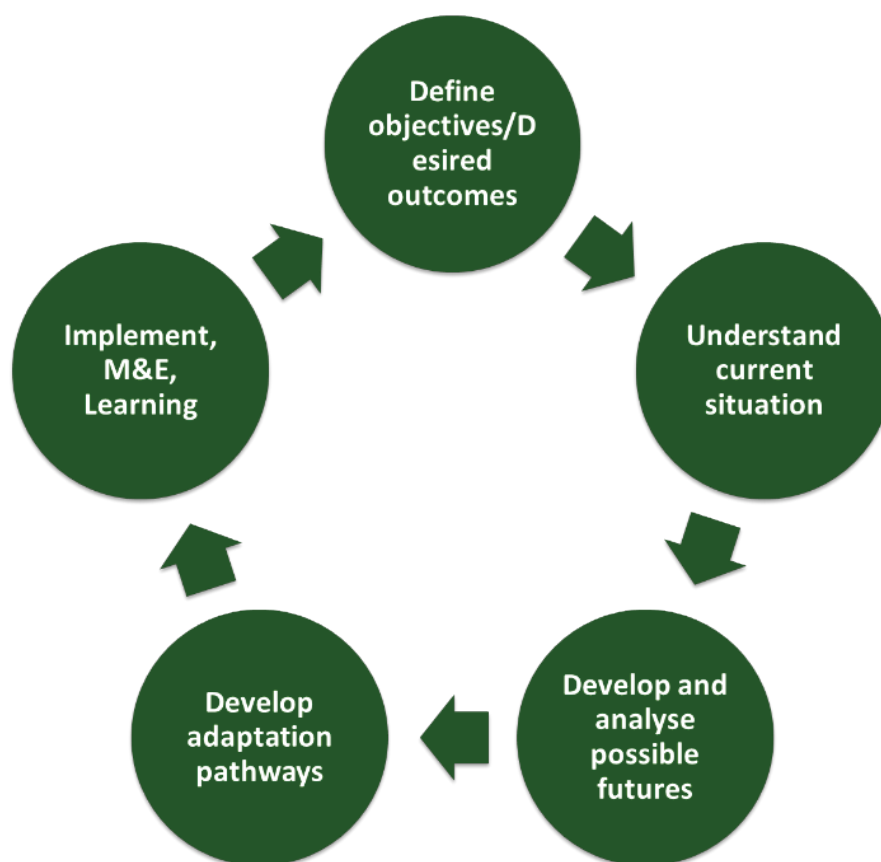


Figure 1: Adaptation Pathways development process for the Hawkes Bay.

1 Catchment workshops

Two case study sites were selected based in part on consultation with Hawke's Bay Regional Council. The study sites – Wairoa and Heretaunga catchments – are broadly representative of the diversity of land-management, climate change, and socio-economic issues facing the region, including soil erosion, drought, water availability, and social and economic vulnerability. They are studies in contrasts – one a remote, hilly, and erosion prone region; the other flat, with diverse land uses focused on high value horticultural and viticultural production.

The catchment based workshops had several objectives:

- 1 To broadly articulate the regional effects of climate change, and how it might potentially impact primary industries in the case study area(s);
- 2 To undertake workshop activities aimed stimulating discussion and provide an opportunity for stakeholders and researchers to identify and reflect on potential impacts from farm- to market, including exposures, and key sensitivities;
- 3 Initiate identification of potential adaptation strategies; and
- 4 Generate interest in the research project, outputs and attendance at the 2nd workshop (April/May) which will develop adaptation pathways.

The workshops were structured in such a way as to achieve the stated objectives (refer to Appendix 1). Seating was arranged café style to facilitate group discussion.

To generate the data required for input to the next stages of the research program, we developed and then followed a structured process. The methods to achieve each objective were as follows:

1.1 Objective 1

Immediately following project and team introduction, the small groups were asked:

“Describe your vision for the productive sector in the region” or in other words

“What are the aspirations/visions for the various sectors in this catchment?”

Information from each group was written on post-it notes (one idea per note) and collected and discussed using nominal group technique.

1.2 Objective 2

Objective 2 had two parts: first, obtain a collective understanding of how the current system operates and what challenges exist; second, highlight how climate change may affect this systems and what opportunities and challenges may arise. Between these group brainstorm sessions a Power Point presentation, followed by Q&A provided an overview of potential climate change for the region, based on the NIWA report prepared by Tait (2017), as part of the first project milestones. The presentation included information about changes in key climate variables, as well as results from some modelling (e.g. maize yields) under different climate scenarios.

To achieve the first part of this objective groups were asked to:

“Using a rich picture describe/draw how the various productive sectors currently function in this area. Please consider including:

Resources that are required for production (e.g., land, water, labour)

The value chain (how does the product get to market?)

What are the current challenges and why?”

Each group was provide with A0 blank paper and coloured pens to complete the task. Once finished, groups explained their thinking to the others in the room.

Following the first activity, a presentation was given on the regional impacts of climate change. The purpose of the presentation was to provide participants with sufficient information about anticipated effects in quite broad terms (e.g. shifts in precipitation, variability and extremes), but not overwhelm them with detail. The focus was on generating discussion, rather than debating the details of anthropogenic climate change. Content enabled participants to engage with the next component of this objective. The following questions were then used to guide participants through the next steps:

“Given what we know about climate change how might the productive sector in this area be affected? (i.e., what will the critical vulnerabilities be?

What might this mean for the area/region?

What could some of the critical issues/challenges and opportunities be?”

In order to do this exercise, large plastic sheets were overlaid on top of original work, and participants were asked to illustrate potential impacts, linking to and building on their previous work and activity.

Groups integrated their own experience/knowledge with information about projected impacts and presented these back to others in the room. As this was being shared, a collective list of items was recorded on a large sheet of paper to highlighted commonality and provide information to support the selection of two key focal areas for Objectives 3 and 4.

1.3 Objectives 3 and 4

Three key areas were selected from the list of common issues and opportunities to prime the group for further discussion on adaptation options. The areas were selected based on their frequency of occurrence and the relevance to with the values and visions described in Objective 1.

Participants were asked in their groups to consider, for the two key areas of focus *“Are there actions (near-term) or long-term strategies that might be used to maximise opportunities and realise regional aspirations in the catchment?”*

Participants were encouraged to be creative and think broadly. Ideas were reported back using to the main group using nominal group technique. Adaptation options and ideas were not evaluated, only

evaluated for future use. The short-term actions and long-term strategies will provide the starting point for the discussion in the subsequent workshops. In the second workshops, participants will begin to consider adaptation pathways and strategies.

The following sections report on the preliminary results from the first series of workshops.

2 Workshop Summary: Wairoa

The Wairoa workshop was held 31 September 2017, between 1 pm and 5pm in Wairoa township at the AFFCO Room, Wairoa Community Centre. Participants were identified through discussion with Hawke's Bay Regional Council staff with strong local connections. Invitations (see Appendix X) were sent to individual, sector organisations, local government and industry, as well as to representatives of local iwi representing local iwi (Ngāti Kahungunu). A diverse range of industries, organisations and interests were contacted.

A total of 19 people attended the workshop, representative of a broad cross section of the community including:

- Wairoa Economic Development Trust
- Maori land development
- Maori land trustees
- Wairoa District Council
- Hawke's Bay Regional Council
- EcoVillage
- Banking and financial services (e.g. Insurance)
- Rural service providers (e.g. Farmlands)
- Farmers and land managers
- Local business owners

2.1 Values exercise (Objective 1)

Participants were asked to "Describe their vision for the productive sector in the region" or in other words "What are the aspirations/visions for the various sectors in this catchment?". Responses are collated in Table 1.

Table 1: Wairoa workshop participants' values and aspirations for the productive sector

Environment	Freshwater Protecting our rivers Water – enough water; surface, below ground – rivers lakes
Cultural heritage	Realise Māori aspirations for the region in concert with regional development.
We must help our communities thrive.	'Employment' – ongoing, sustainable growth Sustainable community, population, etc. Sustainability for everyone. Community support for policies that are adopted Grow all our own food Affordable place to live (key asset, good to retain), lifestyle
Productivity	Remaining/Increasing productivity from/for primary industries
Transport	Internal transportation, cooperation, connectivity, get it to where it needs to go! External/internal
Safety	Shift activities/infrastructure/housing away from areas that are at risk from climate change impacts

2.2 How does the current system work? (Objective 2)

The following section details both how each group believed the primary sector currently functioned in the area, but also how climate change may generate challenges and opportunities. The four groups

used different methods to organise and depict the productive landscape. We have organised them as follows: Pie chart, Mātauranga Māori, Landscape System and Post-Its.

2.2.1 Group 1: Land use pie chart

Group 1 used a pie chart as the central image around which to construct their narrative describing the current production system in the Wairoa catchment. Several key themes relating to the primary sector and current land management in the catchment were identified and discussed (Figure 2a).

Diversity of the land use in the catchment

Forestry is a big part of the district. The block at various stages of growth – developing, growing, trees about to come out, mature blocks, harvested blocks.

Pastoral farming on hill country, sheep beef deer, minor part of flats in dairy

Fertile river flats used for cropping, maize, sweet corn, squash, and flat land and orchards, kiwifruit.

Local opportunities are not realised

There is land which may be under-utilised land. Opportunities exist to expand current land uses but there are infrastructure difficulties due to lack of rail connection, limited road access (only one road to/from Napier and one road to/from Gisborne) and challenges with undulating terrain and topography (roads are narrow, winding and long), which means travel times are longer than average.

Tourism and conservation land may present an opportunity to utilising natural resources. Advances in technology could potentially counteract the effects of remoteness, opening up new modes of transportation and communication (e.g. 5G internet, drones).

Attracting investment to the area is urgently needed, and the community should be endeavour to obtain a share of the multi-billion dollar infrastructure investment targeting regional NZ, to improve road and rail access, streamline logistics (especially for forest products which are currently moved by road), and enhance road access to/from Gisborne and Napier.

Labour issues

There is a shortage of skilled labour in the area to employ in the primary sector. Recruiting skilled labour (skilled employees) and keeping them (attracting and retaining) remains a challenge

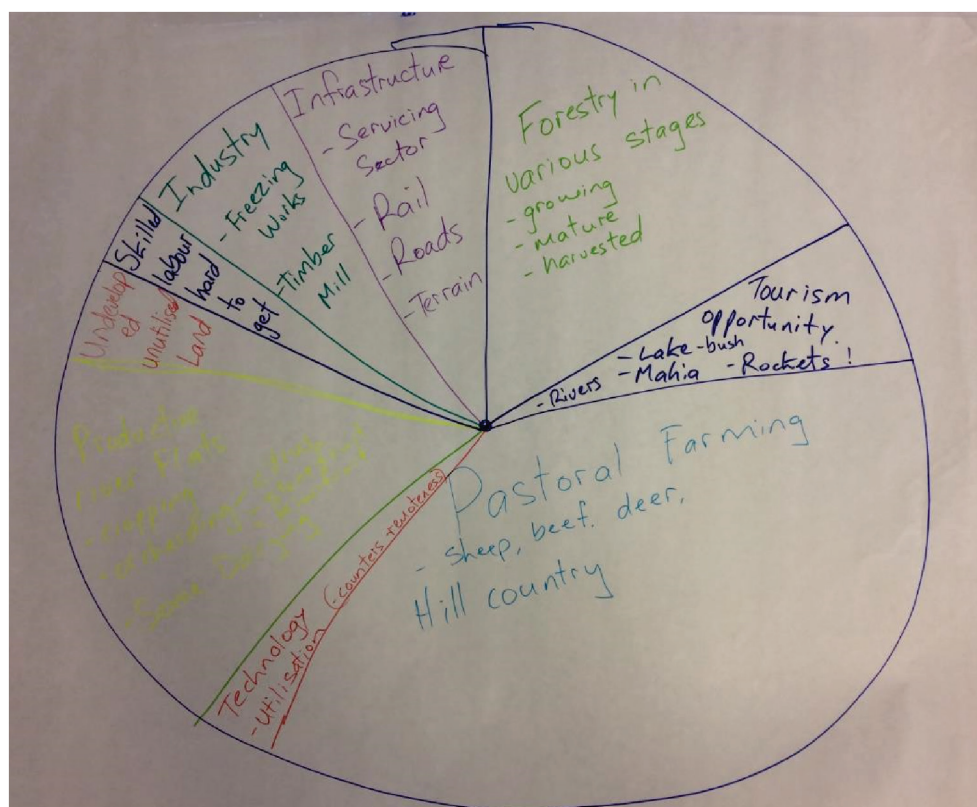


Figure 2a: Wairoa - Group 1 - Productive sector at present

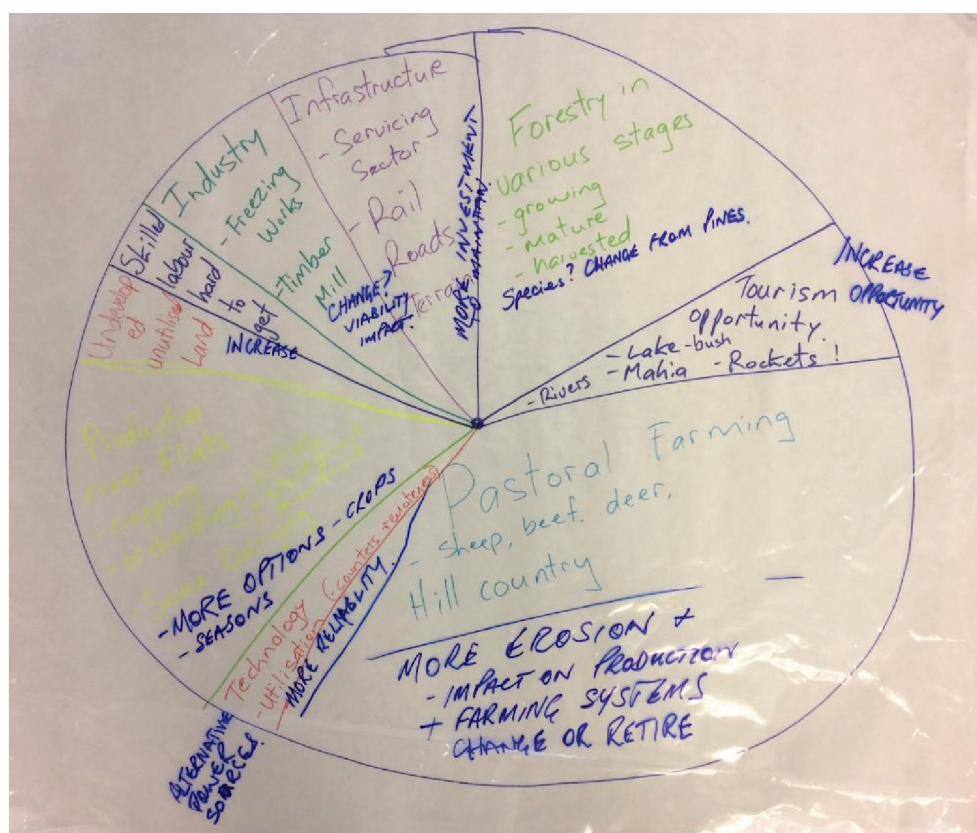


Figure 2b: Wairoa - Group 1 - Productive sector and climate change.

Group 1 identified a number of key themes relating to the primary sector and how climate change might affect it (Figure 2b).

Transportation

Road and rail systems may be disrupted more often and required more investment to maintain them so they provide the desired level of service. This will present challenges with respect to shipping product to markets which rely on timely delivery to ensure quality, and the movement of labour in and out of the area.

Land use

More erosion may be possible in hill country, pastoral farming may need to change or land be retired. In addition, changes in productivity or potential changes in productivity could occur.

New types of crops may be possible generating new income streams and land use options. With warmer temps (e.g. bananas grown in this area?) Native forest and ecosystems may change.

Alternative power sources may be necessary. Infrastructure and power lines may be disrupted and may put more emphasis on technology and alternative energy.

Tourism

New opportunities may be created.

2.2.2 Group 2: Mātauranga Māori framework

Group 2 used Mātauranga Māori as an organising theme around which they constructed a narrative to describe the current production system in the Wairoa catchment. Participants in this group identified several key themes (Figure 3a).

Economic development is needed

Wairoa misses out on investment, therefore we need to make more noise. A lot of regional economic development scheme money is being invested north and south of Wairoa; Wairoa is not mentioned in any of these initiatives.

Raise the profile of Wairoa as a strong candidate for investment. Seeka for example, might be interested in potential land base for kiwifruit and avocado; need permanent, on-the-ground support to set action plans, focused on Wairoa. Wairoa is a low income community, and capital investment is needed to develop new enterprises. Significant natural capital (productive environment, fertile land, soil, climate) however the financial capital is not available in the community.

Current land use relies on the inherent resilience of the landscape, and production of raw commodities (e.g. forest products), with little added value and limited processing capacity, so the full economic benefits are not realised in the community/catchment.

Transport networks are insufficient

Investors lack confidence in the current transportation infrastructure, and its implications for logistics (e.g. just in time delivery, quality control, storage). The current transportation network does not provide sufficient access north and south.

Local capacity and Community ownership is essential

Difficult to talk about primary production, community and landscape as we also require the capacity to carry out our plans. Once we have some momentum, we expect it will be self-sustaining, a positive feedback loop. Community ownership is critical and may overcome some of the barriers associated with outside investment. Locally owned is key to a successful outcome. There may be potential opportunities associated with treaty settlement.

Group 2 also identified several key themes relating to primary industries in the catchment, and the effects of climate change. primary sector and how it may be affected by climate change (Figure 3b).

What new skills might be required?

The group recognised that additional human capital will be required, including skills training, some of which may not yet be available. "Teaching people for skills where there's no jobs yet"

Invasive species and changing species behaviour

We are seeing new things happening in the garden; new weeds, things flowering early.

New Zealand water fern (*Azolla pinnata*) has exploded in recent years. It is a very invasive weed, and likely to spread with a warmer climate. It is very high in nutritional value, reproduces its own biomass in 5-6 days and could develop a market for it.

More endangered species

More endangered species likely as climate change becomes more pronounced

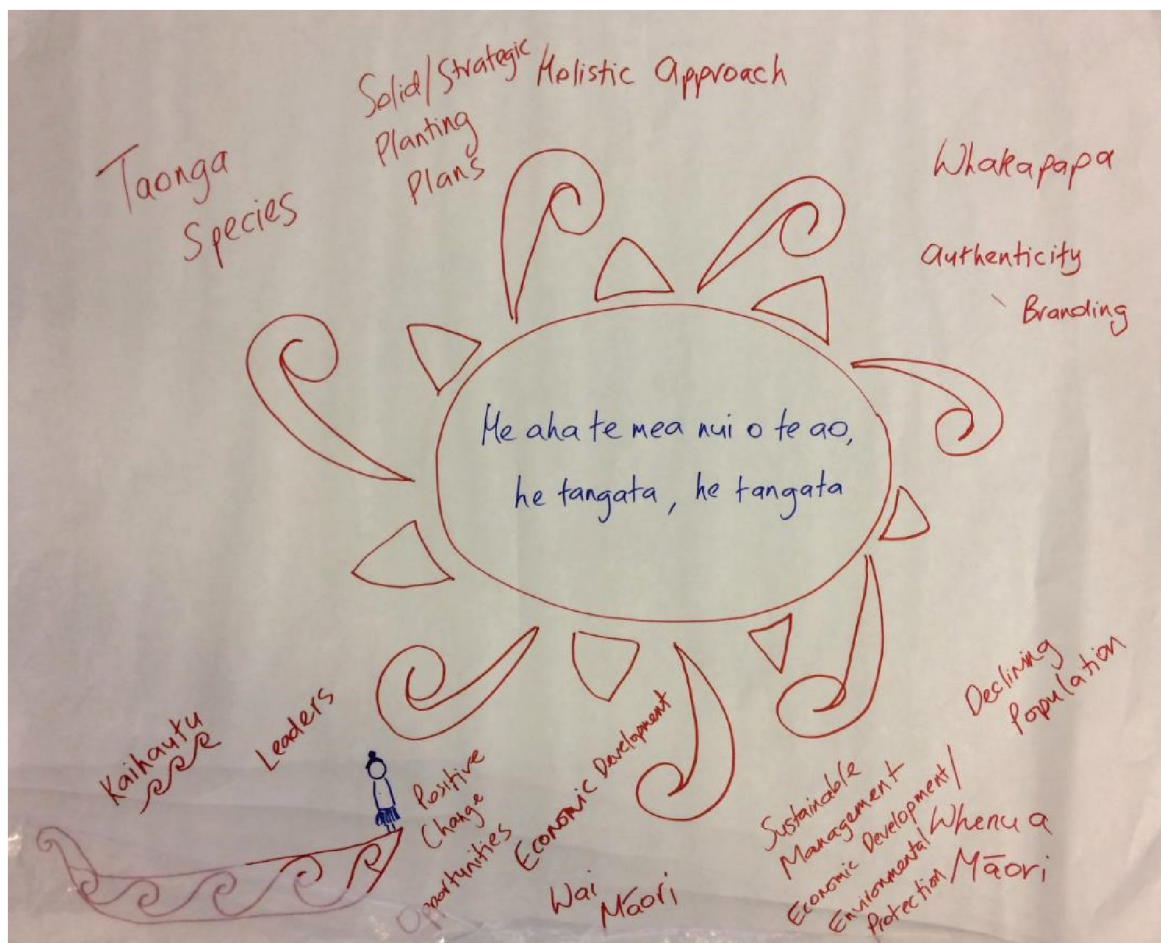


Figure 3a: Wairoa - Group 2 - Productive sector at present

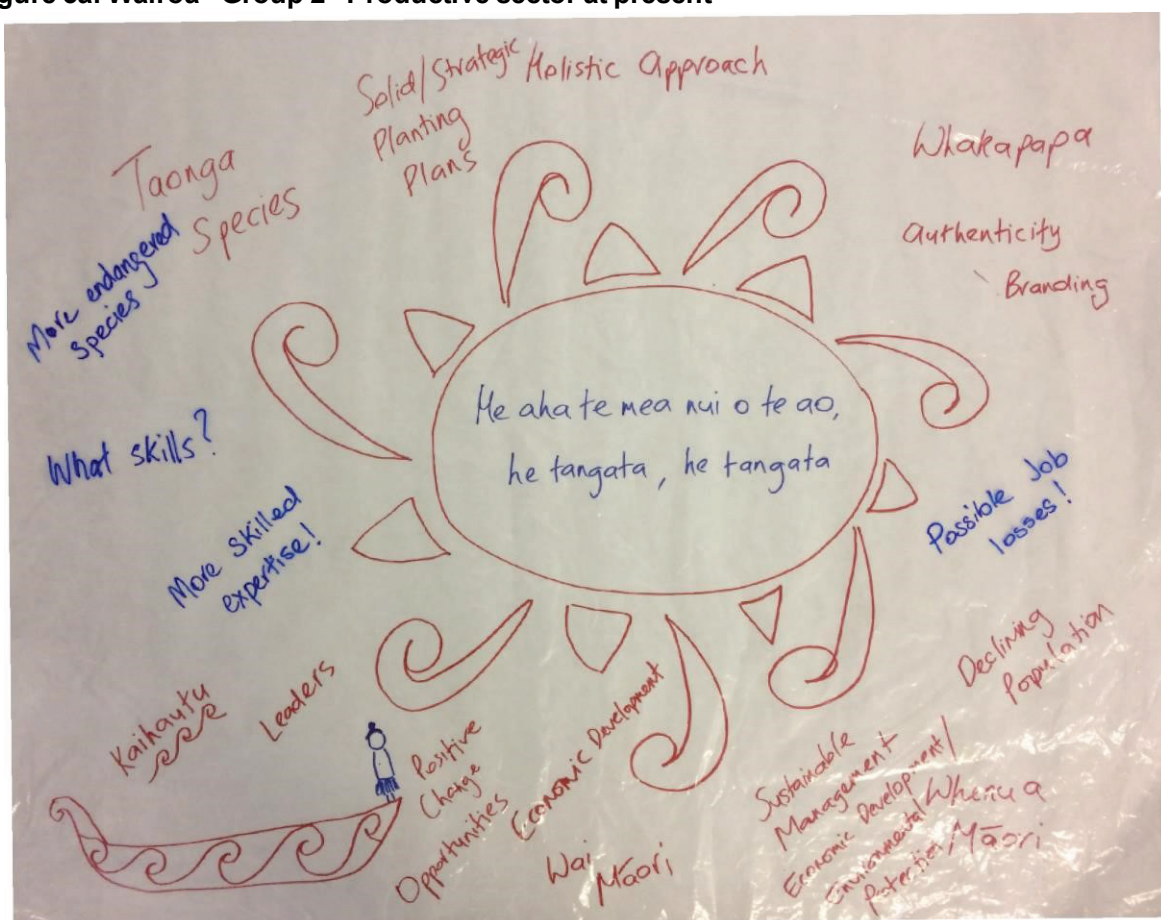


Figure 3b: Wairoa - Group 2 - Productive sector and climate change.

2.2.3 Group 3: Landscape system

Group 3 used a landscape system as the central image to construct their narrative describing the current production system in the Wairoa catchment, and also identified a number of key themes (Figure 4a).

Fragile systems

The local environment is fragile. Hill country is especially sensitive, as well as water quality and quantity, in lakes and rivers. Other issues include extensive soil erosion, sedimentation, land slips, and drop outs, and the effects on transportation and road access (e.g. deposition on roads).

Good climate

Wairoa has good rainfall, productive land, sandstone, good soils, and high temperatures and growing degree days, able to grow diversity of crops.

Engaged community

There is a high level of community participation. Wairoa has one of the highest levels of community participation in the country for local body elections (i.e. engaged citizenry, and exercise of voting rights). There is an awareness of others within the community; consensus on the importance of land; intermingling of communities and people. As one participant said, there is “Lots happening, lots going on, a great place we live in.”

Static population and limited investment

The population is not changing or growing with changes in industry and/or investment. Generally speaking, it is a low-wage economy. However, there is a high-level of cultural awareness between all our communities (i.e. Māori, Pakeha and others)

Tourism potential

The region has high potential as a tourism destination. This is currently unrealised.

Transportation

The biggest challenge is our isolation and issues relating to transportation. Cost of improving road and rail access are extremely high, and would require a broad range of stakeholders to be involved. The community would not be able to do this on its own.

Several key themes emerged from Group 3 around the primary sector and how it may be affected by climate change (Figure 4b).

Impacts on fragile systems

Climate change is likely to exacerbate negative effects of current land management practices (e.g. we will see increased soil erosion due to rain fall extremes). Changes in management practices in hill country – farms and forestry – may further compound these impacts. Increased rainfall extreme events could cause transport disruption and cause localised flooding.

Impacts on infrastructure

Damage to infrastructure will require adaptation and is a huge issue to overcome. New flood protection programs may be required as rural centres/communities are threatened.

Changes in water management, and opportunities for novel crops

Changes in climate variability and extremes may increase demand for more reliable water availability, and/or irrigation, or reticulation. A phenomenal amount of water flows through Wairoa District. Climate

change may also create new opportunities for diverse crops (e.g. Gisborne and Bay of Plenty kiwifruit growers; avocados). How can we turn potential negatives into opportunities?

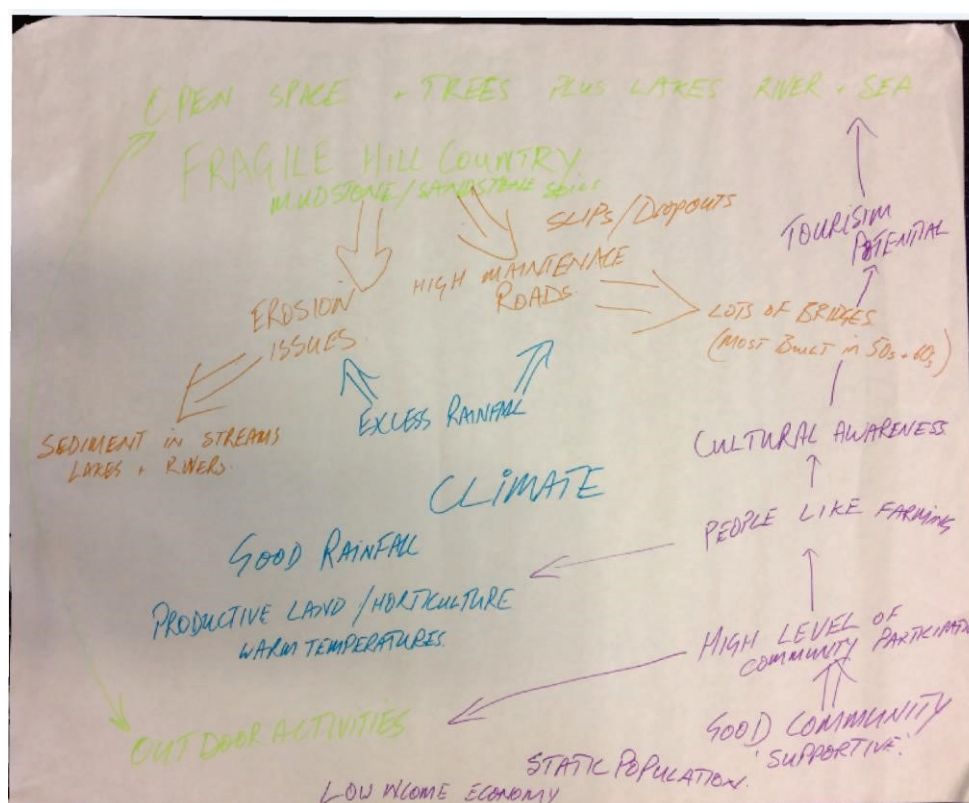


Figure 4a: Wairoa - Group 3 - Productive sector at present

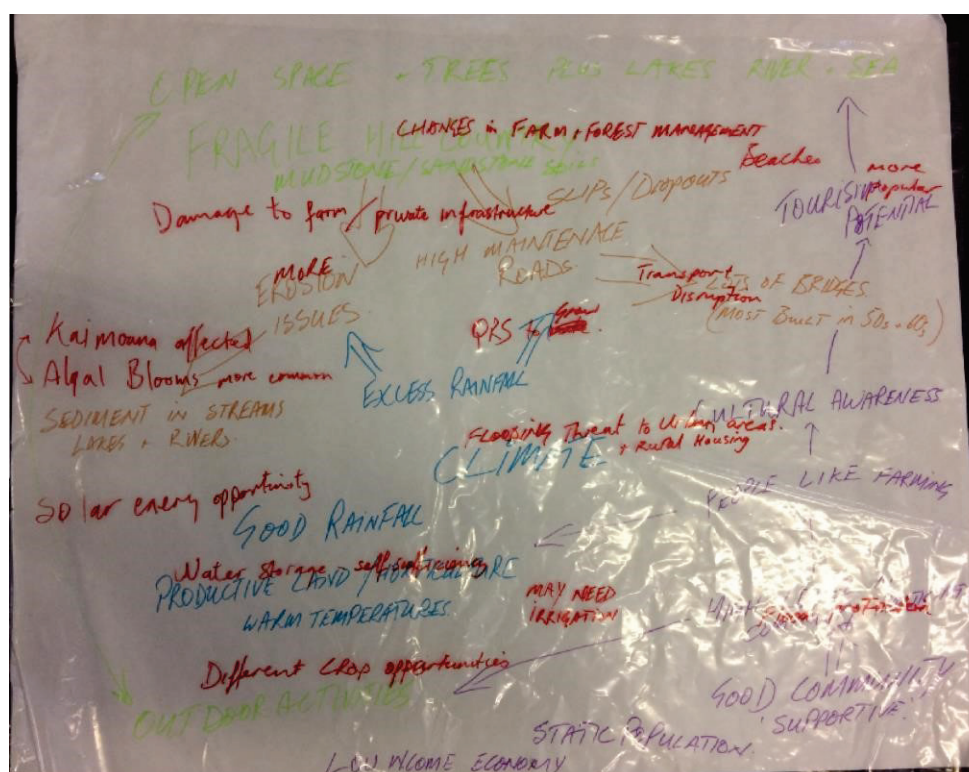


Figure 4b: Wairoa - Group 3 - Productive sector and climate change

2.2.4 Group 4: Post-Its

Group 4 used Post-It notes to organise their narrative of current production in Wairoa. Key themes identified by this group include (see Figure 5a).

Diverse primary sector and economic base

Diverse range of industries operate in the catchment including: pastoral farming, forestry, fishing, cropping and horticulture. Primary industries are able to capitalise on the good land and soil types, and mild climate. There is no shortage of water, but it is a resource we need to maintain. There was a 3-month drought last summer.

Population changes

The regional population is in decline overall. There is some rising employment in primary sector, however as farms convert to forestry operations, there is an overall drop in employment (i.e. fewer people needed to work on forestry conversion once established, than on farm). This in turn has an effect on school enrolment.

Transportation networks

Transportation networks are currently poor. For example, if someone wants to produce their own meat – raise cattle and add value – it needs to be taken out of the district for processing. The region needs better road access, and more robust transportation network processing infrastructure can be developed locally.

Several key themes emerged from Group 4 around the primary sector and how it may be affected by climate change (Figure 5b).

Transportation

Transportation networks are likely to be disrupted with climate change. This will have adverse effects on the movement of key resources in and out of the area.

New crops and land use change

Changes in climate may change the types of crops that could be grown in Wairoa, creating new opportunities. Changes in land use may also require additional regulation, or changes in policy to better manage water availability and soil erosion for example.

Energy supply

Energy demands for cooling/heating will change. Currently reliant on energy supplied to the region rather than local generation. This may become an issue in the future. Future land use changes may in turn have an effect on energy demand (e.g. cold stores, processing).

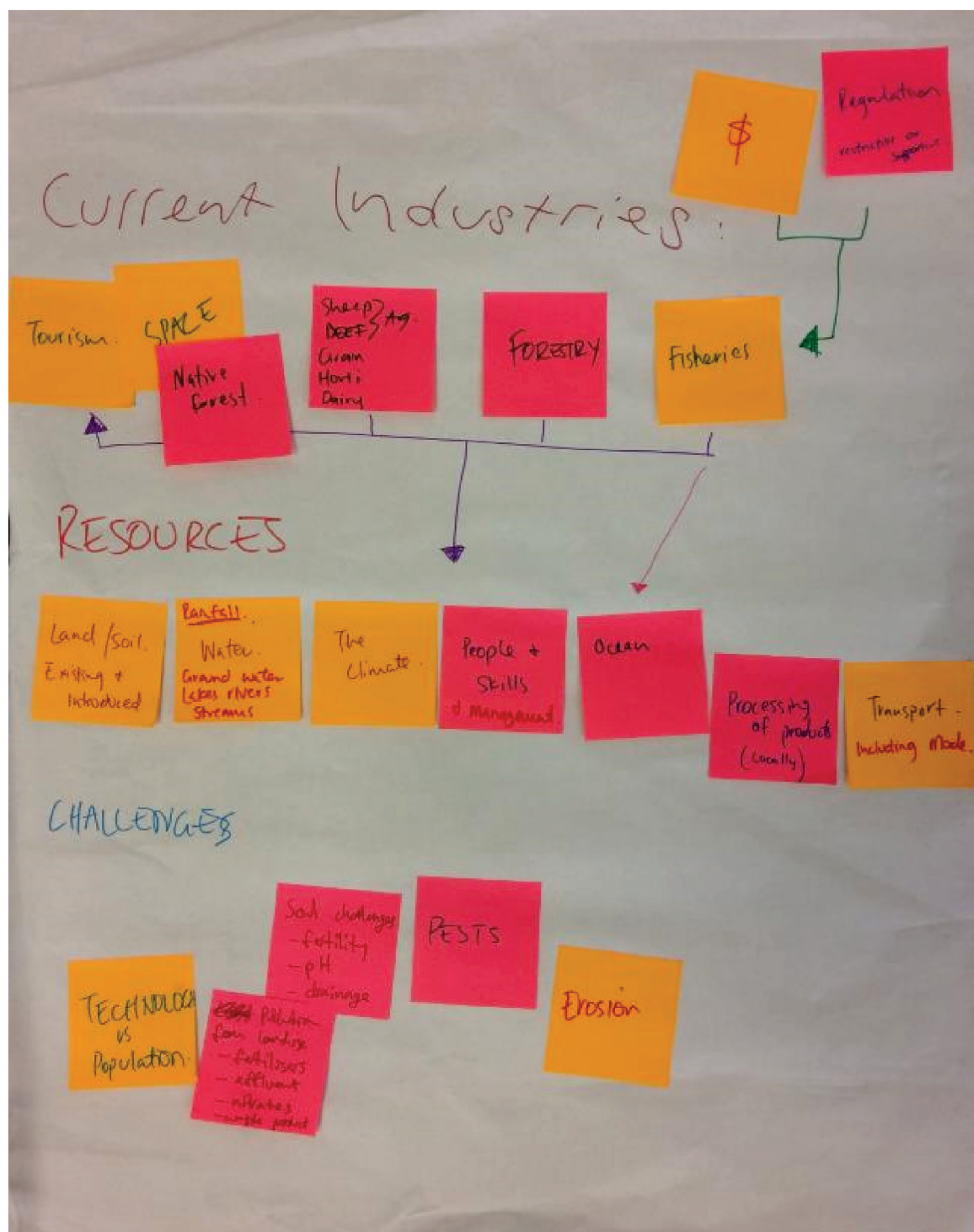


Figure 5a: Wairoa - Group 4 - Productive sector at present



Figure 5b: Wairoa - Group 4 - Productive sector and climate change

2.3 What are the common themes?

As the groups discussed their views on the current situation and the effects of climate change, a list of shared themes was developed – with new items added in the order in which they were discussed.

Common themes included:

- Employment – retaining and attracting skilled labour
- Attracting investment
- Road, rail and transportation infrastructure

- Regional development
- Raw materials moved out of region with no added value
- Reliant on natural capital and landscape
- Capacity to implement plans and strategies
- Fragile hill country
- Changes in technology, reducing no. of jobs available
- Pests (current pests and new pests)
- Regulations and policy (affecting ability to act)
- Water

“Land use” and “transportation” were quickly identified as the most significant challenges for the region, and so were the focus of the subsequent brainstorm on adaptation.

2.4 How could we adapt? (Objectives 3 and 4)

The aim of the adaptation brainstorming was to ‘prime’ the group to explore in more detail at the next workshop. Adaptation pathways will then be developed, based on a more rigorous analysis of adaptation options, their feasibility, who is required to implement them, and any barriers to their application.

Selected adaptation options highlighted by participants included:

Transportation

- Drones
- De-centralised storage and processing systems
- Changes in transportation modes
- Reinstate Railway
- Solar powered trains/trucks

People and skills

- Local research and education
- Added value industries (e.g. packhouse)
- Develop potential for tourism
- Bio-regional cooperatives
- Local research and education

Land use

- Horticultural opportunities: tropical/sub-tropical
- Increasing volume of local exports to support rail
- Biological/Biodynamic agriculture
- Management of intensive grazing
- Enhance native biodiversity (vegetation)
- Afforestation
- Added value industries
- Develop potential for tourism
- Bio-regional cooperatives
- Terracing hill country

3 Heretaunga Plains Workshop

The Heretaunga Plains workshop was held 1 October 2017, from 9 a.m. to 1 p.m. at Te Taiwhenua o Heretaunga, Hastings. Participants were identified through discussion with Hawke’s Bay Regional Council staff, and recruited through existing researcher networks. Invitations were sent to diverse industry and sector representatives, local government, community groups, and iwi – covering a diverse range of interests. The PI (Cradock-Henry) has been involved with the TANK Collaborative Group, working on freshwater management in the Tutaekuri, Ahuriri, Ngaruroro, and Karamu catchments, and an invitation was extended to TANK members in particular.

A total of 14 people attended the workshop, representative of a broad cross section of the community including:

- Hawke’s Bay Regional Council
- Local business owners
- Viticulture
- Horticulture
- Vegetable cropping
- Dairy
- Sheep-and-beef
- Processing
- Rural service providers (e.g. Farmlands)
- Central government (e.g. MPI)

3.1 Values exercise (Objective 1)

Participants were asked to “*Describe their vision for the productive sector in the region*”; or in other words describe “*What are the aspirations/visions for the various sectors in this catchment?*” Responses are collated in Table 2.

Table 2: Heretaunga Plains workshop participants' values and aspirations for the productive sector

Water	Water is essential for production, and to sustain life; Water security – for livestock, people, irrigation systems, rivers
Governance and connection, communication and institutions	Good governance and being connected across scales needs clear understanding issues at local level. Balanced power between levels of government (local, regional, central) and the three main councils in the area. More connection to communities, better understanding and engagement with pressing local issues. Agency, and capacity to solve problems – resilience in all areas (awareness), and everyone knowing that they can play a part in incremental changes to build resilience.
Economic resilience and sustainability	A resilient local economy – without it people will give up, and so how do we change track because the economic resilience of what we are doing is not holding up. Diversified land uses – better understanding of what we could do with the land base that could make us more resilient, and in turn enhance economic resilience and community resilience. Realise opportunity for tourism and primary production. Tomata Mushrooms for example takes people to see production, grab the tourism people doing the wine, not doing the food and production stuff (tourism) well yet. Realise opportunities for value add, and food security. For example we have world class breeding programs, can grow our own seeds and become more resilient and enhance food security. Infrastructure required to support opportunities; opportunities come quickly and we need to be able to realise them, agile, able to grab them.
Resilient infrastructure and people.	Economic diversification to attract diverse population of skilled workers and create additional opportunities. Opportunities come from economic resilience. Identify new opportunities within existing sectors, and have the human capital to actually realise opportunity: sheep milking, plant based protein in diets, and shifts to new foods, but how to process it? Business and industry become nimble; able to move quickly and pick up on opportunities; range of opportunities, capacities and diversification. Empathetic communities – making sure everyone is patient, can understand where people are at (awareness).
Risk awareness	Awareness (full stop); awareness and understanding of the problem. Work on the 80/20 rule, 80% of the region's population is not aware of most things going on around them.
Science for society	Science to back policy and lead to a healthy society. Improve community well-being, and make sure we have the best available science to get adaptation right. We need a place for the future.
Maintain and Enhance Natural Capitals	Improve air quality. Capitalise on sunshine hours, heat units, chill units and the generally favourable climate.

3.2 How does the current system work? (Objective 2)

The following section details both how each group believed the primary sector currently functioned in the area, and how climate change may create new challenges and opportunities. As in the previous workshop, the groups interpreted the instructions in different ways. Below, we discuss the three groups' maps in turn: Food Bowl, Systems, and Geometric Systems.

3.2.1 Group 1: Food Bowl

Group 1 used the idea of a food bowl to develop a narrative for the Heretaunga Plains' current status. Several key themes relating to this were identified (Figure 6a):

Hawke's Bay Food Bowl

The group identified Hawke's Bay and specifically the Heretaunga Plains as a diverse food bowl. A number of different landscape features, a built environment and diverse regional economy co-exist here: water quality, quantity, soils and climate, people and resources, infrastructure transport and energy, marketing, education to develop needed skills, local government support, economic development and tourism.

Lifestyle was also noted. As one participant noted "We have a lifestyle we want to preserve. If we are going to keep that productive ability going, what things might shock the system?"

Infrastructure

The area has well developed infrastructure (e.g. port access) but key assets are currently at risk from extreme events and hazards. For example the 2017 snow storm damaged one of the two main power lines in the region, which caused problems for some farmers. The airport is vulnerable to tsunami risk. Access to high-speed internet in parts of the region has enhanced access to information, although at increased cost. Farmers are increasingly reliant on communications infrastructure.

Water

Water is a key challenge at present, including water quality, quantity, and security.

Group 1 also identified how primary industries might be affected by climate change (Figure 6b).

Changes to the physical factors supporting the food bowl

Increasing challenges with soil erosion, water availability, quality and reliability, therefore likely to become increasingly important to budget and allocate water. Changes in air quality due to increased wildfire risk. To cope with the changes we need to get away from framing climate change impacts in terms of averages, and better understand the extremes.

Biosecurity issues

Biosecurity challenges and incursions more likely due to hot dry weather

Infrastructure

Increasing risk and changes to existing infrastructure; less reliable power supply (e.g. damaging storm events may affect lines); sea level rise may affect Napier Port facilities, limiting market access.

Road changes; bitumen starts to fail in the heat, making travel difficult.

Impacts on the airport either directly due to sea level rise or indirectly or carbon miles/foot printing making it less attractive to tourists (tourism numbers drop).

Increasing production costs

Possible increase in compliance costs, increased production costs; all secondary industries will have higher base costs. Additional capital investment may be required.

The biggest drivers of land use change will be economic. Climate change will have impacts at both ends of the value chain; what is ACTUALLY making us adapt or mitigate?

Changes are likely to be incremental, and only when the effect is felt on the bottom line will change really be prompted/catalysed. Science needs to evolve and become more relevant to industry, to enable us to become more resilient; industry itself also needs to be prepared to change to meet the climate challenge.

Changing land use

Hawke's Bay may become more/less attractive for housing and lifestyle blocks as the climate changes and effects are felt here and elsewhere in NZ, and internationally.

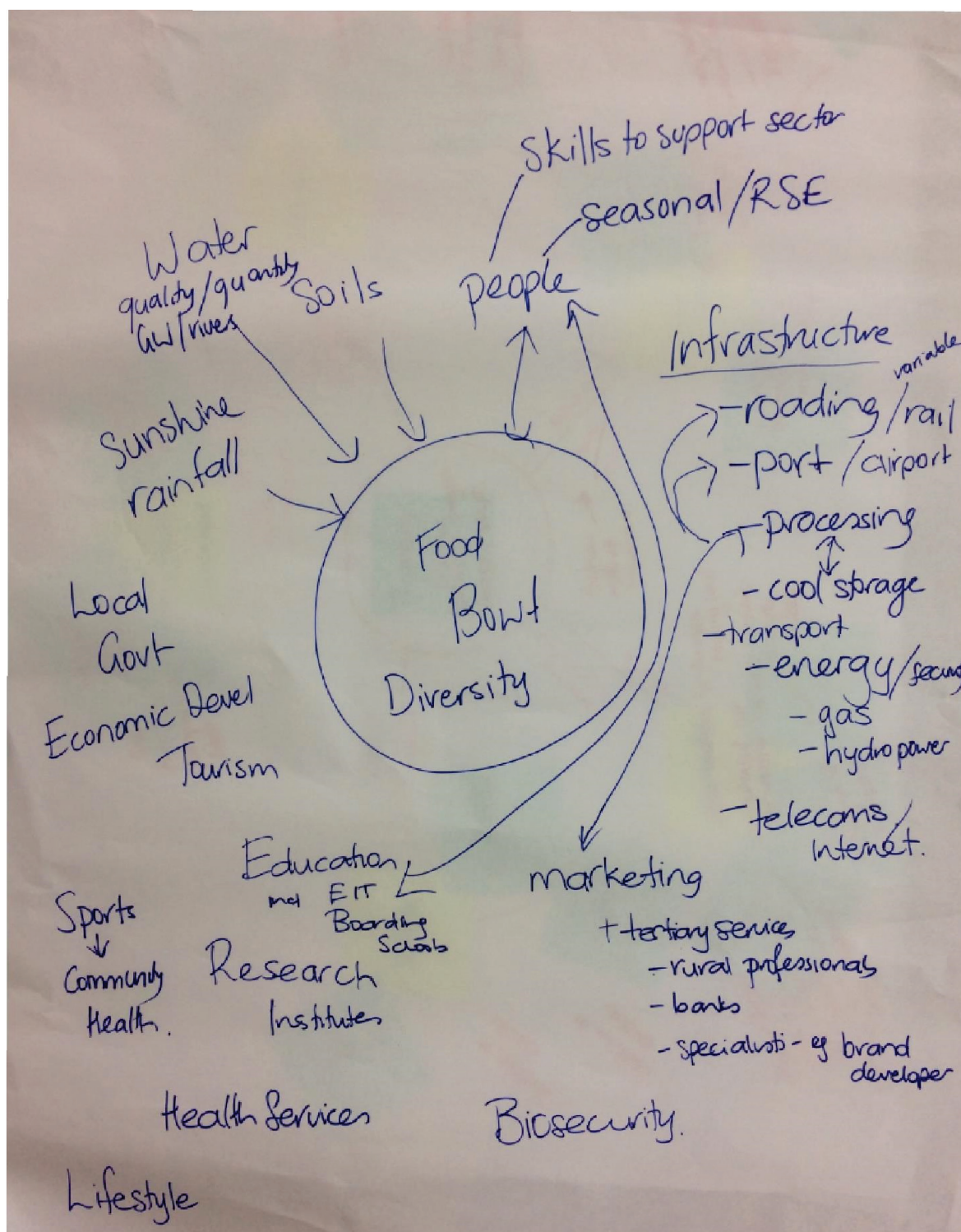


Figure 6a: Heretaunga Plains - Group 1 - Productive sector at present

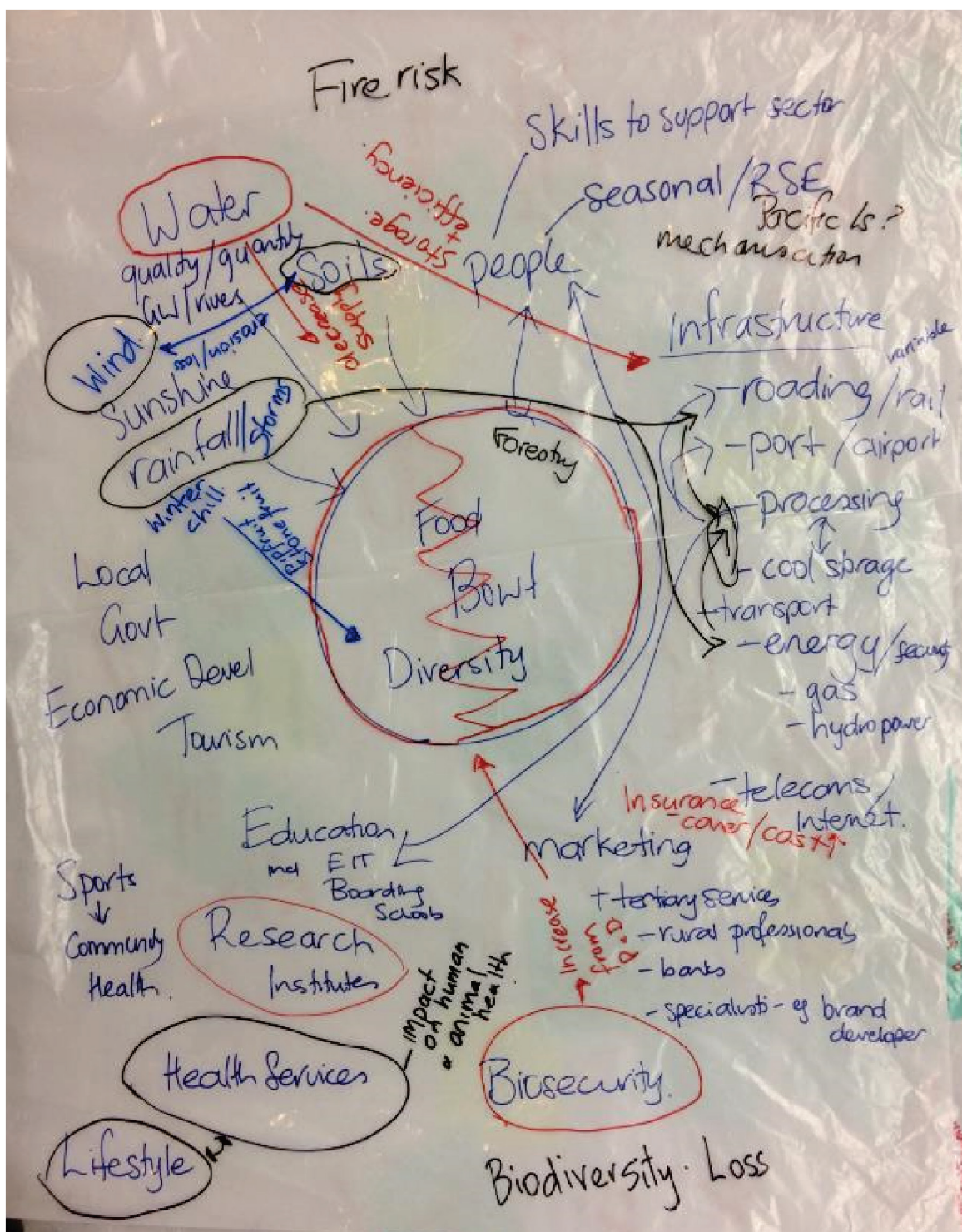


Figure 6b: Heretaunga Plains - Group 1 - Productive sector and climate change

3.2.2 Group 2: System Map

Group 2 produced a system map to portray current production systems on the Heretaunga Plains. This group described their diagram as a set of interacting, interdependent systems. Key themes the group identified include (Figure 7a):

Many interdependent resources are required for production

Critical resources include natural resources (water, land soil, climate), human resources (labour, knowledge) and good and services from other secondary (processing), tertiary (transportation, distribution, sales and marketing) and quaternary (knowledge, legal, and financial) sectors.

Infrastructure

Reliable infrastructure foundational for all sectors.

Influence of politics

Politics affects the system through its influence on resource allocation, and the management of infrastructure. This in turn affects reliability of access to inputs necessary for production, enables adaptability to change, and influences land management, climate change, and biosecurity (e.g. fruit fly, stink bug). Overall community resilience is a function of these things.

Group 2 identified several key themes relating to the primary industries in the region and the effects of climate change (Figure 7a).

Climate change affects the entire system

Effects on climate and water flows through the entire system, and have direct impacts on social wellbeing. Adaptation will be required in all sectors, and need to be better supported through education and research. Research is needed to understand how to make the changes; education is required to develop new skills, to support new and emerging networks, and to manage new problems associated with the changing climate. Information about extremes is more important than averages.

Infrastructure demands

The effects of climate change will require changes and upgrades to infrastructure to ensure resilience. Infrastructure investment may be diverted from primary industries however many community assets require attention, and so this should be prioritised.

Managing resources

There is a need for evidence and examples of how decisions about water might be made in the future with the effects of climate change. How will decisions about water be made? Will we give water away? What about the flow on effects for production and income across interconnected sectors? A lack of moisture on East Coast is significant and investing in infrastructure to alleviate this is hard work. "We need to create good worked examples of what adaptation can look like!", noted one participant.

Movement of skilled labour

Skilled labour is essential for primary industries in Hawke's Bay, and labour might move if parts of an industry shift with changing land uses or climate. Labour movement might in turn, create a short term skills shortage. For example as the wine industry has expanded in Marlborough, skilled workers – including tradespeople – also shifted. The talent pool in Hawke's Bay – a traditional wine-growing region – has been reduced.

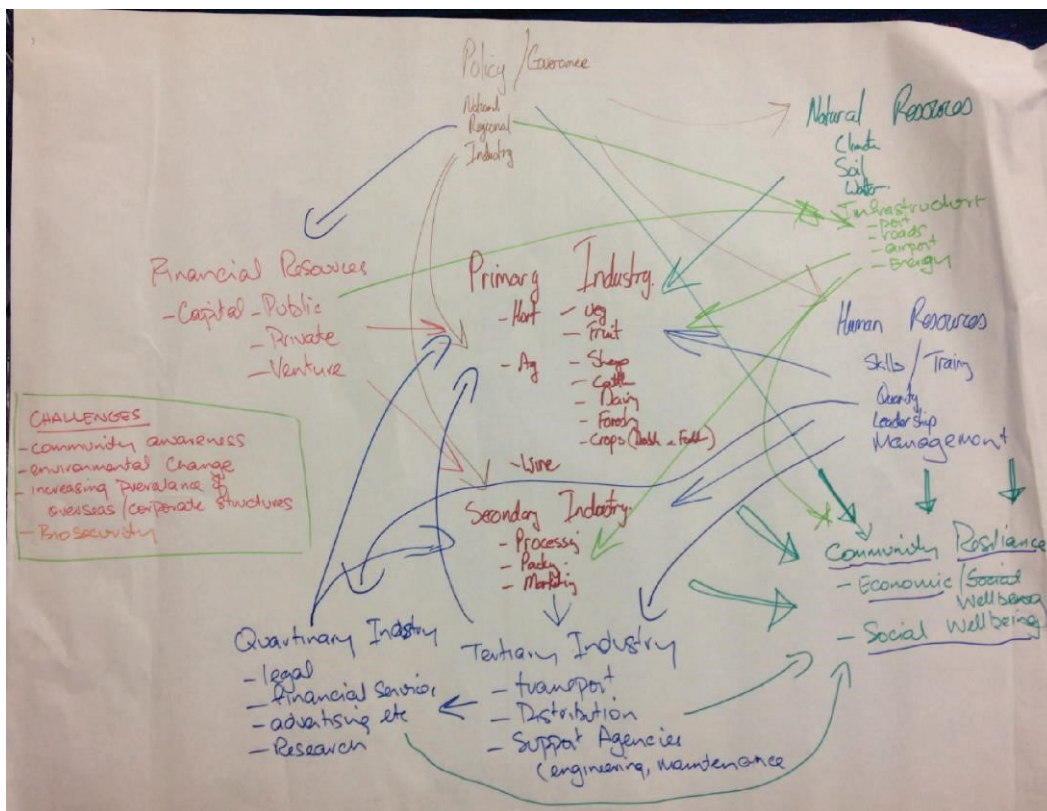


Figure 8a: Heretaunga - Group 2 - Productive sector at present

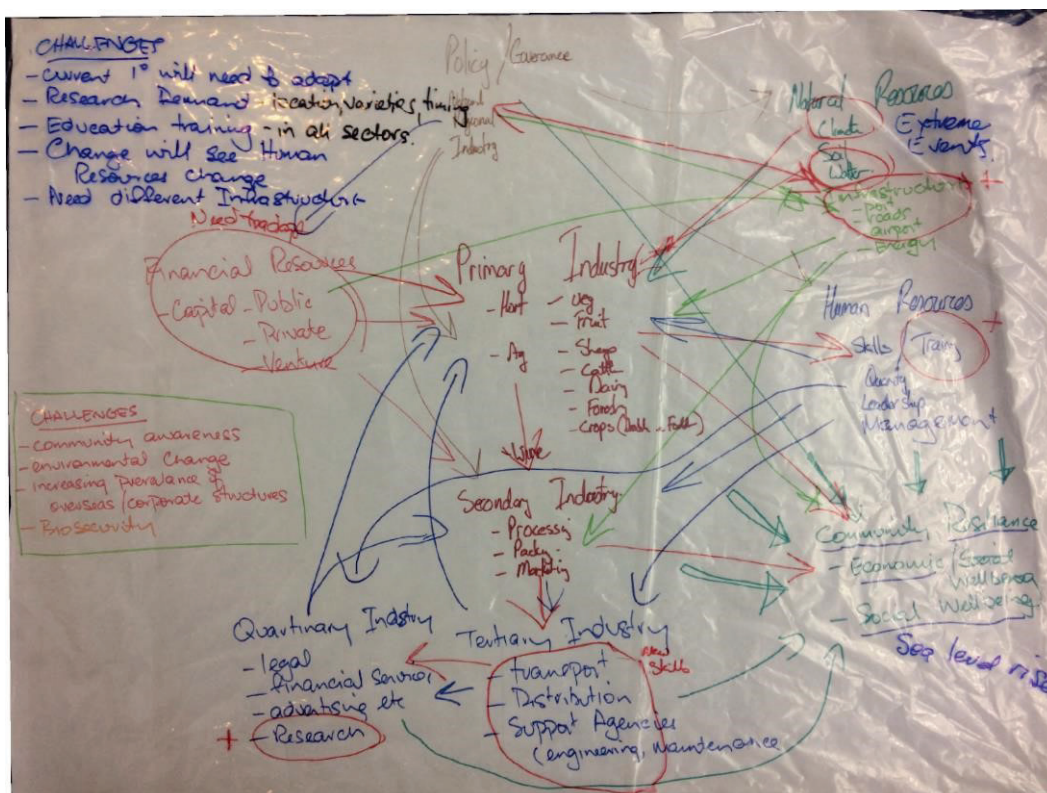


Figure 8b: Heretaunga - Group 2 - Productive sector and climate change

3.2.3 Group 3: Geometric systems map

Group 3 used a geometric systems diagram to describe the Heretaunga Plains. The group also considered the landscape and associated primary industries in terms of an interconnected system. Several key themes were identified (Figure 9a):

Climate and Environment

Production in Heretaunga plains is supported by water availability, air quality and ideal growing temperatures and good soils.

Infra-structure

Reliable power supply, access to the port and good roads underpin production and the service industries.

Export markets

Compliance with rules and regulations is important to ensure continued access to export markets. The region faces possible biosecurity risks due in part to international trade linkages.

Community

There is a lack of community and climate awareness.

Recent changes means that overseas and corporate structures are more common than they used to be. There were a lot of sole traders 30 years ago. This has a big influence on the social, economic and cultural life of the region, and affects community resilience.

Labour has a big impact on the cost of doing business. If minimum wage goes up to \$20/hour, this will cause employers to rethink hiring and staffing levels, which will have an effect on the community.

Group 3 identified a number of issues for the primary industries on the Heretaunga Plains and how they might be affected by climate change (Figure 9b).

Climate and Environment

The group identified a number of factors relating to climate and the environment which were going to “shake up the industry” including: availability of resources – especially water. As the group noted “Should we be building dams for storage? One big dam, or lots of little ones. Of course we are going to need to store water.”

Increased wind speeds, and more frequent gusts are likely to be problematic and fruit will be at greater risk during key times in their development. Soil loss and erosion; lack of winter chilling affecting pip and stone fruit; biosecurity pests and disease will affect the crops we can grow; changes in biodiversity, and loss of biodiversity were also mentioned. The role of pollinators and how they might be affected by climate change was noted.

Pastoral farming is also at risk due to water availability, land use change and the need for extensive farming systems, and potential impacts on animal health.

Communities

The impacts of climate change on health services, and the seasonal movement of labour (which follows harvests throughout the country) may affect community well-being, and service levels.

Changes to business costs

Climate change may result in more damages due to storms, and weather extremes. Available insurance cover, scope of coverage, and the costs of insurance may therefore increase.

How to change practices

Land managers are going to need to change. We have people doing the right things, however the people who are not very flexible will find things difficult. We will all need to change.

People are better at adapting – slowly, incrementally; however it is the random adverse events that knock people about and can severely knock people's resilience (i.e. people can be made broke) and then you are very constrained in terms of being able to move forward. This is particularly difficult to manage for communities: knock out key infrastructure, and people become isolated – this is one of the biggest challenges (e.g. snowstorm in 2016).

Adaptation along a pathway is useful, but we need to consider how long the time frames are for investment decisions (20 – 30 year investment decisions), in 2030... or 2050... it's hard to help people deal with change.

No one responds to regulation; near term changes that will protect their options in the future are what is needed (i.e. coping, system changes).



Figure 9a: Heretaunga Plains - Group 3 - Productive sector at present

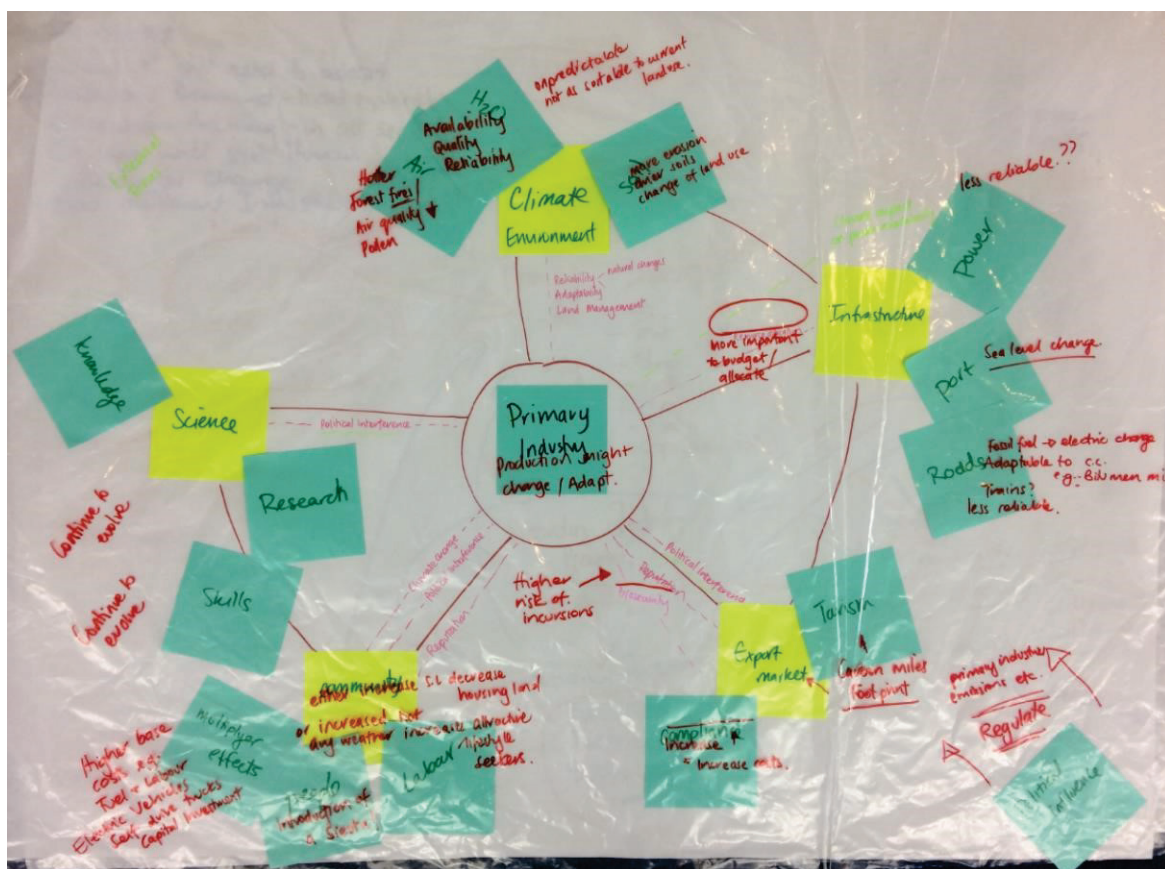


Figure 9b: Heretaunga Plains - Group 3 - Productive sector and climate change

3.3 What are the common themes?

As the groups discussed shared their thinking a list of key themes was begun in the order they occurred (Figure 10). Common themes included:

- Water security
- Land use and land use change
- Managing extreme weather events (more important than averages)
- Weaknesses in roading infrastructure (communities/region cut off frequently)
- No self-sufficient in terms of energy (gas, oil, etc.)
- Internet access (new private providers)
- Maintain reputation (primary sector) via compliance – Political interference: national and local (ecopolitical, NGOs) – Biosecurity (current risks) – fruit fly etc.
- Lack of community awareness with respect to climate change
- Increasing no. of corporate structures and overseas investment in primary sector (fewer players, bigger players).

The biggest challenges for the region include “water”, “climate extremes” and “future land use/land use change”. These three issues were used to do a preliminary brainstorm on adaptation options, and will be discussed in more detail in the subsequent workshop(s).

3.4 How could we adapt? (Objectives 3 & 4)

Data from the adaptation brainstorm will be used to underpin the next steps in the project and enable the construction of adaptation pathways and strategies.

Selected ideas presented include:

Extreme events

- Scenarios to evaluate future changes

- Enhance the role of civil defense
- Hail nets
- Wind machines
- Maintain mental health
- Social safety net enhanced
- Improved communications infrastructure and processes

Water

- Water storage (inc. on-farm and small-scale storage)
- Appropriate crops for climate (e.g. crops with lower water demands) – Efficiency improvements

Land use

- Identify available land use options (What will be possible in the future?)
- Research and development
- Diversification (e.g. more short-term crops, more forestry, more feedlot farming)

4 Conclusions and next steps

The two case study workshops provided an opportunity to gain rich information about the context-specific drivers of change in two sites in the Hawke's Bay region. This information will be used to inform the next steps of the process which includes: (1) additional workshops to explore adaptation options in more detail, and develop adaptation pathways for case study sites; (2) regional economic modelling based on computable general equilibrium (see Appendix 2); and (3) the development of scenarios of future land use for both case study sites to evaluate the robustness of pathways (Appendix 3).

The results of both case study workshops, and the outputs from the regional economic modelling and land use scenarios, will then be used to inform a regional workshop with diverse stakeholders focusing on the social implications of climate change. Informed by the regional economic modelling – which will outline the effects of climate change on regional GDP, as well as trends and shifts in labour, and transportation for example, and the scenarios of future land use – we will develop a regional perspective on adaptation, linking the two case studies with issues, capacities and constraints at the higher level.

The outcome of these case-study and regional workshops will be a series of empirically connected adaptation pathways; guidance for practitioners; and new insights into how best to operationalise adaptation pathways planning across scales, and for complex problems.

Appendix 1 Workshop 1 Run Sheet

Workshop 1: Facilitation run sheet

Aim Characterise the potential impacts of climate change on primary industries in selected Hawke's Bay regions. Workshop activities and discussion will provide an opportunity for stakeholders and researchers to identify and reflect on potential impacts from farm- to market, including exposures, and key sensitivities. Initial discussions relating to possible adaptation options/strategies will be discussed subject to timing.

Activity	Who	Time	Start time
Overview purpose of the project and the respective steps Introductions	Nick	10 mins	1pm
Brief discussion on the vision for the productive sector in the region What are the aspirations/visions for the various sectors?	Paula/ Nick	10 mins	1:10

Question 1: Using a rich picture describe/draw how the various productive sectors currently function in this area - small group discussion with like groups Please consider including: - Resources that are required for production (e.g., land, water, labour) - The value chain (how does the product get to market?) - What are the current challenges and why		45 mins	1:20
Group report back – record discussion.		<u>5 mins per group</u> <u>– 20 mins</u>	2:05
Quick overview of potential impacts of CC on the Wairoa catchment		5-10 mins	2:25
Aim is to provide sufficient information about likely impacts in quite broad terms (e.g. shifts in precipitation, variability and extremes), but not overwhelm with detail. Opportunity at next stage for stakeholders to integrate their own experience/knowledge with information about projected impacts. Link between Q1 and Q2, foundation for consideration of how catchment may be affected.			
Discussion regarding current observations of change and what they have done about it so far		10 mins	2:35
Question 2: Given what we know about climate change (draw on data from report) how might the productive sector in this area be affected? (i.e., what will the critical vulnerabilities be?) Overlay(s) plastic sheets on top of original diagrams, and/or just discuss. - What might this mean for the area/region - What could some of the critical issues/challenges be?		45 mins	3-15
Group feedback - (record)		<u>5 mins per group</u> <u>– and</u> <u>discussion</u> <u>30m mins</u>	<u>4pm</u>
Question 3: Are there actions (near-term) or long-term strategies that might be used to maximise opportunities and realise regional aspirations in the catchment? Small group brainstorm – with feedback - just used as a brief taster for the next workshop. Set homework to this of some more and consider their benefits and costs This will be used to underpin the adaptation strategies in the next workshop		<u>30 mins</u>	<u>4:30</u>
Review, farewell and outline of follow-up workshop (Workshop 2)		5 mins	4:55pm

Appendix 2 Regional Economic Modelling Methodology

Draft methodology for regional economic modelling for input into workshops on adaptation options prepared by Dr Juan Monge (Scion) for Dr Nick Cradock-Henry.

CGEs are a high-level, aggregated representation of a national/regional economy. This type of models have been used in the climate change context by comparing the economic regional impacts (GDP, labour, etc) of implementing various adaptation alternatives.

The NZ-CGE at its current version is a static, national Computable General Equilibrium (CGE) model that takes the latest input-output tables from NZ Statistics as the main input and is well-suited to analyse economic shocks affecting different productive sectors in the national economy. The current basic version of the model will be used mainly to analyse the impacts from environmental, fiscal and

trade policies and economic phenomena on primary (i.e. land-based) industries and their respective value chains. The model aggregates the original set of 106 industries in NZ Stats' input-output tables into 20 industries including horticulture, livestock, forestry as well as their respective downstream manufacturing industries including transportation, retail and wholesale. It includes various agents in the economy such as aggregated primary sectors, government, and an aggregated representative household among others. The model can be applied to a specific region (e.g. Hawke's Bay) by regionalising the national input-output matrix and adjusting total outputs by sectors.

The essential component of this type of models is that it considers the industry interlinkages such as the dairy manufacturing and transport sectors depending on the dairy farm sector. The productive performance of each industry is characterized by production functions taking inputs (such as labour, capital and outputs from other industries) and generating outputs (either sold to other industries or to households). One of the main components of these production functions is productivity or yield, for example m³ of timber/ ha for forestry or kg of milk solids/ha for dairy.

In the specific case of climate change adaptation, the idea would be to create various scenarios of how the economy will evolve from now until a point in time in the future such as year 2100. One of the potential scenarios could be the impacts of climate change on the productivity of key primary sectors in a specific region or NZ. To do this I would use either one or a set of Representative Concentration Pathways. The interesting scenarios for this projects would be the ones including adaptation alternatives.

For the specific case of estimating the regional economic impacts from climate change adaptation, the inputs going into the model are:

- Aggregated productivity shifts by primary industry as a result of the various climate change scenarios. Such changes are measured by contrasting current productivity measures versus a future baseline (i.e. no adaptation measures under climate change) and various counterfactual scenarios (i.e. adaptation measures under climate change)
- The cost of the adaptation measures under various climate change scenarios
- Official labour and Gross Domestic Product (GDP) growth projections reaching the desired time horizon considered in the SLMACC project (e.g. 2050)
- A regional input-output matrix for the Hawke's Bay that can be purchased from Market Economics Ltd or any other supplier. Such input-output matrix will determine the interlinkages between industries and segments along the value chain

The model's outputs are percentage changes obtained by contrasting a future baseline (e.g. no adaptation measures in 2050) versus future counterfactual scenarios (adaptation measures in 2050). Such percentage changes are estimated for:

- Regional Gross Domestic Product (GDP)
- Employment per primary sector and respective value chains
- The value of total output per industry
- Land use change per land-use capability category (if necessary or possible)
- Welfare measures (e.g. compensating variation)

Appendix 3 Land use Scenarios Methodology

Draft scenarios of future climate change for input into surveys and interviews with relevant experts to explore the potential for changes in land use in Wairoa and the Heretaunga Plains. Prepared by Drs Paul Johnstone and Edmar Teixeira (Plant & Food Research) for Dr Nick Cradock-Henry.

Catchments	Climate scenarios	
	Moderate	Extreme
Karamu	0.75°C warmer, mostly in summer/autumn 15 additional "hot days" per year 5 less "cold nights" per year (i.e. frosts) 5% less rainfall annually, mostly in spring 5% more extreme rainfall 120 mm increase in PED deficit (drought proneness) + increase in extreme winds and storms is uncertain	2.5°C warmer, mostly in autumn 60 additional "hot days" per year 10 less "cold nights" per year (i.e. frosts) 10% less rainfall annually, mostly in spring 10% more extreme rainfall 160 mm increase in PED deficit (drought proneness) ++ increase in extreme winds and storms is uncertain
Wairoa	0.75°C warmer, mostly in summer/autumn 30 additional "hot days" per year 5 less "cold nights" per year (i.e. frosts) 5% less rainfall annually, mostly in spring 5% more extreme rainfall 100 mm increase in PED deficit (drought proneness) + increase in extreme winds and storms is uncertain	2.75°C warmer, mostly in summer/autumn 60 additional "hot days" per year 5 less "cold nights" per year (i.e. frosts) 5% less rainfall annually, mostly in spring 15% more extreme rainfall 140 mm increase in PED deficit (drought proneness) ++ increase in extreme winds and storms is uncertain

Glossary:

- **Hot days:** The number of days per year with maximum temperature >25°C
- **Cold nights/frosts:** The number of nights per year with minimum temperature <0°C
- **Extreme rainfall:** 1% top highest rainfall events
- **Potential Evapotranspiration Deficit (PED):** the cumulative difference between potential evapotranspiration (PET) and rainfall from 1 July of a calendar year to 30 June of the next year, for days of soil moisture under half of available water capacity (AWC), where an AWC of 150mm for silty-loamy soils

What impacts do you expect and what are possible adaptations?

- Please consider both within catchment and the broader value-chain from farmer to consumer
- Timeframe to think is the next two generations in New Zealand (i.e. our grandchildren)

Sector: Wine	Expert: Mr Jamie Oliver	
	Without adaptation	With adaptation (and consequences)
Expert "open/free" narrative after being exposed to impacts	• More extremely hot days make harvesting of grapes less efficient as it is unbearable for workers to be in the field. • Higher frequency of cyclones might reduce availability of seasonal workers who remain in Pacific islands to support families. • Transport under high temperatures decrease fruit quality. • Intense rainfall compromise roads and slow transport with creased costs • Ripening is concentrated in few weeks, requires more workers in short window of harvest	• We can then maintain/increase production • Start using mechanical harvesting (High investment in harvesters) • Heterogeneous slope land cannot be harvested (less available area) • Create air space in cargo to aerate fruits during transport (Increase costs as need more trucks) • Investment in more resilient transport with railway (risk of not getting enough political leverage) • New crops: mango and guava for juice (no market)
Productivity	- 20%	+ 20%
Quality	-10%	0%
Scheduling of operations	Slow harvest	none
Cost of production	+30%	+10%
Risk of production failure	5%	0%
Land use options	- grapes, - apples	+ mango, + guava

Appendix C – Expert Interviews

Introduction

The following technical note describes the results of an engagement process with selected industry stakeholders, scientists and end users to develop scenarios as part of the SLMACC-funded project "Applied Adaptation Pathways: Supporting Robust Regional Decision-Making: An Application in Hawke's Bay".

Through engagement and collaboration with end-users, farmers/growers from representative systems, and with the support of key stakeholders, including Hawke's Bay Regional Council (HBRC) our research has begun to synthesize and prioritize climate change impacts for the region, identify management and production thresholds, triggers, and critical decision points.

The process we are undertaking has five stages (Figure 1). The purpose of this section of the report is to provide an update of recent research activity, in particular the 'Development and analysis of possible futures', which fulfils Stage 3. Stages 1 and 2 have been described in detail in the Milestone 3 report. An overview of the methods and results from the workshops is presented and indicative plans to fulfil remaining stages is outlined.



Figure 1: Adaptation Pathways development process for the Hawkes Bay.

1 Scenario development

1.1 Aims and objectives

Consult with production experts to summarise expected impacts of climate change and adaptation options in our two study catchments - how significant are the changes and can sectors adapt quickly?

Capture basic insights that can be tested and refined with the communities involved in workshops to help shape the adaptations pathways process.

1.2 Focus Districts

Wairoa Catchment: Sheep + Beef, Beef, Forestry

Karamu Catchment: Sheep + Beef, Beef, Deer, Short rotation cropping, Perennial crops

1.3 Climate Change Indicators –

Warmer – mostly summer and autumn

- Hot days
- Less cold nights
- Less rainfall, mostly in spring
- More extreme rainfall
- Flood risk
- PED
- Storms

1.4 Issues of Interest –

Productivity change estimate

- Quality change estimate
- Scheduling of operations
- Cost of production
- Risk of production failure
- Land use options

2 Outcome

2.1 Consultation with Industry Experts

Industry experts (farmers, growers and consultants) were provided with a short summary of two climate change scenarios (See Appendix). They were then phone interviewed with each interview lasting between 35 and 60 minutes.

Interviews allowed free conversation, along with targeted discussion relating to the key climate indicators and issues of interest. Many responses crossed between the points.

In contrast to similar surveys in recent years, there was no push-back about climate change. People were focused on building resilient farm systems and responding to adverse climatic influences already impacting their businesses.

3 How significant are the changes?

Respondents noted that the average changes are often not the important ones; severe short-term events can have most impact. To many, it was the increased likelihood of these, rather than generally drier, hotter or droughtier that will make most difference.

The impact of more severe rain and storm events and associated flooding on infrastructure on and off farm was frequently noted.

5% less rain doesn't seem like much different. Our average in the last 7 years is over 1500mm pa.

When you have an increase in storm events, you've got loss of infrastructure and capital – that becomes a threat to the business itself. We have to adapt, somehow, to that.

Big events are what's critical. They generate sediment spikes which impact on aquatic and marine ecosystems – events carry millions of tonnes of sediments, not daily flow.

Big rain events from warmer oceans make flooding more likely – whole region will be severely impacted. Flooding scares me more than anything else, the 1898 floods had a sheet of water from Cape Kidnappers to Eskdale

Increasing heat was seen to have impact but negative impact was associated more with short term severe heat events.

Average warming misses the tipping points we experience – a few days of hot days and nights can be very damaging. Sunburn gets into the apples.

A week of late 20s days in Jan or Feb can write off many of the crops we grow today. Extreme heat can be the limiting factor making irrigation irrelevant. Crop is dead anyway!

Another common area was increased risk of pests and diseases including more trouble from current ones and the risk of new ones establishing.

Easter wet last year had serious impact. Warm rain for three days was devastating. Grape growers don't have chemical controls for that. We may get more Barbers Pole and fly strike which require chemical interventions. In a changing environment we may need more, may not be sustainable long term – resistance etc.

Warmer conditions may give better pollination but maybe more disease – more chemical interventions needed.

4 Can sectors adapt quickly?

Respondents generally noted they are already adapting to many changing conditions and endeavouring to build resilience into their infrastructure and systems. Severe weather events already impact with cost ramifications, so steps are being taken to reduce or mitigate effects.

One of biggest limits to future thinking is how we've done things in the past. Have to keep an eye out for less obvious adaptations – lots of little things give a big effect, incremental improvements e.g. conditioning plants – silver buckshot rather than a silver bullet

Cost of water and relative demand of different crops may change enterprises

We're moving our orchards to 2D plantings to reduce labour and prepare for robotics – this is a bigger driver than climate change.

Cyclones are turning up when we've got fully laden trees, so are putting closer posts in some of new planting.

In a good year lambing early costs 20%, so you'd say I should lamb later. But my system is repeatable – works in both bad and good years.

I had to send the digger up the creek at a cost of \$10-20,000 each time. I have fenced the farm creek differently to lessen the impact. Multiple reasons – it's a pain having to fix everything, but there are also environmental benefits of excluding stock.

What we should be doing for CC we should be doing anyway for resilience

5 Land Use Change

Respondents had different views.

In general, pastoral farming and forestry saw little expectation of enterprise changes as each probably the best use at present and few options.

Annual cropping could see change in crops grown but that changes now in response to markets and is relatively easy. But if processors changed could be different.

Permanent crops (grapes and apples) may ultimately change to more tropical, but current activity suggests status quo. Grapes more interested in expansion to higher terraces, or south to Ruataniwha. Apples mainly focused in/on Heretaunga Plains but see other districts may increase.

Wairoa

Blanket planting forestry [is not such a good option] in steeper farm blocks – you're not going to grow that good a tree, hard to harvest

Forestry risks of losing right to operate/ social licence if events look ugly – we must ensure everyone understands big picture – looks bad for a short time, but nett is much better than alternatives

Karamu

Cost of water and relative demand of different annual crops may change enterprises, but adequate water access is going to be critical even if we change to other crops

The fundamental infrastructure is here; roads, power, port, water adaptable enough to change

Longer term the grape industry might move in response – take advantages of higher terraces and Ruataniwha

Some [grape] land is pretty marginal – if production costs, water storage cost may make it unprofitable

Karamu likely to remain a key apple area, but more mitigation needed. Have committed to a lot of planting – expected to remain 25 years+

6 Sheep + Beef, Beef

The pastoral farming response recognises climate change is likely to have significant effects, but farmers are constantly changing and building systems that cope with adversity. There was little expectation of significant land use change, but rather a constant evolution of practices. While horticultural crops were acknowledged as suitable in some selected sites, in the hill country the key options are grazing, forestry or permanent regeneration.

Sheep and beef farming will continue to evolve as it already does.

I expect we're going to see gradual [climate] change that's going to be unnoticeable in the variability we already experience.

6.1 Impacts of Climate

The impacts expected from climate change are already experienced.

Our [Karamu] location may be making climate change apparent earlier than other places. Look at the number of crickets this year and damage they are doing – how sensitive are our ecosystems??

Respondents anticipate adverse events to be more frequent and maybe larger but are already trying to build resilience into their infrastructure and systems.

Impacts identified include:

- Lack of summer feed due to heat and dryness
- Damage to pasture, roading, fencing from extreme rain events
- Heat stress and effects on stock health

- Need for more stock-water reticulation/storage
- Increased and new pest and disease pressures

6.2 Adaptations

System changes expected include:

- Adjusting lambing times
- Changing grass and fodder species
- Reducing capital stock in favour of trading stock, but must have enough breeding stock
- Protecting against erosion
- Protecting infrastructure such as roading, drains and fences
- Stock water reticulation
- Being alert to changing pest and disease incidence

6.3 Land Use Change

- Not many options in hill country
- Forestry possible on steeper areas but expensive to develop and extract, might not be economically better than sheep
- Need to increase trees for protection of infrastructure assets

6.4 Issues

6.4.1 Production

<i>January Feb period we have lack of weight gain in livestock. Grass growth stops so we have to hold on to our covers.</i>	<i>Ryegrass/clover wrong pasture species for East Coast, we need to change to more sub-clovers and Cocksfoot, but they are hard to establish. Maybe we should be looking in the tropics. Change to Lucerne etc. Doug Avery type system should work</i>
<i>Conditions are certainly going to drop production – less pasture = no feed. Constantly regrassing, scars slow to heal, not productive, reducing carrying capacity, last year we couldn't finish to target weights. Currently farmers use fodder to supplement</i>	<i>Strategic – put in higher nutrient value crops where you can get quick weight gain to compensate, but summer drought makes establishment difficult. It's costly renovating pastures on hill country, variable results – if failure no feed instead of poor feed. Crops may be more unreliable. Finding right crops to grow in warmer temps may be a challenge.</i>
<i>Less spring rainfall is biggest impact on production – affects main lamb crop, natural increase in stock numbers so dry spring detrimental.</i>	<i>Run less capital stock, trading component for sale early spring. Reduce capital stock numbers so can hold in good condition. Might get better production per animal but may be about same tonnes/ha</i>
<i>Everyone can't move to trading stock - this year too expensive as no one carried breeding ewes.</i>	<i>Must have somewhere to carry capital stock so you have mouths to eat the spring/autumn grass.</i>
<i>Must make sure can get critical stock through pinch</i>	<i>Create resilience to give best opportunities for each piece of land.</i>
<i>Hot days will put grass growth on hold longer, but warmer winters will increase it.</i>	<i>We may need to adjust our lambing times.</i>

<i>Warmer winters may increase grass growth, longer shoulders</i>	<i>System adaption to fit pasture growth curves – change lambing time to match. Already ¼ lambs born in July – prime lamb sales for Christmas, ewes gone Sept, lambs in Nov leaves more feed for rest.</i>
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6.4.2 Infrastructure

<i>A good system should be able to cope with extremes. A creek can overflow and cause major problems flood gates, fencing, culverts etc.</i>	<i>Have fenced the farm and creek to lessen the impact. Paddocks used to be fenced into creek for drinking access so needed 2 flood gates – have re-fenced, eliminated gates, replaced with troughs.</i>
<i>When increase events, you've got loss of infrastructure and capital – threat to the business itself. Have to adapt somehow to that</i>	<i>We can do more strategic tree planting, design our farm infrastructure better to cope with big events – 2011 was so large no amount of planning could prepare farm.</i>
<i>Cost of planting culverts, tracks fences etc because more extreme rain events. Farmers are going to face increasing costs to rebuild, may be hesitancy to invest in areas that are prone.</i>	<i>Bigger and bigger culverts don't work in big events – use normal culvert and design for overspill. Can put barriers in where stream settles out – catches timber before it takes out the bridges. We need to rethink fencing (GPS collars) virtual fencing.</i>
	<i>Planting erosion areas and protect infrastructure. Might lose some grazing - 20%?</i>
<i>Regional roading infrastructure hard with poor geology variable to extreme events - another Bola would be problematic.</i>	

6.4.3 Stock Health

<i>Diseases could be major setback in warmer temperatures. It's not so bad in droughts, but heat coming out of drought escalates parasite threats.</i>	<i>A lot of farmers are already seeing the benefits of shading trees – planting on northern slopes get better stock distribution, happier stock so planting a no-brainer.</i>
<i>We are trying to find cattle breeds that cope with heat but still give meat quality wanted.</i>	<i>We'll need to look to genetics and breeding.</i>
<i>Heat and dry elevate need for drinking water but decrease availability</i>	<i>Water storage and reticulation will become more critical – traditional stock dams won't be enough</i>

6.4.4 Land Use Change

<i>A few protective trees on bad country still better than blanket forestry.</i>	<i>Blanket planting forestry in steeper blocks – you're not going to grow that good a tree, hard to harvest. Trying to do other than poplar and willow. Willow can be harvested for stock feed - Cows do well, prime steers don't put on weight</i>
<i>Will be no permanent horticulture - in our valley risk of flooding and cut off too great.</i>	<i>Sheep can be held back for days/weeks or in extreme walk stock.</i>

7 Forestry

7.1 Impacts of Climate

Climate change will impact in various ways, reducing options, increasing costs and risks, reducing quality and yield and increasing the risk of losing social acceptability.

We must have social licence to operate. If people see erosion or sediment in streams we will lose that licence even if forestry is actually the best option.

Forestry is both panacea and problem, radiata is probably still a good solution

Impacts identified include:

- Reduced growth if dryness increases
- Hot days will increase fire risk, cut harvesting days
- Reducing species options if warmer, drier – *P. radiata* is very robust, others less tolerant
- High risk of infrastructure failure from intense rain and storms
- More sediment movement in severe rain events increase environmental impacts
- Volatility in production cost especially associated with infrastructure problems
- If climate change drive increased fuel costs, will impact forestry hard

Cumulative risks can reach tipping point. A lot of small problems can make the overall operation uneconomic/unjustifiable

7.2 Adaptations

Forestry in one form or another may increase on pastoral farms or parts thereof (but note the sheep farmers' doubts).

There are relatively few options for adaptation within production forestry. Forestry is one of the better land protection options, even though at times it carries risks of environmental damage.

The "Billion Trees" goal needs to ensure putting the right tree in right place for right reasons. The drier it is, the more [species] options will be excluded.

System changes expected include:

- Increase in down time due to drought, hot days and fire danger
- Increase in downtime due to infrastructure damage from intense rain and storms
- Increase in riparian planting due to public pressure, even if it is less environmentally beneficial
- Increase in pest and disease control operations
- Possible change of fuels to biogas for transport, on-site wood heating for winching?

7.3 Land Use Change

- Not many options in hill country
- Could be more manuka planting, possibly as riparian margins or replacement of radiata

7.4 Issues

7.4.1 Production

<i>Need water for growth, reduced yield and quality</i>	<i>Drier conditions will result in more defects – resin pockets in radiata</i>
<i>Risk of crop failure reduces alternative species options</i>	<i>P. radiata reasonably robust, Eucalypts more specialised, redwoods require decent amount of soil moisture</i>
<i>Volatility in production cost especially associated with infrastructure problems</i>	<i>Extremes relate to deepening depressions etc, so anticipate they will cause problems.</i>
<i>If lose trees, lose yield but also Cost/unit handled much higher</i>	<i>Determine new economic limits?</i>

<i>Wet ground results in more toppling</i>	<i>We need to think how to manage recovery after adverse events</i>
<i>H&S risk higher</i>	<i>Robotic systems might help reduce H&S risks</i>
<i>Impact on harvestable days if fire danger too high – during a season now 10 days a year shortened – early finish etc. Increase down time if more hot days</i>	<i>Would need to consider increasing capacity to allow for downtime – comes at very significant cost</i>
<i>If Climate Change mitigation drives fuel price increase it will hit forestry hard – energy demanding sector</i>	<i>Would it drive forest energy use to biofuels, wood powered winches? Wood pellets? Can this be economic – sitting in the middle of a natural fuel pile</i>

7.4.2 Infrastructure

<i>At regional level, road failure will hinder access to mills/port/market</i>	<i>Ensure forest operations don't add to risk</i>
<i>Severe risk of infrastructure failure with more extreme rainfall</i>	<i>Increased cost of infrastructure build and repair Operational risk – roads etc fail, equipment is landlocked \$6 - 10,000/day crew cost – who pays?</i>
<i>If exceed design capacity infrastructure failure severe. Cost of bigger pipes etc increase cost</i>	
<i>If people see erosion and wood on beach react unfavourably esp. urban rural divide</i>	<i>Pakuratahi Study conclusion – sediment is greater than pastoral farming after harvest but after 2-3 years, is better again. Recognised Risk period, but less than insidious losses from pasture</i>

7.4.3 Environmental Impacts

<i>Intense rain generates Sediment spikes that impact on aquatic and marine ecosystems – event carries millions of tonnes, not daily flow</i>	<i>Redesign riparian margins, but extremely hard to do. When you leave a native riparian buffer erosion continues for a long time – worse than radiata.</i>
<i>Reduce roading where possible to reduce risks</i>	<i>If can pull wood between two parallel ridges can save a whole lot of roading and sediment risk – if must have a riparian strip it stops that - can give perverse outcomes</i>

7.4.4 Forest Health

<i>Expect increased risk of bugs, even if they're not here yet</i>	<i>Need to have high biosecurity performance to avoid new entrants</i>
<i>Diseases worse in heat and dry (moisture stress = Diplodea kills top of tree)</i>	
<i>Pine beetle epidemic in Canada – not getting killed by cold nights – has been there for ever but conditions favouring it more. Flow on effect - Dead wood is flammable, drier weather so 1m ha forest fires in Canada last year</i>	

7.4.5 Land Use Change

<i>Risk of losing right to operate/ social licence if events look ugly</i>	<i>Must ensure everyone understands big picture – looks bad for a short time, but nett is much better than alternatives</i>
<i>Public perception is indigenous planting fixes everything, but actually 20-year-old native is 3m tall, 20-year-old radiata is 30m tall with much more protective capacity Typically, a riparian zone is blackberry and wilding pines</i>	<i>Can we design systems that achieve better results? Staged native regeneration?</i>

8 Short-term Cropping

8.1 Impacts of Climate

Climate change will impact.

*Scenarios talk about averages, but actually a few short events can be critical.
Several hot days and nights can be worse than floods.*

Impacts identified include:

- A few hot days and nights can cause severe damage
- Higher PED increases need for irrigation
- What has been an adequate water supply will not be in future
- A whole lot of small cuts can make a big difference
- Getting crops out if autumn wetter, especially if heavier rain events
- There may be less cold nights, but it only takes one frost to kill a crop
- Impact of flooding could be disastrous

Cumulative risks can reach tipping

8.2 Adaptations

System changes expected include:

- Change in crops grown to favour earlier maturing
- Change in crops to those suited to warmer climate, less need for coolness
- Plan better, manage each piece of land for potential
- Making sure water can be applied to critical areas
- Breeding/modification for crops with drought and heat tolerance

8.3 Land Use Change

- Likely to see a change in crops grown – warm tolerant, less drought affected
- Some movement to south, higher altitude, shift to Ruataniwha
- But main infrastructure is in Karamu/Heretaunga Plains

8.4 Issues

8.4.1 Production

<i>The Heat side could be on us more quickly than scenarios indicate. A week of late 20° days in Jan or Feb can write off many of the crops we grow today.</i>	<i>Early maturing crops to avoid heat period? Shift production season forward</i>
<i>Canterbury cropping example a couple of years ago, several hot days and nights hit crops worse than floods</i>	<i>Seek new (CRISPA) varieties with low water use etc. temp and drought tolerant</i>

<i>Benefits from less cold nights</i>	<i>May facilitate winter cropping. Extremes might still give a southerly and follow on frosts</i>
<i>Increased drought deficit means what has been adequate water supply might not be enough.</i>	<i>Ensure access to irrigation – more storage, increase system capacity to get water on</i>
<i>More extreme rain - timing matters, how much will be soil captured?</i>	<i>Maintain soil quality for best infiltration and resilience</i>
<i>Wet autumn already impacts carrot harvest!</i>	
<i>We have capacity to add water even if drier than now.</i>	<i>May have to be social change /attitude, but water shortage soon does that</i>
<i>Would have to change crops if can't get more water – less intensive food production = lower production.</i>	<i>Irrigation without adapt will run out of water. Currently 1:10 but won't be enough</i>

8.4.2 Infrastructure

<i>We can handle dry so long as we have water.</i>	<i>Need more water storage, what has been enough may not be in the future New desalination plants in Capetown, 40c/m³ so not so far off our storage costs</i>
<i>"Value of water" becoming more evident now.</i>	<i>Cost of water and relative demand of different crops may change enterprises.</i>
<i>Major catastrophic flood events damaging infrastructure – expect more 1:100+ year events</i>	<i>Dad talked to old guy about 1898 floods a sheet of water from Cape Kidnappers to Bay View pouring out to sea</i>
<i>Big rain events from warmer oceans make it more likely – whole region will be severely impacted.</i>	<i>HBRC to start raising stop banks to 1:500 year event. Droughts don't scare me as much.</i>

8.4.3 Crop Health

<i>If we get early summers, warm oceans, humid easterly, pest and disease issues rife.</i>	<i>Need more chemical controls, but they are reducing</i>
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8.4.4 Land Use Change

<i>Cost of water and relative demand of different crops may change enterprises</i>	<i>Adequate water access is going to be critical even if change to other crops</i>
<i>We're border line temperate sub-tropical so wide range of options; Annual crops can adapt</i>	<i>Fundamental infrastructure is here, roads, power, port, water adaptable enough to change</i>
<i>Mix of crops will have to change: Process crops – peas head south? Sweetcorn and tomatoes can take more heat</i>	<i>Expect CHB to come into its own with apples etc.</i>

9 Permanent Cropping (Apples and Grapes)

9.1 Impacts of Climate

Climate change will impact.

*Scenarios talk about averages, but actually a few short events can be critical.
Several hot days and nights can be worse than floods.*

Climate change report by Salinger 30-years ago seems to be pretty accurate these days!

Cumulative risks can reach tipping points

Impacts identified include:

- Average warming misses the tipping points we experience
- A few days of hot days and nights can be very damaging
- Intense rain events matter, a wet weekend is devastating at flowering/vintage/harvest
- Warmer = better pollination but maybe more disease
- Increase in pest and disease while reducing chemical options
- Current varieties are suited to current climates (and markets for our products)
- More wind would impact apples quality

9.2 Adaptations

Our response needs to be now – too sensitive to worry about 2090! Land Use Change

We're actively looking for varieties that will colour in high heat environments with less diurnal variation

2D plantings to prepare for robotics - reducing labour is a bigger driver than climate change

System changes expected include:

- Increase water access through storage
- Need rootstocks and management to reduce water demand
- New varieties more pest and disease resistant
- Increase use of netting for heat, light, wind control
- Grapes more likely to move to Ruataniwha than apples

9.3 Issues

9.3.1 Production

Grapes	
<i>This year we had one of hottest years ever and some varieties have stalled. Grapes shut down at 35°.</i> <i>Syrah seems to be susceptible – changes flavour profile</i>	<i>Fire risk – in Australia have had problems of smoke taint in wines – need to watch that</i>
<i>More fine days = more light = more UV light – issues in wine quality</i>	<i>change management techniques – manage level of fruit exposure e.g. leave a bit more canopy on</i>
<i>Positive things – less frosts?</i>	<i>BUT Probably can't move away from need for protection</i>
<i>Higher PED so need for water access, storage</i>	<i>Spray Anti-transpirants? But a good dose of seaweed might do the same. Can condition grape vines to get away with less water</i>
<i>Subject to availability of irrigation, dry is nice. Grape land very drought prone, but water critical.</i>	<i>Use 1/3rd of other crops so best value per m³. The last 4 -5 years in HB had strong growth in temperatures but without the increase in ET we'd expect.</i>
<i>A few times last season had to knock off work because worker safety in heat</i>	<i>Can robotics help labour</i>

<i>Losing whole crops in autumn – a wet weekend can be devastating. Will they occur more often?</i>	
Apples	
<i>Average warming misses the tipping points we experience – a few days of hot days and nights can be very damaging. Sunburn gets in.</i>	<i>Use of netting for hail, sunburn, wind. Are getting different effects under different netting and we need to understand what is happening, what we can do. Different colour nets different, Bees get lost</i>
<i>Shorter growing window, poorer quality than longer</i>	<i>We've been told maturity window will be earlier, didn't previously believe that, though this year it did.</i>
<i>Hot days, Trees get stressed, shut down could impact yield and quality</i>	<i>Possibly more overhead netting (hail net) but try filter options UV etc. Can cool, in day, but then warms at night and less colour</i>
<i>More thermal heat load to get out of fruit</i>	<i>Netting can cool in day, but retains at night. Can we use fans to cool?</i>
<i>Warmer and higher PED: Need for water is going to increase</i>	<i>Think new rootstocks are promising lower water use, but we'll still need storage. Need to be using soil moisture and temp sensor info sooner</i>
<i>Less chilling Wider bud break variation</i>	<i>– more chems needed to compensate</i>
<i>Longer flowering would lead to mixed maturity - quality issue</i>	<i>Rootstock selections close, but need more – multi-gene resistance preferred</i>
<i>Autumn rain always problem - 25mm of rain we incur internal damage – need to leave for 3 days to avoid quality loss</i>	<i>Land levelling more critical, drainage problems already there</i>
<i>Cyclones are turning up when we've got fully laden trees,</i>	<i>so are putting closer posts in some of new planting.</i>
<i>Productivity might not change that much – increased dependence on access to water for irrigation, cooling</i>	<i>Would become impractical if too hot, lack of chilling so substitute for alternative crops</i>

9.3.2 Infrastructure

<i>Obvious thing is need for water farming/storage, BUT have a look at saving first</i>	<i>Less obvious is how we use water. We monitor plant with pressure chambers, changed application timing and placement e.g. sub-surface irrigation is saving water by not watering weeds, promoting deeper root development.</i>
<i>All the support infrastructure in in Karamu, not easy to shift</i>	
<i>Flooding could impact, especially if severe</i>	<i>What regional response is required?</i>

9.3.3 Crop Health

<i>Less obvious is effect on insect mortality – e.g. mealy bug controlled by frosts = less severe winters, existing pests worse, but what other new pests??</i>	<i>More prevention and post-event reapplications Industry financially marginal now, can't support a lot more costs</i>
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<i>Easter wet last year was extreme – serious impact. Warm rain for three days was devastating. We don't have chemical controls for that</i>	<i>Can new practices e.g. vine shaking help avoid botrytis (works in Marlborough but not in HB).</i>
<i>For our [grape] industry we only need subtle change in humidity and rain at vintage to severely impact industry profitability.</i>	<i>Impacts could be more dramatic much more quickly with small changes. – Botrytis response to humidity and temp – diff between impact of botrytis at 15o and 20o is severe.</i>
<i>Warmer and wetter = botrytis, downy mildew needing more mitigation. Impacts can be severe</i>	<i>Will need more repeat spraying (anything over 20mm = respray), BUT Last season – could not get vehicle in to do work</i>
<i>More disease risk if warmer more humid conditions. If we overhead spray to cool, we get fireblight!</i>	<i>Rootstock selections close, but need more – multi-gene resistance preferred</i>

9.3.4 Land Use Change

Grapes	
<i>Open new areas such as CHB – 1,000s ha available</i>	<i>Option to open up Ruataniwha</i>
<i>Some land is pretty marginal – if production costs, water storage cost may make it unprofitable</i>	<i>– total change to hemp!!</i>
<i>Sold on premium varieties, can't easily change to hybrid in market so limited to selecting within strains.</i>	<i>May need to review grape varieties – or selections to look to better suited ones.</i>
<i>Initially warming might aid expansion as some areas just too marginal with frost risk. Industry expansion rather than move??</i>	<i>Longer term the industry might move in response – take advantages of higher terraces and Ruataniwha.</i>
Apples	
<i>At industry level, adaptation could be shifting to Wairarapa or South Island – more in Canterbury, Otago??</i>	<i>Expect long term, industry could shift regionally Ruataniwha is windier so is it desirable? Replaced by something else, avocados, mangoes!</i>
<i>Karamu likely to remain a key area, but more mitigation needed. Have committed to a lot of planting – expected to remain 25 years+</i>	<i>Not looking to move to Ruataniwha 100ha just planted at Puketapu, never been there before.</i>

10 Conclusions and next steps

The scenarios will be used in additional workshops with the case study catchments. Two workshops have already been held, and a third, regional-level workshop is planned for mid-August 2018. The workshops have provided additional insight into adaptation options, and context-specific drivers of change in two sites in the Hawke's Bay region.

Additional steps include (1) Regional workshop to explore adaptation options in more detail, and develop adaptation pathways for case study sites and for region; (2) regional economic modelling based on computable general equilibrium; and (3) development of case study and regional adaptation pathways maps. The outcome of these case-study and regional workshops will be a series of empirically connected adaptation pathways; guidance for practitioners; and new insights into how best to operationalise adaptation pathways planning across scales, and for complex problems.

Appendix: Material provided to industry experts prior to interviews

Projected Climate Impacts

General

Warming is expected to be associated with rising snow lines, more frequent hot extremes, less frequent cold extremes, and increasing extreme rainfall related to flood risk in many locations.

Annual average rainfall is expected to decrease in the north and east of the North Island.

Fire weather is projected to increase in many parts of New Zealand.

Regional sea level rise will very likely exceed the historical rate, consistent with global mean trends.

Uncertainty in projected rainfall changes remains large for many parts of New Zealand, which creates significant challenges for adaptation.

Impacts and vulnerability

Without adaptation, further climate-related changes are projected to have substantial impacts on water resources, coastal ecosystems, infrastructure, health, agriculture, and biodiversity. However, uncertainty in projected rainfall changes and other climate-related changes remains large for many parts of New Zealand, which creates significant challenges for adaptation.

Summary of Scenarios of Climate Change

Catchments	Climate scenarios	
	Moderate	Extreme
Karamu	0.75°C warmer, mostly in summer/autumn 15 additional “hot days” per year 5 less “cold nights” per year (i.e. frosts) 5% less rainfall annually, mostly in spring 5% more extreme rainfall 120 mm increase in PED deficit (drought proneness) + increase in extreme winds and storms is uncertain	2.5°C warmer, mostly in autumn 60 additional “hot days” per year 10 less “cold nights” per year (i.e. frosts) 10% less rainfall annually, mostly in spring 10% more extreme rainfall 160 mm increase in PED deficit (drought proneness) ++ increase in extreme winds and storms is uncertain
Wairoa	0.75°C warmer, mostly in summer/autumn 30 additional “hot days” per year 5 less “cold nights” per year (i.e. frosts) 5% less rainfall annually, mostly in spring 5% more extreme rainfall 100 mm increase in PED deficit (drought proneness) + increase in extreme winds and storms is uncertain	2.75°C warmer, mostly in summer/autumn 60 additional “hot days” per year 5 less “cold nights” per year (i.e. frosts) 5% less rainfall annually, mostly in spring 15% more extreme rainfall 140 mm increase in PED deficit (drought proneness) ++ increase in extreme winds and storms is uncertain

Glossary:

- **Hot days:** The number of days per year with maximum temperature >25°C
- **Cold nights/frosts:** The number of nights per year with minimum temperature <0°C
- **Extreme rainfall:** 1% top highest rainfall events
- **Potential Evapotranspiration Deficit (PED):** the cumulative difference between potential evapotranspiration (PET) and rainfall from 1 July of a calendar year to 30 June of the next year, for days of soil moisture under half of available water capacity (AWC), where an AWC of 150mm for silty-loamy soils

Two case study sites were selected based in part on consultation with Hawke’s Bay Regional Council. The study sites – Wairoa and Heretaunga catchments – are broadly representative of the diversity of land-management, climate change, and socioeconomic issues facing the region, including soil erosion, drought, water availability, and social and economic vulnerability. They are studies in contrasts – one a remote, hilly, and erosion prone region; the other flat, with diverse land uses focused on high value horticultural and viticulturally production.

Appendix D – Hawke’s Bay Climate Change Projections

Appendix E – System map articulating regional primary industries in Hawke’s Bay

Hawke's Bay Climate Change Projections

Prepared for Landcare Research New Zealand Limited

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1 Introduction

Landcare Research New Zealand Limited contracted NIWA to produce a report describing downscaled climate change projections for the Hawke’s Bay Region of New Zealand, based on global climate models updated for the publication of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report in 2013 and 2014, and also used in the New Zealand climate change report published by the Ministry for the Environment in 2016 (Mullan et al., 2016).

This report describes climate changes which may occur over the coming century for the Hawke’s Bay. The report does not address the issue of mitigation (reducing greenhouse gas emissions, or increasing “sinks” such as areas of growing forest).

Data for climate factors provided and discussed include temperature, precipitation, wind and evaporation. The climate data (also provided as GIS data files) was requested to provide an indication of what could potentially occur within the region to underpin multi-stakeholder conversations (Hawke’s Bay Regional Council, industries, sectors and others) regarding how the region could be impacted and how they might adapt.

The funding for this report did not allow for new data analysis and modelling, but enabled us to draw on information which is already available from various sources. Much of this information is new, resulting from the latest assessments of the Intergovernmental Panel on Climate Change (IPCC, 2013, IPCC, 2014c, IPCC, 2014b), and scenarios for New Zealand generated by NIWA scientists based on downscaling from global climate model runs undertaken for these IPCC assessments (undertaken through NIWA’s core-funded Regional Modelling Programme). The climate change information

presented in this report is entirely consistent with recently-updated climate change guidance produced for the Ministry of the Environment (Mullan et al., 2016).

2 Background: Global and New Zealand climate change

2.1 Global climate change

This section summarises some key findings from the 2013 and 2014 IPCC Fifth Assessment Reports (AR5) as contextual information for the discussion of past and future climate changes in the Hawke's Bay Region to follow in this report.

2.1.1 The Physical Science Basis (IPCC Working Group I)

The Summary for Policymakers of the IPCC AR5 Working Group I Report (IPCC, 2013) emphasises the following points regarding changes to the climate system:

- ③ Warming of the climate system is 'unequivocal', and since the 1950s, many of the observed climate changes are unprecedented over short and long timescales (decades to millennia). These changes include warming of the atmosphere and ocean, diminishing of ice and snow, sea-level rise, and increases in the concentration of greenhouse gases.
- ③ The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.
- ③ Climate change is already influencing the intensity and frequency of many extreme weather and climate events globally.
- ③ It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.

Continued emissions of greenhouse gases will cause further warming and changes in all parts of the climate system. There are four scenarios named RCPs (Representative Concentration Pathways) by the IPCC. These RCPs represent different climate change mitigation scenarios – one (RCP2.6) leading to very low anthropogenic greenhouse gas concentrations (requiring removal of CO₂ from the atmosphere), two stabilisation scenarios (RCPs 4.5 and 6.0), and one (RCP8.5) with very high greenhouse gas concentrations. Therefore, the RCPs represent a range of 21st century climate policies.

By the middle of the 21st century, the magnitudes of the projected climate changes are substantially affected by the choice of scenario. **Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850-1900** for all scenarios except for the lowest emissions scenario (RCP 2.6).

In contrast to the Fourth IPCC Assessment Report which concentrated on projections for the end of the 21st century, the Fifth Assessment Report projects climate changes for earlier in the 21st century as well in its Summary for Policymakers. As such, **the global mean surface temperature change for the period 2016-2035 (relative to 1986-2005) will likely be in the range of 0.3 to 0.7°C**. This assumes that there will be no major volcanic eruptions (which may cause global cooling) and that total solar irradiance remains similar. Temperature increases are expected to be larger in the tropics and subtropics than in the southern mid-latitudes (i.e. New Zealand).

The full range of projected globally averaged temperature increases for all scenario for 2081-2100 (relative to 1986-2005) is 0.3 to 4.8°C (Figure 2-1). As global temperatures increase, it is virtually certain that there will be more hot and fewer cold temperature extremes over most land areas. It is very likely that heat waves will occur with a higher frequency and duration. Furthermore, in general, the contrast in precipitation between wet and dry regions and wet and dry seasons will increase. With increases in global mean temperature, mid-latitude and wet tropical regions will experience more intense and more frequent extreme precipitation events by the end of the 21st century.

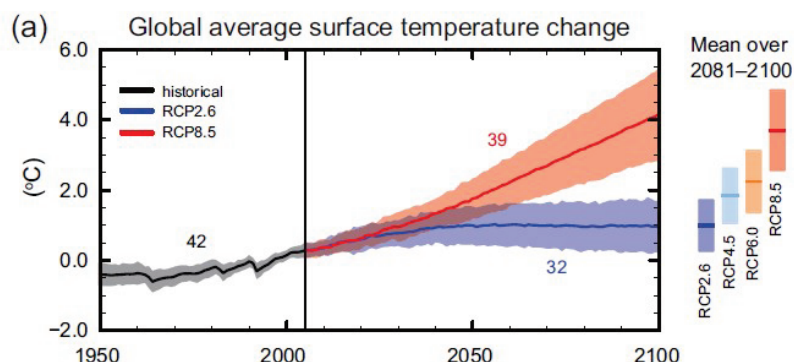


Figure 2-1: CMIP5 multi-model simulated time series from 1950-2100 for change in global annual mean surface temperature relative to 1986-2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP 2.6 (blue) and RCP8.5 (red). Black (grey shading) is the modelled historical evolution using historical reconstructed forcings. The mean and associated uncertainties averaged over 2081–2100 are given for all RCP scenarios as coloured vertical bars to the right of the graph (the mean projection is the solid line in the middle of the bars). The numbers of CMIP5 models used to calculate the multi-model mean is indicated on the graph. After IPCC (2013).

The global ocean will continue to warm during the 21st century. Eventually, heat will penetrate into the deep ocean and affect ocean circulation. Sea ice is projected to shrink and thin in the Arctic. Some scenarios project that late summer Arctic sea ice extent could almost completely disappear by the end of the 21st century, and a nearly ice-free Arctic Ocean in late summer before mid-century is likely under the most extreme scenario. Northern Hemisphere spring snow cover will decrease as global mean surface temperature increases. The global glacier volume (excluding glaciers on the periphery of Antarctica) is projected to decrease by 15-85% by the end of the 21st century under different scenarios.

Cumulative CO₂ emissions largely determine global mean surface warming by the late 21st century and further into the future. Even if emissions are stopped, most aspects of global climate change will persist for many centuries.

2.2 New Zealand climate change

Published information about the expected impacts of climate change on New Zealand is summarised and assessed in the Australasia chapter of the IPCC Working Group II assessment report (Reisinger et al., 2014) as well as a recent report published by the Royal Society of New Zealand (Royal Society of New Zealand, 2016). Key findings from these publications include:

The regional climate is changing. The Australasia region continues to demonstrate long-term trends toward higher surface air and sea surface temperatures, more hot extremes and fewer cold extremes, and changed rainfall patterns. Over the past 50 years, increasing greenhouse gas concentrations have contributed to rising average temperatures in New Zealand. Changing precipitation patterns have resulted in increases in rainfall for the south and west of the South Island and west of the North Island, and decreases in the northeast of the South Island and the east and north of the North Island. Some heavy rainfall events already carry the fingerprint of a changed

climate, in that they have become more intense due to higher temperatures allowing the air to carry more moisture (Dean et al., 2013). Cold extremes have become rarer and hot extremes have become more common.

The region has exhibited warming to the present and is virtually certain to continue to do so. New Zealand mean annual temperature has increased by 0.09°C ($\pm 0.03^{\circ}\text{C}$) per decade since 1909.

Warming is projected to continue through the 21st century along with other changes in climate.

Warming is expected to be associated with rising snow lines, more frequent hot extremes, less frequent cold extremes, and increasing extreme rainfall related to flood risk in many locations. Annual average rainfall is expected to decrease in the northeast South Island and north and east of the North Island, and to increase in other parts of New Zealand. Fire weather is projected to increase in many parts of New Zealand. Regional sea level rise will very likely exceed the historical rate, consistent with global mean trends.

Uncertainty in projected rainfall changes remains large for many parts of New Zealand, which creates significant challenges for adaptation.

Impacts and vulnerability: Without adaptation, further climate-related changes are projected to have substantial impacts on water resources, coastal ecosystems, infrastructure, health, agriculture, and biodiversity. However, uncertainty in projected rainfall changes and other climate-related changes remains large for many parts of New Zealand, which creates significant challenges for adaptation.

Additional information about past New Zealand climate change can be found in Mullan et al. (2016).

3 Projections of future climate changes to 2100

The future climate of the Hawke's Bay Region will be influenced by a combination of the effects of anthropogenic climate change plus the natural year-to-year and decade-to-decade variability resulting from "climate noise" and features such as the El Niño-Southern Oscillation (ENSO), the Interdecadal Pacific Oscillation (IPO), and the Southern Annular Mode (SAM) (see Fedaeff and Fauchereau, 2015). This section outlines the projected changes due to anthropogenic climate change in the Hawke's Bay Region. Note that the projected changes use 20-year averages, which will not entirely remove effects of natural variability.

Predicting future changes in climate due to anthropogenic activity is made difficult because (a) predictions depend on future greenhouse gas concentrations, which in turn depend on global greenhouse gas emissions driven by factors such as economic activity, population changes, technological advances and policies for sustainable resource use, and (b) even for a specific future trajectory of global greenhouse gas emissions, different climate models predict somewhat different amounts of climate change.

This has been dealt with by the Intergovernmental Panel on Climate Change through consideration of 'scenarios' describing concentrations of greenhouse gases in the atmosphere associated with a range of possible economic, political, and social developments during the 21st century, and by considering results from several different climate models for a given scenario. In the 2013 IPCC Fifth Assessment Report, the atmospheric greenhouse gas concentration component of these scenarios are called Representative Concentrations Pathways (RCPs).

Global climate model output based on two RCPs has been downscaled to produce future projections for temperature, precipitation, evaporation and wind for the Hawke's Bay Region (see maps later in this section). The RCPs are based on 21st century climate policies, and thus differ from the previous IPCC SRES emissions scenarios and their 'no-climate policy' (IPCC, 2013). RCP 4.5 is a low-mid range

emissions scenario, which is also called a 'stabilisation' scenario where radiative forcing stabilises by 2100. RCP 8.5 is a scenario with very high greenhouse gas emissions, and radiative forcing continues to increase beyond 2100. Each RCP provides spatially-resolved data sets of land use change and sector-based emissions of air pollutants, and it specifies annual greenhouse gas concentrations and anthropogenic emissions up to 2500 (although this section of the report only considers changes to 2100). RCPs are based on a combination of integrated assessment models, simple climate models, atmospheric chemistry and global carbon cycle models.

NIWA has used climate model data from the IPCC Fifth Assessment (IPCC, 2013) to update climate change scenarios for New Zealand, through a regional climate model (dynamical) process. The dynamical downscaling processes are described in detail in an updated climate guidance manual prepared for the Ministry for the Environment (Mullan et al., 2016), but a short explanation is provided below.

All climate projections start as simulations by global climate models, which have coarse spatial resolution. Dynamical downscaling means using a higher resolution climate model or weather prediction model to get finer scale detail (5 km resolution in this report). Several different models are used to simulate future climate (6 for dynamical downscaling). The projections from each of the models are averaged together, creating an ensemble average (which is displayed in the figures in this section).

Note that in the maps presented here there are some pixels around the coast of the Hawke's Bay region where no projection data are displayed. Data is downscaled only where low resolution cells are land points and overlap high resolution cells. In most cases interpolating over mixed sea and land point creates artificial biases, for example lower temperatures.

3.1 Changes to temperature

The magnitude of the temperature change projections varies with the RCP and with the climate models used. In this report, temperature projections were carried out by dynamical downscaling of two RCPs using NIWA's Regional Climate Model - a stabilisation scenario (RCP 4.5) and a high emissions scenario (RCP 8.5).

3.1.1 Mean temperature projections

The seasonal patterns of projected temperature changes over the Hawke's Region are presented in this section. Projections for 2040 for the RCP 4.5 scenario are shown in Figure 3-1. Figure 3-2 shows corresponding patterns for 2090. Figure 3-3 shows the seasonal patterns of projected temperature increase for 2040 for the RCP 8.5 scenario, and Figure 3-4 shows the corresponding patterns for 2090. These nominal years represent the mid-points of bi-decadal periods: 2040 is the average over 2031-2050, and 2090 the average over 2081-2100. All maps show changes relative to the baseline climate of 1986-2005.

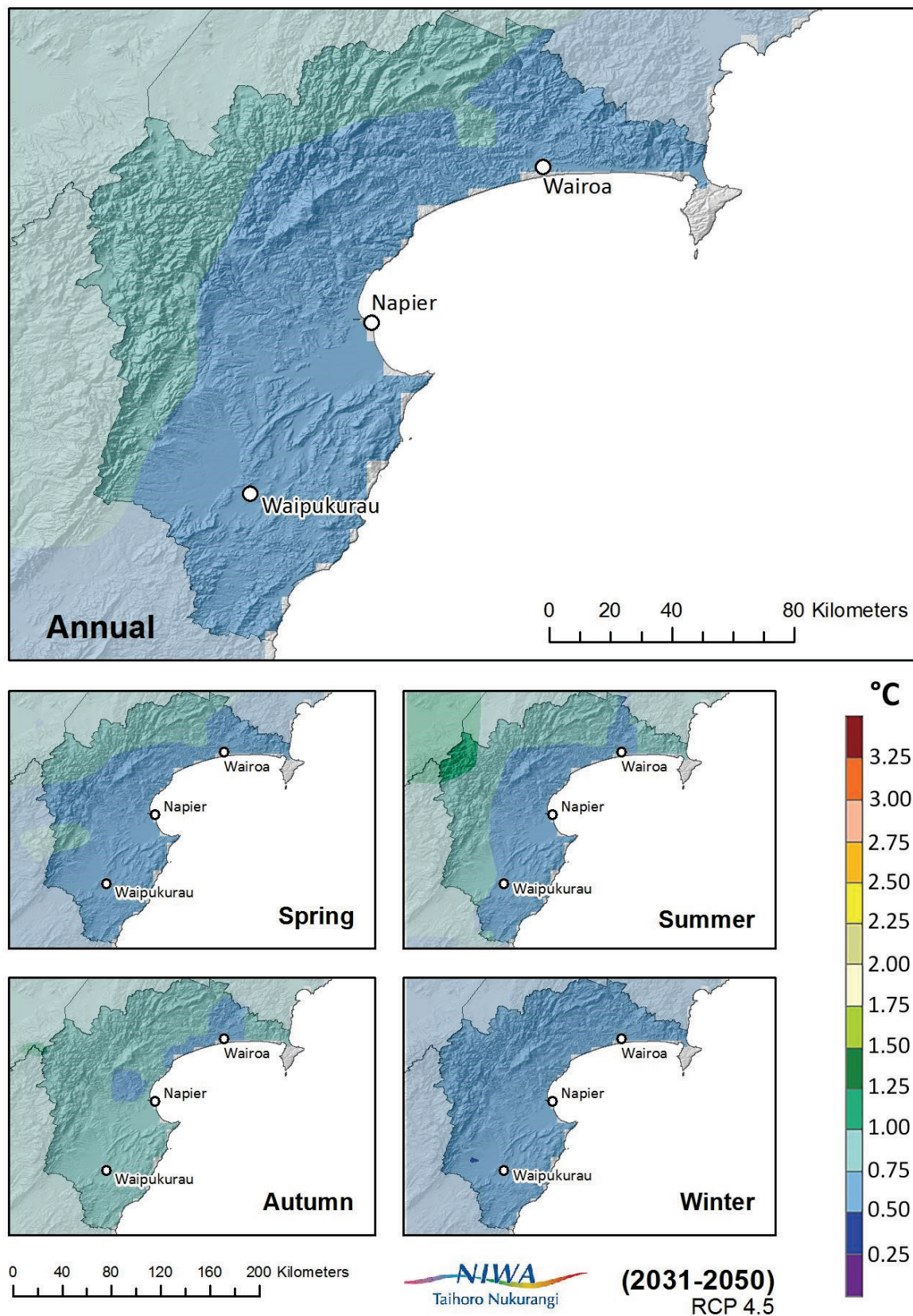


Figure 3-1: Projected annual and seasonal mean temperature changes at 2040 (2031-2050 average). Relative to 1986-2005 average, for the IPCC RCP 4.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

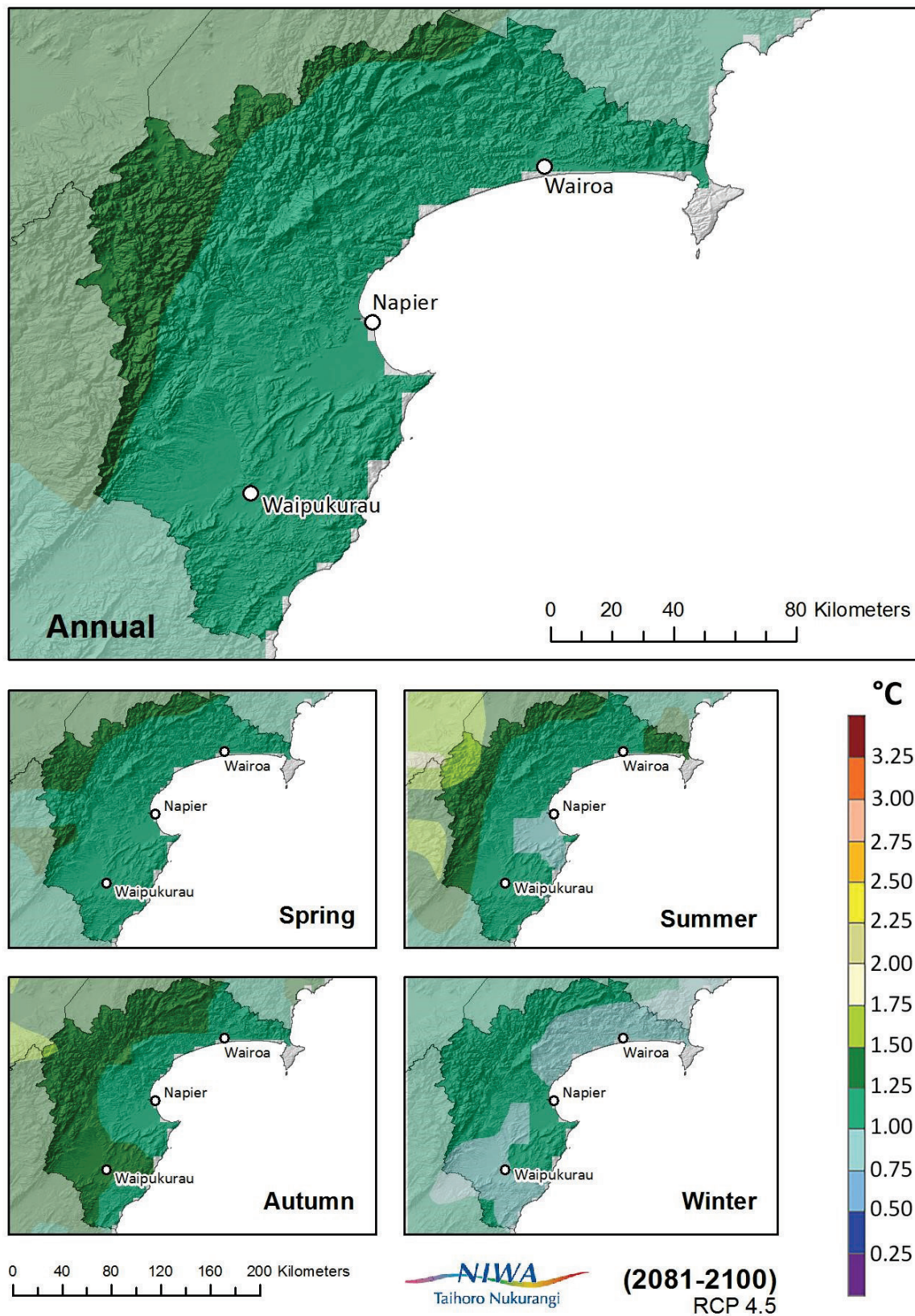


Figure 3-2: Projected annual and seasonal mean temperature changes at 2090 (2081-2100 average).

Relative to 1986-2005 average, for the IPCC RCP 4.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

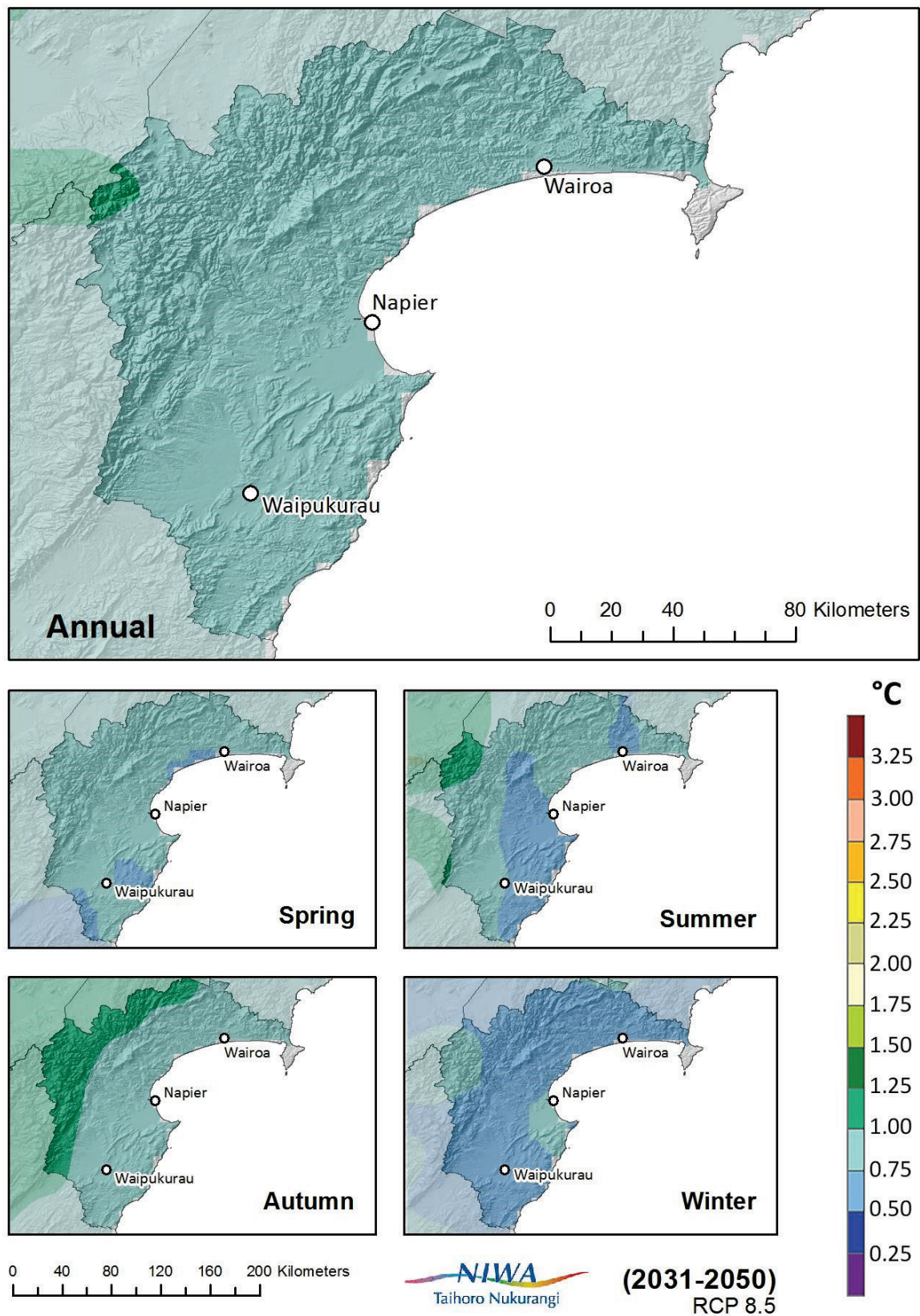


Figure 3-3: Projected annual and seasonal mean temperature changes at 2040 (2031-2050 average). Relative to 1986-2005 average, for the IPCC RCP 8.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

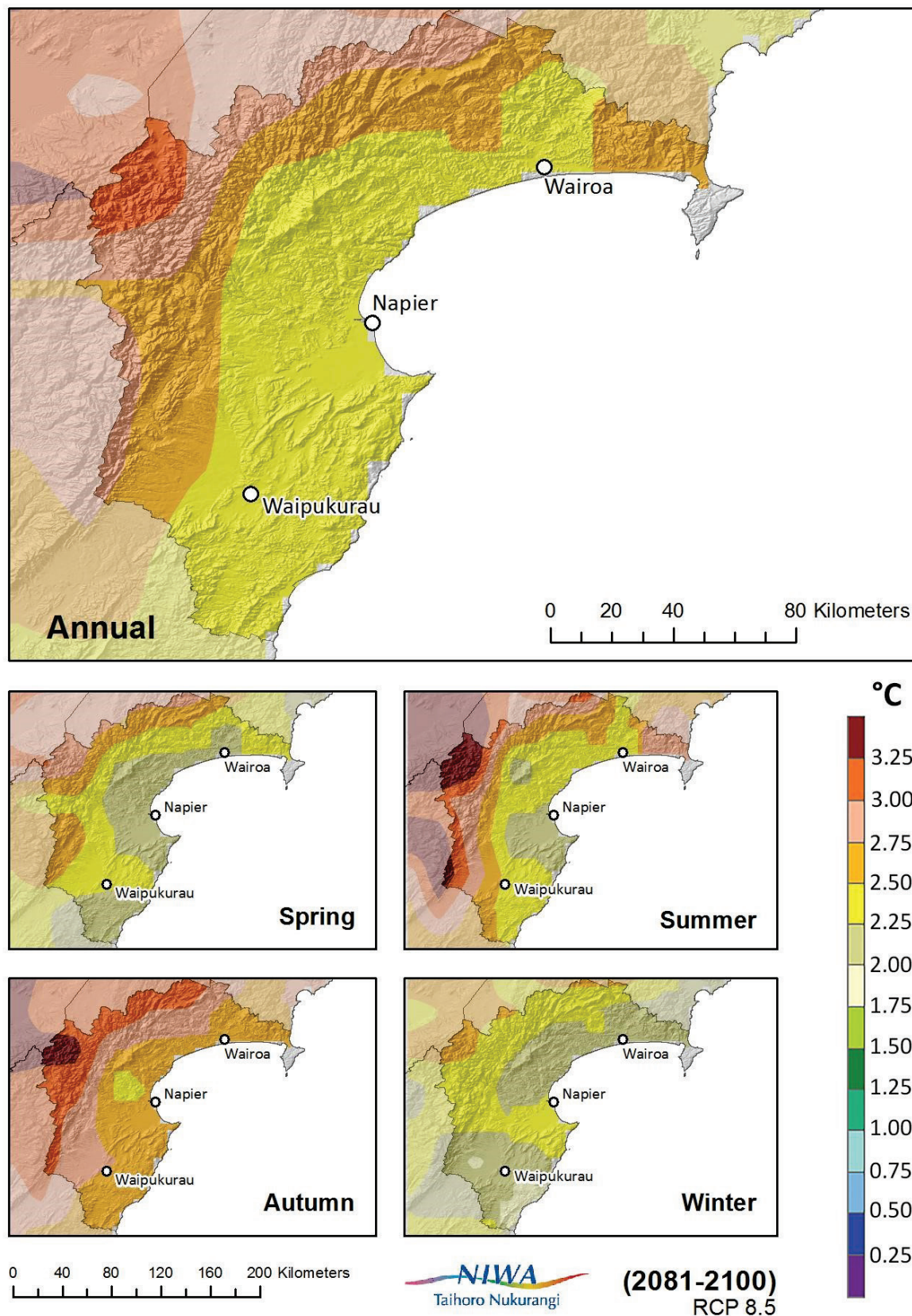


Figure 3-4: Projected annual and seasonal mean temperature changes at 2090 (2081-2100 average). Relative to 1986-2005 average, for the IPCC RCP 8.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

As shown by Figure 3-1, projected future warming in the Hawke's Bay Region at 2040 under the RCP 4.5 scenario is more pronounced over the ranges (Huiarau, Kaweka and Ruahine) when averaged over six climate models analysed by NIWA. Most warming is between 0.5°C - 1°C under this scenario.

Warming is most pronounced in autumn and least pronounced in winter. Figure 3-2 shows mean seasonal temperature change under RCP 4.5 at 2090. A similar pattern is shown to Figure 3-1, but the magnitude of warming is larger. The warming is most pronounced in autumn and summer with the ranges projected to see increases in temperature between 1.25°C and 1.75°C.

Figure 3-3 shows projected warming for the Hawke's Bay Region under RCP 8.5 at 2040 – warming of >0.5°C is observed everywhere. The region is projected to warm by up to 0.75°C - 1.25°C in autumn. By 2090 under RCP 8.5 (Figure 3-4), significant warming is observed over the entire Hawke's Bay Region, with winter observing the least amount of warming and autumn observing the most. The Huiarau, Kaweka and Ruahine ranges are projected to experience increases in mean temperatures during summer and autumn by at least 2.75°C. At the annual scale, a minimum warming of 2.25°C is projected for the region.

As mentioned prior, Figure 3-1 to 3-4 are model ensemble averages. If you look at individual models, some give less warming and others give a faster rate of warming (IPCC, 2013).

3.1.2 Frosts and hot days projections

As the seasonal mean temperature increases over time, we also expect to see changes in temperature extremes. In general, an increase in high temperature extremes, and a decrease in low temperature extremes is expected. Natural variability, of course, will continue to influence the climate of specific years, and the specific time variation of this variability cannot be predicted by the climate models due to the chaotic interactions that affect development of individual weather systems and larger-scale climate modes (such as El Niño events) (Mullan et al., 2016).

For this report, high temperature extremes (i.e. 'hot days') are considered as the number of days per year with a maximum temperature of 25°C or above, and low temperature extremes (i.e. 'cold nights' or frosts) are considered as the number of nights per year of 0°C or below. These extremes were determined directly from the daily dynamically downscaled maximum (for 'hot days') and minimum (for 'cold nights') temperature for each (of six) model by averaging the number of daily exceedances (greater than or equal to 25°C, or less than or equal to 0°C, for hot days and cold nights, respectively) for the selected RCP and time period over the number of years. Finally the climate change signal was computed by averaging the change (with respect to the reference period) over the number of models (6).

The projected increase in the number of hot days per year at 2040 (2031-2050) and 2090 (2081-2100) relative to 1986-2005, for RCP 4.5 and RCP 8.5 is shown in Figure 3-5. Higher elevation areas, particularly around the ranges are projected to experience the least increase in hot days at all time slices and all RCPs.

At 2040, the ranges are projected to experience increases in hot days by no more than 10 days per year for RCP 4.5 and RCP 8.5. Much of the Central Hawke's Bay, Hastings and Napier districts are projected to see an increase of up to 15 hot days per year for RCP 4.5 and up to 20 hot days per year for RCP 8.5. Wairoa district is projected to see up to 20 more hot days per year under both RCP 4.5 and 8.5 with isolated parts of the district projected to experience up to 30 hot days per year for RCP 8.5.

At 2090, the ranges are projected to experience increases in hot days by up to 20 days per year for RCP 4.5 and RCP 8.5. The remaining majority of the region is projected to experience up to 30 more hot days per year for RCP 4.5 and up to 60 more hot days per year for RCP 8.5. Under RCP 8.5 at 2090, parts of Wairoa district and the Takapau Plains are projected to see 60-70 more hot days per year than experienced relative to the 1986-2005 climatology.

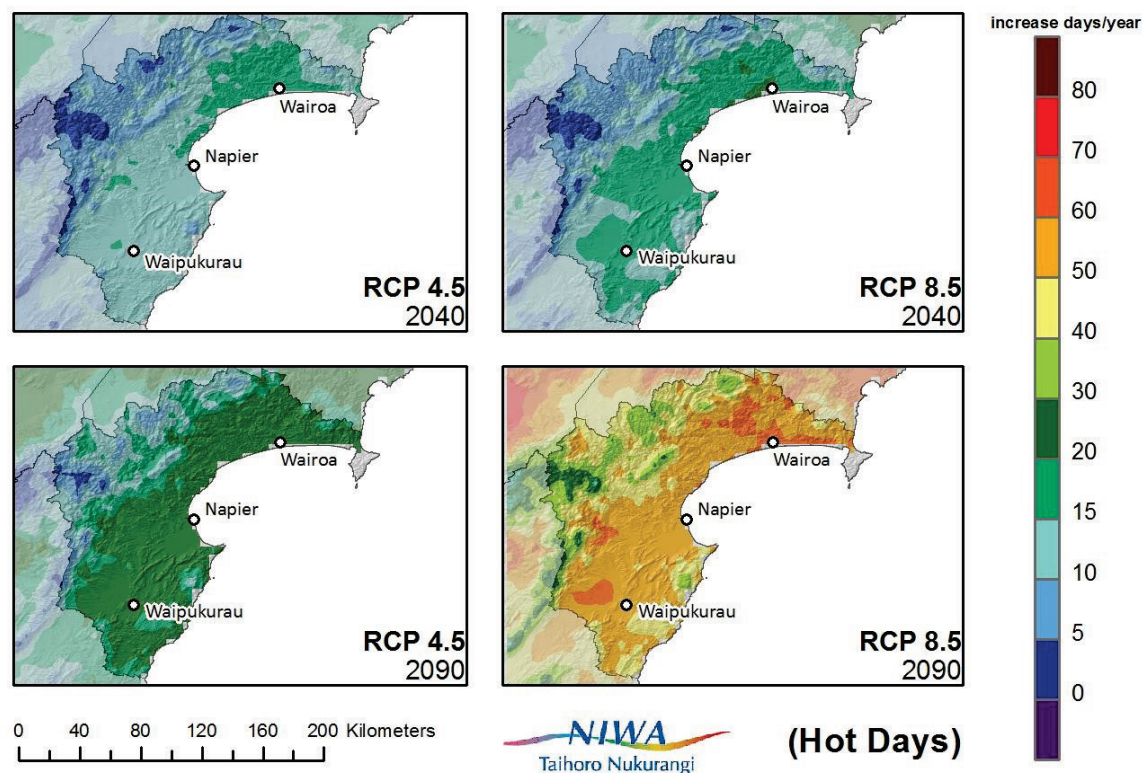


Figure 3-5: Projected increase in number of hot days per year ($T_{max} > 25^{\circ}\text{C}$) at 2040 & 2090 for RCP 4.5 (left panels) and RCP 8.5 (right panels), for the Hawke's Bay Region. Projected change in hot days is relative to 1986-2005. The numbers on the scale refer to the *increase* in the number of hot days. Results are based on dynamically downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. © NIWA.

The projected decrease in the number of cold nights (i.e. frosts) per year at 2040 (2031-2050) and 2090 (2081-2100) relative to 1986-2005, for RCP 4.5 and RCP 8.5 is shown in Figure 3-6. One thing to note is that large parts of the Central Hawke's Bay and Wairoa districts experience 5 cold nights or fewer per year based on the 1986-2005 climatology and so do not show much change in cold nights regardless of the time slice and RCP.

Similar patterns are shown for changes in cold nights at 2040 under both RCP 4.5 and RCP 8.5. Most parts of the region outside the highest elevations of the Huiarau, Kaweka and Ruahine Ranges are projected to experience a decrease of fewer than five cold nights per year. Cold nights at high elevations are projected to decrease by up to 10 nights per year.

By 2090, the pattern for RCP 4.5 is similar to that at 2040 except the area projecting up to 10 fewer cold nights per year spreads to lower elevations. The highest parts of the Kaweka and Ruahine Ranges in the Hawke's Bay region are projected to see up to 20 fewer cold nights. Under RCP 8.5 at 2090, up to 40 fewer cold nights are projected for parts of the Kaweka and Ruahine Ranges. The remainder of the region is projected to see a decrease of up to 10 cold days per year. Given the climatology of the region this means that in the future, some areas such as coastal parts of the Wairoa district and the Takapau plains will very rarely experience frosts.

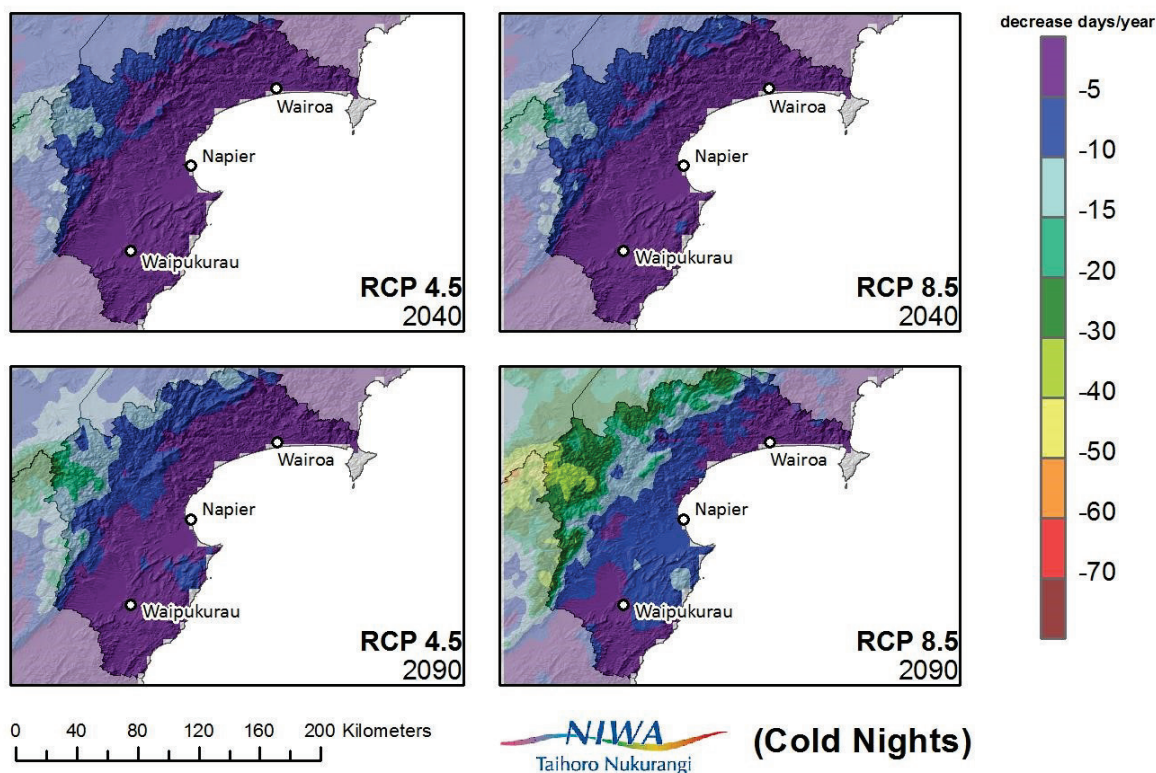


Figure 3-6: Projected decrease in number of cold nights per year ($T_{min} < 0^{\circ}\text{C}$) at 2040 & 2090 for RCP 4.5 (left panels) and RCP 8.5 (right panels), for the Hawke's Bay Region. Projected change in cold nights is relative to 1986-2005. The numbers on the scale refer to the *decrease* in the number of cold nights. Results are based on projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. © NIWA.

3.2 Changes to precipitation

Precipitation projections are presented in this section. Variables covered include seasonal and annual precipitation (Section 3.2.1) and extreme rainfall (Section 3.2.2)

3.2.1 Precipitation projections

The ensemble averages for dynamically downscaled projections, using NIWA's Regional Climate Model, for precipitation are presented in this section. Figure 3-7 and Figure 3- show the projected seasonal patterns of precipitation change over the Hawke's Bay Region at 2040 and 2090 for RCP 4.5, and Figure 3- and Figure 3-105 show the same for RCP 8.5.

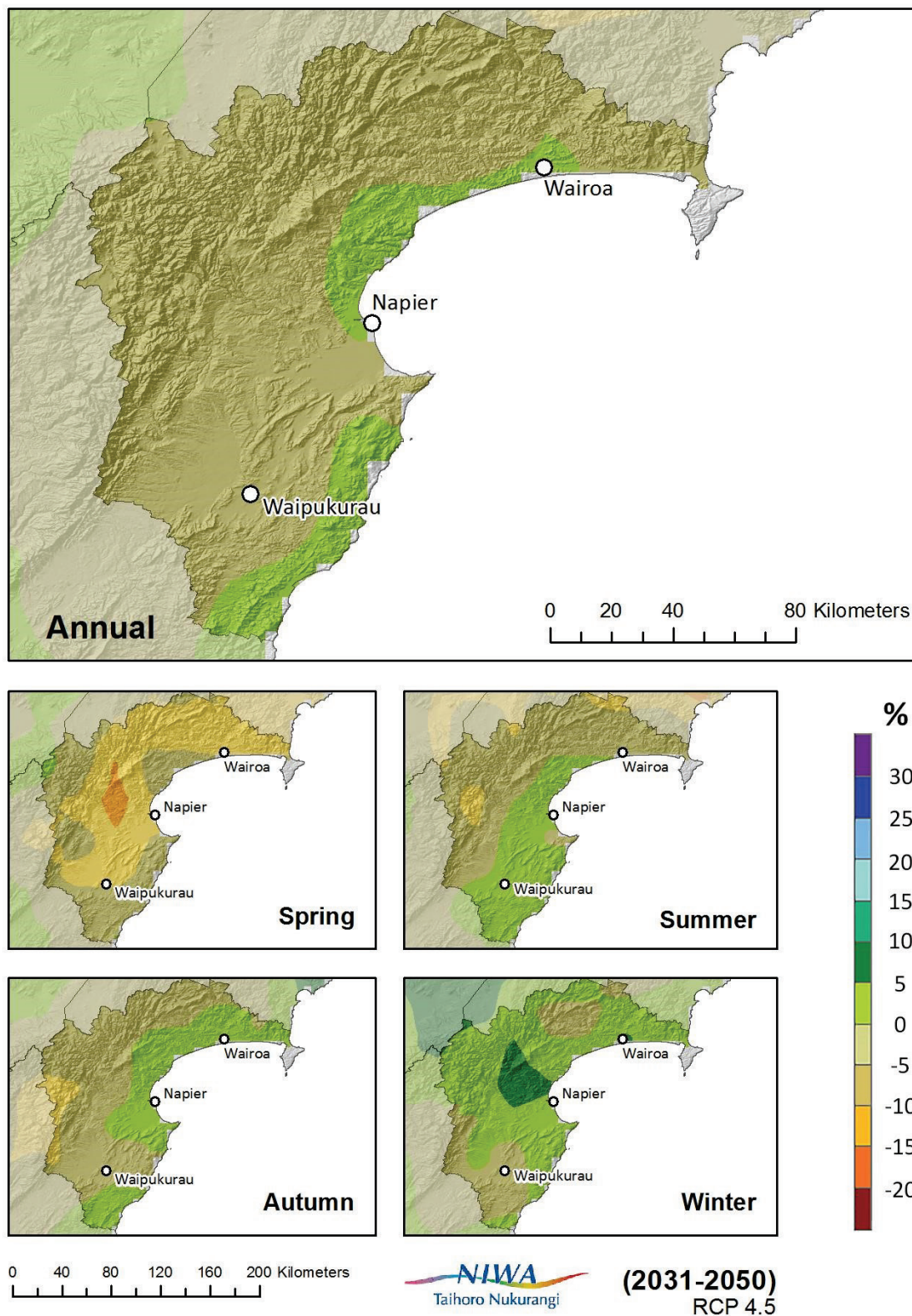


Figure 3-7: Projected annual and seasonal precipitation changes (in %) at 2040 (2031-2050 average). Relative to 1986-2005 average, for the IPCC RCP 4.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

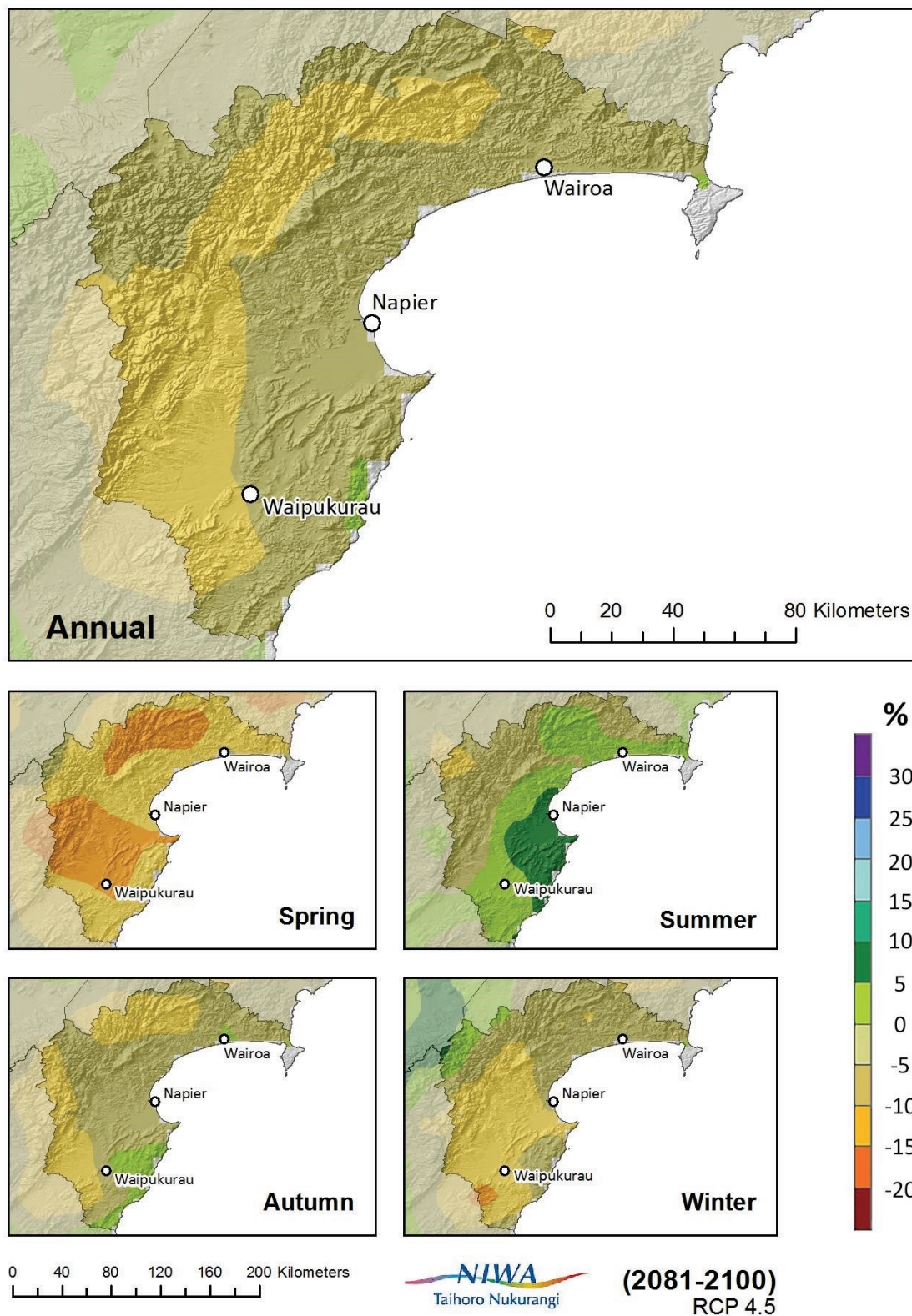


Figure 3-8: Projected annual and seasonal precipitation changes (in %) at 2090 (2081-2100 average). Relative to 1986-2005 average, for the RCP 4.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

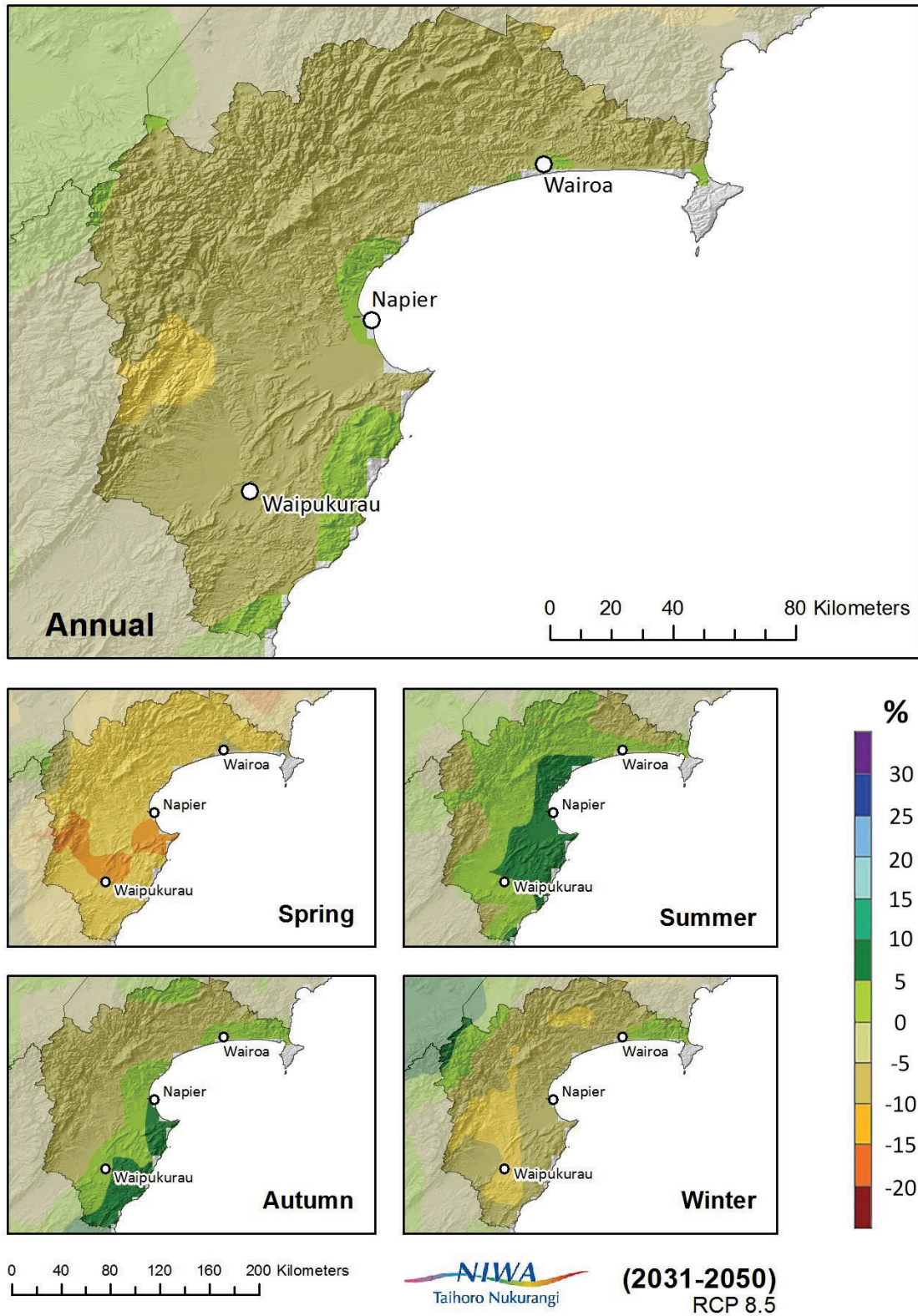


Figure 3-9: Projected annual and seasonal precipitation changes (in %) at 2040 (2031-2050 average). Relative to 1986-2005 average, for the IPCC RCP 8.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

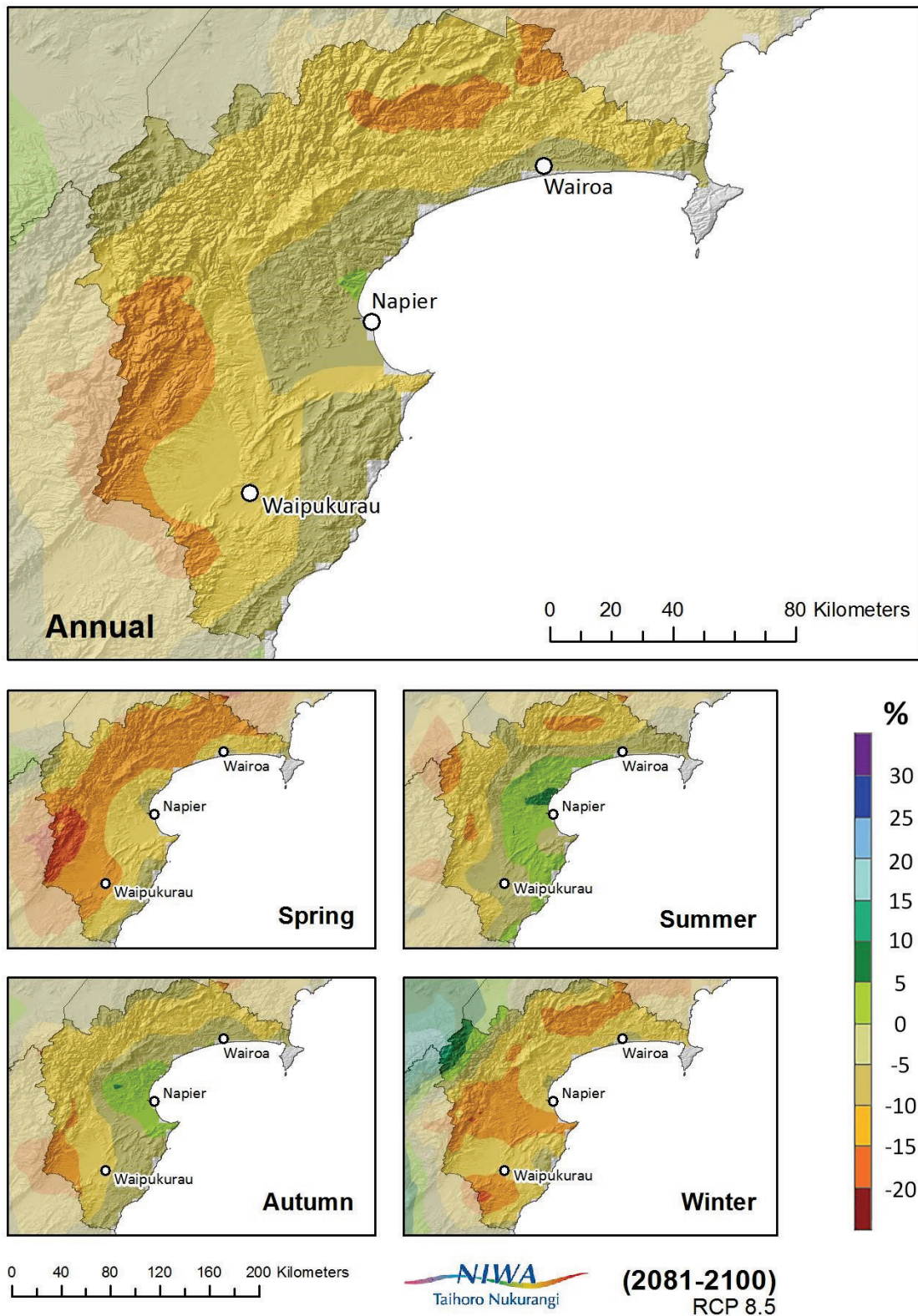


Figure 3-105: Projected annual and seasonal precipitation changes (in %) at 2090 (2081-2100 average).

Relative to 1986-2005 average, for the IPCC RCP 8.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

In general, rainfall is projected to decrease across the region but there are seasonal differences. Under RCP 4.5 at 2040 (Figure 3-7), decreases in annual rainfall of up to 5% are projected for most of the region. The exceptions are coastal areas where an increase in annual rainfall of up to 5% is projected. At the seasonal scale, spring exhibits a drying signal across the region. In parts of the Hastings district the decrease in spring rainfall is projected to be up to 15%. Winter is the season

with the largest increase in rainfall projected, with up to 10% more rainfall projected for parts of the Hastings district. For 2090 under RCP 4.5 (Figure 3-), a greater drying signal is seen across the region, with up to 10% less annual rainfall projected for the ranges. Summer rainfall is projected to have the largest increase in rainfall for Napier and parts of Hastings and Central Hawke's Bay with up to 10% more rainfall projected. Spring is projected to see the largest decrease in seasonal rainfall with up to 15% less rainfall in parts of the region.

Similar patterns are seen for RCP 8.5 at 2040 and 2090, but these patterns are amplified. At 2040 (Figure 3-), summer and autumn rainfall is projected to increase in parts of the region near the coastline by up to 10% while spring and winter shows a decrease in rainfall for much of the region (up to 15% less in parts of Hastings during spring). For 2090 (Figure 3-105), only small areas of the region show an increase in rainfall during summer and spring. The overall pattern during all seasons is for a decrease in rainfall. The decrease in rainfall is most pronounced during spring with parts of the Ruahine Ranges projected to see a decrease in rainfall of around 20%.

3.2.2 Extreme rainfall

A warmer atmosphere can hold more moisture (about 8% more for every 1°C increase in temperature), so there is potential for heavier extreme rainfall with global increases in temperatures under climate change. In its Fifth Assessment Report, the IPCC concluded that the frequency of heavy precipitation events is "very likely" to increase over most mid-latitude land areas (this includes New Zealand) (IPCC, 2013, Table SPM.1). Given the mountainous nature of New Zealand, spatial patterns of changes in rainfall extremes are expected to depend on changes in atmospheric circulation and storm tracks.

Changes in the magnitude of extreme precipitation across the Hawke's Bay Region have been dynamically downscaled using NIWA's Regional Climate Model in Figure 3-. The magnitude of extreme precipitation, as quantified by the changes in the 99th percentile of the daily precipitation distribution (i.e. the top 1% of rain days⁵), shows increases across the region (no part of the region projects decreases in extreme rainfall). The most increases in 99th percentile daily precipitation are generally around the Wairoa district, as well as in the coastal areas of the region.

Under RCP 4.5 at 2040, most areas expect a 5% increase in extreme daily precipitation, with some small parts of the region experiencing up to a 10% and 15% increase in extreme daily precipitation. By 2090 under RCP 4.5, Wairoa and some coastal parts of Hastings and Central Hawke's Bay may receive up to 15% more extreme precipitation.

Under RCP 8.5 at 2040, the majority of the region is projected to see an increase in extreme daily precipitation of up to 5%. However, by 2090, most areas are likely to see at least a 5-10% increase in extreme daily precipitation, with some coastal areas projected to receive up to 20% more extreme precipitation.

As a cautionary aside, the climate models being used do not have the resolution to realistically simulate tropical cyclones, so extreme rainfall from these phenomena are likely to be underestimated in our results.

⁵ Note that the 99th percentile is a relatively low threshold for engineering purposes (see Ministry for the Environment, 2008, Chapter 5.2). We would expect that, on average, approximately one day per year would exceed this threshold.

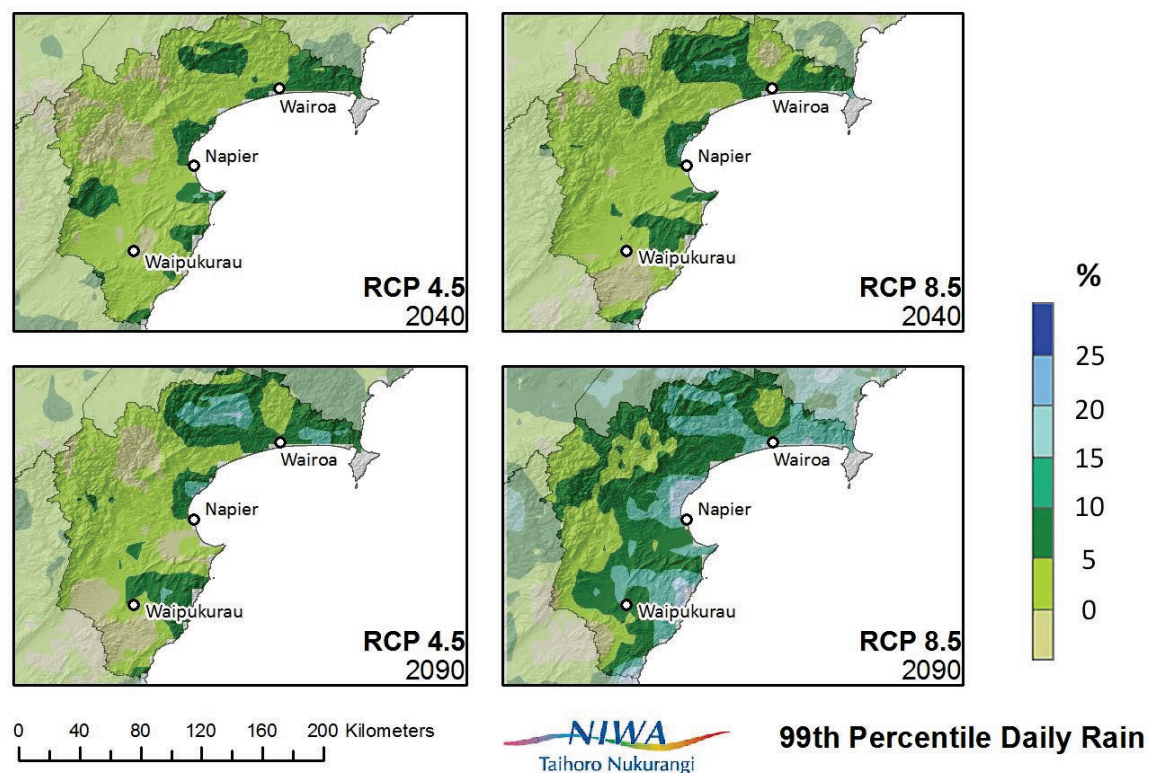


Figure 3-11: Change in the magnitude of the 99th percentile of daily precipitation (in %) for RCP 4.5 and 8.5, at 2040 and 2090. Projected change in 99th percentile of daily precipitation is relative to 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. © NIWA.

3.3 Changes to evaporation and climatic drought

The increase in frequency and intensity of climatic droughts in a changing climate is of deep concern for the New Zealand society and economy, not the least for the stakeholders of the primary sector. Drought intensity is affected by increasing temperature which in turn increases moisture loss through higher evapotranspiration rates, and also by the lack of sufficient moderate intensity precipitation required to recharge aquifers and replenish soil moisture.

Potential evapotranspiration deficit (PED) is the cumulative difference between potential evapotranspiration (PET) and rainfall from 1 July of a calendar year to 30 June of the next year, for days of soil moisture under half of available water capacity (AWC), where an AWC of 150mm for silty-loamy soils is consistent with estimates in previous studies (e.g. Mullan et al., 2005). PED, in units of mm, can be thought of as the amount of rainfall needed in order to keep pastures growing at optimum levels. An increase in PED of 30 mm or more corresponds to an extra week of reduced grass growth.

A regional map of projected changes in potential evapotranspiration deficit is presented in Figure 3-. The maps are plotted with an annual accumulated PED anomaly with respect to the historical annual average.

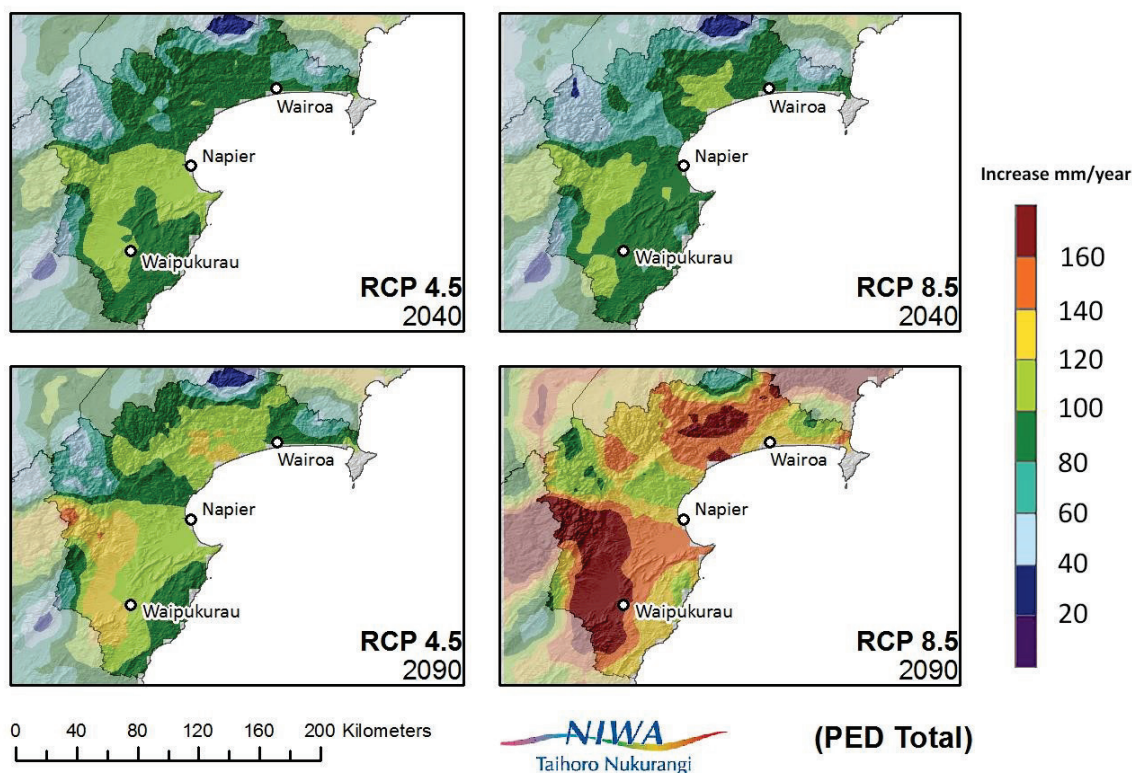


Figure 3-12: Projected changes in Potential Evapotranspiration Deficit (PED, in mm accumulation over the July-June 'hydrologic year') for the Hawke's Bay Region, for RCP 4.5 and 8.5, at 2040 and 2090. Projected change in PED is relative to 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. © NIWA.

As shown by Figure 3-, projected PED varies across the Hawke's Bay Region. Generally, smaller increases in PED are projected for the highest elevations of the Huiarau, Kaweka and Ruahine Ranges, and larger increases in PED are projected for parts of the Hastings district. By 2090 under RCP 8.5, increases in PED of over 160 mm/year are projected for parts of the Wairoa and Hastings districts. This indicates that these areas are likely to become more drought prone in the future.

A NIWA study published in 2011 (Clark et al., 2011) used downscaled climate model results from the IPCC Fourth Assessment Report to examine how the frequency of very dry conditions could change over the 21st century. Three major global greenhouse gas emissions scenarios were used (B1, A1B, and A2), and the final estimates of climatic drought probability were derived from a nationally comprehensive soil moisture indicator.

The study established distinct regional differences across New Zealand in changes to climatic drought vulnerability projected under future climate change, with an increase in climatic drought on the east coast of the North and South Islands being the most plausible and consistent outcome. This is consistent with previous studies on climate change impacts on climatic drought in a New Zealand context (e.g. Mullan et al., 2005). The study concluded that climatic drought risk is expected to increase during this century in all areas that are currently drought prone, under both the 'lowmedium' and 'medium-high' scenarios. The 'drought risk' was analysed in terms of soil moisture levels – drought initiation occurs when soil moisture falls below the historically established 10th percentile for the given time of year for a period greater than one month, and drought termination occurs when soil moisture is above the 10th percentile for one month.

During this century, evidence for increases in time spent in climatic drought is apparent for Canterbury, Hawke's Bay, Gisborne, and Northland (Clark et al., 2011).

Under the most likely mid-range emissions scenario the projected increase in percentage of time spent in drought from 1980-99 levels is about 5% for 2030-2050 and at least 10% for the whole region for 2070-2090 (Figure 3-6). Note that these results are based on the IPCC's Fourth Assessment Report.

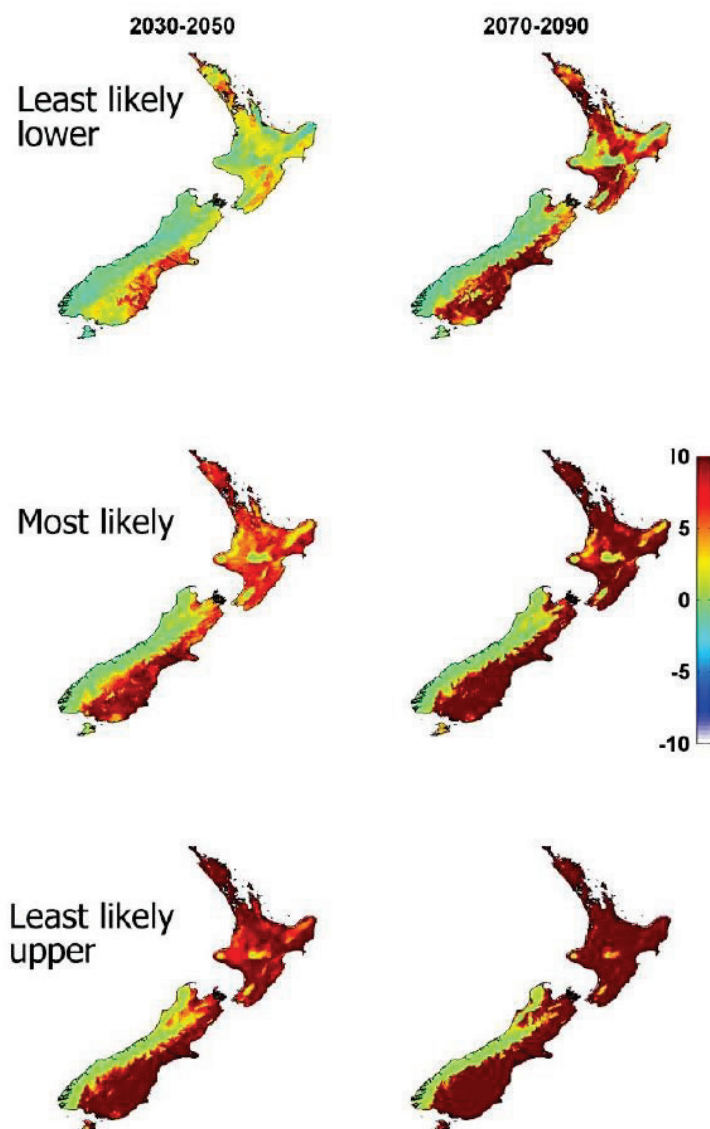


Figure 3-6: Projected increase in percentage of time spent in climatic drought from 1980-99 levels for the A1B emissions scenario. Results summarise 19 global climate models. After Clark et al. (2011).

3.4 Changes to wind and storms

3.4.1 Extreme wind

The 99th percentile of daily-mean wind speed was evaluated over the historical 1986-2005 period at each VCSN grid-point in the downscaled (but not bias-corrected) regional model output data, by Mullan et al. (2016). Figure 3- maps how the 99th percentiles at 2040 and 2090 differ from the current climate for RCP 4.5 and RCP 8.5.

Relatively small increases or decreases in extreme daily winds are projected in Figure 3- for the

Hawke's Bay Region. The greatest decreases are projected for the Napier and Hastings districts. For 2090 under RCP 8.5, a decrease of up to around 3% in the 99th percentile of daily mean wind speeds is projected in these areas. For the remainder of the region, a slight increase in the 99th percentile of daily mean wind speeds is projected.

No seasonal breakdown of extremes is given, but it is expected that the higher winds are primarily due to the increased westerly pressure gradient in winter and spring. Very localised extreme winds from more vigorous summer convection are also potentially a problem in the future, but such events are not resolved by the regional model being used here.

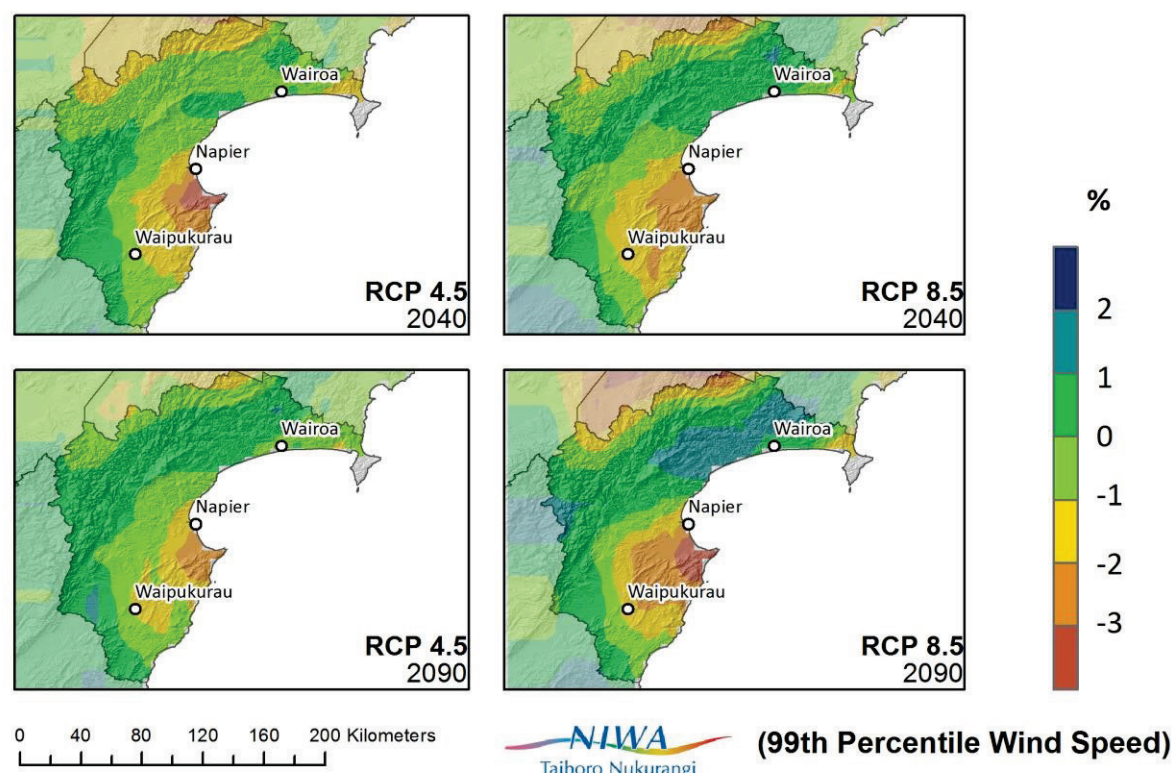


Figure 3-14: Change in the magnitude of the 99th percentile of daily-mean wind speed, for RCP 4.5 and 8.5 at 2040 and 2090. Projected change in 99th percentile of daily mean wind speed is relative to 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. © NIWA.

3.4.2 Storms

Tropical and ex-tropical cyclones

Across the world, it is considered likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged over the 21st century, concurrent with a likely increase in both global mean tropical cyclone maximum wind speed and rain rates (IPCC, 2013). The influence of future climate change on tropical cyclones is likely to vary by region, but there is low confidence in region-specific projections. The frequency of some storms will more likely than not increase in some basins. More extreme precipitation near the centres of tropical cyclones making landfall is projected in some regions including Australia and many Pacific Islands – this is important as tropical cyclones generated in these areas may affect New Zealand.

The Hawke's Bay Region is sometimes adversely affected by cyclones of tropical origin. These storms, which bring heavy rain and strong winds to northern parts of New Zealand, are usually weaker by the time they affect the Hawke's Bay Region. However, occasionally they retain characteristics which

have the potential to cause flooding, generate primary and secondary wind damage to vegetation and infrastructure, and higher-than-normal wave heights and coastal storm surges. On average, New Zealand currently experiences at least one ex-tropical cyclone passing within 550km of the country every year.

Overall, there is significant uncertainty surrounding projections of tropical cyclones into the future. It is likely that storms making landfall will be stronger and cause more damage. However, the IPCC (2013) projections are for tropical cyclones – storms that are in the tropics and thus at their full strength, not ex-tropical cyclones that have undergone extratropical transition where they begin to lose their strength, as they do upon their southwards path where they may influence New Zealand. Therefore, the frequency with which ex-tropical cyclones and other tropical depressions may reach the Hawke's Bay Region in the future is uncertain.

Extra-tropical cyclones

The IPCC comments that the global number of extra-tropical cyclones (the low pressure systems that affect New Zealand every few days, with origins outside of the tropics) is *unlikely* to decrease by more than a few per cent, and future changes in storms are *likely* to be small compared to natural inter-annual variability. This statement applies globally, and regionally-specific changes can be quite different. The storm track response to global warming is more consistent between AR5 models (and between AR4 and AR5 models) in the Southern Hemisphere than in the Northern Hemisphere. Extratropical storm tracks will tend to shift poleward by several degrees (Figure 3-3-15), but the reduction in storm frequency is only a few per cent.

The mid-latitude jet associated with the storm tracks (usually lying well south of New Zealand) is projected to increase in strength (Barnes and Polvani, 2013). This analysis also found that the pattern of variability of the Southern Hemisphere jet was predicted to change in the CMIP5 models; less north-south vacillation was expected in the future, but more pulsing in intensity (with the opposite behaviour in the Northern Hemisphere jet). Just what this means for New Zealand is unclear, however, and further analysis of regional consequences is needed.

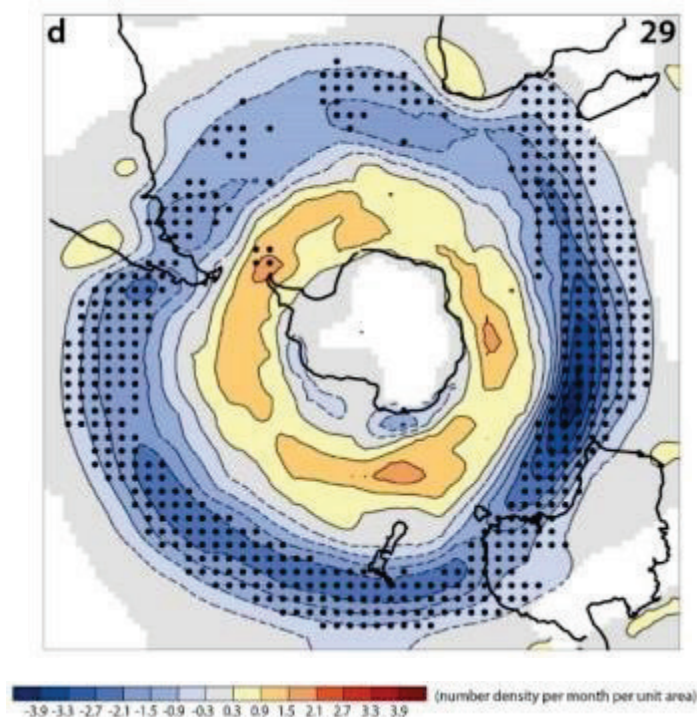


Figure 3-15: Change in winter Southern Hemisphere storm track between 1986–2005 and 2081–2100, under RCP8.5, from a 29-member CMIP5 multi-model ensemble. Blue shading indicates a decrease, and yellow-orange shading an increase in the number of storm 'centres'. Stippling is added where 90 per cent of the models agree on the sign of the change. Reproduced from IPCC AR5 Figure 12.20(d), which gives further detail on the figure and underlying analysis.

One regional study is that of Dowdy et al. (2013), who analysed the IPCC Fourth Assessment projections of “East Coast Lows”, low pressure systems which develop in the Tasman Sea off the east coast of Australia, usually in the winter season, and can have serious consequences with extreme rainfall, winds and waves. Such lows then generally move south-eastwards and affect New Zealand. Dowdy et al. (2013) found that such lows reduced in frequency by 30% (mainly in winter) between the late 20th century and the late 21st century.

Information on possible changes to New Zealand storminess and extremes can be found in Mullan et al. (2011) (based on AR4 global models). Evidence is presented that suggests some increase in storm intensity, small-scale wind extremes and thunderstorms is likely to occur in the New Zealand region.

4 Conclusions

The climate is changing. It is internationally accepted that further changes will result from increasing amounts of greenhouse gases in the atmosphere. In addition, the climate will also vary from year to year and decade to decade owing to natural processes such as El Niño. Climate change effects over the next decades are predictable with some certainty, and will vary from place to place. This report has shown the future projections for some of these changes for the Hawke's Bay Region

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SLMACC Applied Adaptation Pathways

System map articulating regional primary industries in Hawke's Bay

June 2019

Report by:

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Discuss.

Understand.

Act.

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1 Introduction

The purpose of this report is to present and discuss a system map that has been informed by stakeholder interactions in SLMACC Project 405220, on regional adaptation pathways for Hawke's Bay primary industries. The project is led by Manaaki Whenua | Landcare Research (MWLR) with funding from the Ministry for Primary Industries (MPI) through the Sustainable Land Management and Climate Change program (SLMACC).

Climate change is expected to adversely affect primary industries, compounding existing vulnerabilities, creating new ones and confounding decision-making. Although our understanding of potential impacts has improved, the capacity for identifying, evaluating and comparing adaptation options remains limited by poor integration of social and economic studies with biophysical impact assessments and an emphasis on individuals' adaptive strategies.

Researchers have worked with land managers and other primary sector stakeholders over the past two years. This has resulted in a more integrated vulnerability assessment for Hawke's Bay, particularly the case study areas of Wairoa and Central Hawke's Bay. This provides insight to adaptation pathways capable of supporting robust decision-making at multiple scales and across diverse sectors.

Systems thinking methodologies were identified as an approach that could bring together a range of insights sourced across various stakeholder workshops, and present it in an accessible and relevant manner

2 Contributing data and methodology

The information that underpins this system map was generated from multiple sources, using mixed methods and on-going interactions with stakeholders.

The primary source for the system map were results from Workshops 1 and 2 with stakeholders and end users in Wairoa (Northern Hawke's Bay) and Hastings (Central Hawke's Bay). The aim of the workshop was to obtain a collective understanding of how the current system operates and what challenges exist; and second, highlight how climate change may affect this system and what opportunities and challenges may arise.

To achieve the objectives, participants developed/drew a 'rich picture' illustrating how the various productive sectors currently function in the area. The resulting pictures (see Manaaki Whenua | Landcare Research (2018)) have been collated into the system map contained within by the lead author, and supplemented with additional information from subsequent workshops and discussions with the second author.

The technical term a system map is a causal-loop diagram (CLD), but the term 'system map' is used here for ease of reference.

3 What is systems thinking?

The world that we live in is a highly interconnected place of causality and effect. The work of policy development often seeks to respond to undesirable behaviour or patterns being experienced in our natural environment and therefore seeks to influence these causes, to alter or improve the desired behaviour.

Systems thinking is a conceptual framework and set of tools that have been developed to help make these patterns of interconnectedness clearer (Senge, 1990)⁶. They help us understand the structure of a set of various interacting factors that present in behaviour we are trying to understand. This helps us better understand which parts of a system are having the most influence on a certain behaviour and allow us to identify areas of leverage to influence this.

'Systems Thinking' is a name often applied to a range of approaching to thinking about issues holistically. One of these approaches is academic discipline of 'System Dynamics'. System Dynamics originated from the Sloan School of Management at the Massachusetts Institute of Technology, Cambridge, Massachusetts in the late 1960's. The term systems thinking as it is used in this report refers to the concepts articulated by the discipline of System Dynamics (Sterman, 2000).

4 Understanding feedback loops – the fundamentals of systems maps

This section outlines the important fundamentals of systems mapping – balancing loops and how they are correctly annotated. The goal/gap structure is also explained, as this is used to describe how different loops come to operate with different dominance at different times.

4.1 Balancing and reinforcing loops.

Systems thinking is especially interested in systems where loops of causality are identified – these are called *feedback loops*. There are two types of feedback loops, *balancing* and *reinforcing* (Senge, 1990).

In a *reinforcing feedback loop*, the direction of influence (i.e. same or opposite) provided by one factor to another will transfer around the loop and influence back on the originating factor in the *same* direction. This has the effect of *reinforcing* the direction of the original influence, and any change will build on itself and amplify.

Reinforcing loops are what drive *growth or decline* within a system.

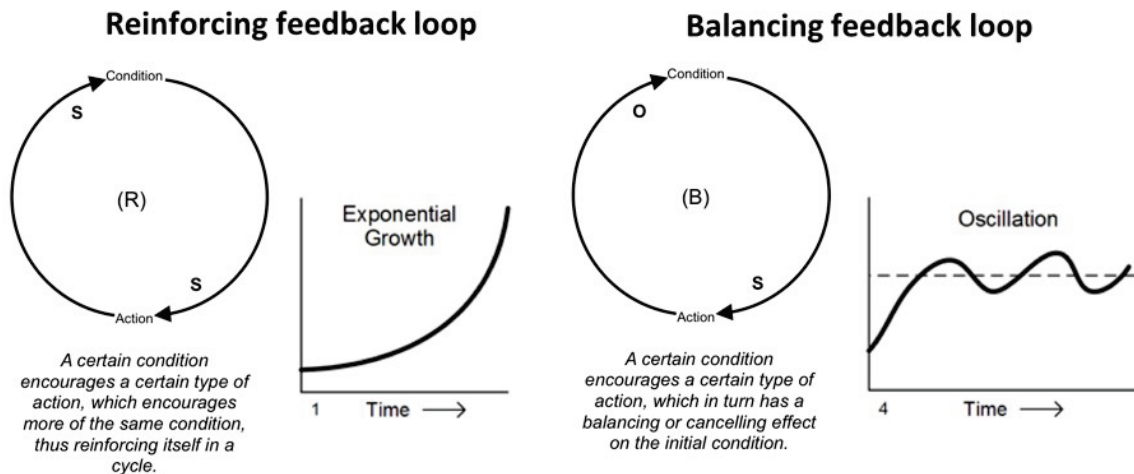
In a *balancing feedback loop*, the direction of influence (i.e. same or opposite) provided by one factor to another will transfer around the loop through that one factor (or series of factors) and influence back on the originating factor in the *opposite* direction. This has the effect of *balancing out* the direction of the original influence.

⁶ For a detailed introduction to the concepts of Systems Thinking, the reader is referred to *The Fifth Discipline – the art and practice of the learning organisation* by Peter Senge (1990) as an accessible introduction.

Balancing loops are what create *control, restraint or resistance* within a system.

The two types of feedback loop are described in Figure 1.

Figure 1. *The two types of feedback loops*



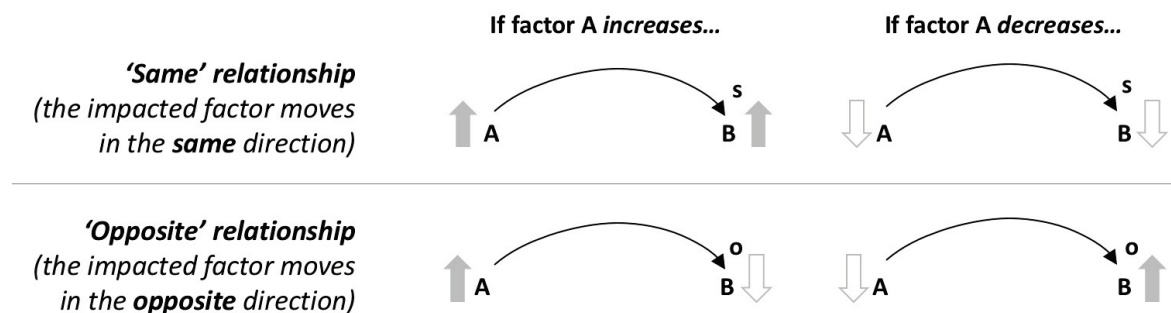
Adapted from Senge (1990) & Ford (2010)

Feedback loops can be made up of more than two variables and can be mapped together to form a system map, or a causal loop diagram. The way that these interact in a wider system helps provide insight into the consequential impacts on systems.

4.2 Annotating loops

The arrows between variables are annotated with either an 's' or an 'o'. These stand for 'same' or 'opposite' and refer to the corresponding direction of change that a change in the level of the first variable, will have on the level of the second variable. An example of this is shown in Figure 2.

Figure 2 *How arrows are labelled in system maps*



Adapted from Sterman (2000)

If there is a distinguishable *delay* between a change in one factor and its impact on another, this is annotated as a *double line crossing the arrow*. An example of this is shown in Figure 3

Figure 3. How delays are annotated on arrows



4.3 Goals and gaps – driving individual loop dominance.

Realising that multiple loops are operating within a system is the first useful insight of systems thinking. A further useful insight is understanding that not all loops operate at the same strength all of the time. Different loops can dominate the dynamic of a system at different times. For example, a system might be dominated by a period of growth, but when some kind of physical limit is approached (e.g. the available space in a pond for algae to grow) a balancing loop will start to dominate, therefore slowing the rate of growth.

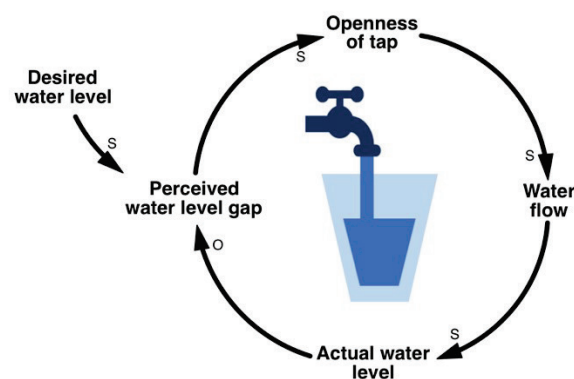
In the system maps that follow, the useful 'goal/gap' structure is sometimes used. This is a node that combines both a desired (or 'goal') level of something, with an actual level of something. This variable, which both these other variables connect into, describes the 'gap' between the desired and actual levels.

The higher the desired level and the lower the actual level, **the greater the 'gap'**. This may lead to stronger activity to increase the actual level, or to reduce the desired level – effectively any activity that seeks to narrow the gap between desired and actual.

The lower the desired level and the higher the actual, **the lower the 'gap'**. This may lead to a decreased activity to increase the actual level, as it is near its goal. Conversely, it may also lead to an increase in the desired level, for as the goal is approached or reached this may lead to an upward review of whatever goal was in place.

The 'goal/gap' mechanism can be recognised throughout the system maps. An example is shown in Figure 4.

Figure 4. Example of a 'goal/gap' structure in a system map



Adapted from Senge (1990)

5 Preface to the descriptions of the system map

Systems mapping, by definition and necessity, is generally represented at a reasonably aggregated (or summarised) level. This is because the intent of systems mapping is to best describe the *broad inter-relationships* within a system and how they generate the *behaviour* (the dynamics) of the system. This is different to other approaches that undertaken highly detailed analyses of a certain part of the system, in order to better understand that particular part. Systems mapping techniques are scalable, so they may also be used at a detailed level of a system. This is determined by the particular interests of the researcher.

The systems map contained within this report is intended as a helpful *companion* to other, more detailed, analyses of primary production in Hawke's Bay.

The following sections describe the system map in detail. Broadly an agnostic tone has been taken to the primary production described, as describing a broad range of primary production is the main intent. Yet any particular industry or sector can read this map from their own perspective.

Reference is also made throughout the map to various *capital stocks*. These reflect the capitals outlined in the New Zealand Treasury's *Living Standards Framework* (LSF) (NZ Treasury, 2018). This is an attempt to align the system mapping done here, and potentially future research, with the LSF. These capitals are shown as **boxed variables on the map**. Each of these capitals could be the subject of their own system map, so reference to them is necessarily aggregated here and may be developed further in future research.

The map has been developed as an 'archetypical' system for either case study area. It is considered that the core influences and tensions represented in these maps are shared across the two case study areas of Wairoa and Central Hawke's Bay.

6 Description of system map

At its most fundamental level, the activities occurring in the primary industries in the case study areas, seek a return on investment from a particular type of landuse. This productive landuse occurs within the natural capital constraints of the region. At the same time this landuse spurs investment in – and is constrained by the levels of – financial & physical capital; human capital; and social capital.

The level of primary production is therefore the main focus of the system map. The initial feedback loops that are described therefore, emanate from there. The feedback loops increase in number as they travel further from the main factor of *Primary production*.

The numbering of the feedback loops is NOT an indication of the importance of that loop. It is merely a numerical identifier. When variables are described in the text they are *italicised*.

This section builds up the system map piece by piece. The overall system map is shown in Figure 13.

6.1 Profit, capital investment and capital dependency (R1, B8, R2, & R3A/B)

The core of the system map is based around the reinforcing loops relating *Primary Production* to *profit* and investment in *physical capital*. These loops show the obvious connection that increased *primary production* generally leads to increased *profit*. In turn, greater *profits* generally result in increased amount of *land in production*, which in turn leads to increased *primary production*. This forms a reinforcing feedback loop (**feedback loop R1**).

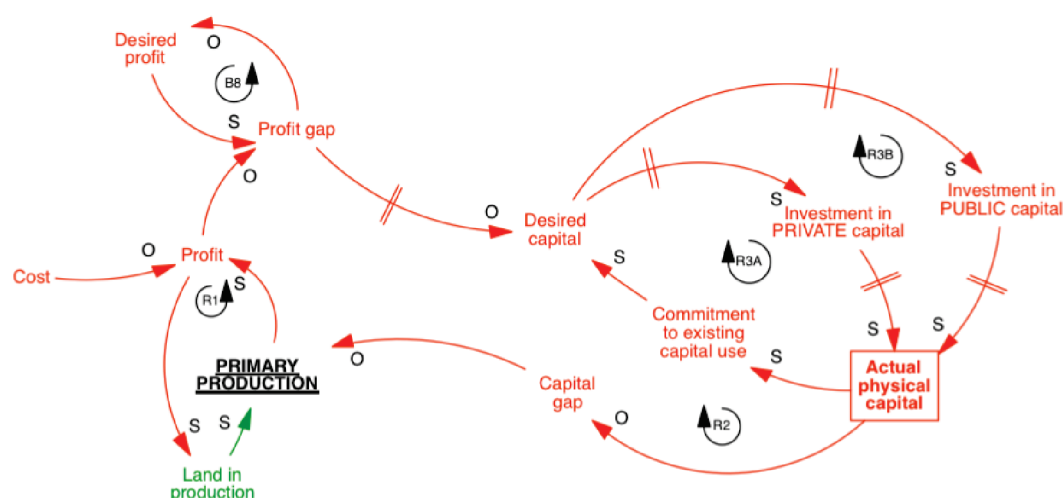
Cost is an input to *profit*, so this is shown linked to that as an opposite relationship – the greater the cost, the lower the profit.

The relationship between *desired profit* and the *profit gap* is the first of many balancing loops that are described in this summary. Remember, balancing loops are the source of control, restraint and resistance in systems, so they are very important. Without balancing loops to keep them in check, reinforcing loops will operate out of control. So, both are required to describe the types of behaviours that we observe within a system.

What this loop describes is the relationship between *desired profit* and the *profit gap* – which is itself the difference between *desired profit* and *profit*. An increase in *profit* will decrease the gap between *desired profit* and *profit* – In other words you are approaching or achieving your goal! As a consequence, if this gap is low (i.e. you are meeting your profits or targets), then this is likely to encourage an increase in the *desired profit* (**feedback loop B8**). In turn this will increase the *profit gap*, which, if not closed, may temper *desired profit* downwards once again.

Generally, a decrease in the *profit gap* (i.e. you are reaching your targets) leads, over time (delay), to an increase in the level of *desired capital*, as meeting your goals spurs greater desired further profits and more, or more efficient, production (i.e. capital) is seen as the pathway to achieve this. The desire for more capital will eventually (delay) be one of the inputs to an actual *investment in capital*, which in turn (once built - delay) leads to a greater level of *actual physical capital* (**feedback loop R2**). Capital can be either PUBLIC or PRIVATE, so two branches of this feedback loop are represented.

Figure 5. Profit, capital investment and capital dependency (R1, B8, R2 & R3A/B)



At the same time that R2 is operating, any increase in the physical capital relating to any particular landuse (e.g. milking shed, packing plant, mill etc) also increases the commitment that a landowner has to that particular landuse. This reflects the sunk costs represented by all previous investments in capital and increases the *commitment to existing capital use*. This commitment to the same landuse or infrastructure, further increases the *desired capital* for that landuse or infrastructure, creating another reinforcing loop (**feedback loop R3A/B**). This loop is also represented with two pathways, one for private capital and one for public.

These three feedback loops (and the influence on them from desired profit) broadly describe the important relationship between primary production and profit. This fuels more *land in production* and the increases the desire for capital and subsequent investment in capital. It also explains the path dependency to that existing landuse that arises from these influences (via the commitment to existing capital use loop).

6.2 Financial capital and the gap between desired and actual capital (R4 & B1)

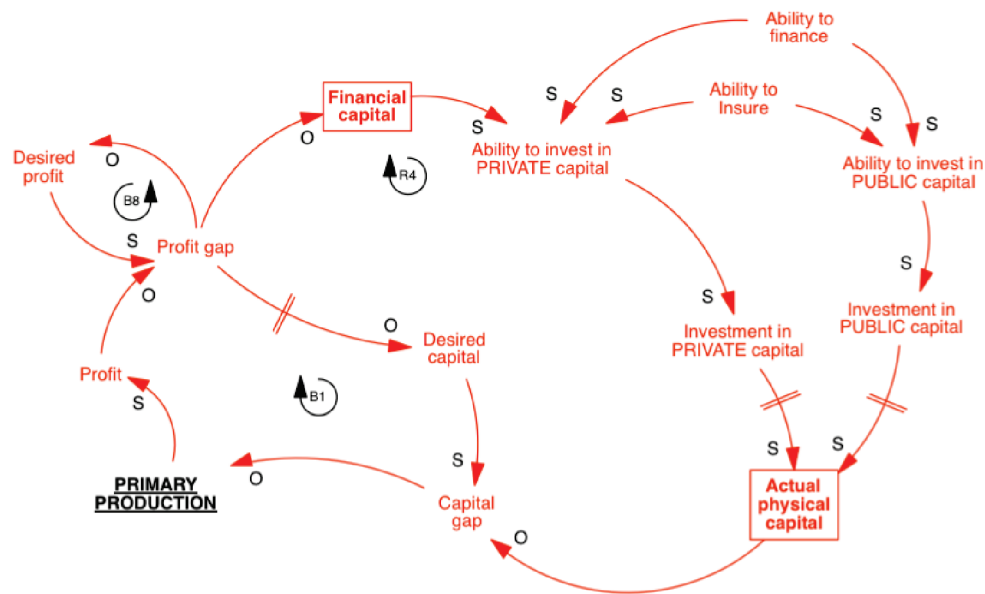
The previous loops described the desire for capital investment and the subsequent capital dependency that arises from it. These loops describe the reinforcing relationship of primary production with financial capital; and the balancing effect of the relationship of the gap between desired capital and actual capital.

As profit increases, it also increases the *financial capital* of any particular landowner. They are likely to have better cashflow and a lower debt to equity ratio. In turn, this increases their *ability to invest in PRIVATE capital*. The *ability to invest in PUBLIC capital* is also shown here, accounting for the significant capital that is provided by municipal or public service providers.

The previous section described how the desire for capital was the other input to a decision to invest, thus any investment decision is dependent on the desire for the capital it, and the ability to make the investment. Any new investment (either public or private) will lead (after a delay to implement it) to additional *actual physical capital*. In turn, more capital will decrease the gap between the amount that is desired (that is – you are achieving your goals!), and consequently, because capital goals are being met, primary production will increase (**feedback loop R4**).

It is important to note that the *ability to finance* and the *ability to insure* affect both a private producers ability to invest, as well as a municipality or public service provider. This is captured by the two nodes of *ability to finance* and *ability to insure* influencing both public and private capital.

Figure 6. Financial capital and the gap between desired and actual capital (R4 & B1)

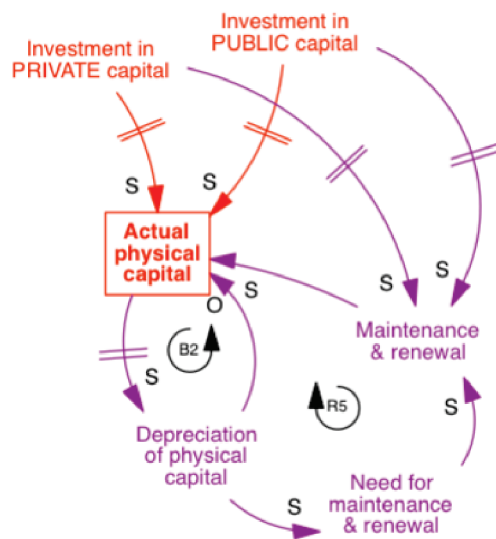


As described in feedback loop R2, as *primary production* increases (or decreases) so too does *profit*, reducing (or increasing) the *profit gap*, which increases (or decreases) the *desired capital*. *Desired capital* also influences the upper part of the *capital gap* – that is, the level of *desired capital* forms the upper part of the goal/gap equation relating to the physical capital. The greater the *desired capital*, the higher the goal, therefore the more likely it will be that there remains a gap to close. Hence this relationship is a *same* relationship (they both change in the same direction). As this gap *increases*, there is *less primary production* in relation to the amount that is desired, so the anticipated *primary production* is lower than expected, which flows on into lower *profits* than expected (**feedback loop B1**). In turn, this continues to flow round the loop back into *desired capital* again. If *profits* remain low, then it is likely to reduce the amount of *desired capital*, thus reducing the gap again. This act of ‘balancing’ in a balancing loop is what tempers out the positive or negative reinforcing activity of a reinforcing loop.

6.3 Decay, maintenance and renewals (B2, R5 & R6)

Regardless of how much *actual physical capital* a primary producer may have, it will inevitably suffer from the effects of ageing and decay. This will be at different rates for different sorts of capital, and due to different types of effects, but it will happen as surely as night follows day.

Figure 7. Decay, maintenance & renewals (B2, R5 & R6)



The relationship between *actual physical capital* and *decay of physical capital* is a same relationship. This does not mean that the more capital there is the *faster* it decays. This system map is agnostic about the *rate* of decay and assumes it occurs at a constant rate, regardless of the quantity.

This relationship is a *same* relationship because, even if the rate of decay is constant, the more *actual physical capital* that a farm or an industry has, the more decay there will be to deal with. In turn, a greater amount of decay in capital will reduce the quality of the capital, perhaps affecting its ability to perform to expectations. This is another ‘balancing’ feedback loop (**feedback loop B2**).

The more decay occurs, the more *maintenance & renewals* will be required. As a result, maintenance and renewals ‘replenishes’ the *actual physical capital*. This is not necessarily with additional levels of capital (that comes from investment in new capital), rather, ensures that it remains of good quality, is able to last longer and continue to perform to expectations (**feedback loop R5**).

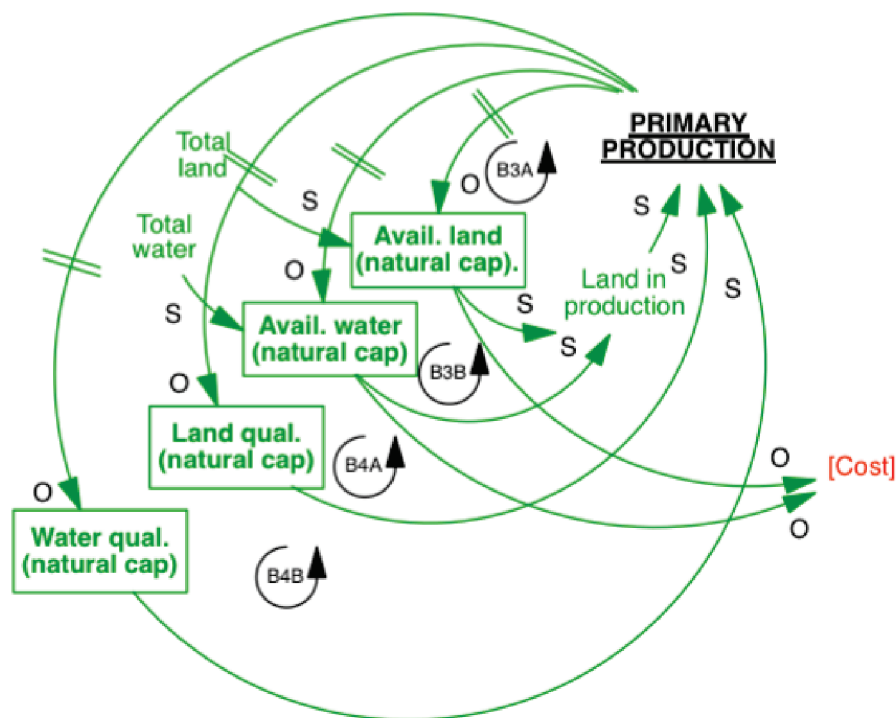
So long as both these two loops operate at a rate that is consistent with each other – that is, maintenance is done at a rate that is consistent with decay – then the amount of *actual physical capital* will remain at a constant amount. If the decay loop was to dominate then the actual physical capital will reduce in quality and/or quantity. This decay loop is one of the loops identified as a place in the system where Climate Change will have an impact, for more information on this see section 6.5.3.

6.4 Natural capital (B3A/B & B4A/4B)

The loops described to date have focused on the very necessary inputs of *financial* and *physical (built) capital* to *primary production*. While these are important there is another, absolutely critical, capital that supports primary production – *natural capital*.

Natural capital includes land and soil, water, plants, animals (NZ Treasury, 2018). In this system map these variables are named *available land*, *available water*, *land quality* and *water quality*, representing the quantity and quality split of land and water. The plant or animal capital that are obviously produced by these systems are not named but are assumed in the operation of the system themselves. Omitting these plants or animals may at first seem illogical. Yet it is a deliberate omission to ensure that the system map is focused on the underlying farm production landscape and systems, and their relevant *financial*, *physical* and *natural capitals*, which support whatever is being produced – be that plant or animal. These feedback loops are described below.

Figure 8. Natural capital (summary)



The greater the *available land* or *available water*, then the larger the amount of *land in production*, in turn increasing the amount of *primary production*. Yet both land and water are a finite resource, so the *more* land or water that is used for *primary production*, then the less *available land or water* there will be to be converted to productive use. Consequently, this is a balancing loop – it will cancel itself out over time (**feedback loops B3A and B3B**).

The less available land and water there is, the greater the *cost* will be to acquire these, thus increasing the *cost* of production. The *cost* node shown here is the same as that shown elsewhere in the diagram. It is simply replicated twice to avoid messy arrows being drawn all over the diagram. This mirrored *cost* node also feeds directly in to *profit*, as shown elsewhere in the system map.

Also, the very real constrain of the actual amount of land and water has also been included (*total land* and *total water*). This is important for water in particular, as the constrained amount of this resource – however much that will be under climate change – will be critical to how the system operates in the future.

Land quality and *water quality* form similar balancing loops. All other things being equal, the better the *land quality* and *water quality* then the more the *primary production*. Yet an increase in this primary production will, over time (delay), have some kind of impact on the *land quality* and *water quality*. Different land uses will have different types impacts with different delays in presenting, but this map acknowledges that they generally all have some kind of impact (**feedback loops B4A & B4B**).

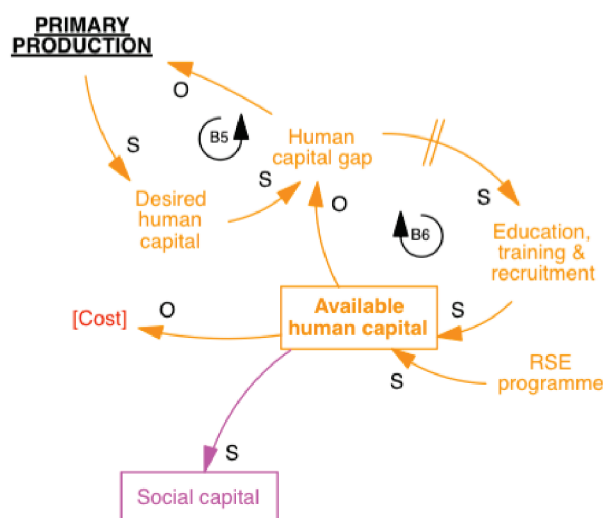
6.5 Human capital (B5 & B6)

In addition to the *natural*, *financial* and *physical capitals* that support *primary production*, the other critical supporting capital is *human capital*. *Human capital* is best articulated as the things that enable individuals to participate fully in society. This is people's skills, knowledge their mental and physical health (NZ Treasury, 2018).

The *human capital* that was considered most relevant to *primary production* is predominantly the skills and knowledge required to work in an industry.

The system map describes how an increased level of *primary production* increases the *desired human capital* – that is, the demand for skilled labour. This is the upper part of the goal/gap structure, in that the greater the demand for skilled labour, the greater the 'goal'. If the *desired* level increases, then the *human capital gap* is also increased, which in turn means that there is a shortage and not as much *primary production* can be supported (**balancing loop B5**). This highlights the constraining (balancing) force that labour supply has on *primary production*.

Figure 9. Human capital (B5 & B6) As the *Human capital gap* increases, this will encourage



(over time – a delay) an increase in *education, training & recruitment* (sometimes from outside the region) of skilled labour will occur. This will increase the *available human capital*, which in turn reduces the *human capital gap*. In other words, your human capital goals are being met!

The more your human capital goals are met (the *lower the human capital gap*), the better able you are to support/increase *primary production* (**feedback loop B6**).

Social capital is defined as the norms and values that underpin society (e.g. law, government, etc) (NZ Treasury, 2018). While this is not fully explored in this system map it is noted that *human capital* (i.e. the capital of the individual) has a same relationship with *social capital* (i.e. the capital of the collective).

6.5.1 Market drivers and quality of production practices (B7, R7A/B & R8)

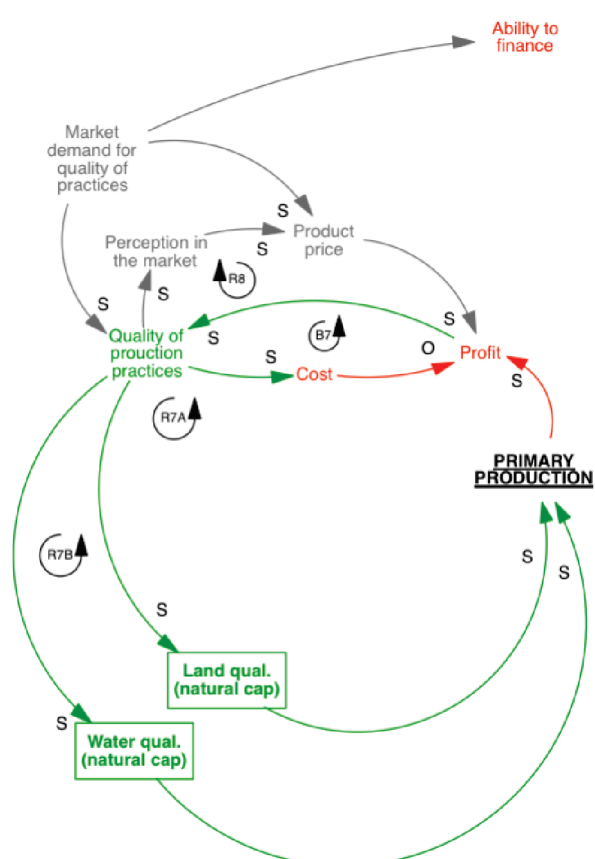
The previous sections have described the various loops where *financial & physical, natural* and *human capital* play a central role. This section describes loops where market forces influence the broader system, impacting factors from several of these loops.

Section 6.4 described how the main interactions between *primary production* and *natural capital* were balancing loops. In these primary production systems, an important additional influence on *land* and *water quality* is the *quality of the production practices*. In general terms, an increase in *profits* increase enables the *quality of production practices* to be increased,

which increases the *quality of land and water*. In turn this improved quality increases the *primary production* which in turn increases *profits*. These influences form virtuous reinforcing feedback loops, ones that continues to improve on themselves (**feedback loops R7A & R7B**).

At the same time however, some of this cycle is countered by the increasing *costs* that are realised due to the increased *quality of production practices*. The relationship between *production practices* and *costs* forms a balancing feedback loop where an increase in the *quality of production practices* leads to increased *costs*, which reduces *profit*, which in turn leaves less money available to invest in *quality of productive practices* (**feedback loop B7**).

Figure 10. Market drivers and quality of production practices (B7, R7A/B & R8)



Yet, another important feedback loop at play here is the relationship with how the *quality of production practices* can improve the *perception in the market* of the produce, which can increase the *product price*, which in turn increases *profit*, which allows more money to be invested in the *quality of production practices* (**feedback loop R8**).

Any of these loops may dominate at different times and the actual quality of land and profit realised will be a function of these interacting forces.

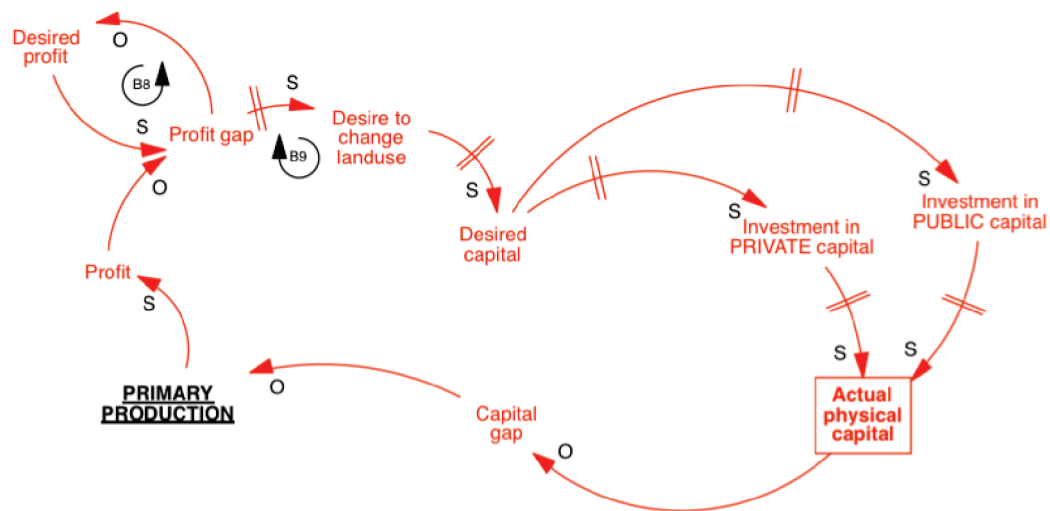
In particular, the power of market drivers should not be underestimated. Although the *market demand for quality of practices* is not directly part of this feedback loop, it influences two key variables in it – *quality of production practices* and *product price*. The higher the *market demand for quality of practices* then the higher the *quality of production practices*, and the higher the *product price*.

It should also be noted that the *market demand for quality of practices* also influences the *ability to finance* the production activity. This is because the more that the market demands quality practices, the more finance institutions will want to see that these are the type of practices that producers are investing in – in order to ensure their own return on investment. This therefore influences the financial capital and investment loops (R4 – see section 6.2).

6.5.2 Desire to change landuse (B9)

This section describes the final individual loop that is described in the system map. This is the *desire to change landuse* loop. This is a loop that acts counter to the *commitment to existing capital use* loop (R3).

This loop is likely to lie weak (or dormant) most of the time. Yet it is more likely to become active the longer *profit* remains low. If *profit* remains unsustainably low for long enough, this will eventually (after a delay) increase the *desire to change land use* sufficiently that a decision to change land use may be made. When this occurs, there is a strong impact on the level of *desired capital*, the *investment in capital* and eventually the *actual physical capital* (all with delays). This is a balancing loop (**feedback loop B9**) that eventually will lead to the increasing of profits from a new land use. However this will take time and this loop will need to operate for some time before any path dependency that results from this emerges.



For example, given the lack of any of the new type of capital that may be required for new landuse (e.g. a bottling plant instead of stock yards), there will need to be significant investment in capital to make up the shortfall. A large *capital gap* is likely to remain for a while, thus ensuring *primary production* and *profit* are low for some time, before the *actual physical capital* begins to catch up and *production* and *profit* rise.

6.5.3 Where Climate Change will impact the system

It may also do this by increasing the rate of decay for physical infrastructure, from both the impacts of storm events, and through the impact that a possible changing to the ambient climatic conditions may have on the standard rate of decay. For example, sea level rise may mean assets buried in the ground decay faster.

Secondly, Natural capital such as land and water are likely to be dramatically affected. These are the foundation on which primary production is based and it is likely that their quality may be impacted by Climate Change.

For example, extreme weather events may impact the physical elements of land or water. Some sections of land may be washed away or inundated, while the route of water courses may be altered, affecting their proximity to productive land. Further, the quality of the natural capital may be eroded further through the contamination of aquifers through salt water intrusion or other impacts.

Some natural capital may experience changes in ambient conditions dramatic enough to render them no longer suitable for the landuse for which they have traditionally been used. For instance, changes in the water retention of the soil, the temperature or the humidity.

Thirdly, Climate Change is expected to significantly impact farmers ability to both *finance* and *insure* their capital. *Primary production* in New Zealand is heavily reliant on national and international finance and insurance markets and New Zealand assets may only form part of the risk exposure for these institutions. So, a change in the perception of risk in these markets is likely to have a significant impact on both producer's *ability to finance* and *ability to insure*.

For a more detailed discussion of the impacts of climate change on the risks associated with financing and insurance, see Connolly (2018) and Lawrence et al. (2018).

Figure 12 ***Summary system map – Where Climate Change impacts the system.***



6.5.4 Climate Change adaptive capacity

The final addition to the system map is to identify what the major contributors to *Climate Change adaptive capacity*. In summary, adaptive capacity to Climate Change is a function of the four major capitals: *Financial and physical capital*; *natural capital*; *human capital*; and *social capital*.

This map demonstrates how *physical* and *natural capital* are likely to be adversely affected by *Climate Change impacts*, while also being two (obvious) inputs to *Climate Change adaptive capacity*. This will mean that adaptive capacity in these areas is likely to be more adversely affected than other areas.

With the natural capital nodes (i.e. *land quality* and *water quality*), both *Climate Change impacts* and the *climate change adaptive capacity* are in close proximity. Like many other areas in the system map one could be tempted to connect these into a loop. For example, some might argue that increased *climate change impacts* will decrease *land* and *water quality*, which in turn will decrease *climate change adaptive capacity*, which in turn will make *climate change impacts* worse. However, this is not the case.

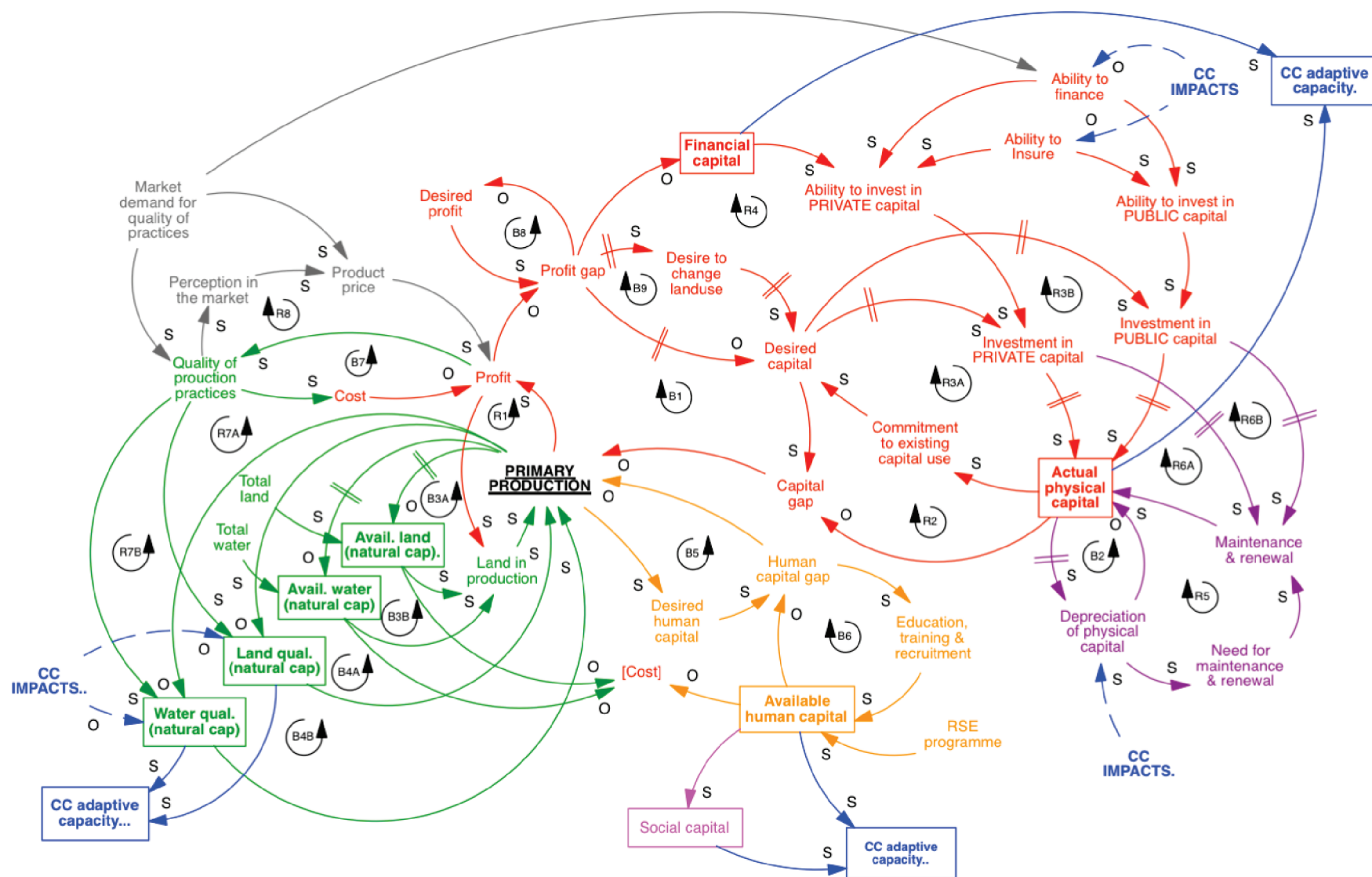
Climate Change adaptive capacity does not lessen the physical *impacts of climate change*. Rather it increases the way in which these can be avoided or mitigated. If any loop was to be drawn, it should probably be to *quality of production practices*.

For *financial* and *physical capital* these impacts are separated by greater distance (within the system). Yet the impacts on *physical capital* through a reduced *ability to finance* and *ability to insure*, as well as an increase in the *decay of physical capital* will directly impact an industry or community's *Climate Change adaptive capacity*. The link through *financial capital* will be when *climate change impacts* flow through the system through lower *primary production* and lower *profit*, thus reducing *financial capital*.

Human capital is not directly impacted by *climate change*. Although there may be some impact on people's health, the individual knowledge and skills that have are likely to remain the same and be useful contributors to *Climate Change adaptive capacity*.

Likewise, *social capital* is not directly impacted by Climate Change. In fact, it is not strongly represented in this model at all. This is not surprising given the focus of the data gathering on the *natural* and *physical capital* required for primary production. Yet *social capital* will be a significant contributor to *Climate Change adaptive capacity*, highlighting that the adaptation of these systems will draw very heavily on capital stocks that are not necessarily intimately linked into the system. This could be a fruitful area for further future research.

Figure 13. Summary system map – Influences of Climate Change adaptive capacity.



7 Summary and conclusion

This report presents and describes a causal-loop diagram (or system map) of the archetypical primary production systems operating in two case study areas in the Hawke's Bay.

These were built by the lead author from data collected by the second author via workshops with stakeholders in Wairoa and Central Hawke's Bay. 'Rich picture' techniques were used to elicit information from workshop participants. The system map described here is believed to be a good summary representation of the many inter-connected influences and tensions operating within these systems.

The mapping of Climate Change impacts onto this system, as well as the mapping of how the system influences Climate Change adaptive capacity, makes this a useful tool for describing understanding and exploring applied adaptation pathways.

The system map is, by necessity and design, an aggregated approach to understanding such complexity. Yet it provides a useful tool for exploring all of these inter-connections in an accessible and communicable way. The system map in this report is intended to be applied to any primary production industry, regardless of the focus or starting conditions, to help articulate where climate will impact and how adaptation may be applied or approached.

These maps were developed with constrained time. Given more time and potentially greater stakeholder/industry involvement in the future, this system map may be able to be developed to a greater extent in the future.

8 References

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