Supporting Land Use Adaption for a Climate Changed Future

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Executive Summary

Farmers deal with climate and weather on a daily basis. They have developed farm systems that accommodate climatic variations, such as extended periods of dry or flood events. These systems are designed for variation, to a point, depending on the local experience and perceived likelihood of an extreme climatic event occurring. Farms typically have the capacity to work with nature's 'normal' climatic variance. However, there is clear evidence that the climate is changing. This change is pushing the boundaries of what is normal, known, and expected, and farmers need to adjust their businesses accordingly.

The *Supporting Land Use Adaption for a Climate Changed Future* project aims to improve farmers' knowledge of a changing climate and enhance their ability to apply that knowledge to action on-farm. It identifies how industry can engage more effectively with farmers on the issue of a changing climate.

The project commissioned The Agribusiness Group (an independent agricultural consultancy firm) to review existing climate change research 'through the eyes of a farmer'. The desktop review investigated the climate data available, the way it is presented, who is involved in the research, the range of decision support tools available, and the impact of asset life cycles. The review proposed several changes to the approach for climate change messaging which would improve farmer engagement with the topic.

Following on from the desktop review, several focus groups were carried out. These discussions explored farmer attitudes toward climate change. Generally, farmers feel they are continually adapting and changing their businesses and adapting to a changing climate is one of many issues they respond to. To them, adaption makes logical business sense.

For farmers, it is not a question of whether to adapt or not, but rather what to adapt to and how.

Four themes emerged, 'meaningful information', 'effective channels', 'adoption support', and 'critical farm infrastructure'. These themes identify where support for farmers would enhance adaptation to a changing climate.

A significant challenge identified is how climate change information is presented to farmers for it to be meaningful to them. The meaningfulness appears to be lost in the complexity of the climate change models and how the data and information from these models are communicated. Furthermore, farmers emphasised the importance of using language and data that can be applied on-farm. The desktop review discussed the value of providing climate change data at a district scale

which would enhance farmers' ability to explore on-farm application of the data. Farmers who had tried alternative farm practices and land uses, highlighted that there are often gaps in technical information which, if addressed, would aid in adaptive responses to climate issues.

Farmers are very aware of the sources of climate change information, and a farmer's propensity to act is significantly influenced by their view of the credibility of those sources. High-level climate change research is undertaken predominantly by Crown Research Institutes (CRI) with more applied research and practice change support provided by farmer levy organisations and other organisations such as irrigation companies. CRI's are well respected and the irrigation companies are described by farmers as trusted sources, whereas the levy organisations are more variable in how they are perceived. Both the desktop review and the farmers identified the value of greater interaction between researchers and farmers when designing and delivering climate change research to maximize the on-farm potential of the research.

Adoption support is identified as an important enabler for change in both the desktop review and by farmers themselves. Citing their preference for peer-to-peer learning, farmers described their elevated level of trust in farmer colleagues, while the desktop review notes greater confidence for change arises from farmers working together. Farmers detailed the value of being able to see new or innovative practices operating on-farm and witnessing the innovation in place helps them to understand the effects of change on other parts of the farm system.

When considering land-use adaption, both the renewal of aging dairy sheds and the water consent renewal process may disrupt the normal pattern of land-use across the district. Specifically, dairy farming and irrigated agriculture are of particular significance because of their scale (irrigated land covers 220,000 ha or 2/3rds of the Ashburton plains) and their economic contribution (dairy farming contributes $1.129B to the local economy).

An analysis of building consents suggests that 40% of all milking sheds in the district will be at the end of their economic working life from 2040 – 2048. The significance of this is that renewing the dairy shed is a major farm investment that largely determines the use of land for a long time on from the investment. An analysis of the timing of water consent expiries indicate that over 78% of water consents will be up for renewal from 2030 – 2040. Furthermore, it is likely that more than 78% of the irrigated land will be affected because the major irrigation company consents which cover 110,000ha, will fall due in this period. The significance of this is that access to a reliable source of irrigation water is a major driver of land use, profitability and productivity.

The asset renewal and water use re-consenting process do not necessarily represent land-use change per se, but the period of 2035 – 2045 will require a large cross section of farmers to make a conscious land use decision, whether it is to change or maintain the land use status quo.

Farmers are engaged with a changing climate. To support their adaption response, they need to understand how a changing climate relates to their farm, how the climate will be different from what they know and have experienced, and what it means for their business. With language and data that is meaningful, farmers will engage with research that they perceive is most relevant to them. With the right support, they will confidently explore and test new ideas with their peers and identify practical solutions to use on-farm. An approach which incorporates all of these elements will enable meaningful and effective change and will support resilient businesses for a climate changed future.

Introduction

Weather and the climate are topics close to a farmer's heart. They can create opportunities and present challenges for all farming. A deep understanding of climate and weather is fundamental to successful farming, with farmers basing critical business decisions on many years of observing and experiencing climate first-hand.

As climate changes, farmers need to adapt.

From small tweaks to existing practices, to wholesale land-use change, climate adaption spans a continuum of change. Determining what land-use response is appropriate, ultimately rests with the people at the 'coal face', the farmers. They need to be supported with quality research and science to make timely, well-informed decisions.

By working together, farmers supported by industry and the scientific community can understand what our climate future will look like and what to do about it. This will enable farmers to minimise risk and utilise opportunities emerging through a changing climate.

Background

The *Supporting Land Use Adaption for a Climate Changed Future* project aims to improve farmers' knowledge of climate change and enhance their ability to translate knowledge into action on-farm. This action will range from refinements to the farm system to broad-scale land-use change, which is otherwise known as climate change adaption. Adaption at a farm level must be driven by farmers as farmers are best placed to respond practically to a changing climate. Critically, adaption is dependent on the farmer's ability to make well-informed and knowledgeable decisions, and put that knowledge into practice.

The project aims to understand farmer's perspectives on climate change so industry can fine-tune their research, communications, and extension initiatives to better support farmers to adapt. Tailoring climate change messaging to farmers will improve their engagement and help them identify opportunities and risks for their businesses. This will support informed decision-making, accelerating on-farm climate change adaption.

Numerous parties are active in the climate change research space; however, it is unclear to what extent farmers are acting on this research. Anecdotally, farmers do not appear to be strongly engaged with the topic, which is assumed to lead to low levels of adaption. In contrast to this view, farmers have a vested interest in understanding climate change as their whole business model is based on climate. It makes good business sense to understand the topic so they can future-proof their business. If farmers are not strongly engaged, it may be because of barriers such as what and how climate change is communicated, rather than indifference about the topic.

A recent report, 'Barriers to Diversification[1]' (2020) identifies several factors which drive a farmer's appetite for changing the use of their land. These factors are identified as; biophysical, economic, technological, individual, societal, and regulatory factors. Climate change, which incorporates the biophysical, societal, and regulatory factors presents both an opportunity and threat to the whole farm system. If farmers act with confidence, they can protect and future-proof their business. If the opportunities and risks are well understood and acted upon in a timely way, a changing climate may provide a farm business with the opportunity to transition to new or alternative land uses that deliver positive environmental, financial, social, and cultural outcomes.

[1] Hunt, J., Journeaux, P., & Allen, J. (2020). Barriers to Diversification. Report to Our Land and Water – National Science Challenge.

The Project Approach

The project was approached in two parts. Firstly, a desktop review of existing climate change research and an analysis of critical farm infrastructure were undertaken. This was followed by several focus groups which gathered farmers' perspectives on climate change.

1. Desktop review of climate change research and critical farm infrastructure:

   Existing climate change research was reviewed 'through the eyes of a farmer by farm business consultants, The Agribusiness Group. They were engaged as they work closely with farmers as farm consultants and farmer group facilitators, and have experience in industry climate change initiatives. For the desktop review, they considered a range of factors such as the breadth of climate change work currently available, which organisations are involved, and the decision tools available for farmers to use. The purpose of the review was to identify gaps in climate change information and understand if there are barriers that could be addressed to enhance engagement with farmers.

   The review also analysed the economic life of key assets such as dairy sheds and irrigation consents. Data was gathered from the Ashburton District Council and Environment Canterbury records. Knowing the age of an asset enabled an estimate to be made for the "end of useful life" and to understand the timing of major strategic decisions affecting land use.

2. Farmer perspectives and feedback on climate change.

   Several focus groups were run to gather farmer perspectives on climate change and explore themes identified in the desktop review. The focus group participants broadly reflected the make-up of farming in the district. The focus group composition considered their farming type (such as dairying, arable, sheep, and beef farming), business career stage (such as early, mid, and late-career), and the location of their farm businesses (such as lower-, mid-, upper-plains, and high-country). Each focus group was facilitated by a respected local farmer. The groups explored several key questions relating to climate change.

The focus group discussions were transcribed digitally. The themes that emerged from the desktop analysis were compared and contrasted to the focus group discussions. These findings were collated and reviewed by the project working group, which is comprised of farmers, farmer levy-funded bodies, and industry organisations. These parties were involved because they provide different insights on climate change adaptation. Farmers understand the practical implications of change and climate, the industry levy bodies have extensive experience in farmer behavioural change initiatives, and irrigation companies hold a non-sector and long-term view of land use, particularly in relation to irrigated land uses.

The Four Themes

The project identified several points that could improve farmer engagement and reduce barriers to responding to a changing climate. These were grouped into four interconnected themes – information, channels, adaption support, and critical farm infrastructure. The themes are as follows:

Meaningful Information:

The project highlighted issues and opportunities to improve the flow of information to farmers about climate change. The desktop review highlighted the complexity of climate change models and difficulties with how the data from these models are communicated. Several gaps in technical information were noted, particularly in relation to feed production and livestock production, and their significance at a farm level was discussed. The farmers emphasised that they won't change unless they have confidence that their circumstances will improve as a result. Farmers identifying gaps in technical information indicated a desire to keep learning so they can respond knowledgeably to climate risk and opportunities.

Through both the desktop review, and the farmer focus groups, improvements to the way climate data is presented, the level of detail, and the language presented to farmers were identified

Effective Channels: Farmers place a high value on credible information sources and stated that those who are 'trusted' channels have a significant influence on their decision-making. Farmers noted the influence of a trusted source which helps them cut through a large amount of information and acts as a sounding board. They stated that they need information that is accurate, timely, and relevant to the business. Independence was also noted as important, such as the Crown Research Institutes, but also recognized that commercial parties could be useful if their biases were clearly identified. Farming is driven by evidence-based practices, and research that has direct practical application was raised as important.

Adaption Support: Adaption support was a major discussion point in the focus groups. Farmers provided insights as to how information can be more farmer-friendly and therefore potentially more easily adopted. They discussed the importance of farmer-to-farmer learning and they noted the importance of being able to model practice changes before committing to action. They want to understand the impact of decisions on the whole farm system and where possible de-risk their business from any changes they might introduce.

Critical farm infrastructure: Farming land uses are enabled or limited by the on-farm infrastructure and consent conditions granted. The physical infrastructure on the land such as milking sheds (dairy), grain silos (arable), or shearing sheds (sheep farming), will strongly influence the land use. Investment into different infrastructure must be made to transition to an alternative land use. Another major driver of land use is access to water for irrigation. Without access to irrigation water, the land use options are greatly limited compared to those with access.

Supporting Climate Change Adaption

To enhance climate change adaption, farmers need more meaningful information provided by parties who are trusted and understand what farmers need, and that they can explore land use options in a supportive learning environment, as shown in figure 1 below.

In the sections that follow, the report identifies ways in which climate change research can support on-farm action more effectively. It describes how the language of climate change needs to work for farmers, with data that is applicable on-farm and at a scale that is relevant at an individual farm level. It discusses the need for information sources that are credible to be working with farmers who contribute their knowledge to the research and the delivery approaches of the information. It highlights that practical research delivered through farmer-to-farmer learning will drive change at a grassroots level and help farmers de-risk changes to their systems. Finally, the importance of the life cycle of the business and its influence on land use is discussed. The project findings are summarized in figure 1 below.

Summary of the Desktop Review and Farmer Insights

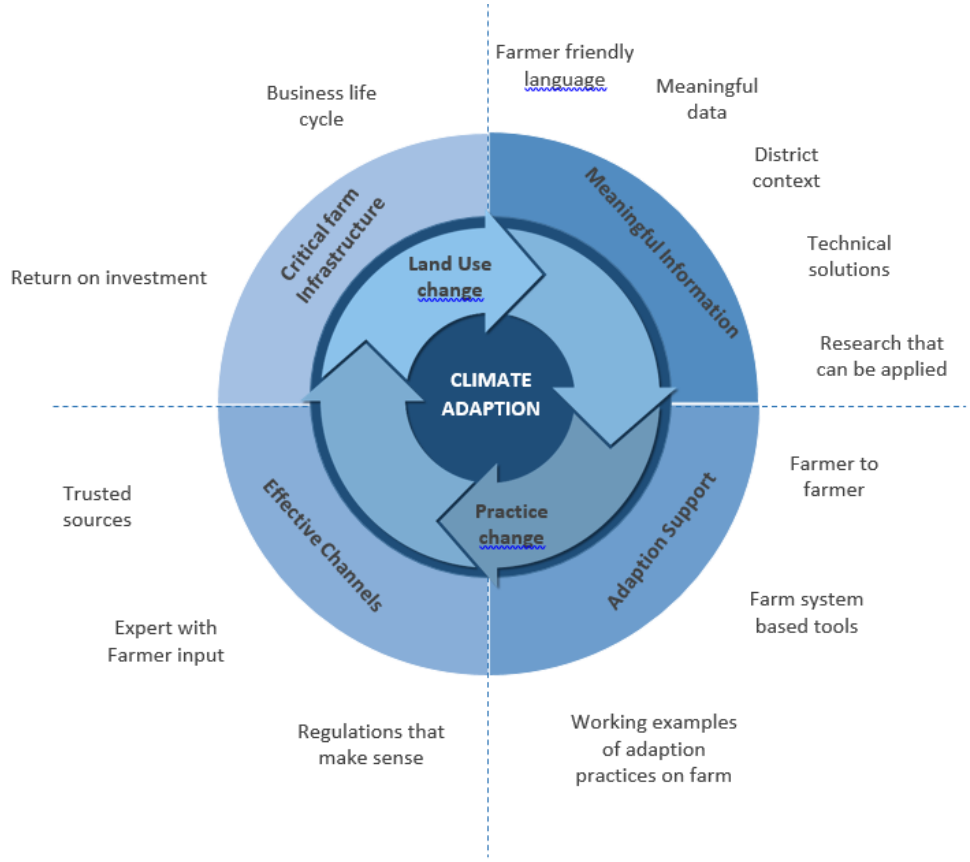

Figure 1

Change is already happening, but a clearer direction is desired

Adaption and practice change on-farm was a major discussion point for farmers. Farmers identified that they needed to adapt to a changing climate but also to market intelligence, animal health, and environmental regulations. Consistently, they asserted that farming today requires continuous improvement, and that adapting to any risk is 'business as usual' rather than something that requires additional focus. The farmer quotes below reflect this sentiment; that changes to market prices have incidentally caused their farm to be better at identifying the effect and managing the changing climate.

> *"I think we've changed; I mean as technology and science have changed in the farms. We put in water monitoring. It wasn't because of climate change; it was just because our water was reasonably pricey. So, we wanted to make sure that we make good use of it. ... I don't know if we've necessarily been doing it for climate change, but it will actually help if it becomes more noticeable.*
> *Dairy farmer 3*

As farmers feel they naturally adapt their system to changes, they argued whether pre-emptive change is needed. It is not whether they *should change*, but rather, *is there a sound reason to change?* Motivation for change is strongest when there is clarity on why, how, and what changes should occur. Farmers discussed personal experiences of industry bodies being frustrated by a lack of farmer engagement with technology.

> *"… they said, 'Well, why won't farmers change?' … and I said, these things made sense; moisture sensors and pivots and so on… but if farmers don't believe it'll make any difference, they won't do it"*
> *Dairy farmer 7*

Climate change communication

Both the desktop review and farmers highlighted that the language and the information about climate change need to be presented in a clearer and more concise way. The desktop review stated that *'The climate data that represents the potential impacts, is not well presented to the farmer audience',* and continues, '*The climate data that is presented to represent the potential impacts is poorly understood by farmers. For example, the information presented in this* [desktop review] *report represents the average of six different models and is reported as the average of a twenty year period for two potential outcomes one of which RCP8.5 is highly unlikely to occur because we are already limiting our emissions of GHG'*[2].

The review commented further stating, *'Farmers like to see information that relates to their farm system type in order to make decisions about the impact it may have on their business'*[3]. Farmers highlighted the need to have climate change information presented in a form that they can use for decision making at a farm level. For them, it is valuable to have research and information that has direct application to their business's operating environment rather than a high-level view of climate impacts.

> *"We need research that's relevant...that you can actually do. I want to go home from a field day and say, I can do that. I can do that tomorrow. What I see coming out, it's a lot of big pictures and it's not something that I can change".*
> *Arable farmer 2*

Climate change versus changing climate

Farmers also highlighted that the language used in the climate change discussion is important. When it comes to terminology, they were clear on the difference between 'climate change' and a 'changing climate'. While the difference appears subtle and nuanced, for farmers there is a big distinction.

> *"Yeah. I hate the words climate change, I prefer to talk about a changing climate because there's a real subtle difference and it's a very important difference".*
> *Livestock farmer 5*

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[2] The Agribusiness Group. (2022, p.15). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

[3] The Agribusiness Group. (2022). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

According to farmers, 'climate change' is inseparable from politics, policy, and rules, and according to them, it does not necessarily enable good environmental outcomes. When discussing 'climate change', their comments gravitated to politics and policy, with notable levels of cynicism, whereas when discussing a 'changing climate', their comments were more constructive and forward-looking.

"Climate change is a really cool thing to believe in, as long as it's somebody else's fault and somebody else's problem".
Arable farmer 4

Farmers stated that a 'changing climate' is a natural process, something they have observed and experienced personally. They recognize the cycles of the weather and climate and acknowledge that the climate seems to be changing.

"We think that climate change is pushing the limits of what we can do [in our farming operation], we're going to need to make more investments to cope with the extreme events we are experiencing."
Livestock farmer 4

Farmers appear to relate more positively to the language of a 'changing climate'. Using 'changing climate' phrasing is likely to support a more constructive, future-focused discussion when compared to using the term 'climate change'.

Meaningful Information

Both the desktop review and the farmer comments identified the importance of how climate change information is presented. This includes making sure data is meaningful, and can be applied on-farm.

Providing farmers with meaningful data

The desktop review discussed the challenges of presenting the climate change data in a way that is meaningful for farmers. Typically, the climate change data identifies variations from the current average conditions as calculated by different climate change scenarios expressed in Representative Concentration Pathways (RCP's) e.g., RCP 4.5 or RCP 8.5. The desktop review suggested that the data could be more useful if presented differently from an average of RCP scenarios. The desktop review stated '*We believe that it would be better to express the likely changes as a result of climate change as a continuum rather than an average of two periods'*[4].

Presenting data as a deviation from the average could understate the significance of the change because the averaging process could 'hide' the volatility of the data.

When farmers discussed models that showed a temperature of 1.5 degrees from average, many considered this business as usual.

"We are only gonna get one and a half degrees…"
Dairy farmer 10

[4] The Agribusiness Group. (2022, p.15). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

This could be due to the experience of farmers who work within a climate that varies more widely than 1.5 degrees on a daily, seasonal, and annual basis. The desktop review goes on to state, "*The average figures do not offer significant variation from the present to concern farmers, so they are not motivated to engage. Therefore, the significance of a change in the average needs to be better presented to the farmer*"[5].

Presenting climate data as a change to average may not motivate an adaption response. It is conceivable that a farming operation may have tolerance for the projected average climate variations within their farm system and therefor do not see the need to act differently because of a change to average temperatures.

"So it's gonna depend on what combination of climatic factors change, as to what sort of decisions you're going to make or what might change as far as the way your farm operates."
Livestock farmer 5

Future-proofing for extreme events

Extreme climate events are of significant interest to farmers. Farmers understand their natural resources well, having built up a wealth of knowledge of their climate over many years, and in some cases generations. Many recognise there is a change in the frequency of extreme climate events.

"Climate change isn't it's getting hotter, or it's getting colder, we're having more extreme weather events more often."
Livestock farmer 4

Their farming operations are designed around known variations of climate, with some redundancy built into their physical infrastructure and management capacity to allow for the occasional extreme event. If climate change is altering the frequency and characteristics of extreme climate events, farmers will be very interested to understand what that might look like at a farm level so they can manage the changing risks for their businesses.

"…if the humidity goes up and the cows are hotter, therefore, they're going to struggle with heat and drink more water. They might drop in production. You're gonna have to think about your decision-making and how you make things work. You're probably going to have to change your system, and it's a case of what are the sorts of things you might have to change. "
Livestock farmer 5

The desktop review highlighted gaps in the climate change data associated with extreme events. It stated that *"The missing data is the potential variability which will give farmers a much better view of the impact because it will highlight the extreme events both in terms of the severity, duration, and the probability of them happening. When that information is made available then farmers can make*

[5] The Agribusiness Group. (2022, p.15). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

adjustments to their core farming system to allow for their farming systems to operate within the climate change which they are experiencing"[6].

The review suggested that if farmers better understood the severity, duration, and probability of extreme events in a climate-changed future, they would be better equipped to adapt their farming systems.

Presenting these data points would inform decision-making around infrastructure capacities and farm policy such as wind protection, water containment, farm equipment capacity, animal welfare, feed reserves, shade and shelter, and the financial implications.

Making climate change models relevant at a district level

The desktop review identified that climate change data is often presented at a regional and national level. There appears to be potential to provide climate change data at a more localised level, though caution was urged in the desktop review stating *"we are not sure whether the accuracy of those figures would provide any further certainty to the information because of the uncertainty and limitations that are inherent in the manner in which the information was derived"*[7]. Further work should be undertaken to determine the robustness of the climate change data if it is presented at a district or catchment level.

The review suggested that if credible data can be established at a district level, there would be value for farmers to utilise the modelling data because it will relate more directly to the climate associated with their farm location.

More localised data could inform farmers of their climate risks and opportunities for their business. This information could inform short-, medium- and long-term decision-making and would enable farmers to proactively manage their business risks and drive climate change adaptation strategies. On-farm opportunities may arise from modelling localised climate conditions for frost frequency, wind, rainfall, evapotranspiration, and degree days. These may give rise to new land use options which are currently not considered. To utilise these opportunities, a clearer understanding of the specific climate conditions in an area will be important. For example, average annual wind speed change, while being a useful data point, might not be the limiting factor for some land uses. The constraint with wind might be peak wind gusts rather than the change to average, as is commented by a farmer,

> *"And it's the wind around too, you can probably grow hops, no problem at all in Canterbury. But what I am saying is that with the wind we get, it'll get ripped down."*
> *Dairy farmer 10*

[6] The Agribusiness Group. (2022, p.15). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

[7] The Agribusiness Group. (2022, p.8). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

Currently available climate data is high level with a wide range of possible outcomes, as shown in Summary Table 1 of the desktop review[8]. The Table shows the number of hot days under RCP 4.5 and RCP 8.5 (Mid Century) are modelled to increase by 10 – 40 days per year. While these numbers provide a general understanding of the direction of climate change, farmers stated that they wanted a greater level of localised detail to help them understand the nature of the climate risk so they can respond accordingly. Using hot days as an example, if data was available that highlighted the frequency of successive hot days rather than just stating 10 – 40 additional hot days, farmers could review their livestock policies and pasture species selection in light of the projected climate conditions and heat tolerance requirements. Furthermore, the data could align more specifically to location. Some areas may be affected at the lower end of the hot day scale (10 extra hot days) while others may have to deal with the more extreme end of the scale (an extra 40 days). From a farm management perspective, these are very large climate variations that will require very different on-farm climate adaption responses.

High-level models may miss subtle changes in microclimates that could be utilised for alternative land use. If district-level data identifies these changes, it could be a game-changer, enabling farmers to consider alternative land uses better matched to the emerging climate for their immediate area.

Research that can be applied to farm

A salient point made by several farmers was the importance of climate change research which can be applied directly on farms. Both the farmers and desktop review noted that current climate change research tends to be high level, with the desktop review adding that the impacts are '*supported by theoretical constructs alone'*[9]. Furthermore, the desktop review states, *"Much of the current scientific information on climate change has not been translated into a form which is easily understandable by farmers so they are not aware of it or the implications for their farming systems in terms of the required transition or how they can operationalise the information"*[10]. Farmers reported difficulties in identifying the 'so what' for the data, which limited their ability to implement adaptive practices.

> *"…. I do think there is quite a disconnect between some of our scientists and our farmers. Scientists are looking for a project and they do the thing they think we want, but they don't necessarily know what it is."*
> *Livestock farmer 3*

Farmers emphasised the value of research that they could take home and use straight away, rather than high-level theory.

It is important to consider the role climate change research has in informing strategic decision-making across a wide audience, not just farming. However, this does not preclude the data from being transformed into practical and meaningful information. Being deliberate about the 'so what' with climate change data is critical for farmer engagement and adaption.

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[8] The Agribusiness Group. (2022, p.10). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

[9] The Agribusiness Group. (2022, p.3). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

[10] The Agribusiness Group. (2022, p.51). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

Broadening farmer's technical knowhow

A changing climate will create opportunities and new challenges for farm businesses. While soils and topography will largely remain unchanged, climate change will alter growing conditions, affecting animal and plant production as well as associated pest and disease issues.

The desktop review explored 'Projected Impacts' of climate change which are summarised in Table 4 of the desktop review[11]. The projected impacts are characterised by broad statements which provide a general direction of travel, rather than information that can support system-based decision making. This generalised commentary is helpful to a point but does not provide sufficient clarity to make substantive on-farm change and the desktop review notes, "*There is a wealth of information available on the projected impacts of climate change but much of it is supported by theoretical constructs alone"*[12]. An example of this was provided in the desktop review when quoting previous research on pasture production and climate change. '*Increasing carbon dioxide concentrations is expected to increase overall annual production and growth rates of pasture. Pasture growth will become more variable and unpredictable but declines in pasture production during the summer months will be offset by the warmer temperatures in winter and spring'*[13]*.* In this statement, the farmer is faced with the proposal that there will be increased biomass production (and therefor higher stocking rates and greater livestock production) at a different time of year (suggesting a change to winter grazing policy and winter stock rates) coupled with less reliable pasture growth (therefore suggesting stocking rates should be reduced). A reasonable farmer response to these contrasting suggestions is to not implement systems change until there is greater clarity or observable climate change effects on pasture production.

Some production systems will be better able to adapt to a changing climate than others. Farmers will respond by re-positioning their businesses. At a practical level, this will involve learning and doing things differently. This is the case for one sheep and beef farmer who is thinking about a range of practical issues such as foot health through to sales and marketing implications of changes in lambing dates. Technical resources on the effects of climate change on this particular business will help guide decision-making in a number of areas of their sheep system.

> *"I'm starting to think about with merinos, is foot rot going to become more of an issue or less of an issue. If it gets hotter and drier, are we going to shift our lambing date? If we shift our lambing date, and our lambs are earlier, does that then change what store lambs are available for finishing farmers to buy?"*
> *Livestock farmer 5*

Another farmer was thinking about the genetics of their herd, and how profitability will compare to current, while also wanting to understand how this will all impact their environmental footprint.

[11] The Agribusiness Group. (2022, p.27). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

[12] The Agribusiness Group. (2022, p.3). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

[13] The Agribusiness Group. (2022, p.16). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

"...so there's still some low-hanging fruit, and stocking rate to me is probably one. How much can we improve the genetics of our herd, dropping our stocking rates to 3.3 cows per hectare and still be as profitable? And that's kind of low-hanging fruit. I see that resource efficiency gain with what seems to be a win-win for the environment and the bottom line."
Dairy farmer 11

To be successful, farmers will need to broaden their technical know-how in order to identify and act on opportunities emerging through a changing climate.

The review went on to identify gaps in knowledge such as plant and animal genetics, animal welfare and husbandry, agronomy, and human resource. The gaps point towards additional and new knowledge required for a practical response to changed growing conditions at a farm level.

"There doesn't seem to be a central source in the farming community of clear information about what is going on. We're plucking it from Beef and Lamb, from FAR, from DairyNZ. We don't have time to sit down and go to these different places [on-line] to look at the current issues in the climate scene."
Arable farmer 6

Farmers are noticing gaps in the technical information which are arising as they challenge their own thinking about their farm systems and consider management options.

Effective Channels

The desktop review identified a number of organisations involved in climate change research. These include NZ Greenhouse Gas Research Centre (NZAGRC), Pastoral Greenhouse Gas Research Consortium (PGgRc), AgResearch, Land Care, NIWA, Deep South, and Ministry for the Environment (MfE), and Ministry for Primary Industries (MPI), Our Land and Water, DairyNZ, Beef and Lamb NZ (B+LNZ), Foundation for Arable Research (FAR). Several of these organisations focus mainly on higher-level research, while others undertake science and extension, while others focus primarily on farmer uptake[14].

The desktop review noted that *'much of the research which is carried out in New Zealand is done in collaboration with other research providers'*[15] and it also noted that a number of organisations are working collaboratively through initiatives such as NZAGC and PGgRc.

Farmers acknowledged that they have a variety of information channels available to them. The ones they use are channels they deemed trustworthy. Farmers identified that high-level research that provides context must come from a credible source whereas research that informs on-farm adaption needs to come from a credible source, be engaged with farmers, and support the practical application of the research at the farm level.

[14] The Agribusiness Group. (2022, pp. 29-34). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

[15] The Agribusiness Group. (2022, p.29). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

"…if you want to see change, it's got to be collaborative. So the industry bodies are learning, but it's still not good enough."
Livestock farmer 2

The power of trusted sources

A trusted source is a vital member of the farm team. They will vary from farmer to farmer and may be an organisation or more likely, an individual within an organisation. Importantly, they help the farmer cut through the information clutter and identify what is useful and relevant. They can hold significant influence.

Farmers described industry levy-funded organisations with varying levels of positivity. The general sentiment was they should be supporting adaption at a farm level. The farmers noted levy organisations have an important role in gathering successes and learnings from early innovators and sharing those learnings with the wider farming community. However, they recognised levy-funded organisations were not entirely independent, as they have a vested interest in the sector that funds them. In the case of land-use change, farmers were apprehensive that they would not get the best advice on multi-system land uses from levy organisations because they may not have expertise in farm systems outside the specific sector they represent.

Irrigation companies were identified as trusted sources. While these organisations do not undertake climate change research, they actively encourage continuous improvements on-farm and support the implementation of good farm practice and advanced mitigation. Trust for these companies appears to be related to the fact they are not aligned to any particular sector, they have frequent engagement with farmers, and are perceived to hold a long-term view of land use in the district.

"Most irrigation companies are pretty credible as information sources. It's about sending [information] out from credible places, and farmers will buy into it."
Dairy farmer 2

Research expertise combined with farmer input

The desktop review highlighted there to be a '*plethora of research reports on the impacts and adaptation options for responses to climate change'* and followed on stating *'Much of the current scientific information on climate change has not been translated into a form which is easily understandable by farmers so they are not aware of it or the implications for their farming systems in terms of the required transition or how they can operationalise the information'*[16]. This theme was continued in the desktop review stating, '*Much of the science that has been carried out into climate change has not been carried out with any interaction with, or translation into a form that is accessible to, the people who it is designed to help'*[17]. A similar sentiment emerged from the farmer discussions.

Farmers stated that they were interested in being more involved in identifying and designing the focus of climate change research and the approaches taken to support adaption. This is borne from

[16] The Agribusiness Group. (2022, p.51). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

[17] The Agribusiness Group. (2022, p.51). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

a desire to have more research that is strongly linked to application on the farm. This is where farmers saw the real value.

"FAR, Foundation for Arable Research, seem to be a far more positive industry group than what you hear about the other ones. There's a close relationship between those doing the research and the farmers, and those research guys are out there on farms all the time, talking to us wanting to know what we want to know. And that works."
Arable farmer 2

"DairyNZ does some good stuff but is generally behind. There is some very good stuff, in terms of nutrient/ nitrogen leaching. It's all very farmer-driven or facilitated which is quite useful.
Dairy farmer 4

However, the desktop review notes '*Although there are good research results which demonstrate a framework for developing resilience strategies the knowledge that is required to both instigate and run the development of a resilience strategy is held by third parties not by the farmers'*[18]. Farmers in the focus group also commented.

"There's a bunch of work being done for the government … but they're not farmer-facing with the information. A lot of people just find farmers for some reason really difficult to engage with, it's like they're almost scared of them. We just have to crack on and find someone who is interested and engaged."
Industry 2

"… we've got a massive disconnect between farmers and researchers, we're poles apart."
Dairy farmer 1

It seems if the outcome is climate change adaption by farmers, there was a strong view, at least within the focus groups, that farmers should be more involved in co-designing the research and delivery.

Regulations that make sense

Farmers had a lot to say about the new and emerging regulations, particularly greenhouse gas, He Waka Eke Noa, and the freshwater nitrogen limitations. At the time of the focus groups (May 2022), the He Waka Eke Noa industry proposal had recently been released and was front of mind, whereas the freshwater regulations have been in place for nearly two years. The desktop review highlighted the difficulty farmers were having in prioritising their efforts, stating '*Farmers are currently concentrating on understanding mitigation of the amount of emissions of GHG's in order to comply with He Waka Eka Noa and aren't engaged with the issues around adaptation'*[19]. This issue appeared

[18] The Agribusiness Group. (2022, p.54). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

[19] The Agribusiness Group. (2022, p.51). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

to be compounded by what farmers described as mixed messages prompted by some legislation, and the difficulty for farmers to navigate several significant changes to legislation at the same time.

*"We're supposed to adapt or change being young and cool, but even I can't keep up with the changing regulations. Every time we get out of bed, you go, What the bl***y hell are we doing this for?"*
Arable farmer 3

Farmers reported difficulty in implementing change because they were unclear about how to achieve the expected outcomes. Additionally, they noted regulations that prescribed management practices which reduced their ability to adapt to a changing climate.

"If every cow in New Zealand eats five percent of their diet as fodder beet, it would be enough to reduce our first tier of our GHG. But then the flip side to that is we can't grow fodder beet because of the nutrient regulations around leaching and intensive winter grazing. It's like, which one do we actually attack here?"
Dairy farmer 6

Farmers recognized legislation and policy are outside of their control despite being the ones that need to change their systems. This is difficult when farmers perceive the rules do not make good practical sense. They cited a number of new rules in place which may create perverse behaviours creating worse outcomes.

"They're saying to control Nitrates, you can only put in this many hectares of winter feed. They don't care if it's fodder beet or if it's kale or whatever it is. You're limited to your hectares. Well, that's not controlling the effect, it's just controlling inputs. You can double the number of cows on your farm just like that, because the only thing they're controlling is the input.
Dairy farmer 6

The farmers acknowledged the need for change and emphasised engaging with farmers when developing regulations. They highlighted the need for rules to be working to achieve their intended purpose.

Adaption Support

Farmer to farmer

The desktop review highlighted the value of farmers working in groups to explore system options, stating '*Farmers working together and learning from one another is a powerful tool in building confidence to make changes in their businesses'*[20]. It continued saying '… [in the] *farmer group environment where they are comfortable; farmers question one another on the positives and negatives of a particular system or management technique. Support from other farmers also taking on the same challenges of new ideas or techniques is known to be a catalyst for change'*[21].

[20] The Agribusiness Group. (2022, p.65). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

[21] The Agribusiness Group. (2022, p.66). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

Farmers emphasised the value of exploring on-farm adaption as a group where they valued the ability to pose questions and seek advice from the collective wisdom of their peers. They acknowledged that farmers learn best from farmers, particularly with complex system issues such as climate change adaption. The author of the desktop review noted their professional experience where they *'often saw groups of farmers look at one part of a system multiple times in different environments to help the decision making process'.* One farmer stated;

Farmers will trust farmers, and the innovation will go to foster innovation, and innovation will come from within.
Dairy farmer 1

Tackling complex system changes through expert-supported farmer groups is a well-proven approach for exploring and implementing change. The desktop review highlights the importance of expertise to keep challenging and updating the knowledge of the group. *'Ongoing support and regular engagement from advisors and peers ensures that farmers can maintain progress and have access to relevant and up to date information. Having the support of an advisor or a mentor checking in with a farmer on a regular basis gives that farmer the opportunity to ask questions or get clarity around a challenge they have'*[22]. The group approach will build confidence to act, as farmers draw on the experience of those who have done it before.

*"And the leading guys [farmers] would do it before the bl***y industry, just give us the time and the innovations, and the leading guys will do it."*
Dairy farmer 9

Critically, in the group setting farmers recognized the need for expert input. The expertise is tailored to the needs of the group, not the other way around. Expertise can be for technical knowledge and for supporting the operation of the groups.

"I think that's one cool thing that the industry is beginning to do … They are starting to engage farmers through surveys or through information pamphlets and discussion groups… The industry is starting to support us in that sense."
Livestock farmer 4

Working examples of practice change on farm

Building on the desire for applied research, farmers expressed a strong interest in being able to visit and see adaptation practices in a working environment. This reflects the practical inclination of farmers. As kinesthetic learners, touching and doing is an important enabler for learning and building confidence.

"In order to adopt new technology or new farming systems, you need to see credible examples like demonstration farms."
Dairy farmer 5

[22] The Agribusiness Group. (2022, p.66). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

Farmers valued being able to see the impact on the wider farm system and the practical implications of change. This view is supported by the desktop review which states, *'Change of a system can take a long period of time and seeing that change through a whole cycle is often needed to ensure [farmers] have the knowledge to confidently make the change.'*[23] Farmers also recognised the importance of not introducing too much change so they can analyse the effects. Additionally, changes to farm systems take a long time to implement.

"We're dealing with a biological system that takes at least 12 months to make some incremental change. You've also got animals that take two to three years to get into a system, then, five years have gone before you can make a change. This is why we need time."
Dairy farmer 9

Being able to observe the implications of changes to demonstration or peer farms before they need to make the changes themselves, will give farmers confidence. It ensures farmers are making the best changes for their financial, social, and environmental position.

Farm-systems based tools

The desktop review explored the decision support tools available and noted that, while there is a number available, *"None of the farmer available tools are able to incorporate climate change parameters into the one model and only Farmax is able to incorporate production, GHG and financial data for pastoral systems"*[24]. Farmers also commented on this gap, noting that no model could identify the effects of change across different parts of the farm system, particularly the financial implications.

"How would you make the decision; you'd need to have the confidence to know that if you're going to change your farm system, say if you're gonna go to hops, which uses 400 units of N. You'd have to know that you weren't actually going to be worse in terms of your Nitrate leaching. You'd have to have confidence in the modeling or whatever you're going to use, Overseer, to know that you're actually making progress. And the other externalities, you might be ticking the box for greenhouse gas, but you might not be for water quality."
Dairy farmer 5

Farmers highlighted an issue with decision support tools that only focus on one or some parameters. They felt these could be limiting because they do not show the implications of changes and how they affect the whole system. This reduced their confidence in change as they could not get a full appreciation of how changes will affect different parts of the farm system

[23] The Agribusiness Group. (2022, p.68). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

[24] The Agribusiness Group. (2022, p.4). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

Critical Farm Infrastructure

Return on investment

The desktop review highlighted the importance of the return on investment when considering changes stating, *'As with most businesses, farm system change, and adaption will require a positive return on investment and economic profitability for it to be a considered option.'*[25]

Farmers discussed farm assets such as irrigation infrastructure and milking sheds and commented on the importance of getting a satisfactory return on their investments. They noted the importance of annual profitability and utilizing an asset for its full economic life.

> *"I think one of the biggest problems is confidence. If I'm going to spend a million bucks changing my system, how do I know that someone's not gonna write something off that I've done, and it's completely wrong."*
> *Dairy farmer 7*

They discussed how profit and return on investment factors influence their willingness to change their farm system, noting how they also consider the economic cost of a stranded asset should they substantively change their land use. They discussed the difficulty in departing from 'safe' practices and changing away from what is familiar and tested, particularly when further capital might be required

> *The other challenge we've got is the co-op [Fonterra] has been our best friend, but it's also a weakness because too many farmers invested in stainless steel. They don't actually want to de-invest in that stainless steel, so they just keep on that treadmill. I'm a thorough co-op man, and I think you know, we've got stuck on this treadmill we've all invested on the stainless steel now it's really hard to get out of that again.*
> *Dairy farmer 6*

The desktop review noted the need for greater understanding of the impact infrastructure investment has on climate change adaptation, stating *'…[the economics and return on investment] are important factors to consider for farmers when looking to engage them in a new idea or topic, it needs to be financially rewarding at the appropriate risk level for them to start the process.'*[26] Farmers highlighted that simply if it makes good financial sense, they will move quickly to adopt change.

Business life cycle and land-use change.

Over time, regulations and the changing fortunes of farming systems may create tensions for change that lead to alternative land uses. When considering the potential for land-use change, both aging dairy sheds and the water consent renewal process may play a significant role across the district.

In the Ashburton District, dairy farming accounts for $1.129B of the local economy and 63% of Nett farm income for the district. Irrigated farming covers approximately 2/3rds of the Ashburton District

[25] The Agribusiness Group. (2022, p.66). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

[26] The Agribusiness Group. (2022, p.66). *Supporting land use adaption in a changing climate – Desktop review.* Ashburton District Council.

Plains, or 220,000ha[27]. Both farm inputs have a significant influence on land use in the Ashburton District.

The Desktop Review – Critical Farm Infrastructure (Appendix 1) showed from the '*building consent records in the Ashburton District Council that 230 milking sheds were built from 2007 to 2015*[28]*. This equates to 40% of all dairy milking sheds in the district'*. Using the IRD calculation of a 33.3-year[29] economic life for a dairy shed, those sheds will reach the end of their economic life between 2040 and 2048 meaning 40% of all dairy sheds in the district may or may not be replaced during that period[30]. This figure represents a large proportion of dairy farming in the district and a change away from dairying will have a material effect on land use across the district.

Leading up to this period, dairy farmers will assess the merits of dairy farming compared to alternative land uses. Replacing an aging dairy shed is a significant capital investment and a decision whether or not to replace a milking shed, will be carefully considered in the light of climate suitability, regulations and the prevailing economics of dairying compared to other land uses.

Furthermore, the Desktop Review – Critical Farm Infrastructure (Appendix 1) showed that '*during the period 2030 – 2040, 1235 water use consents will expire from a total number of 1577 water use consents in the district. This represents 78% of all consents, however, the area of land involved in this process will be greater than 78% of land as the water consents of all three irrigation companies will fall due'*[31]. The renewal process is significant because '*the implementation of the National Policy Statement for Fresh Water Management may introduce new or different consent conditions for water use than has previously been the case. This may change the viability or feasibility of some land uses under those new conditions'*. A material change to the feasibility or viability of a land use under a different water use consent could result in changes in irrigated land use affecting 220,000 ha of the Ashburton District plains.

The water use consent renewal process is currently underway, and an analysis of the location and number of consents as demonstrated in Figure 3 'Geographic Distribution of Water Use Consents and the timing of Expiry'[32] indicate clusters of consents, particularly near the Ashburton and Hinds rivers.

Comparing the timing of water use consent renewals and dairy shed renewals demonstrates a convergence of both around the early 2040's. This points towards a period where the strategic

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[27] Fitzgerald, R. and McDowell, E. (2022, p.1). *Critical Farm Infrastructure – Desktop review.* Ashburton District Council.

[28] Fitzgerald, R. and McDowell, E. (2022, p.2). *Critical Farm Infrastructure – Desktop review.* Ashburton District Council.

[29] Reference – IRD265, General Depreciation rates guide - Dairy shed and yard (including pipe work bails, railings and gates)

[30] Fitzgerald, R. and McDowell, E. (2022, p.2). *Critical Farm Infrastructure – Desktop review.* Ashburton District Council.

[31] Fitzgerald, R. and McDowell, E. (2022, p.6). *Critical Farm Infrastructure – Desktop review.* Ashburton District Council.

[32] Fitzgerald, R. and McDowell, E. (2022, p.5). *Critical Farm Infrastructure – Desktop review.* Ashburton District Council.

direction of many farms across the district will be carefully reconsidered, and depending on the circumstances of the day, may be a catalyst for land use change.

These ‘strategic disruptors’ did not appear to faze the farmers in the focus groups. They emphasized that they are businessmen and women first, and that business logic drives their land-use decisions. They would change in response to new or different opportunities if they make good business sense. One dairy farmer described the change to dairy farming over the past fifteen years as a land-use change in response to the market.

“Market signals have been the strength to date, for driving land-use change in Canterbury. We only go to where the profits are, and if the profit is in dairy we will go there. Something else and we will go there as well. [Dairy farming] has been our biggest strength today, but that may not be the case in 5, 10, 15, 20 years’ time. Effectively, we're going where the market is.”
Dairy farmer 6

Recommendations:

The desktop review and the farmer feedback have identified several ways in which the approach to engaging with farmers about a changing climate can be refined.

The recommendations of the *Supporting Land Use Adaption a Climate Changed Future* project are summarised as follows:

1. Use language that farmers engage with, such as the term 'changing climate',
2. Build the changing climate messaging around farmer's experiences of operating a business in a changing climate,
3. Create practical information resources that recognise the knowledge farmers need to navigate a changing climate. This includes when discussing extreme climate events, giving meaningful data on the frequency, duration, and intensity of events,
4. When presenting changing climate data, also present the 'so what' for that data so farmers can understand the impacts associated with the data,
5. Confirm the feasibility and robustness of district level changing climate data,
6. Describe the district scale level of climate effects so that farmers can assess the impacts on their farm business,
7. Present adaptation to a changing climate as a rational business decision,
8. Involve farmers in identifying the research topic and delivery approach for changing climate research,
9. Provide working examples of adaption in a farm setting for farmers to take home and try themselves,
10. Leverage organisations that farmers consider to be trusted sources of information,
11. Approach adaptation through farmer-to-farmer learning with implementation support,
12. Engage with farmers to establish regulations that are workable and make practical sense,
13. Consider business life cycles and understand how these influence land use.
14. Develop decision support tools that incorporate a farm system view of practice change.

Appendix One

Desktop Review – Critical Farm Infrastructure

Background

Key farm infrastructure was studied in the desktop review to understand the age, and therefore the timing of infrastructure renewal across the Ashburton District. Two major pieces of farm infrastructure were analysed; dairy milking sheds and water use consent expiry (irrigation consents). Both assets have a major influence on land use, and their renewal stage represents a significant decision point and a sizeable investment for the farm business. The rationale for studying these was:

Dairy Farming and Milking Sheds:

- Dairy farming is a significant industry in the district and changes to dairy farming land use will affect employment and the wider district economy.
- Dairy farming contributes 63% of total Net Farm Income for the district amounting to $1.129B in the local economy.
- The milking shed is a critical farm asset that is essential for dairy farming land use.
- Determining the age of dairy sheds based on their building consent enables the calculation of the end of the economic life of a milking shed.
- Understanding the age, and therefore the remaining economic life provides an insight into when important strategic decisions will be made in relation to dairy farming.

Irrigation and Water Use Consents:

- Irrigated farming provides substantial benefits to the district through higher farm productivity and land use options which may not otherwise be possible without irrigation.
- Three major irrigation schemes and a multitude of independent irrigators hold water use consents involving 79% of the plains of the Ashburton District: totaling approximately 220,000 hectares.
- The use of water for irrigation is a consent-controlled activity.
- Water use consents have a finite lifespan, and a farmer must secure a consent renewal in order to continue irrigated farming.
- The current environmental reforms, including the National Policy Statement for Freshwater Management (NPS-FWM 2020), have introduced a new approach for managing water use by considering Te Mana o te Wai[33].
- The implementation of the NPS-FWM may introduce new or different consent conditions for water use than has previously been the case, which may change the viability or feasibility of some land uses under those conditions.

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[33] [33] Essential Freshwater Te Mana o te Wai factsheet (environment.govt.nz)

- Through the desktop analysis, a geospatial assessment of the water use consent expiry dates shows the timing and geographical location of farms when they need to renew their water use consents.
- This may indicate future points in time where farmers are faced with making significant strategic decisions about their land use.

Dairy Land Use and the Milking Shed

Dairy sheds are a critical asset for dairy farming with the hygienic and efficient collection of fresh milk an essential activity of a dairy farm. Modern dairy sheds can service large herds in a time-efficient manner which makes large-scale dairy farming possible. These sheds are also very expensive to build, as they are often equipped with state-of-the-art control systems and technology.

The decision to build or renew a milking shed is a major decision involving a large capital investment. This is generally made once in a generation. When considering erecting or renewing a milking shed, the farmer will be evaluating the strategic direction of the business, and with it the likely land use for the foreseeable future. A decision to renew the milking shed is a decision for dairy land use, while a decision not to renew the shed will lead to an alternative land use. The decision to dairy farm is not binding and as a milking shed ages, land-use change can occur independently of the lifespan of the milking shed. However, for this to occur, the farmer will have to weigh up alternative land uses while discounting the value of the milking shed and the opportunities in dairy farming. From a business perspective, a decision to write off the value of the milking shed and change to an alternative land use is generally easier as the shed approaches the end of its economic life.

Analysis of Consents – Milking Sheds

An analysis of Ashburton District Council building consent records since 1993 shows an elevated rate of dairy milking shed construction for a period of eight years between 2007 and 2015. During that period, 230 dairy milking sheds were built which equates to 40% of all the district's milking sheds[34]. This period averaged 26 sheds per year compared to an average of ten sheds per year for the previous 14 years.

Figure 1 shows the age distribution of milking sheds in the Ashburton District and their constructed value

[34] Based on 576 dairy businesses in Ashburton District - https://ecoprofile.infometrics.co.nz/Ashburton District/Businesses/Structure

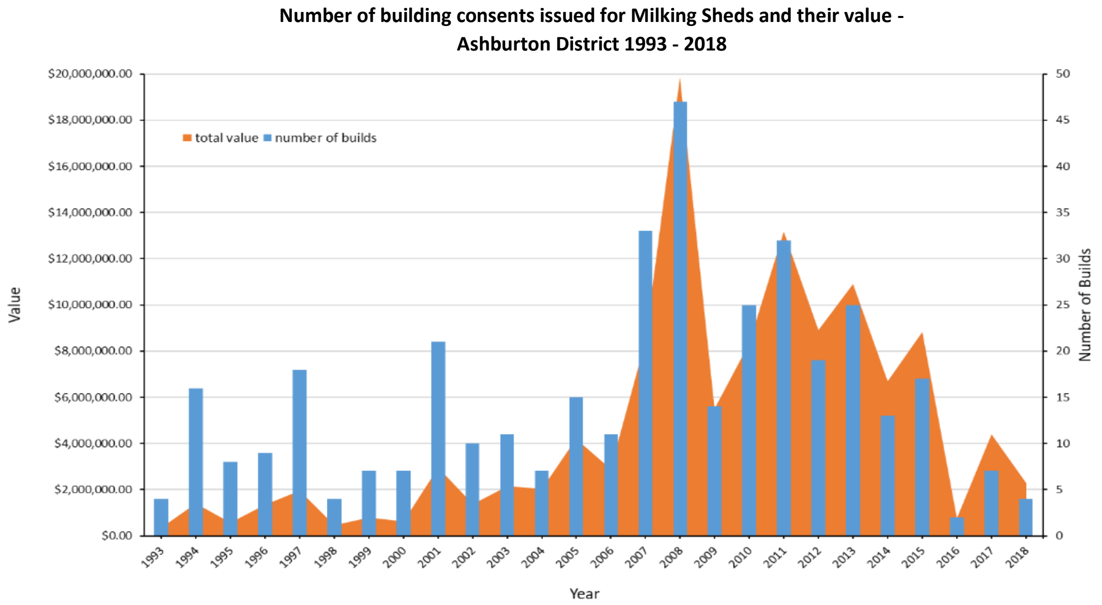

Figure 1

The Inland Revenue Department (IRD) lists the economic life of a dairy milking shed as 33.3 years[35]. When the construction date of a milking shed is recalculated with the 33.3-year economic life, the peak period for shed renewal equates to the period 2040 – 2048, as shown in Figure 2.

Figure 2 shows the age breakdown of dairy milking sheds shown at the end of their economic life.

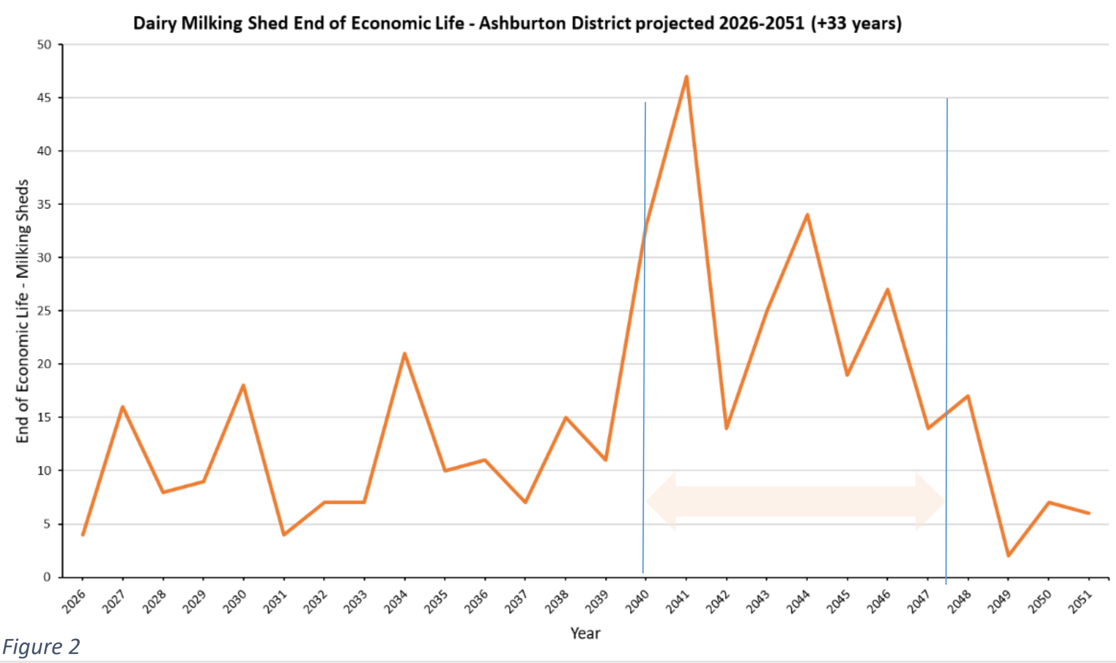

Figure 2

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35 Reference – IRD265, General Depreciation rates guide - Dairy shed and yard (including pipe work bails, railings and gates)

Figures 1 and 2 show that many dairy milking sheds will come up for renewal during the decade of the 2040s'. While this does not represent land-use change, it is a significant period of disruptive thinking where farmers will decide whether they make a significant capital investment in renewing the dairy shed. The dairy milking shed renewal decision point may be the catalyst for land-use change, especially if the fortunes of dairy farming do not compare as favorably as other land use options.

Ashburton District Council consent records were examined for both arable farming and sheep and beef farming to identify equivalent critical infrastructure to support those land uses. It was considered that grain drying facilities for arable, and the shearing shed for sheep farming might provide similar criticality. Unfortunately, only a small number of building consents have been issued for those structures and the data set was considered too small to make a credible judgment about infrastructure renewal as it might influence land use.

Irrigation and Land Use

A significant influence on land use is access to water for irrigation purposes. Irrigated agriculture in the Ashburton District offers very different land-use options than that of dryland farming. It also provides higher productivity and higher gross farm revenues per hectare than dryland farming. Irrigated agriculture is more complicated than simply applying water to a dryland system. It requires the physical infrastructure to apply the water, such as the irrigators and pumping equipment, it requires a different set of skills to manage farming with irrigation water, and it has different financial investment and cashflow implications.

Changes in the conditions of use of irrigation water may disrupt farm businesses that are reliant on irrigation water for their farm systems. Depending on the types of changes, if any, there may be a minimal disruption or potentially, a dramatic disruption.

Irrigated farming requires consented access to water which is structured through a water use consent which is held by the Regional Council. Water Use Consents, when issued, are time-bound, and have various conditions of use associated with each consent.

Approximately two-thirds of the plains of the Ashburton District are currently under irrigation.

Originally introduced in 2014, the NPS-FWM (2020) introduces new approaches to how Te Mana o te Wai is applied. Te Mana o te Wai imposes a hierarchy of obligations[36] that may change the conditions for the water use consents as they are renewed. If significant changes to the consent conditions occur, they may influence land use as farmers adapt their businesses to operate within the conditions of their water use consent.

Analysis of Consents – Water Use Consents

To understand the breadth and timing of potential disruption to irrigated agriculture in the Ashburton District, the expiry dates of water use consents were analysed. The data was sourced from Environment Canterbury and was geospatially mapped to identify clusters of change in areas in the district

Figure 3 shows the distribution and timeliness of consent renewal.

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[36] Essential Freshwater Te Mana o te Wai factsheet (environment.govt.nz)

Geographic Distribution of Water Use Consent and the Timing of Expiry.

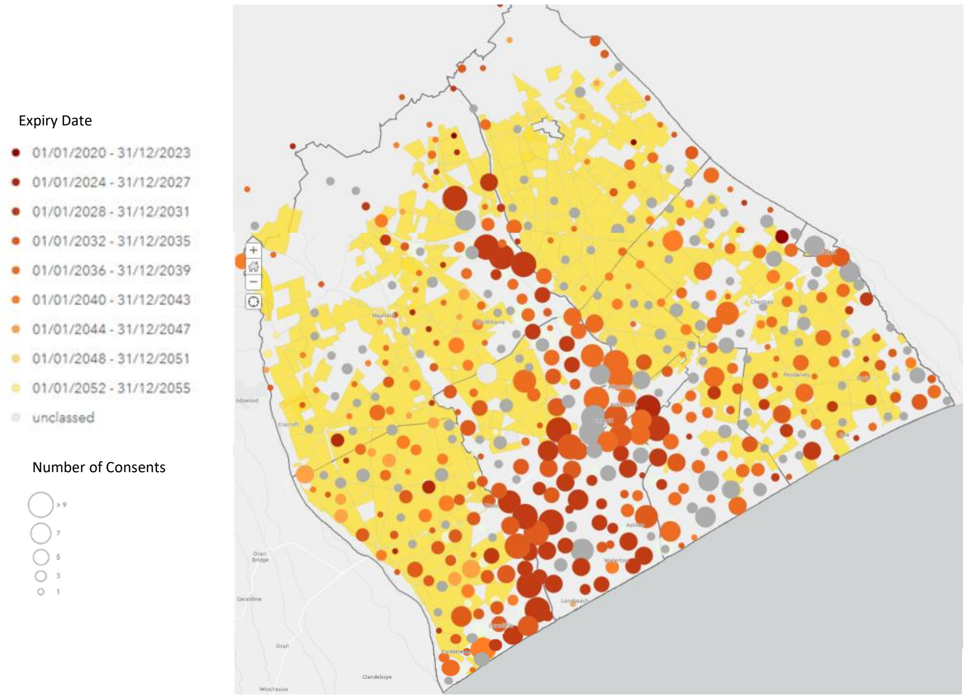

Figure 3

The consent expiries identified in figure 3 show three-year period groupings, with the bigger-sized dots indicating larger groupings of farms in the same area with similar consent expiry dates. The smaller dots represent smaller groupings of farms in the same three-year period. For example, the greatest number of immediate expiries will occur in the Ashburton Forks, Lowcliff and Hinds areas, as shown in the large dark-red colour dots in figure 3. Their consents will expire before 2023. In the period after that, 2024 -2027, there are several clusters of consents falling due along the southern bank of the Ashburton River, and another grouping in Hinds again. These are shown in the second darkest colour red dots. As the red colour of the dots become lighter, the further away in time the consent expiries fall due. The grey dots do not have a specified expiry date. The large yellow areas in the background of the map represents the three irrigation companies, MHV Water, Ashburton Lyndhurst Irrigation Limited (ALIL) and Barhill Chertsey Irrigation Limited (BCI). Their water use consents expire in 3035 for BCI, and 2040 for MHV Water and ALIL. The irrigation companies cover approximately 110,000ha or half of the irrigated area of the Ashburton District's plains.

Figure 4 demonstrates the number of water use consents in the Ashburton District, and their expiry dates.

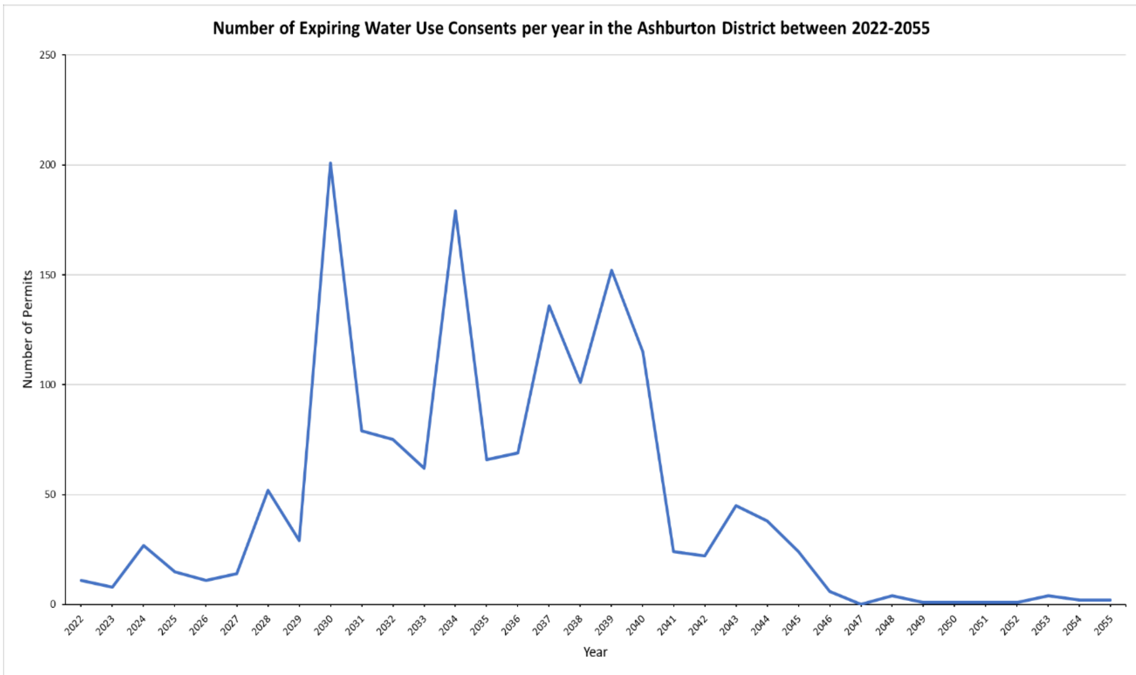

Figure 4

During the period 2030 – 2040, 1235 consents will expire from a total number of 1577 in the district. This represents 78% of all water use consents, however, the area of land involved in this process will be greater than 78% of land as the water consents of all three irrigation companies will fall due during this period. Those companies represent approximately 110,000ha of irrigated land.

A sizeable majority of water use consents will come due leading up to the year 2040. If the water use consent conditions change significantly, it will change the way irrigated farms operate and the viability of some land uses. The current general direction of travel for freshwater management suggests that the conditions for water use will become stricter. It is conceivable that this may lead to land-use change in some areas or even be more widespread across the district.

Appendix Two

Focus group participants

Farmer identifier	Attributes
Dairy 1	Mature dairy farmer, male, coastal location, agri-leadership
Dairy 2	Early career dairy farmer, sharefarmer, male, coastal plain's location,
Dairy 3	Mid-career dairy, female, arable enterprise, upper plain's location, agri-leadership
Dairy 4	Early career dairy, male, multi-farm owner, coastal plain's location
Dairy 5	Early career dairy, professional background, male, arable enterprise, central plain's location.
Dairy 6	Corporate dairy farming, multi-farm business, early-mid career, male, geographic spread
Dairy 7	Mid-career, multi-farm dairy owner, male, upper plain's location, agri-leadership
Dairy 8	Sharemilker, male, early career,
Dairy 9	Dairy farmer, male, central plain's location, agri leadership,
Dairy 10	Dairy farmer, mid-career, male, central plain's location, large scale.
Dairy 11	Dairy farmer, mid-mature career, male, central plain's location
Dairy 12	Sharemilker, male, mid-career, male, central plain's location
Arable 1	Arable farmer, male upper plain's location, mid careers, agri-leadership
Arable 2	Arable farmer, male, upper plains, mid-mature career, livestock enterprise
Arable 3	Arable and horticulture farmer, female, central plain's location, early career
Arable 4	Arable farmer, male, upper plain's location, mid-mature career, agri-leadership, livestock enterprise
Arable 5	Arable farmer, early career, male, upper plain's location, livestock enterprise
Arable 6	Arable farmer, male, mid-career, mid-plain's location, livestock enterprise
Livestock 1	Livestock farmer, early career, male, central plain's location,
Livestock 2	Livestock farmer, mature career, male, upper plain's location, agri-leadership
Livestock 3	Livestock farmer, female, early career, agri-industry, central plain's location
Livestock 4	Livestock farmer, female, early career, agri-industry, upper plain's location.
Livestock 5	Livestock farmer, female, mid-career, upper plains location, agri-leadership
Industry 1	Agri-industry, male, early career, Ashburton location,
Industry 2	Agri-industry, female, mid-career, costal plain's location
Industry 3	Argi-industry, male, mid career,
Industry 4	Agri-Industry and dairy farming, mid-career, female, central plains location.

Appendix Three

Desktop Review - Supporting Land Use Adaption in a Changing Climate.

“Achieving Outcomes by Building Capability”

The AgriBusiness Group™

Supporting Land Use Adaption in a Changing Climate – desktop analysis.

(Contract No. 21/22RPF043)

Prepared for Ashburton District Council

Prepared by The AgriBusiness Group

March 2022

Contents

Please Read

Executive Summary

The AgriBusiness Group (TAG) was engaged by the Ashburton District Council (ADC) to carry out a desk top analysis which is the first stage of the ADC project “Supporting Land Use Adaption in a Changing Climate.” The projects aim is to empower farmers to explore new and alternative land use options by having a clearer understanding of opportunities emerging through climate change. The purpose of the project is to build farmer’s confidence to explore and act on land use options that deliver positive environmental, financial, social, and cultural outcomes.

This desktop analysis explores factors which influence a farmer’s openness to consider and knowledgeably act on climate change impacts and land use. Firstly, the desktop analysis assesses existing climate change research, decision support tools and behaviour change research. Then, in the context of Canterbury, the analysis identifies any barriers, gaps or constraints which limit Canterbury farmers from exploring alternative land use options in a changing climate.

Climate Change Data

Summary of climate change projections for Canterbury. (Modified from NIWA, 2020).

Climatic Factors	Historic (average over 1986-2005)	Mid Century	Late Century
Annual mean temperature	10-14°C for most coastal and inland low-elevation locations	Increase of 0.5-1.5°C (RCP4.5 and 8.5)	Increase of 0.5-2°C (RCP4.5) and 1.5-3.5°C (RCP8.5)
Hot days (≥25°C)	Most low elevation areas have 10-30 hot days in summer	10-40 extra days per year (RCP4.5 and 8.5)	10-20 extra days (RCP4.5) and 20-60 extra days per year (RCP8.5)
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Annual average rainfall	500-800 mm	Variations in change within the region. Majority to see minor changes to annual rainfall of ±5%	Same applies as mid century
Snowfall	0-1 snow days in low elevation eastern areas, 1-10 snow days in Mackenzie Basin and other inland areas, 25-100 snow days in higher elevation alpine regions.	Number of snow days reduces everywhere. Largest reduction seen in the coldest mountainous areas where there is a high number of snow days. Places that currently receive snow may experience increased rainfall from melted snow drops in the future, causing larger winter floods	Same applies as mid century

Annual mean wind speeds		Increase between 0-5% for most areas. 0-2% reduction for isolated inland and coastal areas (RCP4.5 and 8.5).	Increase between 0-5% (RCP4.5) and 2-10% (RCP8.5)
PED per year*	Low-elevation eastern areas and westernmost alpine areas experience between 0-300 mm. Higher elevation areas in central parts of Canterbury experience 200-400 mm.	Increase in accumulated PED for most of Canterbury, meaning more droughts. Most parts of eastern Canterbury to experience an increase in accumulated PED of 50-100 mm by 2040 (RCP 4.5 and 8.5). Some inland areas to experience an additional 100-150 mm.	Increase by 100-200 mm for many inland parts of Canterbury (RCP8.5)
Flood		Increase in floods for most parts of Canterbury. Some increases between 50-100% by 2036-2056 (RCP4.5 and 8.5).	Increase in floods exceeding 100% in some areas of Canterbury (RCP8.5).
Mean annual low flow**		Decrease for most of region. Some eastern areas (particularly south of Christchurch) to increase (RCP8.5)).	Decrease for most of region. Many areas decrease well over 20%.
Mean sea level	Has likely been rising at 3.2 mm/year since 1993.	Predicted to increase further. Increased coastal erosion and flooding.	Same applies as mid-century

The climate data that represents the potential impacts is not well presented to the farmer audience. For example the information presented in this report represents the average of six different models and is reported as the average of a twenty year period for two potential outcomes one of which RCP8.5 is highly unlikely to occur because we are already limiting our emissions of GHG. It is confusing, complex and very high level. Farmers like to see information that relates to their farm system type in order to make decisions about the impact it may have on their business.

We believe that it would be better to express the likely changes as a result of climate change as a continuum rather than an average of two periods.

The average figures that are presented do not offer significant variation from the present to concern farmers, so they aren’t particularly motivated to engage.

The missing data is the potential variability which will give farmers a much better view of the impact because it will highlight the extreme events both in terms of the severity, duration, and the probability of them happening. When that information is made available then farmers can make adjustments to their core farming system to allow for their farming systems to operate within the climate change which they are anticipating.

Specific data on Mid Canterbury should be generated from the downscaled data that has been presented for Canterbury so that farmers can relate to the information.

In the risk assessments that have been carried out in Canterbury the issues of long term drought and reduced water availability have been highlighted as requiring immediate attention. These are issues that are beyond individual farmers ability to address.

Projected Impacts

There is a wealth of information available on the projected impacts of climate change but much of it is supported by theoretical constructs alone.

Gaps in our knowledge include:

- The impact of extreme weather events on drought, wind and extreme rainfall.
- How the risk of pests and diseases will shift with climate change.
- Where the trade-off between increased temperatures and pasture resilience and quality lies.
- What is happening in the plant and animal breeding industry in relation to the genetic changes that will be required for the animals in the future.
- The impact of climate change on nitrogen leaching pulses as a result of drought accumulation and extreme rainfall events.
- The impact of heat stress on livestock, particularly deer.
- The impact on crop pollination.
- The impact on the mental health of farmers as a result of the increased frequency and severity of extreme events.
- The economic impact of climate change on both a farm and regional scale.
- The genetic change in our livestock required.
- The change to infrastructure required.
- Knowledge of the range of crops that can be grown (NZ and Australia overseas).
- Horticultural opportunities.
- Maintenance of our open pasture and intensive cropping system.
- Work conditions. Reducing barriers.
- Energy opportunities.

Research

As befits the enormity of the degree of change which is likely to occur and the requirement for people to limit the amount of climate change into the future by reducing their emissions of greenhouse gases the whole subject of climate change related research has been widely encouraged in New Zealand by the New Zealand government and to a lesser extent by private institutions.

The vast majority of the funding for climate change research comes from the Government via MBIE, MPI and MfE.

All of the current primary production Crown Research Institutes are involved in climate research either individually or in collaboration with other organisations on a wide range of research projects which incorporate both mitigation and adaptation projects. NZ Greenhouse Gas Research Centre is focused on mitigation strategies both for New Zealand and the Pastoral Greenhouse Gas Research Consortium is an industry funded consortium which aims to make the research available to farmers.

NIWA are a core research provider in the climate change space and are the host one of the national science challenges.

There is a plethora of research reports on the impacts and adaptation options for responses to climate change.

Farmers are currently concentrating on understanding mitigation of the amount of emissions of GHG's in order to comply with He Waka Eka Noa and aren't engaged with the issues around adaptation.

This lack of engagement is also related to the time scale of required action and farmers planning horizons.

There is a complete dearth of information on the subject of when farmers should start to make changes to the system because there is a lack of information on triggers or thresholds of when climate adaptation will occur.

Although there are good research results which demonstrate a framework for developing resilience strategies the knowledge that is required to both instigate and run the development of a resilience strategy is held by third parties not by the farmers.

There is a distinct lack of information around the specific options that are available to farmers to intensify their current farming systems in response to climate change.

Much of the current scientific information on climate change has not been translated into a form which is easily understandable by farmers so they are not aware of it or the implications for their farming systems in terms of the required transition or how they can operationalise the information.

Much of the science that has been carried out into climate change has not been carried out with any interaction with, or translation into a form that is accessible to, the people who it is designed to help.

The potentially significant positive impact of increased CO_2 concentrations, changing temperatures and rainfall (the CO_2 fertilisation effect) has not been proven outside the laboratory in New Zealand.

Little work has been done into demonstrating through modelling of innovative feed flexibility, practices, and strategies that allow farms to capitalise on excess biomass when it is available and avoid losses associated with climate induced downturns in production which are both responses to the expected extreme events.

Decision Support Tools

None of the farmer available tools that are able to model the farm system are able to incorporate climate change parameters into the one model and only Farmax is able to incorporate production, GHG and financial data for pastoral systems.

There is no specific climate adaptation modelling capability for the arable sector which is available for farmers to use. It may be that the existing tools that are available to farmers and consultants are sufficient to model the production and financial impacts if sound data is available to feed into those models.

It is our opinion that the vast majority of farmers aren't engaged in running decision support tools and where they are used on farm they are used by consultants on behalf of the farm owners.

There are many examples of decision support tools that farms can use to calculate their GHG emissions, and in some instances test various mitigation strategies. Many farmers are being exposed to their use because of the requirement to “know their number” under He Waka Eka Noa.

Drivers of Behaviour Change

Figure 1 below displays the thought process that people go through as they consider a new behaviour, process or system with each stage building on the information needed to make a decision. The key with this process is the encompassing Group Think that sits within and around each of the individual components. The influence of a group on an individual’s decision making can be powerful at all stages. Each of the stages is expanded on within this report.

Figure 1 Cycle of Behaviour Change

1 Background

The AgriBusiness Group (TAG) was engaged by the Ashburton District Council (ADC) to carry out a desk top analysis which is the first stage of the ADC project "Supporting Land Use Adaption in a Changing Climate." The projects aim is to empower farmers to explore new and alternative land use options by having a clearer understanding of opportunities emerging through climate change. The purpose of the project is to build farmer's confidence to explore and act on land use options that deliver positive environmental, financial, social, and cultural outcomes.

This desktop analysis explores factors which influence a farmer's openness to consider and knowledgeably act on climate change impacts and land use. Firstly, the desktop analysis assesses existing climate change research, decision support tools and behaviour change research. Then, in the context of Canterbury, the analysis identifies any barriers, gaps or constraints which limit Canterbury farmers from exploring alternative land use options in a changing climate.

The outcome of climate change impacts is an assessment of the breadth of work currently available, and which organisations it has been carried out by. This identifies gaps in knowledge that need addressing which will be useful to farmers in the Ashburton District to make informed decisions about future land uses.

The outcome of the decision support tools is an identification of the available land use decision support tools with an identification of the gaps in decision support tools and constraints to uptake of existing tools.

The scope of this desktop analysis is to include:

- An assessment of Climate Change data and information, with application to the Ashburton District.
- Identifying Climate Change research that has previously been completed and research which is currently underway.
- Summarise the outcomes of the Climate Change research.
- Identify the parties who have undertaken Climate Change research.
- Consider the effectiveness of Climate Change data and information and its usability for farmers to implement land use change.
- Identify decision support tools that support land use (system) change including the Integrated Farm Planning tool.
- Consider the availability of data, the language and messaging of the information, the accessibility of information and tools and the effectiveness for supporting farmers to explore land use change options.

2 Climate Change Data

The relationship between climate change and agriculture is especially important for farmers in Mid-Canterbury, who are not only exposed to the impacts that climate change will bring but also face some of the toughest environmental regulations in the country. The gradual changes in climate that will occur present an opportunity for farmers to adapt at both a small scale, such as waterway protection, and a larger scale, such as significant land use change. Although climate change poses a significant threat to farmers, each time events such as droughts occur, new knowledge on methods are gained to adapt to future events (Tonkin & Taylor Ltd, 2021).

Climate change is the long-term shift in temperature and weather patterns. Although climate change can be caused naturally, such as from variations in the solar cycle, the main driver in recent times globally is from human activities causing an increase in greenhouse gas concentrations. The effects of climate change in Mid-Canterbury have already been shown, however, the speed and severity of these is expected to rapidly advance. These effects include increases in temperature, annual precipitation, extreme rainfall, drought, winds, volatility, storms, and frosts. Although some positive impacts will arise from these, the majority are negative (NIWA, 2020)[1].

2.1 Scientific methodology

The scientific methodology used in the creation of this data by NIWA is summarised in this section. We have included it in this report because we believe that it is important to consider the methodology used in the creation of the projected impacts before we consider the findings.

2.1.1 Representative Concentration Pathways

Future climate change projections are considered under four scenarios of future greenhouse gas concentrations, called Representative Concentration Pathways (RCPs) by the IPCC. The four RCPs project different climate futures based on future greenhouse gas concentrations, determined by economic, political and social developments during the 21st century.

RCP2.6 is a mitigation scenario requiring significant reduction in greenhouse gas emissions, RCP4.5 and RCP6.0 are mid-range scenarios where greenhouse gas concentrations stabilise by 2100, and RCP8.5 is a ‘business as usual’ scenario with greenhouse gas concentrations continuing to increase at current rates. Projections for the future climate in Canterbury are presented for RCP4.5 and RCP8.5 in this report.

2.1.2 Climate Modelling

Climate model simulation data from the IPCC Fifth Assessment has been used to produce climate projections for New Zealand. Six climate change models (GCM) were chosen by NIWA for dynamical downscaling. These models were chosen because they produced the most accurate results when compared to historical climate and circulation patterns in the New Zealand and southwest Pacific region. Downscaled climate change projections are reported at a 5 km x 5 km resolution over Canterbury. Climate projections present the average of the six downscaled models. Climate projections are presented as a 20-year average for two future periods: 2031-2050 (termed

[1] NIWA. (2020, February). *Climate change projections for the Canterbury Region.* Environment Canterbury. https://www.ecan.govt.nz/your-region/your-environment/climate-change/climate-change-in-canterbury/climate-change-projections-for-canterbury/

‘2040’) and 2081-2100 (termed ‘2090’). All changes are shown relative to the baseline climate of 1986-2005 (termed ‘1995’).

2.1.3 Hydrological Modelling

NIWA’s TopNet model is used in this study. TopNet is a spatially semi-distributed, time-stepping model of water balance. The model is driven by time-series of precipitation and temperature, and additional weather elements where available. TopNet was run continuously from 1971 to 2100, with the spin-up period 1971 excluded from the analysis. The climate inputs were stochastically disaggregated from daily to hourly time steps. The simulation results comprise time-series of modelled river flow for each computational sub-catchment, and for each of the six GCMs and two RCPs considered. Hydrological projections are presented as the average for two future periods: 2036-2056 (termed ‘mid-century’) and 2086-2099 (termed ‘late-century’). All maps show changes relative to the baseline climate (1986-2005 average).

2.1.4 Limitations of the modelling.

NIWA list the limitations of their modeling as being:

- The models reported may not accurately capture how extreme events are changing.
- The average of six models is used in this report, which gives no indication of the range of results that the models project. Using the average result balances out the errors that may be apparent in each model.
- The time periods chosen for historic and future projection span 20-year periods. This is seen as a relatively short timeframe to understand average conditions in the historic period and in the future, as there is likely an influence of underlying climate variability.
- Care needs to be taken when interpreting grid-point-scale projections such as those presented in the tables in the report. The underlying climate data are Virtual Climate Station data, which are interpolated from physical climate stations. Therefore, the data from these grid points may be slightly different to on-the-ground observations, due to the interpolation procedure (particularly if the grid point is surrounded by multiple different stations or if there are no stations nearby). It is useful to look at broader patterns between grid points, e.g. coast vs. inland, and the magnitude of change at different time periods and scenarios, when considering the values.

2.2 Climate Projection Results

Canterbury is set to experience more severe climatic conditions compared with what is currently experienced (NIWA, 2020). The extent to which these climatic conditions will develop is dependent on exactly how much greenhouse gas emissions increase. **Table 1** summarises the latest predictions made by NIWA as to the likely climate changes Canterbury is expected to experience.

It should be noted that the information presented in this report is the average results for Canterbury as that is the level that it is reported at in the NIWA report. As we have previously discussed the Canterbury data has been taken from a representation of Canterbury’s weather which has been derived from models that have been downscaled to report the changes that occur at a grid of 5 x 5 km’s. Therefore it is possible for the data for Mid Canterbury to be reported for the Mid Canterbury district alone. While the results of the Mid Canterbury data would be different on average and for any given site, we are not sure whether the accuracy of those figures would provide any further certainty to the information because of the uncertainty and limitations that are inherent in the manner in which the information was derived.

As can be seen from Figure 2 there is very little difference between the Mid Canterbury data alone from the data for the whole of Canterbury apart from the data presented from the end of century data under RPC 8.5.

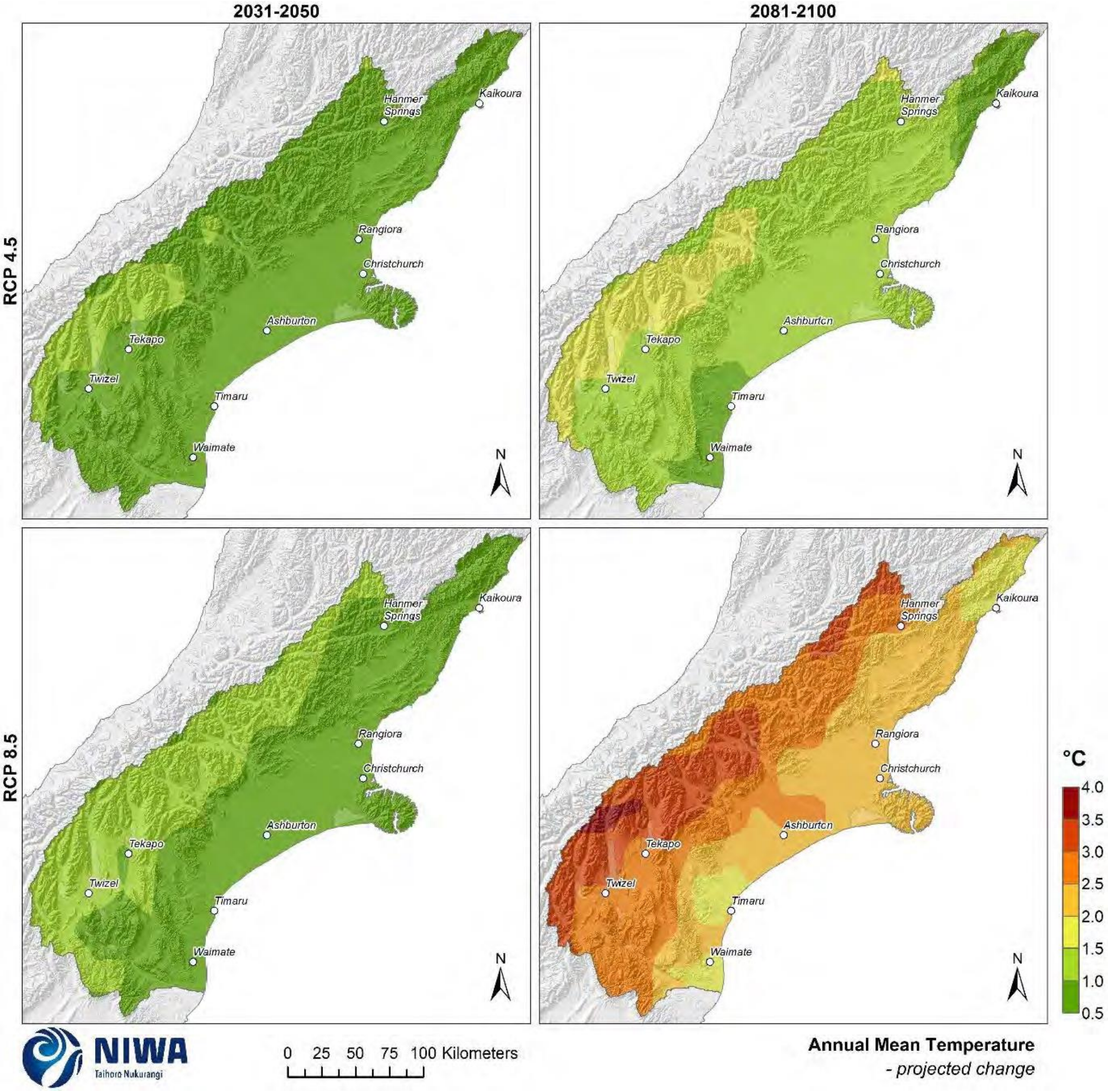

Figure 2: Projected annual mean temperature changes by 2040 and 2090, under RCP4.5 and RCP8.5. Climate change scenarios: RCP4.5 (top panels) and RCP8.5 (bottom panels). Time periods: mid-century (2031-2050; "2040" – panels on left) and end-century (2081-2100; "2090" – panels on right). Changes relative to 1986-2005 average, based on the average of six global climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km.

Table 1: Summary of climate change projections for Canterbury. (Modified from NIWA, 2020).

Climatic Factors	Historic (average over 1986-2005)	Mid Century	Late Century
Annual mean temperature	10-14°C for most coastal and inland low-elevation locations	Increase of 0.5-1.5°C (RCP4.5 and 8.5)	Increase of 0.5-2°C (RCP4.5) and 1.5-3.5°C (RCP8.5)
Hot days (≥25°C)	Most low elevation areas have 10-30 hot days in summer	10-40 extra days per year (RCP4.5 and 8.5)	10-20 extra days (RCP4.5) and 20-60 extra days per year (RCP8.5)
Frost days (≤0°C)	Most low elevation areas have 10-50 frost days in winter	10-30 fewer days per year	5-20 fewer days (RCP4.5) and 10-50 days (RCP8.5) per years
Annual average rainfall	500-800 mm	Variations in change within the region. Majority to see minor changes to annual rainfall of ±5%	Same applies as mid century
Snowfall	0-1 snow days in low elevation eastern areas, 1-10 snow days in Mackenzie Basin and other inland areas, 25-100 snow days in higher elevation alpine regions.	Number of snow days reduces everywhere. Largest reduction seen in the coldest mountainous areas where there is a high number of snow days. Places that currently receive snow may experience increased rainfall from melted snow drops in the future, causing larger winter floods	Same applies as mid century
Annual mean wind speeds		Increase between 0-5% for most areas. 0-2% reduction for isolated inland and coastal areas (RCP4.5 and 8.5).	Increase between 0-5% (RCP4.5) and 2-10% (RCP8.5)
PED per year*	Low-elevation eastern areas and westernmost alpine areas experience between 0-300 mm. Higher elevation areas in central parts of	Increase in accumulated PED for most of Canterbury, meaning more droughts. Most parts of eastern Canterbury to	Increase by 100-200 mm for many inland parts of Canterbury (RCP8.5)

	Canterbury experience 200-400 mm.	experience an increase in accumulated PED of 50-100 mm by 2040 (RCP 4.5 and 8.5). Some inland areas to experience an additional 100-150 mm.	
Flood		Increase in floods for most parts of Canterbury. Some increases between 50-100% by 2036-2056 (RCP4.5 and 8.5).	Increase in floods exceeding 100% in some areas of Canterbury (RCP8.5).
Mean annual low flow**		Decrease for most of region. Some eastern areas (particularly south of Christchurch) to increase (RCP8.5)).	Decrease for most of region. Many areas decrease well over 20%.
Mean sea level	Has likely been rising at 3.2 mm/year since 1993.	Predicted to increase further. Increased coastal erosion and flooding.	Same applies as mid-century

* Potential evapotranspiration deficit (PED) is the most sensitive measure of drought intensity. It is the total amount of water required by irrigation or rainfall to maintain plant growth at levels unconstrained by water shortage. It is measured in mm of accumulation.

**Mean annual low flow is classified as the mean of the lowest 7-day average flows in each year of a projection period (NIWA, 2020)

2.3 Climate Change Risk

There have been two assessments of the potential risks to the Canterbury region from climate change. The first was an initial risk screening[2] which was then followed up with a risk assessment[3]. It is presumed in this report that the risks that are inherent in the Canterbury risk assessments are equally applicable to Mid Canterbury.

2.3.1 Risk Screening

In the report they summarise the risks as:

The result of these meetings was a list of risks that are predicted to have the greatest effect across the Canterbury region. These risks were measured based on the climate hazards that affect them, and the impact that the risk is likely to have on the region. For the risks in the built environment, natural environment, and economy value domains, over 180 risks were identified. Of these, 55%

[2] Tonkin and Taylor 2020: Canterbury Climate Change Risk Screening
[3] Tonkin and Taylor 2022: Canterbury Climate Change Risk Assessment

were assessed as moderate, major or extreme risks. Within those three value domains, 46% of risks were identified as priority risks, having a big impact on the region.

Climate hazards that might affect the economy domain include flooding, fire, higher temperatures, drought, storms and wind, reduced snow and ice, marine heatwaves, and changes in ocean chemistry. These hazards will likely affect livestock, crops, forestry, fishing and aquaculture, and tourism.

The priority risks that were identified in the screening report which are relevant to the primary industries are shown in Table 2.

Table 2: Priority risks identified in the Canterbury Risk Assessment Report which are relevant to the primary industries.

Category	Risk	Assessment*
Livestock	Drought	
	Higher air temperature.	
Crops	Higher air temperature	
	Flooding	
	Higher annual rainfall	
Exotic Forestry	Storms and winds	
	Increased fire conditions	
	Higher mean air temperature	
Surface water availability and quality.	Reduced volume of snow and ice.	
	Lowering of mean annual rainfall.	
	Flooding	
Groundwater availability and quality	Mean annual rainfall	
	Drought	
	SLR and salinity stresses	

*

Extreme	
Major	
Moderate	

2.3.2 Climate Change Risk Assessment

In this report the author's state:

This report outlines the risks related to physical climate change that the Canterbury Region faces. The report centres around Te Tūtei o Te Hau (an integrated framework) aligned both with a Te Ao Māori worldview, and with the National Climate Change Risk Assessment (NCCRA) framework. It provides decision makers within relevant Councils with the technical information to enable *prioritisation of the risks outlined, and to enable them to plan for action through development of strategic and long-term plans.*

In the report they outline their methodology as including:

The risk assessment method is framed by the International Panel on Climate Change (IPCC) and is consistent with that used during the screening stage in 2020. This CCRA involved:

- *Establishment of a Papatipu Rūnanga Project Steering Group (RPSG), to guide and advise on engagement and Te Ao Māori content.*
- *Co-development of the Te Tūtei o Te Hau (integrated framework) with the RPSG.*
- *Risk rating based on assessment of exposure and vulnerability.*
- *Refinement and description of human and governance related risk.*
- *A literature review, including gaps analysis, to build detailed understanding of priority risks.*
- *Risk aggregation, aligning risks to the new integrated framework, to allow for easier communication and reporting as part of this project.*
- *Stakeholder engagement, aligned to stakeholder and partner needs, including targeted subject matter workshops, focus groups, kānohi-ki-te-kānohi hui (face to face meetings), insights questionnaires (surveys), and targeted phone calls.*
- *Five case studies, chosen by participants, to explore interacting risks, recognising that the impacts of climate change will not occur in isolation, and risks will interact propagate through systems, creating multiple pressures across value areas.*
- *Identification of opportunities.*

In the section on Agriculture (crops and livestock) they comment that;

The highest identified climate change risks to agriculture include risks to livestock farming due to higher temperatures and drought, and risks to crops due to higher temperatures, drought, storms and wind. The exposure of agricultural land to drought and warmer temperatures will increase over time. Livestock farming is extremely sensitive to the reduction in water availability that is likely to be associated with drought. Livestock are sensitive to temperature increases, as these can cause heat stress.

The adaptive capacity of livestock to increased drought is rated as low. However, agriculture is rated as having a higher adaptive capacity to increased temperatures, as farmers have the potential to change stock breed or adjust farm management practices (e.g., shade) to suit a changing climate.

Crops are sensitive to damage from storms, wind, flooding and increased pests, and are extremely dependant on water availability. The potential to change crop cycles and adjust timing or varieties will provide some adaptive capacity.

They summarise the risks to agriculture in Table 3.

Table 3: Summary of risks to agriculture.

Risk statement	Risk: Present	Risk: 2050 (RCP8.5)	Risk: 2100 (RCP4.5)	Risk: 2100 (RCP8.5)	High level description
Risk to crops due to drought	High	Extreme	Extreme	Extreme	Projected increase in drought potential is likely to impact crops. Crops are extremely dependent on water availability for irrigation.
Risk to crops due to storms and wind	Moderate	Moderate	High	High	Projected increases in storms and wind will increase exposure of crops to flooding, wind and storm damage. Crops are highly sensitive to damage from flooding and storms which can destroy crops. Change of crop cycle, timing or varieties may provide some adaptive capacity, also changing management measures such as wind shelter breaks
Risk to crops due to higher mean temperatures	Insignificant	Low	Moderate	Moderate	Projected increase in temperatures may increase pests and irrigation demand. Change of crop cycle, timing or varieties may provide some adaptive capacity or increased use of pesticides.
Risk to livestock due to drought	High	Extreme	Extreme	Extreme	Projected increase in drought potential is likely to impact livestock farming. Livestock farming is extremely dependent on water availability to sustain optimum grass growth and for stock drinking water. Relocation of stock or feed supplementation may reduce impacts of drought on stock.
Risk to livestock due to higher mean temperatures	Insignificant	Low	Moderate	Moderate	Projected increase in temperature are likely to impact livestock farming. Livestock are moderately sensitive to temperature, which can lead to heat stress and lower milk production. The impacts of temperature on herds may be reduced through breeding for temperature resilience.

In relation to water demand they comment that:

Warmer temperatures and drought are likely to result in increased water demand. This includes increased irrigation to compensate for soil moisture loss through evapotranspiration, and increased stock water for thirsty stock under increased temperature. Irrigation is widespread in Canterbury, and many farmers will be affected by further pressure on water storage, water regulation, water storage access and irrigation availability (Stakeholder 2021). Reduced availability will contribute to the significant existing regulation challenges that farmers face in Canterbury (Kalaugher, 2015).

They also comment that:

Gradual changes in the climate may occur in a way that allows farmers to adapt, for example by planting weather tolerant native species for shelter, fire resilience, and waterway protection, or retiring marginal land that is vulnerable to flooding or erosion (MPI, 2019). The history of agriculture is based on adaptation, where farming practices have evolved to adapt to new territories and climates for centuries. Droughts and other climatic challenges pose a constant threat *to farmers, and the knowledge gained from previous methods of adaptation may be a valuable key to future adaptation in the face of unprecedented change (AgResearch, 2008).*

It should also be noted that in the section where they have done a brief analysis of future opportunities one of the examples is on viticulture and the other is on increased horticultural opportunities. Both of these future opportunities continue the natural progression of Canterbury farmers of intensification to new and more profitable land uses.

2.4 Weather Data Barriers, Gaps and Constraints to farmer engagement.

The climate data that represents the potential impacts is not well presented to the farmer audience. For example the information presented in this report represents the average of six different models and is reported as the average of a twenty year period for two potential outcomes one of which RCP8.5 is highly unlikely to occur because we are already limiting our emissions of GHG. It is confusing, complex and very high level. Farmers like to see information that relates to their farm system type in order to make decisions about the impact it may have on their business.

We believe that it would be better to express the likely changes as a result of climate change as a continuum rather than an average of two periods.

The average figures that are presented to not offer significant variation from present to concern farmers, so they aren't particularly motivated to engage.

The missing data is the potential variability which will give farmers a much better view of the impact because it will highlight the extreme events both in terms of the severity, duration and the probability of them happening. When that information is made available then farmers can make adjustments to their core farming system to allow for their farming systems to operate within the climate change which they are experiencing.

Specific data on Mid Canterbury should be generated from the downscaled data that has been presented for Canterbury so that farmers can relate to the information.

In the risk assessments that have been carried out in Canterbury the issues of long term drought and reduced water availability have been highlighted as requiring immediate attention. These are issues that are beyond individual farmers ability to address.

3 Projected Impacts

This section lays out the range of possible impacts that have been gained from a literature review of the subject.

3.1 Irrigation

Over 220,000ha of farmland in Mid-Canterbury is irrigated. Farm systems without irrigation will face the most severe impacts from climate change through the increased frequency and length of droughts. Although there is unlikely to be variation in groundwater recharge in Mid-Canterbury from climate change, there will be greater demand on groundwater from increased irrigation (Kenny, 2001)[4]. This is caused by an increase in the frequency of potential evapotranspiration deficit days and subsequent droughts. The efficiency and management of irrigation systems will become increasingly important, including infrastructure for water harvest and storage (Kenny, 2001).

Improved water storage systems will enable water capture during high rainfall periods of the year for efficient and productive use across drier conditions. The alternative is to change farming practices in areas such as pasture and livestock, so they adapt to the increased drought conditions (Palmer, 2009)[5].

Water demands are also likely to increase because of heat impacts on stock (Tonkin & Taylor Ltd, 2021)[6].

3.2 Livestock Feed

3.2.1 Pasture Production

Increasing carbon dioxide concentrations is expected to increase overall annual production and growth rates of pasture. Pasture growth will become more variable and unpredictable but declines in pasture production during the summer months will be offset by the warmer temperatures in winter and spring. In addition, the increased concentrations of atmospheric carbon dioxide will subsequently increase plant growth through photosynthesis and water use efficiency (Keller et al, 2021)[7].

With an early advancement of pasture growth, it may become preferable for farmers to bring forward operations, such as lambing dates (Palmer, 2009). During drought periods on unirrigated farms, shorter rooting pasture species such as ryegrass may struggle to survive. When this is combined with pests such as grass grub and Argentine stem weevil, pasture production can

[4] Kenny. (2001, September). *Climate Change: Likely Impacts of New Zealand Agriculture.* Ministry for the Environment. https://environment.govt.nz/assets/Publications/Files/impacts-agriculture-sep01.pdf

[5] Palmer, J. (2009). The future of pastoral farming in a changing climate. *Journal of New Zealand Grasslands, 71,* 69-72. https://doi.org/10.33584/jnzg.2009.71.2773

[6] Tonkin & Taylor Ltd. (2021, October). *Canterbury regional climate change risk assessment.* Environment Canterbury.

[7] Keller, E., Lieffering, M., Guo, J., Baisden, T., & Ausseil, A. (2021). Climatic factors influencing New Zealand pasture resilience under scenarios of future climate change. *Journal of New Zealand Grasslands, 17*, 105-122. https://doi.org/10.33584/rps.17.2021.3458

significantly decrease (Rollo et al., 1998)[8]. Farms with deep rooting species, such as lucerne and chicory, will be better off as pasture production will not be affected as significantly. Unirrigated farms that are unprepared for extended droughts may have to use winter feed stores. Although this will solve the feed deficit in the short term, it will cause additional stress in the subsequent winter from reduced feed availability.

With a changing climate, areas that have been previously unfavorable for the growth of a particular pasture species may now become favorable. For example, lucerne is a species grown in summer drought-prone areas of New Zealand such as Central Otago and inland Canterbury. However, areas that are likely to become more drought-prone could be suitable for lucerne growth. Increased carbon dioxide levels will see a stronger response from legumes in general compared with grasses. Increased species distribution of productive pasture can improve overall pasture persistence on a farm and the performance of livestock (Ministry for Primary Industries, 2020)[9].

3.2.2 Unwanted Species

Although climate change can provide advantages for the distribution of productive pasture species into new areas, it can also increase potential areas that pest and lower-feed quality species can inhabit. Climate change affects pests and lower-feed quality species through several factors, including altering their geographic range, habitat suitability, response to extreme events such as droughts, the annual number of generations and abundance. It is well established that pests and lower-feed quality species which are currently limited by cool temperatures are likely to increase their geographic range to warmer areas in New Zealand (Mansfield et al., 2021)[10].

Although limited information is available on exactly which unwanted pasture and pest species pose a threat to Mid-Canterbury, studies elsewhere have proved the extent to which these can spread, particularly for sub-tropical grasses. Paspalum experienced a 1.5º shift in latitude from mid-Waikato/East Cape to Wanganui/Cape Kidnappers between 1976 and 1988 due to warmer conditions (Kenny, 2001). Although sub-tropical grasses do provide a source of feed during periods of low soil moisture, the performance from livestock grazing is reduced, such as milk solids production.

3.3 Animal Health

3.3.1 Livestock Pests and Diseases

Livestock are no exception to the change in the distribution of pests and diseases. A prime example is Fasciola hepatica, also known as liver fluke. It is a parasite identified as a risk to Canterbury agriculture as climate change worsens. Liver fluke infects the liver and bile ducts of cattle and sheep and can cause serious economic damage through symptoms such as poor milk and meat production. It is common for infected livestock to become weak and die. With climatic

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[8] Rollo, M., Sheath, G., Slay, M., Knight, T., Judd, T., & Thomson, N. (1998). Tall fescue and chicory for increased summer forage production. *Journal of New Zealand Grasslands, 60,* 249-253. https://doi.org/10.33584/jnzg.1998.60.2284

[9] Ministry for Primary Industries. (2020, March 12). *Climate variability will affect dairy farming in New Zealand.* Climate Cloud. https://climatecloud.co.nz/assets/all-assets/Climate-Change_Dairy-v1.5.pdf

[10] Mansfield, S., Ferguson, C., Gerard, P., Hodges, D., Kean, J., Phillips, C., Hardwick, S., & Zydenbos, S. (2021). Climate change impacts on pest ecology and risks to pasture resilience. *Journal of New Zealand Grasslands, 17*, 105-122. https://doi.org/10.33584/rps.17.2021.3458

changes, Canterbury is predicted to experience a 186% increase in infection risk by 2090 (Haydock et al., 2016)[11].

Facial eczema is a disease also predicted to become a risk for Canterbury farmers. Although no information was gathered for Mid-Canterbury specifically, there was noteworthy information collected for Christchurch. Sheep are particularly susceptible to facial eczema as they graze closer to the base of the sward than cattle. Stock infected with facial eczema commonly experience weight loss, decreased production and skin photosensitivity. Facial eczema is often found in areas with warm, overcast, and showery weather of at least three days, or hot fine weather with long overnight dew periods. Christchurch currently has a spore count of zero, so facial eczema is classified as low risk. However, with the projected climate for the year 2090, this is projected to increase to a moderate risk with more favorable conditions (Dennis et al, 2014)[12].

For dairy cows, a major health issue likely to increase in severity is mastitis. By 2050, increased temperatures and rainfall may cause an increase in the incidence of mastitis. There may also be indirect effects causing an increased incidence of mastitis such as a power outage, where cows cannot be milked (Vallee et al., 2020)[13].

To maintain livestock and pasture health in response to climate-induced changes in pests, parasites, and diseases, it is likely there will be an increase in preventative and treatment measures such as parasiticides and pesticides (Tonkin & Taylor Ltd, 2021). Therefore, the risk of these chemical substances entering the food chain increases as well as the risk of parasiticides and pesticide resistance in livestock and pastures. This has implications for the safety, distribution, and consumption of livestock products (United States Environmental Protection Agency, n.d.)[14].

2.4.2 Heat Stress

Climate change can increase the occurrence of heat stress in livestock and affect their productivity, health, and welfare. Cattle are affected through an increased body temperature and respiration rate. This reduces feed intake, milk and meat production and fertility. Under New Zealand conditions, a three-day average temperature of 21°C at 75% humidity will begin to cause a decrease in the milk production of Holstein-Friesian cattle. Sheep are affected through an increased respiration rate, body temperature, water intake and a reduction in feed intake, milk yield

[11] Haydock, L., Pomroy, W., Stevenson, M., & Lawrence, K. (2016). A growing degree-day model for determination of *Fasciola hepatica* infection risk in New Zealand with future predictions using climate change models. *Veterinary Parasitology, 228,* 52-59. https://doi.org/10.1016/j.vetpar.2016.05.033

[12] Dennis, N., Amer, P., & Meier, S. (2014). Predicting the impact of climate change on the risk of facial eczema outbreaks throughout New Zealand. *Proceedings of the New Zealand Society of Animal Production, 74,* 161-163. https://www.researchgate.net/publication/264544757_Predicting_the_impact_of_climate_change_on_the_risk_of_facial_eczema_outbreaks_throughout_New_Zealand

[13] Vallee, B., Wada, M., Cogger, N., Kelly., Marshall, J., Benschop, J., Macara, G., Tait, A. (2020, October). *Effects of climate change on grazing livestock health in New Zealand.* Ministry for Primary Industries. https://www.mpi.govt.nz/dmsdocument/45574-Effects-of-climate-change-on-grazing-livestock-health-in-New-Zealand

[14] United States Environmental Protection Agency. (n.d.). *Climate impacts on agriculture and food supply.* City of Chicago. https://climatechange.chicago.gov/climate-impacts/climate-impacts-agriculture-and-food-supply

and liveweight gain. In addition, heat stress in sheep can also cause impaired liveweight reproduction and lower birth weights in lambs (Schütz, 2011)[15].

Livestock are considered to have a low adaptive capacity to increased drought. However, external factors can be managed to increase the adaptive capacity of agriculture to rising temperatures through changing stock breed or adjusting farm management practices e.g., providing shade (Tonkin & Taylor Ltd, 2021).

3.4 Livestock Classes

Climate change is predicted to change the species composition of red meat producing livestock in Canterbury. As the mean temperature and rainfall increase, breeds or even species will be replaced. Sheep and deer numbers are expected to decrease while cattle numbers increase. **Table 2** demonstrates the current percentage of sheep, beef, and deer in Canterbury at 60%, 34% and 6% respectively with a mean temperature of 10.7°C. However, with the worst-case scenario of a mean temperature of 13.7°C by 2100, the percentages are predicted to change to 39%, 59% and 2%.

The percentage of cattle is predicted to increase over the years as they have higher disease and parasite resistance and shorter anestrus lengths. Sheep are prone to a higher number and risk of diseases than cattle when in warmer temperatures, such as facial eczema, as discussed earlier. Deer are similar and in addition, are more susceptible to ticks than cattle. As sheep and deer have longer anestrus than cattle, their range of potential mating and birthing dates is limited as well as optimal fecundity levels. These factors make it more difficult to match pasture growth curves to optimize production (McRae et al 2018)[16].

Table 2: Predicted species percentages for Canterbury, based on predicted mean temperatures under different models* of climate change.

Current		**RCP2.6**		**RCP4.5**		**RCP6.0**		**RCP8.5**	
Mean temp (°C)	Sheep Beef Deer	Mean temp (°C)	Sheep Beef Deer	Mean temp (°C)	Sheep Beef Deer	Mean temp (°C)	Sheep Beef Deer	Mean temp (°C)	Sheep Beef Deer
10.7	60% 34% 6%	11.4	55% 40% 5%	12.1	50% 46% 4%	12.5	47% 49% 3%	13.7	39% 59% 2%

[15] Schütz, K. (2011). Heat stress in farm animals. *Proceedings of the New Zealand Society of Animal Production, 71*, 178-202. http://www.sciquest.org.nz/node/147226\

[16] McRae, K., Rowe, S., McEwan, J. (2018). Potential alterations in New Zealand sheep, beef cattle and deer numbers due to climate change: what can genetics offer? *New Zealand Journal of Animal Science and Production, 78*, 146-150. brief-communication-potential-alterations-new-zealand-sheep-beef-cattle-and-deer-numbers-due-climate.pdf (nzsap.org)

* The four models, known as representative concentration pathways (RCPs), include one mitigation pathway (RCP2.6, which requires removal of some of the CO_2 presently in the atmosphere), two stabilisation pathways (RCP4.5 and RCP6.0) and one pathway with very high greenhouse gas concentrations (RCP8.5) (From McRae et al, 2018).

3.5 Crops

3.5.1 Crop Production

Limited information has been provided on the impact of climate change on cropping in Canterbury specifically, however nationally, it is expected that climate change will have an overall positive impact on cropping. Depending on crop sowing time, there is potential for the higher temperatures to allow temperate crops to be sown earlier and therefore mature faster. Although higher temperatures could decrease yields, it is possible for the higher levels of carbon dioxide to offset this through increased growth. However, growth from increased carbon dioxide will require an increase in nitrogen fertiliser applications to realise the increased yield potential (EcoClimate, 2008)[17].

Higher summer temperatures and a reduced risk of frost also open the opportunity for increased maize grain production in Canterbury, particularly from 2030 onwards. For crops to benefit from climate change, there must be sufficient water availability, especially during drought periods. This is particularly relevant for maize which has a later growing season compared with crops such as wheat and a higher soil moisture demand (Kenny, 2001).

The timing of fertiliser applications and pest control management may need to shift to accommodate changes in seasonal temperatures (Kenny, 2001). As rainfall periods increase in intensity, some harvested crops may require drying facilities and additional machinery. Different types of machinery, such as tractors or tyres, may allow for easier management of waterlogged soils and to reduce soil damage and compaction. There is also a risk that waterlogged soils may delay crop planting in spring, reduce plant strike following planting, or cause considerable crop damage later in the season (Butler et al, 2019)[18].

3.5.2 Crop Pests and Diseases

Like pasture diseases, climate change affects pests and diseases through numerous factors, including altering their geographic range, habitat suitability, response to extreme events such as droughts, the annual number of events and abundance. Crop pests and diseases currently limited by cool temperatures are likely to increase their geographic range to warmer areas in New Zealand (Mansfield et al., 2021). Increased episodes of heavy rainfall and subsequent increase in flooding events can contaminate land. This can spread antibiotic resistant organisms and increase the risk

[17] EcoClimate. (2008). Costs and Benefits of Climate Change and Adaption to Climate Change in New Zealand Agriculture: What do we know so far? Motu. https://www.motu.nz/assets/Documents/our-work/environment-and-resources/lurnz/Costs-and-benefits-of-climate-change-and-adaptation-to-climate-change-in-New-Zealand-agriculture-what-do-we-know-so-far.pdf

[18] Butler, M., Cope, J., & Doogue, J. (2019, September). *The impacts of climate change in Canterbury: a summary of the literature.* Environment Canterbury. https://cms.itstimecanterbury.co.nz/assets/1909_CC-impacts-in-Canterbury_ECan.pdf

of fungal growth. This could cause an increase or introduction of residues in food and a potential increase in foodborne disease (Lake et al., n.d.)[19].

It is likely that the fall armyworm, which is a pest of maize, will eventually inhabit Mid Canterbury. As climate warming allows, it will spread southwards from Australia, where it can spread to New Zealand through increasing frequency and strength of westerly weather patterns. The moth is a strong flier, so has the potential to infest distant maize crops in summer before returning to warmer locations in winter (Mansfield, 2021).

Although there is an increased risk of some crop diseases, many will experience no/minor change from climate change. For grapevine downy mildew in Canterbury specifically, Beresford., & McKay (2012)[20] concluded there is unlikely to be a major effect on infection risk.

3.5.3 Crop Pollination

Crops in Canterbury are pollinated by a variety of insects. These include honeybees, bumblebees, native bees and flies. Pollinator diversity is important to maximise crop yields. Climate change can affect the pollinator activity windows through altering foraging periods as well as their behavior. Some species, such as honeybees, will benefit from climate change. Honeybees are likely to increase foraging activity over the crop flowering period, as there will be an increase in bee abundance and extended foraging times. However, species such as short-tongued bumblebees and fly species such as orange hoverflies will be negatively affected. The optimal foraging conditions are predicted to decrease from an increased number of hot days (>25°C) (Howlett, et al 2013)[21].

Although the impact on other species is unknown, it is likely Leioproctus and Lasioglossum bees, blowflies, green soldier flies and drone flies will experience a change in population from climate change. Therefore, although there will be an overall increase in honeybee abundance with climate change, pollinator diversity is expected to decrease (Howlett, et al 2013). A lack of biodiversity is a significant issue as, if a deadly pest or disease entered the New Zealand honeybee population, it could result in large economic losses to crop growers as there is not a sufficient number of alternative species to pollinate.

3.6 Labour

Increased temperatures are likely to make working conditions more difficult for workers. The effects of heat stress can have other flow on impacts. For example, increased illnesses from heat stress may hinder agricultural worker's ability to work. Therefore, they experience reduced income with flow on effects to the economy as a result. A reduced ability for agricultural workers to carry out

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[19] Lake, R., Bolton, A., Brightwell, G., Cookson, A., Benschop, J., Burgess, S., & Tait, A. (n.d). *Adapting to climate change: Information for the New Zealand food system.* Ministry for Primary Industries. https://www.mpi.govt.nz/dmsdocument/28164-Adapting-to-climate-change-Information-for-the-New-Zealand-food-system

[20] Beresford, R., & McKay, A. (2012, September). *Climate change impacts on plant diseases affecting New Zealand horticulture.* Ministry for Primary Industries. https://www.mpi.govt.nz/dmsdocument/4085-Climate-change-impacts-on-plant-diseases-affecting-New-Zealand-horticulture

[21] Howlett, B., Butler, R., Nelson, W., Donovan., & The New Zealand Institute for Plant & Research Ltd. (2013, September). *Impact of climate change on crop pollinator in New Zealand.* Ministry for Primary Industries. https://www.mpi.govt.nz/dmsdocument/4101/direct

tasks may reduce food security and affect the mental health of workers from a lack of work (Tonkin & Taylor Ltd, 2021).

3.7 Financial Planning and Supply Chain

Climate change will significantly affect the financial planning of Mid-Canterbury farms.

The costs of climate change can be divided into two components:

- Costs directly related to changes in temperature, rainfall etc. through their effect on biomass production and the demand for energy or human health.
- Costs of adjustment of transition, especially for the cost of stranded assets and destroyed assets in the case of temporary severe events (EcoClimate, 2008).

Climate change will affect the global export market, which will require farmers to find a delicate balance between conservatism and risk taking when planning to remain competitive. It is unknown yet the extent to which climate change will positively or negatively affect Canterbury's export potential, in addition to the strong exposure Canterbury agriculture already experiences. There has also been no account for the changes in the prices of inputs or outputs that may be caused by shortages or surpluses of products or by policy responses to these shortages or surpluses (Kenny, 2001).

In addition, disruptions to agriculture supply chains are likely. Flooding and other sudden extreme events can disrupt transport routes. Agricultural products cannot efficiently move through the supply chain. This is particularly concerning for the dairy industry. Dairy cows are typically milked twice a day, with stored milk collected and transported within one to two days for processing. Alterations in the frequency of milking can cause serious animal health issues and subsequent decreases in milk production and transport disruptions can cause milk to become unsafe for human consumption (Welth & Marshall, 2017)[22].

3.8 Drivers of Land Use Change

Land has always been used and modified to meet the material, social and cultural needs of humans (Briassoulis, 2009)[23]. When considering this, it is important to understand the difference between land use and land cover. Land cover is defined by the physical or biological categorisation of land, such as forest or grassland. In comparison, land use is defined by the purposes regarding land cover, such as pastoral farming (Meyer and Turner, 1994)[24]. This section of the literature review focuses on land use, particularly for significant events where the overall nature of the farm is visibly changed. Rural land use change can be classified in a general sense into (Britton and Fenton, 2007)[25]:

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[22] Welth, M., & Marshall, S. (2017, October 19-20). *Modelling New Zealand dairy production: The impact of traceability between the farm and the factory* [Paper presentation]. New Zealand Agricultural and Resource Economics Society (NZARES) Conference, Rotorua, New Zealand. https://ideas.repec.org/p/ags/nzar17/269525.html

[23] Briassoulis, H. (2009). Factors influencing land use and land cover change. *Land Use, Land Cover and Soil Sciences.* Vol I -Factors Influencing Land Use and Land Cover Change. https://www.eolss.net/Sample-Chapters/C12/E1-05-01-03.pdf

[24] Meyer, W., Turner, B. (eds). (1994). Changes in Land Use and Land Cover: A Global Perspective. Cambridge University Press

[25] Britton, R., & Fenton, T. (2007). *Identification and analysis of drivers of significant land use change.* Environment Waikato Technical Report 2007/40. Environment Waikato. Hamilton.

- Forestry to pastoral use
- Current dairying to intensive dairying
- Pastoral use to cropping/horticulture
- Any land to renewable energy
- Pasture to forestry
- Any land to urban/rural residential/infrastructure.

Many factors drive land use change, with interactions and influences between each of these factors, as categorised by AgFirst (2017)[26] are covered in the following sections.

3.8.1 Biophysical Factors

These are inclusive of a range of biophysical factors which can affect land use decisions:

- Soil type – free draining or not, suitability for horticulture compared with pastoral agriculture, depth of topsoil, fertility.
- Topography – how flat or steep the land is, aspect of the land, suitability for mechanised farming, erosion risk.
- Climate – the amount of rainfall, how windy, sunshine hours, degree of seasonal variation, temperatures at various times of the year.
- Availability of water – for irrigation or domestic/industrial consumption, quality of water.

3.8.2 Economic Factors

This is inclusive of a range of factors roughly classified as "economic":

- Profit – costs and returns from specific land uses and how they compare
- Capital – accessibility of capital for investment, development and seasonal finance. This can vary largely at an individual level.
- Markets – availability of market/s for the land use, proximity to market.
- Infrastructure – availability of infrastructure to support the proposed land use, such as servicing firms, processing firms and/or marketing firms. How quickly necessary infrastructure be completed if not already present. Infrastructure can also include road transport and landscape factors such as airports and availability/accessibility of irrigation.
- Information accessibility – availability of information/advice regarding the proposed land use change.
- Accessibility of skilled labour required for the proposed land use activity.
- Land tenure – secured property rights enhance the incentive to consider long-term land use decisions. Uncertain land tenures can result in a focus only on short-term farming activities.

3.8.3 Technological Factors

An understanding of how technology influences a farm system can result in the ability to change land use in cases which was previously not thought possible. When the technology for farms or

[26] AgFirst. (2017, August). *Analysis of drivers and barriers to land use change.* https://www.agfirst.co.nz/wp-content/uploads/2020/11/Drivers-and-Barriers-to-Land-Use-Change-Report.pdf

farm system management knowledge is well understood, land use change that may not have previously been possible can be undertaken. For example, the development of aerial top-dressing allowed for the fertility of steep hill country to be significantly improved. This meant stock numbers could be increased, with a subsequent increase in the profitability of hill country farms. A second example is the development of artificial drainage and frost protection systems. This meant the soil quality could be improved and/or a climatic condition could be combatted to provide a more favorable environment for crop growth.

3.8.4 Societal/Regulatory Factors

There is a large social pressure on agriculture to meet the "societal license to farm," particularly surrounding animal welfare and the environmental impacts of land use. Regulations enforce this and have the direct potential to affect not only land use but land use change. This is through either:

- Regulations around discharges, such as nutrients, agri-chemicals and greenhouse gases
- Other regulatory/incentive frameworks, such as taxation and subsidies.

There are also wider forces from society that influence the supply of food. These include an increased global population, increased demand for agricultural land for urban housing and shifts in diet choices.

3.8.5 Individual Factors

Individual factors can influence people's thought process towards land use change. These can include age, education and experience, family circumstances, attitude to risk, access to capital, access to information and attitude to change. For example, a sheep and beef farmer may not wish to change land use to dairy as they prefer to spend mornings with their children and have more free time on the weekends. This is demonstrated by the responses to the 2015 Survey of Rural Decision Makers (Landcare Research 2015)[27] to the question on land use change, as demonstrated in **Table 3**.

Table 3: Primary reason for not changing land use/intensifying/increasing size of farm

Reason	Frequency	Percentage
Lack of financing	48	10.2%
Lifestyle decision	252	53.6%
Environmental decision	42	8.9%
Anticipate retiring soon	59	12.6%
Other	69	14.7%
	470	100%

[27] Landcare Research. (2015). *Survey of rural decision makers 2015.* https://catalogue.data.govt.nz/dataset/survey-of-rural-decision-makers-2015

3.9 Behaviour Change

Behaviour change in agriculture in New Zealand tends to follow the standard model (Rogers and Shoemaker) [28] of innovators, early adopters, early majority, late majority and laggards. An important trait of farmers who are open to change is they want to see proven examples and evidence of the changes or technology before they implement it themselves (Red Meat Profit Partnership 2019) [29].

Behaviour change can be thought of as a progression through a series of stages or a process of increasing readiness (MPI 2015)[30].

- Stage one being pre-contemplation where there is little awareness and unlikeliness to change.
- Stage two is contemplation where a level of awareness and planning is occurring along with assessing the pros and cons of an idea or opportunity.
- The third stage is preparation where the pros outweigh the cons.
- Stage four is where action starts to take place and is also often the stage where action may stop if a person is not well prepared.
- Stage five is maintenance where the behaviour change is continuing, or the opportunity fully adopted and in production.
- The final stage is termination where there is no desire to change back to the previous behaviour.

Societal and human factors are driving the need for land use change and therefor behaviour change in the current environment just as much as the impact of the climate on our current ability to continue farming as we are. The pressure from society and the consumer to produce and supply carbon zero products and reduce greenhouse gas emissions is stronger now than it ever has been leading to changes needing to occur in farming systems.

There are a wide range of behavioural theories relating to human behaviour all of which combined contribute to the decision-making process around changing behaviours. The three main guiding considerations are:

- behavioural beliefs which are beliefs about the likely consequences of the behaviour,
- normative beliefs which are beliefs about the normative expectations of others and
- control beliefs which are beliefs about the presence of factors that may facilitate or impede performance of the behaviour[1].

The report undertaken by AgFirst[31] is a comprehensive review of decision making in the face of climate change and biological greenhouse gases for our agricultural community.

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[28] Rogers, E.M. & Shoemaker, F.F. (1971) *Communication of innovations; a cross-cultural approach.* Free Press, New York.

[29] Extension Design Project Final Report. Red Meat Profit Partnership. https://www.rmpp.co.nz/site_files/13089/upload_files/ExtensionDesignProjectFinalReport(1).pdf?dl=1

[30] Over the Fence: Designing extension programmes to bring about practice change. Ministry for Primary Industries 2015.

[31] AgFirst. Literature Review and Analysis of Farmer decision making with regard to Climate Change and Biological Gas Emissions.

There are several factors that drive the uptake of new farming systems or changing a current system, they range from awareness of what the change entails through to how easy it might be to implement trials of the change within the farm system to assess its compatibility and the observed value of making that change.

Behaviour change can be modelled or displayed in various ways. The decision-making process can help you identify the underlying motivations and barriers for behaviour change[32]. Barriers to change and understanding those are just as important to opening people up to the opportunity to change. Knowledge transfer incorporates a lot of the behaviour change theories. In order for change to occur the information must be transferred in the right way at the right time and often multiple times as mentioned in both the AgFirst[1] and RMPP[27] report key findings.

The process of awareness, interest, preparation/evaluation, action/implementation, adoption, and maintenance/review is important in the knowledge transfer space. In the farming sector ideas may be trialed on a small scale to test the idea within the farm system or it may be tested or reviewed in a peer's system being visited and monitored during the annual cycle for its fit into a farm system before being upscaled or discontinued.

Ensuring changes in behaviour are possible and effective, a well-designed extension programme needs to be designed and implemented. Work done through the RMPP programme researched and highlighted the importance of an extension programme that is designed to fit the circumstances[27]. The report also reiterates those from the AgFirst report that farmer awareness, complexity of the issue, system fit, benefits to the system and the ability of the farmer to adapt the opportunity are all important factors in behaviour change, process change or technology adoption.

The impact of the RMPP Action Network programme was assessed through case study farms/groups and could be viewed as a report on behaviour change and process or technology adoption (RMPP 2020)[33]. Key performance indicators such as increases in lamb survival to sale, increase in sheep revenue, EBITRm, increases in productive areas of land and reductions in costs (eg, animal health, fertiliser) were identified and reported across multiple groups. All groups and farms were making changes within their business to achieve the results, behaviours had to change and be maintained for the results to come through.

3.10 Projected Data Barriers, Gaps and Constraints to farmer engagement.

The current situation compared to the future situation as detailed in the literature review is shown in Table 4. The gap between them has been used to detail our current gaps in knowledge around the potential impacts.

[32] Department of the Prime Minister and Cabinet: Behavioural Change Models, a summary of different models. https://dpmc.govt.nz/our-programmes/policy-project/policy-methods-toolbox/behavioural-insights/behavioural-change-models

[33] Measuring the impact of RMPP Action Network, Case Studies, November 2020 https://www.rmpp.co.nz/page/reports/

Table 4: the current situation and the future situation in mid-century taken from the literature review.

Category	Current	Mid Century
Annual Mean Temp	10 - 14°C	Warmer by 0.5 – 1.5°C
Hot Days	10 - 30	20 - 70
Frosts	10 - 50	0 - 20
Average rainfall	500 – 800 mm	± 5%
Snow	Variable	reduces
Winds		Increase 0 – 5 %
Potential evapotranspiration deficit	0 – 400 mm	50 – 550 mm
Floods		Increase by 50 – 100%
MALF		Decrease
Mean sea level		Increase
Irrigation	Restrained from any further extraction.	Greater demand due to higher PED, heat. Efficiency demands will increase. Water storage demands will increase.
Pasture production	Maximised pasture production at 12 K DM for dryland 24 K DM for irrigated.	Dryland – increased drought PED will limit potential production. Irrigated – Growth rates will increase, and the growing season will extend. Deeper rooting species and heat growing ranges will need to be adopted.
Unwanted species.	Limited due to seasonal factors	Climate limitations will be reduced so expect more intrusions.
Livestock pest and diseases	Limited due to seasonal factors	Climate limitations will be reduced so expect more intrusions.
Heat stress	At the edge of current productivity under heat.	More shelter. Change of genetics.
Livestock classes	Current optimum for finances.	More cattle less deer.
Crop production	Current optimum	Potential for higher yields due to increased growth rates and a longer season. Potential to grow more varieties as temp rise.
Crop diseases	Under control	Potential for increased risk but not big.
Crop pollination	Limited by unfavorable weather conditions at flowering.	Increased foraging times over the flowering period.
Labour		Heat will make working conditions more difficult.
Financial and supply chain		Increased extreme events have the potential to disrupt supply chains.

3.10.1 GAPS in current knowledge.

The impact of extreme weather events on drought, wind and extreme rainfall.

How the risk of pests and diseases will shift with climate change.

Where the trade-off between increased temperatures and pasture resilience and quality lies.

What is happening in the plant and animal breeding industry in relation to the genetic changes that will be required for the animals in the future.

The impact of climate change on nitrogen leaching pulses as a result of drought accumulation and extreme rainfall events.

The impact of heat stress on livestock, particularly deer.

The impact on crop pollination.

The impact on the mental health of farmers as a result of the increased frequency and severity of extreme events.

The economic impact of climate change on both a farm and regional scale.

The genetic change in our livestock required.

The change to infrastructure required.

Knowledge of the range of crops that can be grown (NZ and Australia overseas).

Horticultural opportunities.

Maintenance of our open pasture and intensive cropping system.

Work conditions. Reduce barriers.

Energy opportunities.

4 Climate Change Research

As befits the enormity of the degree of change which is likely to occur and the requirement for people to limit the amount of climate change into the future by reducing their emissions of greenhouse gases the whole subject of climate change related research has been widely encouraged in New Zealand by the New Zealand government and to a lesser extent by private institutions.

Because a significant proportion of New Zealand's export income comes from the primary industries and at the same time, they are the single most emitter of GHG there is a corresponding requirement to investigate the way that famers can both mitigate and adapt to climate change.

Mitigate in this report is described as lessening the amount of GHG emissions. While some of the climate change research is concentrating on new and novel ways that we can reduce the amount of emissions. There is also a recognition that this mitigation can also encompass land use change from changes in livestock mixes through to complete land use change, for example from livestock to forestry. This is partially driven by the He Waka Eka Noa[34] initiative which is a partnership between the peak producer group bodies and government which is tasked with gradually bringing the primary sector into the national emissions targets which will ultimately result in New Zealand achieving net carbon zero status by 2050.

Adaptation in this report is described as a process of change which will result in the primary production sector becoming better suited to its environment.

4.1 Research Organisations

The following is a list of and a brief description of each of the major players in the research sector. It should be pointed out that much of the research which is carried out in New Zealand is done in collaboration with other research providers.

4.1.1 NZ Greenhouse Gas Research Centre (NZAGRC[35])

The NZAGRC's goal is to discover, develop and make available practical and cost-effective technologies and practices for New Zealand farmers and growers to reduce agricultural greenhouse gas emissions.

The NZAGRC's strategic goal and objectives focus specifically on:

- Reducing emissions of biogenic methane and nitrous oxide from land-based industries, including through land use change and redesigned farm systems
- Carbon sequestration in agricultural, horticultural and cropping soils
- Advancing research and development to the point where mitigation solutions can be directly applied by industry or transferred to a third party for delivery/commercialisation.

They partner with other initiatives and organisations (for example, the Our Land and Water and Deep South National Science Challenges, MPI, DairyNZ, Beef + Lamb NZ, PGgRc and commercial companies) to undertake work on (or advance) the following topics:

- Land use change

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[34] https://hewakaekenoa.nz/
[35] https://www.nzagrc.org.nz/

- Technology transfer, extension and outreach
- The interaction between, and co-benefits of, mitigation and adaptation—developing resilient land-based industries, including with water, forestry and other natural resource management policies
- Commercialisation

Direct research into forestry (for example, the impacts of a changing climate on carbon storage in forests) and agricultural adaptation (for example, farm-system change to adapt to new pests and diseases and temperature change) are not in our scope. However, as adaptation strategies cannot be separated entirely from mitigation strategies, their work looks at the interaction of increased temperatures, increased atmospheric carbon dioxide concentrations and modified management processes on future soil carbon stocks.

The majority of its research program is devoted to the development of mitigation strategies, but it has done some work in adaption studies in the dairy and sheep and beef sectors but recognises that this type of work is now lead by the industry sectors.

4.1.2 Pastoral Greenhouse Gas Research Consortium (PGgRc[36])

The PGgRc is a commitment by the pastoral sector to address emissions, while ensuring New Zealand's economic wealth is not compromised. Ultimately, it aims to deliver knowledge and economically viable mitigation practices or products that will help New Zealand farmers manage greenhouse gas emissions, while increasing productivity. At an operational level, PGgRc works towards achieving that by focusing on the creation and development of intellectual property relating to greenhouse gas reducing technologies and practices.

While New Zealand makes only a small contribution to global emissions, the country's reputation as a trading nation implies an obligation to contribute fairly towards the global effort to reduce greenhouse gas emissions and the risks from climate change.

PGgRc's objectives are to:

1. Undertake a greenhouse gas emissions mitigation research programme
2. Deliver the research results to New Zealand and, where appropriate, globally
3. Maximise research opportunities and benefits for New Zealand farmers and – where compatible with this priority – commercialise for financial gain
4. Share financial rewards with stakeholders, primarily New Zealand farmers

It is an unincorporated joint venture involving AgResearch, Beef + Lamb New Zealand, DairyNZ, DEEResearch, Fertiliser Association, Fonterra, Landcorp Farming and PGG Wrightson.

Much of its research program is devoted to the development of mitigation strategies.

4.1.3 DairyNZ[37]

DairyNZ leads some research programmes and is partnering with others e.g., AgResearch, LIC and CRV, in other projects. This includes research into different farm system options, such as feed

[36] https://www.pggrc.co.nz/
[37] https://www.dairynz.co.nz/

types and use, improved fertiliser and effluent use, and options for on-farm sequestration of carbon.

DairyNZ is also carrying out and investing in farm systems research primarily through the Pastoral Greenhouse Gas Research Consortium and works closely with the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) to reduce greenhouse gas (GHG) emissions. The research will ensure the products are suitable for New Zealand pasture-based systems and help achieve our GHG targets. Our aim is to ensure the most relevant products are available for our farmers sooner.

Dairy sector climate change research that DairyNZ is involved in includes:

- Evaluating promising technologies for methane reduction and delivery of these methane inhibitors at the herd level.
- Ensuring the NZ inventory is up to date and accurate so that farmers are rewarded.
- Providing technical leadership and farm systems knowledge that focuses on Greenhouse Gas reduction
- Supporting farmers to reduce methane on-farm
- Methanogen Vaccine
- Selective breeding (low methane animals)
- Low methane forages
- Genetics research.

4.1.4 AgResearch[38]

Climate change research in AgResearch is held within their resilient agriculture section which has the aim of “Empowering sectors to manage, respond and adapt to both gradual and sudden changes in circumstances or environment, while enabling them to deliver functions needed by farming families, local communities and the value chain”. They are a key part of much of the research which is carried out on climate change.

4.1.5 Landcare[39]

Landcare’s ambition is that New Zealanders use our land, soil, and water resources wisely. Finding a healthy way to balance land and ecosystem use is critical to our future prosperity, using information and tools to support effective management of our land resources. Their aim is to use land more sustainably and he whenua koiora (better use resources for intergenerational well-being).

Their role is to improve knowledge of how the land responds to human pressures, understand the potential limits to land-use intensification and other development, and discover what drives natural resource management decisions. This will improve the primary sector's economic and environmental performance and will support the provision of wider ecosystem services.

They have contributed significantly to development of adaption pathways through participatory processes.

[38] https://www.agresearch.co.nz/our-science/resilient-agriculture/
[39] https://www.landcareresearch.co.nz/discover-our-research/land/

4.1.6 Plant and Food Research

While specific climate change is not a large part of Plant and Foods research program, they have developed a climate change strategy for the primary sector which is based on the concept that they have a responsibility to the primary sector and our industry clients to ensure our science will provide resilience to cope with the ongoing challenge of climate change. This is important for preserving the economic viability of these sectors in the longer term. They also recognise that it's true that climate change will put demands on current business models, but it may also open new possibilities, such as growing new crops.

4.1.7 NIWA [40]

As well as hosting the Deep South challenge NIWA has climate change as part of its core research services. Under the Adaption criteria the say that their aim is to help your business or organisation plan for climate change adaptation. They assess risk to infrastructure, help with land use planning and can advise on adaptation strategies and resilience building.

Their data, infrastructure and technical capabilities allow them to offer a range of services that include:

- Developing detailed climate change projections for a location, for your assets or infrastructure, or across a sector.
- Helping you understand the potential climate impacts, risks and opportunities that matter to you.
- Teaching adaptive pathways thinking as a mechanism for adaptation planning.
- Translating and communicating knowledge to enable you to make decisions for your future.
- Advice and risk exposure assessments for meeting the regulatory requirements related to the Taskforce on Climate-related Financial Disclosures (TCFD).

They have developed a climate adaptation toolbox which helps you find out about the changing climate, what it might mean for your business, organisation, or community and what you can do about it.

They have also developed some serious games that can be used as a tool to engage people in climate change. One of these games is one which investigates changing flood exposure on a farm.

4.1.8 Foundation for Arable Research (FAR[41])

FAR has the aim of: Adding value to the business of cropping. It supports New Zealand's arable farmers by creating new knowledge, tools and technologies to support responsible and profitable farming.

FAR has had a role in advancing the arable sectors position in mitigation of GHG's and has also been involved in a range of research activities relating to adaptation to climate change.

[40] https://niwa.co.nz/
[41] https://www.far.org.nz/

4.1.9 Our Land and Water[42]

Our Land and Water is one of the science challenges that was established by the New Zealand Government which is hosted by AgResearch. Their objective is to enhance the production and productivity of New Zealand's primary sector, while maintaining and improving the quality of the country's land and water for future generations.

One of their areas of work is Land Use Opportunities: Whitwhiti Ora which they believe will help land stewards assess diverse land use opportunities and make decisions with confidence that both the whenua and its people will prosper.

To become better land stewards, we need to bring the right information together so we can make smarter decisions about our land use. To improve the vitality of te Taiao, we will embrace ancestral knowledge about listening to the land and integrate this knowledge with technology and science.

Some excellent knowledge, data and tools are available to help make decisions about land use, but there are also some big gaps. Our research brings together biophysical, cultural, social and economic information to help fill some of these gaps.

The vision for this research is to identify a much greater range of suitable land opportunities and a greater diversity of benefits for New Zealand.

Research completed to date includes:

- Climate Change Impacts on Land Use Suitability
- Regenerative Agriculture, Soil Health and Climate Change
- The Potential Impact of Climate Change on Stream Water Quality
- How Will a Changing Climate Affect New Zealand's Primary Industries
- Precision Irrigation Can Mitigate the Risk of Contaminant Loss from a Changing Climate
- How Will Global Changes Influence NZ Agriculture? Inside 'The Matrix'
- Growing Kai Under Increasing Dry
- Report: Planning for Increasing Drought is Needed Now
- Drought: What to Grow and Where?

4.1.10 Deep South[43]

Deep South is another of the national science challenges which is hosted by NIWA which has the mission of; to enable New Zealanders to adapt, manage risk and thrive in a changing climate. One of their research sectors is that of Impacts and Implications. It states that this program aims to make sure that New Zealanders can properly consider and evaluate key impacts of climate change. They are also making sure that communities, end-users and stakeholders consider climate change in multiple contexts and make robust decisions about adaptation. This involves taking a 'big picture' view. We need to explore how the many and varied impacts of climate change will interact with each other.

Primary industry topics which they research include:

- Primary sector preparedness for climate change.
- Climate change and its impacts on our agricultural land.
- Climate water and wine.

[42] https://ourlandandwater.nz/
[43] https://deepsouthchallenge.co.nz/

- Climate change and drought: the future of farms and rural communities.
- Making robust decisions about New Zealand's water.
- Tools for decision makers.

4.1.11 Ministry for the Environment (MFE[44])

MFE is a large funder of climate change science. Their aim is to be able to provide evidence of climate change, how our activities are contributing to climate change and how climate change affects New Zealand. They have sections on their website which report on:

- Evidence of climate change.
- Science of climate change.
- About sea level rise.
- How our activities contribute to climate change.
- How climate change affects New Zealand.
- How climate change affects Māori.
- Climate change projections.

4.1.12 Ministry for Primary Industries (MPI [45]

MPI has historically been a large funder of climate change research. MPI aims to understand climate change and how it affects farming systems, livestock management, crops, horticulture, and forestry. They are also interested in how primary producers can adapt to a changing climate.

They have four key research areas:

- Greenhouse gas inventory
- Sustainable land management and climate change
- Methane, nitrous oxide and soil carbon, and farm systems mitigation in agriculture
- Agricultural greenhouse gas.

The Sustainable land management and climate change (SLMACC[46]) research program helps the agriculture and forestry sectors with challenges arising from climate change. It annually funds a range of research projects focusing on adaptation and extension in relation to climate change.

They list a vast number of research project reports on their website[47] that are arranged under the topic headings of:

- Mitigation.
- Cross cutting issues.
- Adaptation.
- Forestry.

4.2 Relevant Research Reports

The following is a summary of the findings of research reports that we feel are relevant to the topic and the area of Mid Canterbury.

[44] https://environment.govt.nz/
[45] https://www.mpi.govt.nz/
[46] https://www.mpi.govt.nz/funding-rural-support/farming-funds-and-programmes/slmacc/
[47] https://www.mpi.govt.nz/funding-rural-support/farming-funds-and-programmes/slmacc/slmacc-research-reports/

4.2.1 Water Supply Reliability in Mid Canterbury

This report by Aqualinc (Aqualinc 2011[48]) provides estimates of:

- the potential effects of climate change on weather elements (e.g., daily rain, temperature),
- mean daily river flows,
- irrigation water demand and water supply reliability for one catchment and associated irrigated area (Rangitata River in Canterbury).

They have used the data from the 12 models used in the IPCC Fourth Assessment Report which has been downscaled to 5 km and the current climate (2011) is compared with 2040.

They report that climate change projections for 2040 within the study area indicate:

- Annual average temperatures about one degree warmer than the average for 1980–99.
- Changes in annual average precipitation range from increases of up to 400mm/year in the Rangitata headwaters to little change on the Canterbury Plains.
- Changes in annual average potential evaporation for 2040 range from increases of 60mm/year on the Canterbury Plains, to small decreases in the headwaters of the Rangitata.
- In terms of seasonal changes, the largest projected increases in precipitation for the headwaters are in winter and spring, while small changes in seasonal rainfall patterns on the Plains are projected to occur.
- Seasonal warming is least in spring and early summer; otherwise, the warming is uniformly distributed through the year. The increases in potential evaporation are largest in spring and summer on the plains.

The main differences between modelled flows for the current and 2040 climate are:

- Mean flows for 2040 are projected to be about 8 m3/s larger than under the current climate (about an 8% increase in mean flow)
- The monthly mean flow is projected to increase or stay the same in 10 months of the year, and to reduce by 1–2 m3/s in December and January
- The months with greatest projected absolute increase in flow are August, September and October (each increased by ~18 m3/s compared to the model flows for the current climate)
- A reduction in groundwater recharge from the land-surface of about 10%.

The main changes projected for irrigation, drainage and water supply reliability are:

- Average annual irrigation water use is projected to increase by about 6%
- Average annual drainage from un-irrigated land is projected to decrease by about 10%
- Average annual drainage from irrigated land is projected to decrease by about 3%
- Water supply reliability from surface water and groundwater sources is projected to reduce.

Under current allocation policies, the area of land able to be irrigated would be reduced by 10%. If the groundwater allocation zone is already fully allocated, or within 10% of being fully allocated, the existing irrigators would, in theory, face a reduction in their allocations of up to 10%.

Where surface water is used for irrigation, it substantially mitigates the effects of climate change on groundwater recharge. The lack of a sufficiently reliable source of surface water for irrigation will

[48] Bright J, et all (2011): Projected Effects of Climate Change on Water Supply Reliability in Mid-Canterbury.

limit the size of both the groundwater supplied irrigation area and the surface water supplied area, to a total area well short of the potentially irrigable area on the Canterbury Plains.

Storing surface water is a critically important climate change adaptation measure.

4.2.2 Resilience

In their initial report looking at resilience of Dairy farms in the Bay of Plenty (Craddock-Henry, et al: 2018[49]) the authors found that:

A model of a climate-change resilient dairy farm was developed and refined through the course of the research (Figure 1). The model shows that the farm is only as resilient as the things and people on which it depends and therefore a number of critical factors that impact on farm-level resilience were identified at the sub-regional and national/global levels.

In their subsequent report (Craddock-Henry, et al: 2019[50]) found that:

The resilience indicators identified in this study were characterised first as aspects of resilience, and then linked to quantitative indicators, successfully tested and reviewed with stakeholders, and applied using economic modelling. The central focus of study was on farm-level resilience, as opposed to regional economic resilience. As a result, most of the identified indicators measure aspects at the farm level. However, a farm is only as resilient as the resources, processes and people on which it depends, and the research identified the importance of factors at the sub-regional and national/global levels. This study, therefore, further validates the findings of socio-ecological resilience studies, which have found that resilience dynamics need to be assessed across multiple spatial scales and across a range of indicator types.

The assessment framework developed and presented here provides a robust methodology to determine which farm system components influence the farms' resilience to a range of risks and which are critical for specific risks. This framework can help the sheep and beef sector identify system vulnerabilities and risks, and develop and support specific adaptation or resilience-building strategies.

In investigating social process to develop a resilience strategy AgResearch (Small 2012[51]) the research's purpose was to in collaboration with Aohanga Incorporation, develop a science-based climate change resilience strategy for Aohanga's multiple owned Owahanga Farm Station and to develop a social process framework for engaging rural communities and land-owning Iwi incorporations in climate change mitigation and adaptation.

Through a series of iterative workshops (hui) they investigated the research partner roles, Aohanga's information needs, identification of potential mitigation and adaptation strategies and the fit of those strategies with Aohanga's values and aspirations. They then were able to come to agreement on a resilience strategy for Aohanga.

They found that:

The social process framework includes a range of potential elements sorted into three stages: Pre-engagement, engagement, and post engagement elements. The social process framework

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[49] Cradock-Henry N, Mortimer C, (2018): Operationalising resilience in dairy agroecosystems.
[50] Cradock-Henry N, McCusker K, Ford S: (2019) Impacts, indicators and thresholds in sheep and beef land management systems.
[51] Small B, (2012): Aohanga Incorporation: Climate change mitigation and adaptation: A social process framework for engagement and the development of a climate change resilience strategy.

elements may be selected for use dependent upon the particular circumstances of the community involved.

And that:

One important lesson, which echoes previous findings from public and community engagement research, is the necessity to allow adequate timeframes for community organisations to discuss, consider and respond to the issues and engage with the scientific community in the development of policy and strategy.

4.2.3 Pathways Planning

In this Pathways Planning research (Cradock-Henry et al: 2019[52]) they:

….. 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 exposure sensitivities 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.

Their key findings were:

- ➢ The trend towards hotter and drier conditions in Hawke's Bay is of significant concern to stakeholders.
- ➢ Impacts will be felt across multiple domains, requiring a linked-up and coordinated approach to adaptation.
- ➢ Best practice is likely to contribute to adaptation through incremental change.
- ➢ Best practice alone is insufficient, and transformational adaptation may be required.
- ➢ Transformation will require multi-agent negotiation and collaboration.
- ➢ Adaptation planning is enabled and enhanced by the participation of affected stakeholders.
- ➢ Stakeholders increasingly demand information to support adaptation decision-making and action.
- ➢ Applied adaptation pathways provide a useful framework for strategic planning for primary industries, but it is not without its limitations.

In summary they found that:

[52] Cradock-Henry et al, (2019): Applying adaptation pathways Climate change adaptation planning for Hawke's Bay primary industries MPI Technical Paper No: 2021/16

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.

4.2.4 Crops

In this study (Crop and Food: 2008[53]) the authors used existing crop models to simulate the likely yield respond to climate change in 2040 and 2090 from growing maize followed by winter wheat. They modelled three different sowing dates across six regions of New Zealand including at Lincoln. They found that maize yields were found to increase the further South they moved, and that the biomass of winter wheat increased by 13-19% by 2040 and 17-38% by 2090.

4.2.5 Intensification Options

In this report the ARGOS Research Group (ARGOS: 2014[54]) use the information gained in their research report Evaluating Intensive Trajectories to give some intensification options for farmers in the context of climate change.

They have found that:

…..there are some intensification strategies that provide a means for New Zealand pastoral farmers to better adapt to climate change, capture further efficiencies and/or secure market access into high value markets. Four promising pathways which could be used in the sheep/beef and dairy sectors to drive climate-smart intensification are:

*1. **Improved risk management strategies** - are needed to cope with greater frequency, intensity and uncertainty of climate changes. These risks include: adverse natural events; financial uncertainty and hardship associated with variable climate, emergence of new plant and animal diseases or pests and the stress on biocontrol systems; and social factors – health, community wellbeing, mental health and cultural impacts.*

*2. **More efficient production** - using good management practices and efficient use of resources and technologies that improve both profitability and environmental outcomes.*

*3. **Habitat and biodiversity enrichment** - greater diversity of habitat and species increase the potential to benefit from the ecosystems services provided by a healthy environment and agro-biodiversity in particular. Shelter greatly reduces lambing losses from severe spring storms, increases milk production and will become more important as the number of days of extreme heat increases. Trees also provide erosion control, reduce flooding, help water quality and may provide a source of income.*

*4. **Adding value rather than just volume to production** - options maybe limited for individual farmers but there may be opportunities for industries or companies. For example, many Chinese and Indian consumers are willing to pay 20–40% extra for New Zealand produce with verified credentials for animal welfare, water care, reduction in GHG emissions and biodiversity care.*

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[53] Trolove S, et al (2008: Forage crop opportunities as a result of climate change.
[54] ARGOS (2014): Climate Smart Intensification options for New Zealand Pastoral Farmers. A farmer's guide to intensification options in the Context of Climate Change

4.2.6 Technology Transfer

In their report (SCION: 2015[55]) the aim is stated as to identify novel methods of technology transfer and communication in order to support adaptation planning in the primary sector.

They found that:

… the majority of research projects address the potential impacts of climate change with only limited stakeholder interactions, and emphasised the communication of facts, concepts and general ideas rather than how best to operationalise climate information for adaptation decisions. Examples of successful communications strategies that engaged with stakeholders to explore complexity and co-create potential pathways to adaptive solutions were identified and highlight the need to better understand an actor's ability, willingness or capacity to act and its relationship to framing climate change messaging. Many climate change projects in New Zealand address the potential impacts of climate change with limited interaction with stakeholders meaning change in the primary sector will likely face substantial resistance because the social and economic contexts of the issues have not been adequately accounted for.

The review of critical decision points and levers of action through systems analysis, revealed six potential key leverage points to influence adaptation behaviour. It should be noted however, that the capacity to influence leverage points are likely to lie across the primary sectors, government organisations and institutions; and other entities, and will therefore require greater coordination, cooperation and communication across governance regimes.

Lastly, the research identified a range of alternative mechanisms that will afford better learning by decision makers in the primary sectors. Given that information needs will increase exponentially, given the scale and extent of changes that will be required (Kirchoff et al., 2013), mechanisms will need to address and take advantage of opportunities associated with diversification and any increase in biological productivity, as well as overcome barriers such as the ability to act or access and use of capital.

4.2.7 Social Science Research Strategy

In this research report (ESR 2012[56]) they present a social science research strategy on responding to climate change in the land-based sectors in New Zealand, including the context for the Strategy development and the technical reviews and consultation which led to the Strategy.

The report identifies the key research questions and then synthesis these to come up with the following seven research outcome areas and objectives that are part of developing a research strategy for responding to climate change.

1. **Innovation, dissemination and up-take of practices** in New Zealand land-based sectors that will mitigate and/or adapt to the effects of climate change.
2. **Market development** based on production practices in New Zealand land-based sectors that mitigate the effects of climate change.
3. **Policy support** on New Zealand's strategic direction in relation to climate change and its implications for land-based sectors.

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[55] Dunningham et al (2015): Innovative and targeted mechanisms for supporting adaptation in the primary sector.

[56] ESR (2012): Responding to climate change in the land-based sectors: A Social Science Research Strategy for New Zealand.

4. **Understanding the challenge of climate change** from multiple perspectives in order to support engagement.
5. **Innovative approaches to decision-making, governance and participation** that span from national to local levels of governance and incorporate stakeholder and Māori perspectives.
6. Understand **factors that impact resilience, adaptability and transformability** in the New Zealand land-based sectors.
7. Effective approaches trans**-disciplinary and participatory research methods** and policy formation that integrate the expertise of bio-physical and social scientists, Māori, policy development, and practitioner stakeholders.

4.2.8 Impacts and Adaptation

This report (Clark, 2012[57]) is an extremely comprehensive review of the topic of climate change in New Zealand. It reports the issue across the following chapters:

- Chapter 1. Background: General approach and evaluation methods for land-based sector adaptation
- Chapter 2. Climate: The changing climatic environment for New Zealand's land-based primary sectors
- Chapter 3. Dairy: Adapting dairy farming systems in a changing climatic environment
- Chapter 4. Sheep & Beef: Hill country sheep and beef: impacts and adaptations to climate change
- Chapter 5. Broad acre Cropping: Adapting broad acre farming to climate change
- Chapter 6. Horticulture: Adapting the horticultural and vegetable industries to climate change
- Chapter 7. Forestry: Long-term adaptation of productive forests in a changing climatic environment
- Chapter 8. Water Resources: Water resource impacts and adaptation under climate change
- Chapter 9. Multi-sector: Multi-sector adaptation and sector-wide implications.

The individual chapters are published separately.

Chapter 1 Background

Chapter 1 sets the scene for the main theoretical principles of adaptation, as well as management approaches which allow theory to be meaningfully connected to practice.

The two major concepts that are in this chapter which are particularly relevant to this work are firstly the theoretical frameworks of climate change adaptation, vulnerability and resilience as shown in the following table.

[57] Clark A, et al (2012): Impacts of Climate Change on Land-based Sectors and Adaptation Options

	Vulnerability	*Resilience*
Origins	Hazards research & analysis	Ecological systems theory
Main concepts	Risk management Exposure Impacts Thresholds Vulnerability Coping range	Tolerance & recovery of systems Persistence Transformability States Interconnectedness & dynamics

And the establishment of a simple framework which introduces the three categories of adaptation as:

- **Tactical adaptation**. This involves modifying the existing production system using current, well-known management techniques. Primary producers have a number of management responses that they can readily adjust now with good levels of confidence, high levels of knowledge and relatively minimal investment.
- **Strategic adaptation**. This involves changing to another known production system, or making substantive changes to current systems, where practices and technologies are well known. This level of change may be warranted given mid to high level climate change.
- **Transformational adaptation**. This involves innovation to develop completely new production systems or even industries. It is also described as 'transformational change'. This is the least well defined level of adaptation as the knowledge is not fully developed let alone realised as adaptive capacity. It can be defined as a process of change, as well as a set of identifiable options. This type of adaptation may be necessary for extreme levels of climate change – where there is clear evidence that climate has moved to a new regime where current practices are not viable. New knowledge and practices are developed from collaborations between producers, researchers and specialists. Larger levels of investment are required to develop new adaptations with arguably more risk.

In summary it makes the very important point that:

Theoretical discussion of this type is not always received well in the primary sectors, which are focussed on taking pragmatic decisions in a highly operational and practical environment. However, in this case, discussion of background theory has been necessary – as the very understanding of adaptation is continually evolving, and there is increasing recognition of the opportunity to modifying the traditional decision making paradigm.

Chapter 2 Climate

This chapter sets the scene for climate change projections across the following themes:

- Global climate change.
- Change in the New Zealand region.
- Regional scenarios of climate change.
- Climate science for adaptation.

It has not been possible to determine exactly what data has been used to compile their expectations of climate changes in New Zealand btu assume that because they reference the Fourth International Climate Change report that it is based on that older data than what we are working with currently.

It is interesting to examine the following table on the 2008 projections and particularly the degree of confidence expressed.

Table 2.4. Main features of New Zealand's climate change projections (Source: MFE 2008). The degree of confidence placed by the authors of the source report in the projections is indicated by the number of stars in brackets (see Table notes for legend).

Climate variable	*Direction of change*	*Magnitude of change*	*Spatial and seasonal variation*
Mean temperature	Increase (****)	All-scenario average 0.9°C by 2040, 2.1°C by 2090 (**)	Least warming in spring season (*)
Daily temperature extremes (frosts, hot days)	Fewer cold temperatures and frosts (****), more high temperature episodes (****)	Whole frequency distribution moves right	
Mean rainfall	Varies around country and with season. Increases in annual mean expected for Tasman, West Coast, Otago, Southland and Chathams; decreases in annual mean forNorthland, Auckland, Gisborne and Hawke's Bay (**)	Substantial variation around the country and with season	Tendency to increase in south and west in the winter and spring (**). Tendency to decrease in the western North Island, and increase in Gisborne and Hawke's Bay, in summer and autumn (*)
Extreme rainfall	Heavier and/or more frequent extreme rainfalls (**), especially where mean rainfall increase predicted (***)	No change through to halving of heavy rainfall return period by 2040; no change through to fourfold reduction in return period by 2090 (**)	Increases in heavy rainfall most likely in areas where mean rainfall is projected to increase (***)
Snow	Shortened duration of snow season (***), Rise in snowline (**), Decrease in snowfall events (*)		
Wind (average)	Increase in the annual mean westerly component of windflow across New Zealand (**)	Approximately 10% increase in annual mean westerly component of flow by 2040 and beyond (*)	By 2090, increased mean westerly in winter (>50%) and spring (20%), and decreased westerly in summer and autumn (20%) (*)
Strong winds	Increase in severe wind risk possible (**)	Up to a 10% increase in the strong winds (>10m/s, top 1 percentile) by 2090 (*)	
Storms	More storminess possible, but little information available for New Zealand (*)		
Sea level	Increase(****)	At least 18–59 cm rise (New Zealand average) between 1990 and 2100 (****)	
Storm surge	Assume storm tide elevation will rise at the same rate as mean sea-level rise (**)		

Notes:
**** Very confident, at least a 9 out of 10 chance of being correct. Very confident means that it is very unlikely that these estimates will be substantially revised as scientific knowledge progresses.
*** Confident.
** Moderate confidence, which means it is more likely than not to be correct in terms of indicated direction and approximate magnitude of change.
* Low confidence, but the best estimate possible at resent from the most recent information. Such estimates could be revised considerably in the future.

The following sector based chapters all provide a very detailed and comprehensive review of the impacts of climate change on the sector, a modelling of the climate change impacts on the sector and a detailed discussion about the possible adaption pathways.

The following sections repeat the presentation of the impacts in tabular form and the relevant discussion about the gaps in knowledge.

Dairy

Table 3.6. Adaptation knowledge summary for the dairy sector.

Driver	Impact	Tactical	Strategic	Transformational
Higher seasonal temperature	• Changes to seasonal herbage yield • Earlier reproductive development • Increased weed and subtropical C_4 grass ingress into pastures • Reduced herbage quality • Increased geographical spread of pests and diseases	• Change stocking rates • Lengthen lactations • Produce more silage/hay • Alter calving patterns • Alter grazing rotation lengths • Improve pasture assessment and monitoring • Use alternative pasture/crop species that are more heat-tolerant • Sow endophyte-containing species • Use crops to break pest cycles	• Use newly developed plants adapted to warmer temperatures	• Use newly developed plants adapted to warmer temperatures • Invest in research to genetically modify plants for increased heat-tolerance
Heat stress	• Reduced intake • Reduced production	• Alleviate by cooling during milking • Minimise animal movement during the day	• Outdoor shades • Cow selection for heat tolerance	• Move away from heat stress regions
Cold stress	• Improved cow welfare • Reduced feed efficiency	• Shelter	• Wintering systems for supplement feeding	• Winter housing in cold regions
Low water availability	• Reduced herbage yield • Reduced pasture persistence • Increased weed and subtropical C_4 grass ingress into pastures • Reduced herbage quality	• Use irrigation where available • Use alternative pasture/ crop species that are more drought-tolerant/water use efficient • Reduce stocking rates • Improve pasture assessment and monitoring • Use supplementary feed to fill feed deficits • Conduct pasture renewal	• Use newly developed plants adapted to drought or that are more water use efficient • Invest in new irrigation infrastructure • Invest in infrastructure required to store and distribute supplementary feeds • Revegetation and soil organic carbon management to improve groundwater recharge and maintain soil moisture	• Use newly developed plants adapted to drought or that are more water use efficient • Invest in research to genetically modify plants for increased drought-tolerance and/or water use efficiency
Waterlogging and flooding	• Reduced herbage yield • Reduced pasture persistence • Increased weed and subtropical C_4 grass ingress into pastures • Reduced herbage quality	• Reduce stocking rates in prone regions • Improve pasture assessment and monitoring • Use more supplementary feed to fill feed deficits • Conduct pasture renewal	• Invest in infrastructure required to store and distribute supplementary feeds	
Increased CO_2 concentrations	• Increased herbage yield (potential depends on N available to plants) • Increased legume content in pastures • Increased water use efficiency	• Increase stocking rates • Lengthen lactation period • Produce more silage/hay • Alter calving patterns • Increase pasture diversity • Increase fertiliser applied		

Key knowledge gaps for the Dairy sector are listed as:

- The impact of increasing CO2 concentrations and changing temperature and rainfall patterns on New Zealand pasture and crop plants is not fully understood: particularly in regard to the potential interactive effects between the three variables. Furthermore, research into the effect of these variables on plant molecular processes is still in its infancy, or not yet begun, in many pasture species.
- Farmers are likely to investigate alternative pasture and/or crop species. Information that would be useful to them is likely to include:
    - .. comparisons of seasonal trends in plant quality and yield for a number of different species in a range of environments
    - .. comparisons between seasonal milk production responses to alternative species and perennial ryegrass
    - .. investigations into the compatibility and benefits of different species within a diverse pasture in a range of environments
    - .. understanding how these changes integrate with current nutrient and water use efficiency goals as well as the role of soil carbon.
- By itself, projected increases in average temperature of 2°C would seem to pose little or no direct environmental threat to health and productivity of dairy cows. This is because ruminants have a wide thermoneutral zone and an ability to shift this zone through physiological acclimation mechanisms. Breeding will improve over time as more traits are identified and are measurable.
- Key innovations into the future will revolve around feed flexibility, practices, and strategies that allow dairy farms to capitalise on excess biomass when it is available and avoid losses associated with climate induced downturns in production.

Sheep and Beef

The sheep and beef sector report is not as detailed as other reports but concentrates its analysis on three models that represent 70% of the sector nationally being Southland, Waikato and Hawkes Bay.

Table 4.15. The impacts of projected climate change on hill country sheep and beef enterprises. The groups in bold type are those responsible for, or interested in, the adaptation. The adaptations in normal type are those used in our Farmax simulations. The underlined adaptations are potentially useful strategies that were not appraised in our study; and the italicised adaptations are those often cited as relevant but not considered as effective as those in normal script.

Impact	*Tactical*	*Strategic*	*Transformational*	*Comments on further work required*
Changed seasonality in pasture growth; in particular, increased spring growth and loss of autumn 'shoulder' in Southland and Hawke's Bay	Earlier lambing Faster lamb growth rates (through higher plane of nutrition) Increased flexibility in stock number **(land managers)** Increased feed conservation (hay) **(land managers)**	Faster lamb growth rates and increased reproductive efficiency (through selection and breeding) **(land managers and researchers)** <u>Out of season lambing</u> **(land managers, processors)** *Irrigation*		More regions need to be assessed
Increased variability in annual feed supply, particularly in Hawke's Bay	Increased flexibility in stock number **(land managers)** Purchase of supplementary feed and feed conservation **(land managers)**	Exchange of stock and feed between regions **(farming community, policy makers)** <u>Increased unit size</u> **(land managers, finance institutions)** Faster lamb growth rates and increased reproductive efficiency **(through selection and breeding)** (land managers and researchers) *Grow drought tolerant species*	<u>Change location</u> **(land managers; banks, regional councils, farming community)** <u>Change whole farming system or land use type</u> **(land managers)**	Need to assess whether climate change will alter the capacity to move stock and feed between regions

In the report they conclude:

- Changes in average annual pasture production by 2040 were modest and largely positive.
- Changes in seasonality – primarily increased spring growth and reduced autumn and summer growth – were evident at all sites.
- Variability in annual and seasonal production increased in Hawke's Bay.
- Adaptations to the 2040 conditions resulted in unchanged (Hawke's Bay) or increased (Waikato and Southland) gross margins.
- The adaptations used were not outside the biologically feasible options possible today – but did involve changes in reproductive efficiency and animal growth rates that are only currently achieved on the highest performing farms.
- Hay making was an important tool for converting excess spring growth into dollars and for controlling pasture quality. The practicality of this adaptation on the scale required would need to be assessed further.
- There will probably be increased demand for stock and feed movement between farms and regions.

Cropping

This report concludes that there is a wide range of adaptive measures to harness the opportunities and mitigate the threats of climate change on broad acre cropping systems in New Zealand.

Table 5.3. Summary of adaptation knowledge for the broad acre cropping sector.

Driver	***Impact***	***Tactical***	***Strategic***	***Transformational***
Increase in CO_2	- Increased photosynthetic rates - Decreased transpiration rates	- Manage nutrient and water supply to enable higher yield potentials and to maintain crop quality	- Ensure access to irrigation to enable higher yield potentials	- Develop new varieties with enhanced yield potential
High temperature	- Shortening crop cycles - Increased/decreased photosynthetic rates - Increased respiration rates -Increased/decreased canopy expansion rates -Increased/decreased pest pressure	- Change sowing date - Change crop variety	- Change crop species - Develop new varieties better adapted to warm environments	- Change location - Change farming activity
Low rainfall	- Reduced canopy expansion rates - Reduced RUE - Limit nutrient uptake	- Change in sowing date - Change in crop variety - Use irrigation and/or increase its efficiency - Conservation agriculture to increase soil water retention	- Change species - Develop varieties better adapted to drought - Develop new irrigation infra-structure -Precision agriculture (e.g., VRT irrigation)	-Change location -Change farming activity
High rainfall	-Limited soil workability -Limited root respiration - Increase in pest pressure - Plant lodging -Nutrient losses to groundwater	-Change in sowing date -Change variety -Soil management (e.g., conservation agriculture, drainage)	-Develop more resilient varieties and species -Develop drainage systems	-Change location -Change farming activity
Heat stress	-Impairment of reproductive processes causing low harvest index	-Change sowing dates -Change to more resistant crop varieties	-Develop heat-stress resilient varieties -Irrigate to ensure transpirational cooling	-Prospects of improved resistance with microorganism association -Change farming activity
Extreme climate (storms, severe droughts, high winds and floods)	-Yield damage	-Change in sowing date -Change to more resistant varieties - Implement and improve biotic control techniques	-Change species -Develop new varieties -Develop forecasting and monitoring programmes	-Change to alternative cropping systems -Change farming activity

Knowledge gaps include:

- There is very little 'practical' information available from field experiments and pilot-studies specifically designed to quantify the effectiveness and costs of the different adaptation options.
- There is a requirement to continue to improve crop models to both assess impacts and identify adaptation options such as changes in the frequency and intensity of rainfall, the frequency and magnitude of extreme events, yield damage caused by biotic factors.
- Methods for quantifying and communicating assessment uncertainties.
- Addressing cost–benefits from adaptive options by objectively considering the value of ecosystems' services (e.g., clean water, clean air and sustainable use of land resources) in linked biophysical/economic assessments.

Horticulture

The horticulture report concludes that the likely impact on the big three crops of apples, kiwifruit and grapes is positive.

Table 6.2. Summary of adaptation knowledge and strategies.

	Apples	Grapes	Kiwifruit
Tactical	Winter pruning* † Summer pruning* † Sunburn protection* † Overhead netting for protection* Enhanced irrigation management* †	Winter pruning* † Summer pruning* † Over-vine netting for protection* Enhanced irrigation management* †	Winter pruning* † Summer pruning* † Girdling* † Chemical enhancement of flowering* † Overhead netting for protection* Enhanced irrigation management* †
Strategic	New cultivars * † New irrigation schemes*	New cultivars* † New irrigation schemes*	New cultivars* † New irrigation schemes*
Transformational	Contraction in existing areas, and expansion into new regions*	Contraction in existing areas, and expansion into new regions*	Contraction in existing areas, and expansion into new regions*

* New Zealand developed knowledge
† Internationally sourced knowledge

The authors of this report comment that modelling of the vegetable sector is worthwhile particularly in relation to the likely availability of irrigation water.

Forestry

The forestry sector chapter has a great deal of detail as to the adaptation options of a large range of forestry operations. In summary it concludes that the forestry sector has the tools to develop adaptation to climate change for the forestry sector. They do however acknowledge that the sector faces some large challenges which include the uncertain impact of increased CO2 levels on forest productivity and the fact that the investment period is for such a long period which means that there is potential for them to planting varieties that they are not sure are suitable for future climatic conditions and the very long time period that it takes to develop new germplasm.

Table 7.2. Potential climate impacts on selected forest operations and generic risks. Asterisked items (*) are the main climate drivers of risk and impacts. Sources of adaptation options are Pinkard et al. (2010) and Seppala et al. (2009).

	Increasing temperature	*Increasing rainfall*	*Decreasing rainfall*	*Increasing wind*	*Increasing wind and rainfall*	*Increasing CO_2 concen-trations*
Forest operations						
Site selection	*	*	*	*	*	
Species selection		*	*	*	*	
Establishment	*	*	*		*	
Silvicultural and forest management				*	*	
Fire management	*	*	*	*		
Pest and Disease Management	*	*	*	*		
Weed Management	*	*	*			*
Forest operations (infrastructure and harvesting)		*			*	
Estate planning						*
Generic Risks						
Productivity risks						
Ecosystem services		*		*	*	

Water Resources

The authors conclude that with less reliable water supplies and greater evaporative demand, water demand for irrigation will most likely increase. Droughts are most likely to become more severe in most regions, particularly in eastern regions where drought is already severe at times. Flooding is likely to become more intense due to higher storm intensities, but absolute amounts are highly uncertain. This all points to the likelihood that there will be increasing demand for irrigation water and reduced supply in Mid Canterbury.

Table 8.6. Options to adapt to changing water resources in New Zealand.

Tactical	***Strategic***	***Transformational***
. Identify thresholds for production systems . Changing cropping and grazing calendars . Changing crop varieties . Conservation agriculture . Improving soil nutrient management . Greater irrigation . Irrigation efficiency . On-farm water storage . Reduce erosion and freshwater contamination . Avoiding salinisation of groundwater . Changing stock numbers . Review infrastructure in terms of climate change projections . More efficient water resource management	. Changing crop species . Developing new crop genotypes . Precision agriculture . Monitoring and forecasting programmes . Expanding and improving access to irrigation . Reduce the extent of taller vegetation in water-short areas . Offset groundwater abstraction with artificial groundwater recharge . Scheme committees and future asset management decisions . Involvement in local and national water policy and planning processes . Collaborative processes . Incorporate climate change risks into resource and hazard management . Incorporate climate change risks into new and existing infrastructure . Research and development	. Improving crop uptake and conversion efficiency potentials . Different land uses . Re-evaluate the societal values behind water allocation . Inter-regional water transfers . Research and development

Table 8.7. Prioritised knowledge gaps pertaining to water resource impacts.

Priority	*Knowledge gap*
High	. National impacts on river flow at the seasonal scale . Changes to groundwater recharge for important aquifer systems . Effects on low flows and reliability for abstraction . Hydrological and ecological effects of altered water supply and resource use . Economic, social and environmental implications of water-related adaptation choices . How water resource management policies could be changed to accommodate climate change risks and uncertainties . Understanding the hydrological and water resource variability and changes of the past in more detail
Medium	. Changes to groundwater flow and levels . Identification of bores vulnerable to coastal salinisation . Effects on spring-fed streams and ephemeral rivers . Comprehensive hydrological assessments of catchments of high significance (e.g., Waikato, Waitaki) . Erosion and sediment yield in representative catchments around the country . Protocol for testing the emergence of climate change trends among hydrological observations . Preliminary studies of the effects on aquatic habitat vulnerability and environmental flows . Indicative assessments of flooding changes in more regions around the country . Preliminary studies of the design and operation of water storage needed to offset effects of climate change . Preliminary assessments of the potential role of groundwater in offsetting reductions in surface water reliability . Comparisons of climate change impacts with other drivers of change: Interdecadal Pacific Oscillation (IPO), ENSO, land use change, economic growth . Economic, environmental and social costs and benefits of implementing water resource-related adaptations . Identification of land uses that are better suited to the prevailing water resource projections including uncertainties . Understanding climatic, social and economic drivers of water use . Water balance studies of lakes and wetlands . Effects of climate change relative to climatic variability and other sources of change (e.g., increase in demand) . Effects on surface water quality, particularly water temperature
Low	. Effects on evaporation from irrigation races, dams and reservoirs . Effects on whole irrigation system efficiency . Division of the country into regions of coherent hydrological responses . Impacts on irrigation efficiency due to changes in evaporative demand

Multi Sector

In this section the review the impact of climate change on the indirect production impacts which haven't been considered in the individual sector reviews. They identify that there is much less information available on both the impacts and on possible adaptation strategies.

They cover:

- Environmental impacts.
- Pest and diseases.
- Pressures on regional infrastructure.
- Socio economic.

They have identified that:

- A changing climate is both an opportunity and a challenge for land sectors.
- A key decision will be when to act.
- There is no 'one size fits all' approach to adaptation.

- Land managers and professionals will determine the success of the adaptation options used.
- In the longer term, more impacts may emerge from severe or uncertain climate changes.
- The greater the change in climate, or the impacts of that change, then the more likely that transformational options will be required.
- Action can be taken now to expand our range of options to prepare for the future, no matter what climate scenario eventuates.
- Adaptation is a way of future proofing land-based sectors and the New Zealand economy to a changing climate.

4.3 Research Barriers, Gaps and Constraints to farmer engagement.

Farmers are currently concentrating on understanding mitigation of the amount of emissions of GHG’s in order to comply with He Waka Eka Noa and aren’t engaged with the issues around adaptation.

This lack of engagement is also related to the time scale of required action and farmers planning horizon.

There is a complete dearth of information on the subject of when farmers should start to make changes to the system because there is a lack of information on triggers or thresholds of when climate adaptation should occur.

Although there are good research results which demonstrate a framework for developing resilience strategies the knowledge that is required to both instigate and run the development of a resilience strategy is held by third parties not by the farmers.

There is a distinct lack of information around the specific options that are available to farmers to intensify their current farming systems in response to climate change.

Much of the current scientific information on climate change has not been translated into a form which is easily understandable by farmers so they are not aware of it or the implications for their farming systems in terms of the required transition or how they can operationalise the information.

Much of the science that has been carried out into climate change has not been carried out with any interaction with or translation into a form that is accessible to the people who it is designed to help.

The potentially significant positive impact of increased CO2 concentrations, changing temperatures and rainfall (the CO2 fertilisation effect) has not been proven outside the laboratory in New Zealand.

Little work has been done into demonstrating through modelling of innovative feed flexibility, practices, and strategies that allow farms to capitalise on excess biomass when it is available and avoid losses associated with climate induced downturns in production which are both responses to the expected extreme events.

5 Decision Support Tools

Outcome: Identify land use option decision support tools, gaps in decision support tools and constraints to uptake of existing tools.

The following analysis of the available decision support tools identifies whether they meet the requirements of decision support tools from the following perspectives:

- Ability to incorporate climate change parameters,
- Ability to model production,
- Ability to model greenhouse gas,
- Ability to model financial,
- Incorporation of all four in the one model,
- Ability to model a range of scenarios.

5.1 Decision support tools which support land use options.

5.1.1 Farmax

FARMAX is a decision support tool for pastoral farms that was developed by AgResearch which was commercially launched in 1993. The tool is designed for accredited consultants to use alongside farmers to monitor, plan, and review their farm system to create the best profitable outcome by modelling scenarios to see how changes affect biological and financial feasibility. FARMAX can support farmers in various ways including (but not limited to) pasture growth, production reporting, supply / demand reporting as well as GHG reporting. FARMAX8 reports biological GHG emissions for CO_2, CH_4 and N_2O in carbon dioxide equivalents. (FARMAX, 2020)[58]. Most importantly FARMAX can validate whether a farm system is feasible or not.

The core requirement to run FARMAX is the entry of pasture growth rate information which is used to generate a pasture supply curve which is then used in the validation of the information that is entered as to the number of livestock as to whether the system is feasible or not.

FARMAX8 is a version of the original FARMAX tool that can model greenhouse gas based off the farm system in its current state as well as run basic potential system scenarios.

Although FARMAX8 can model how changes affect the biological and economic feasibility the model is limited to a pastoral farm setting.

There could be several constraints when it comes to farmer uptake of using FARMAX8. Constraints include, a farmer must use an accredited consultant to access FARMAX8 opposed to being able to complete the modelling themselves, creating an ongoing cost of utilizing the tool. The main constraint will be due to the farm system.

FARMAX8 is a pastoral only model and this will limit its potential use in integrated farm systems such as arable or horticultural systems.

[58] FARMAX. (2020). Retrieved from FARMAX.

Table 5: FARMAX ‘s ability to meet the requirements of decision support tools.

Climate Change	Production	GHG	Financial	Incorporation	Scenarios
X	✓	✓	✓	X	✓

5.1.2 DairyNZ Whole Farm Model

The DairyNZ Whole Farm Model (WFM) is a research model that is described as being highly complex and that detailed input is required to set up farm scenarios. That is why it is not available for general use although it is available for DairyNZ staff to investigate scenarios as a user pays operation.

The WFM provides outputs for pasture growth and animal production on a daily basis, and economic results on an annual basis. Daily weather inputs also allow for fine-scale simulation of climate effects. It is a continuously developing model that is used for a range of analyses of different farming systems and has been evaluated and reviewed. It is based on three fully integrated modules: a mechanistic model of cow metabolism (Molly); a weather-driven pasture growth module (BASGRA) and a management/economic module.

The WFM provides an option for the pasture module to replicate CO2 fertilisation by adjusting the fertility response curve which means that it does have the ability to factor this element into any future climate change projections.

Table 6: DairyNZ Whole Farm Model‘s ability to meet the requirements of decision support tools.

Climate Change	Production	GHG	Financial	Incorporation	Scenarios
✓	✓	✓	✓	✓	✓

5.1.3 APSIM

The **A**gricultural **P**roduction **S**ystems s**IM**ulator (APSIM) is a comprehensive model developed in Australia and New Zealand to simulate biophysical processes in agricultural systems, particularly as it relates to the economic and ecological outcomes of management practices in the face of climate risk. It is also being used to explore options and solutions for the food security, climate change adaptation and mitigation and carbon trading problem domains. From its inception twenty years ago, APSIM has evolved into a framework containing many of the key models required to explore changes in agricultural landscapes.

APSIM is structured around plant, soil and management modules. These modules include a diverse range of crops, pastures and trees, soil processes including water balance, N and P transformations, soil pH, erosion and a full range of management controls. APSIM resulted from a need for tools that provided accurate predictions of crop production in relation to climate, genotype, soil and management factor while addressing the long-term resource management issues.

The APSIM model has been used extensively in the research sector in New Zealand across the pastoral, arable and horticultural sector with the SCRUM-APSIM module having been developed by Plant and Food in order to model the vegetable growing sector.

ASPIM's capability to model the impacts of climate change is very well developed but at this point it is only available on a limited range of crops. It can model a change in:

- maximum and minimum temperatures,
- daily rainfall,
- daily radiation and
- CO_2 concentration.

The APSIM modelling framework is made up of the following components:

- A set of biophysical modules that simulate biological and physical processes in farming systems.
- A set of management modules that allow the user to specify the intended management rules that characterise the scenario being simulated and that control the simulation.
- Various modules to facilitate data input and output to and from the simulation.
- A simulation engine that drives the simulation process and facilitates communication between the independent modules.

In addition to the science and infrastructure elements of the APSIM simulator, the framework also includes:

- Various user interfaces for model construction, testing and application
- Various interfaces and association database tools for visualisation and further analysis of output.
- Various model development, testing and documentation tools.
- A web-based user and developer support facility that provides documentation, distribution and defect/change request tracking.

The APSIM model has been extensively peer reviewed and is entirely based on peer reviewed research results.

The APSIM model is freely available for non-commercial use. It is quite complicated in the way that it is setup and the manner in which it runs over time so it is best run by operators that are experienced in its use.

Table 7: APSIM's ability to meet the requirements of decision support tools.

Climate Change	Production	GHG	Financial	Incorporation	Scenarios
✓	✓	✓	X	X	✓

5.1.4 E2M Enviro Economic Model

The E2M model is an environmental and economic model that uses linear programming techniques to undertake analysis on farm. The model can be used by dairy, sheep and beef farm operations that can input information such as financial data, pasture growth, supplement feed and nitrogen fertiliser use. E2M is an optimization model that then takes the full farm system approach by combining prediction of animal production from feed and energy intakes (farm grown or brought in feeds) and calculates the best financial outcome for the farm system. Other outputs of the program include a summary of the farms CO_2e split between CH_4 and N_2O.

E2M can create both a current base scenario as well as where the farm operation could be. The benefit of running scenarios through the E2M program is that the program is efficient at finding diminishing returns for the farm business (E2M Enviro Economic Model, 2021)[59]. The scenarios are run by adjusting information to the outputs opposed to the inputs. This is a key difference of E2M compared to other models available for farmers to utilize in adopting land use change. However, a limitation of running this scenario could be loss in production within the farm system due to the program not focusing on increased production to achieve efficiencies in reducing GHG emissions.

Constraints of uptake using the E2M model is that it is a model that is not seen to be supported widely or externally peer reviewed but it has been part of a project with Landcare Research and DairyNZ. The main constraint will be is that it is not adequately peer reviewed and the model is being promoted by a sole consultant as well as the program being interpreted as not supporting increased production on farm.

Although E2M can be used for dairy operations, the model does not include effluent application to land. Other gaps that can be identified in the tool is that it does not include New Zealand soil data, although it has been commented that they can be included. Not being able to determine volatilization from soils will reduce confidence in the N_2O emission results.

Table 8: E2M's ability to meet the requirements of decision support tools.

Climate Change	Production	GHG	Financial	Incorporation	Scenarios
X	✓	✓	✓	X	✓

5.1.5 ProductionWise[60]

ProductionWise has been developed by the Foundation for Arable Research. Its main use is as an online crop management tool which is mainly used as a record keeping device although it does have the ability to do future planning at a paddock and whole farm scale.

It has capability to carry out the following activities:

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[59] E2M Enviro Economic Model. (2021). *E2M Technical Forward.*

[60] https://productionwise.co.nz/

- Farm mapping.
- Paddock recording.
- Grain record keeping.
- Farm Planning.
- Reporting. (extensive)
- Gross margins.
- Shared reporting ability.

Production wise can be used via an app on any mobile device.

Table 9: Production Wise's ability to meet the requirements of decision support tools.

Climate Change	Production	GHG	Financial	Incorporation	Scenarios
X	✓	✓	✓	X	✓

5.1.6 Integrated Farm Planning

Integrated farm planning is an initiative of the Ministry of Primary Industries[61] (MPI). It is designed to bring all of the farm planning initiatives into one place. It is thought that it will:

- streamline compliance
- reduce duplication and costs
- improve information sharing across the primary industries and between regulators and industry assurance programs
- help you achieve your business goals
- make it simpler to meet business and regulatory requirements.

MPI's website says that work has begun to tackle hurdles to information and data sharing. It is our analysis that this initiative is designed to make the current plethora of farm planning tools all talk to each other and so avoid the requirements to duplicate the requirements of reporting to central government requirements, regional council requirements and the many commercial supply requirements that are in the primary sector already and which are growing in number.

It is our assessment that it is designed to bring planning tools like Environment Canterbury's (ECan) Farm Environment Plan and things like Irrigo's Authorised Land Use documents and Horticulture New Zealand's NZGAP in line so that they are able to talk to each other and avoid the repetition of information required to be supplied.

We see this initiative being a long way off encompassing decision support tools within its framework.

5.1.7 Existing consultant based tools.

There are a plethora of individual planning tools that have been created by consultants that are utilised in both planning and scenario testing by consultants. They vary greatly in their technical elements and their ability to model the elements required to plan for climate change adaptation. The majority of them are Excel based and require that assumptions as to production parameters

[61] https://www.mpi.govt.nz/agriculture/farm-management-the-environment-and-land-use/integrated-farm-planning-work-programme/

are entered into them and they then are able to calculate the financial outcome. These tools will be used to test the financial impacts of land use changes that are proposed to be made as a result of climate change and so would benefit from provision of technical data on the production impacts of climate change on whatever land use is proposed to contribute to their accuracy.

5.2 Decision support tools which support greenhouse gas reporting.

There are a huge number of tools that are available for farmers to use to test the impacts of any changes that they make on the emissions that will result in terms of GHG's alone. The major tools that are used in New Zealand are reported here.

5.2.1 Overseer

OverseerFM is an online farm management and planning tool. The tool is based off 30 years of scientific research (Overseer, 2022)[62] to provide a way to estimate how key nutrients are cycled within a farm system as well as GHG. The model is available for the majority of farm system types including Dairy, arable, sheep, beef, deer, and horticulture. The model requires training but is available for anyone to access at a fixed annual cost.

The tool requires detailed inputs of the farm system such as climate, soil, effluent, stock, crop, supplementary feed, fertiliser, irrigation, fuel usage and electricity usage. OverseerFM is driven by the input of production from animals and arable and horticulture crops and elements like the kilograms of dry matter (Kg DM) is back calculated from the production.

Outputs of the tool are nutrient budgets for key nutrients on farm, GHG emissions and carbon sequestration by forestry over time. Regarding GHG emissions, OverseerFM provides total farm emissions Carbon dioxide equivalents (CO_2 e) which is broken down by CH_4, N_2O and CO_2. The reporting also demonstrates CO_2 equivalent /ha broken down by CH_4, N_2O, CO_2 and the source of each of the gases (AgFirst, 2021, p. 17)[63]. When calculating N_2O emissions, these are driven by nitrogen in excreta. OverseerFM is also able to account for the difference in nitrogen content for different feed types and allows user to represent more off-paddock structures and manure management systems (Cecile de Klein, 2019, p. 2)[64]

Users of OverseerFM can take advantage of the tool to optimise nutrient use, compare different scenarios, plan, and generate environmental reports (Overseer, 2022)[65]. Potential scenarios that can be run could include but not limited to, adjusting stocking rate, breed, or type, reducing fertiliser usage, reducing electricity and fuel consumption, as well as incorporating trees into the farm operation. The disadvantage of running potential scenarios through OverseerFM is that it is difficult to directly compare the total CO_2 emissions with biological emissions as they are displayed in separate reports (AgFirst, 2021, p. 40)[66] .

Constraints of using OverseerFM to report GHG in a farm operation is the inability of the model to monitor real time data. Therefore, the model does not take into consideration seasonal differences

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[62] Overseer. (2022). *Overseer*. Retrieved from Overseer: https://www.overseer.org.nz/overseerfm

[63] AgFirst. (2021). *Review of Models Calculating Farm Level GHG Emissions.*

[64] Cecile de Klein, M. R. (2019). *Assessment of tools for estimating on-farm GHG emissions - final repot.* agresearch.

[65]OverseerFM:https://assets.ctfassets.net/bo1h2c9cbxaf/2hXZitpjGxPU9BgcmVj4QV/fee4616fbe3d2c0d6e44db90fd963c2d/2022_Overseer_development_roadmap_diagram.pdf
[66] AgFirst. (2021). *Review of Models Calculating Farm Level GHG Emissions*

due to the 30-year average climate data. Another constraint identified is that users do have the ability to be able to easily model unfeasible farm systems.

5.2.2 B+LNZ GHG Calculator

The Beef + Lamb New Zealand GHG calculator is a free tool that allows sheep, beef, and deer farmers to measure and report on farm GHG emissions and sequestration (Beef + Lamb, 2021)[67]. The calculator considers the farms stock reconciliation, fertiliser usage, woody vegetation cover. The tool was created to help the red meat sector to understand and report GHG emissions. The tool is also He Waka Eke Noa approved.

Farmers can use the model to generate future scenarios of their farm system and understanding how they can reduce their carbon footprint. Farmers can calculate the impact of future adaptation around changes to stocking rate and fertiliser and vegetation cover.

The calculator is easy to use, requires minimal training and easily accessible. However, gaps that have been identified that can contribute to adaptation of land use is that it does not calculate crops, especially forage crops or pasture species that could reduce N_2O such as plantain.

The B+LNZ GHG Calculator also has a supporting planning tool where farmers can document management or system changes that potentially influence GHG emissions, such as moving from full ploughing to minimum till/direct drilling or changing stock classes such as no longer grazing dairy cows over winter. This same tool also puts a framework in place for ongoing management and mitigations of current and future GHG emissions and breaks down management practices on a gas-by-gas situation giving the farmers an opportunity to understand where their best gains could be made.

5.2.3 Fonterra / AIM

The Fonterra method is based on the Agricultural Inventory Model (AIM) developed by the Ministry for Primary Industries (AgFirst, 2021, p. 16)[68]. The AIM method uses a generic or national average approach to estimate animal energy requirements and dry matter intake (Cecile de Klein, 2019)[69]. Main inputs into the method are daily milk production, aggregate information on cow numbers, supplement, and nitrogen fertiliser input with and without inhibitors sourced from annual farm dairy records. The output from using the method is CO_2 e/(effective) ha, split into CH_4 and N_2O, and the sources of each gas, the farm emissions relative to a benchmark group as well as the emissions intensity (kg CO_2 e/kg MS).

AIM has benefits in being able to achieve accurate emission estimates for farm systems based upon the way it calculates energy demand with only needing a handful of data points. However, the accuracy, adaptability, and ability to account for mitigations or consider trade-offs are limited (Cecile de Klein, 2019)[11] and the method can only handle changes within the stock numbers. This may create constraints on uptake with the difficulty to model future scenarios, mitigations, or land use change with the method.

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[67] Beef + Lamb. (2021, July). *Greenhouse Gas Calculator*. Retrieved from Beef + Lamb: https://beeflambnz.com/knowledge-hub/PDF/blnz-ghg-calculator.pdf

[68] AgFirst. (2021). *Review of Models Calculating Farm Level GHG Emissions.*

[69] Cecile de Klein, M. R. (2019). *Assessment of tools for estimating on-farm GHG emissions - final repot.* agresearch.

Gaps that could be considered within the model is the detail required. As stated previously the model works off default values and approaches, opposed to farm specific detail. This makes it difficult to generate environmental and economic scenarios when it comes to considering adopting land use change to reduce emissions.

5.2.4 Horticulture NZ

The HortNZ emissions calculator (approved by He Waka Eke Noa) is a simple spreadsheet that is available to growers to calculate their emissions. The tool solely requires tones of nitrogen fertiliser usage for the farm operation and calculates the total tones CO_2e (Horticlture New Zealand, 2022)[70].

Operators will be able to use the calculator to calculate future scenarios if they are planning on reducing nitrogen applications for mitigation emissions on farm. This could limit farmers to use other mitigations when it comes to adopting land use change regarding reducing GHG emissions on farm as there is very little information provided within the spreadsheet to support land use change.

Gaps in using the calculator will be the inability to break down where the total tones CO_2e. is coming from within the farm operation. Not being able to break it down to block level will create difficulty when it comes to adopting mitigations for land use change within the farm operation.

5.2.5 E-Check (Foundation of Arable Research)

E-Check is a simple emissions calculator in a form of a spreadsheet that is available online. The emissions calculator has been produced by the Foundation of Arable Research (FAR) which has been assessed by He Waka Eke Noa for the use within arable farm systems (FAR , 2022)[71]. Inputs into E-check include nitrogen fertiliser purchase record and stock purchase and sales records. Outputs of the spreadsheet breakdown the long-lived emissions (N_2O and CO_2) and short lived (CH_4) emission based on kg CO_2 -e as well as kg CO_2-e/ha. There are no calculations around nitrogen leaching or an economic analysis aspect to E Check.

For arable farmers who use this tool to calculate their emissions they will have the ability to model scenarios if they were to adjust inputs regarding fertiliser applications (amount and product) or stock information (adjustment to quantity or stock classes). Minimal information is provided within the spreadsheet of further potential mitigations as well as an economic analysis a farm business could implement to reduce GHG emissions. Information supporting potential mitigations is provided in a separate GHG farm planning module.

The model is easily accessible and simple to follow. However, a constraint when it comes to uptake the use of the model for future farm systems is the model's inability to include specific crops as well as soil and carbon sequestration. For arable systems these will be essential to calculate for scenarios for long term reductions.

Gaps in the calculation include the inability to change stock breed or include supplementary feed especially if it is for a mixed cropping system for understanding CH_4 reduction further. Another gap

[70] Horticlture New Zealand. (2022). *Know your number' emissions calculator*. Retrieved from Horticulture New Zealand: https://www.hortnz.co.nz/environment/he-waka-eke-noa/know-your-number-emissions-calculator/

[71] FAR . (2022). *Greenhouse Gasses*. Retrieved from Foundation of Arable Research: https://www.far.org.nz/environment/greenhouse_gases

is transport, fuel and electricity usage are not included in the calculation. Within arable systems this will be a contributor when it comes to sowing and harvesting the crops.

5.2.6 Ministry for the Environment Calculator

The Ministry for the Environment (MfE) calculation is a spreadsheet available online for any business to use, including farmers. The spreadsheet requires 'simple' inputs such as planted forest area, average stock numbers, total kilograms of nitrogen fertiliser and total kilogram of lime applied. The model uses these inputs to calculate CO_2 emissions. The spreadsheets main outputs are total CO_2, CH_4, and N_2O by source (Ministry for the Environmnet, 2020)[72].

Users can use this tool to understand how adapting mitigations of land use change can affect emissions by source opposed to farm block level, especially if forestry is going to be incorporated into the equation. However, when using the tool to calculate emissions there is very little information on providing farmers with opportunities to implement different practices / land uses on farm. There is also the ability to be able to create a reduction in GHG emissions but also an unrealistic farm system.

Constraints of the model will be its inability to model methane and nitrous oxide from dung and effluent. For livestock farmers, understanding a 'base scenario' of where they are at in terms of N_2O as well as the ability to run future scenarios especially for understanding CH_4 emissions.

One gap that is identified in the spreadsheet is the aggregate or average use of stock numbers. Through research it has been highlighted that stock contribute significantly to CH_4 emissions, and in a farm operation that is looking at land use change (e.g., breed or adjustments to stock class) if this is unable to be broken down to stock class it will be difficult for farm business to utilize the tool when it comes to running scenarios.

5.3 Barriers, Gaps and Constraints to farmer engagement with tools.

None of the farmer available tools are able to incorporate climate change parameters into the one model and only Farmax is able to incorporate production, GHG and financial data for pastoral systems.

There is no specific climate adaptation modelling capability for the arable sector which is available for farmers to use. It may be that the existing tools that are available to farmers and consultants are sufficient to model the production and financial impacts if sound data is available to feed into those models.

[72] Ministry for the Environmnet. (2020, December). *Measuring Emissions: Emission Factors Workbook 2020*. Retrieved from Ministry for the Environmnet: https://environment.govt.nz/publications/measuring-emissions-emission-factors-workbook-2020/

6 Drivers of Behaviour Change

Our literature review pulled together information about how our farming community best learn and adopt new technologies or practices. Throughout this section we will expand further on some of the known and proven techniques to report on how the information on the necessary changes to farming systems as a result of climate change can be presented to farmers in order to encourage firstly engagement in the decision-making process but also confidence to make changes to their farming system.

Figure 1 below displays the thought process that people go through as they consider a new behaviour, process or system with each stage building on the information needed to make a decision. The key with this particular process is the encompassing Group Think that sits within and around each of the individual components. The influence of a group on an individual's decision making can be powerful at all stages. Each of the stages is expanded on within this report.

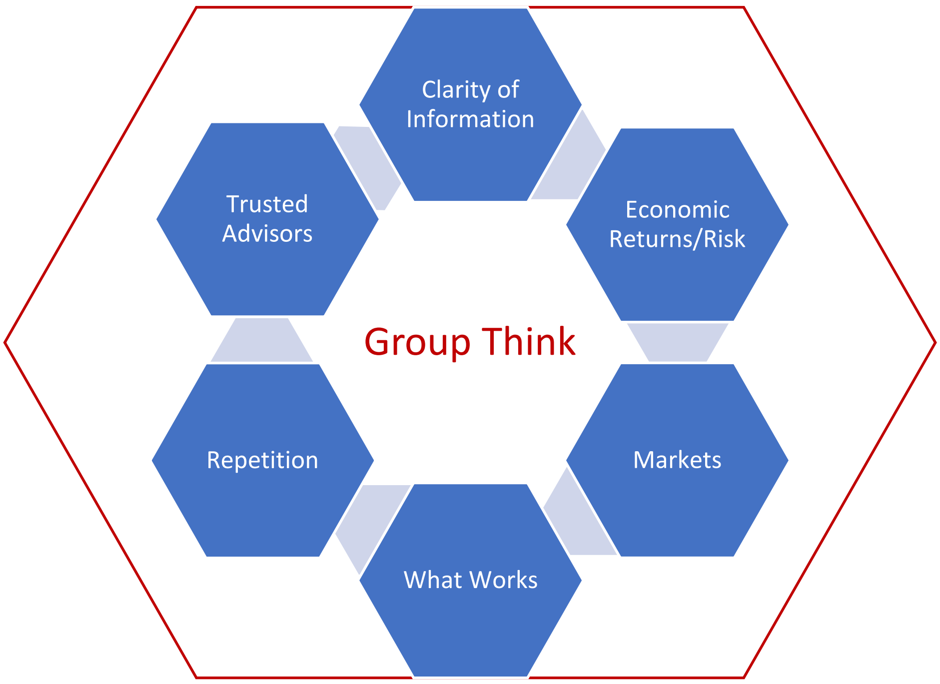

Figure 3 Cycle of Behaviour Change

Behaviour change is a process that takes time, repetition and knowledge. To be able to provide farmers with the information they need to consider change and be in charge of the process they need to be presented with accurate and reliable information with a long-term perspective that considers environmental, economic and social impacts to their business, the ability to continue farming for generations into the future is something many New Zealand farmers strive towards achieving.

6.1 Clarity of information

There is a large amount of information to take on board in the climate change space and much of it is filled with technical information that can be difficult to interpret and understand how it impacts a specific farming business. Industry good organisations such as Beef + Lamb New Zealand[73], DairyNZ[74], Foundation for Arable Research[75] and Horticulture NZ[76] create some resources that are specific to their industry but also resources that can be utilised across the sectors. They are resources that their users will understand and be able to utilise without having to read many technical papers and resources.

Offering the correct resources to the audience and understanding what your audience needs is important to the beginning of the engagement process, putting dairy farming related resources in-front of arable farmers is not beneficial to the arable farmer. Although having the dairy resource available to them if they were to consider it as a farm systems change opportunity is an important factor to ensuring they have the right information at their fingertips that has been created from a reliable source. It is also important to ensure the information is appropriate for the stage of consideration that the farmer is at, entry level through to detailed gross margin and return on investment information for them to take on board the information in the context for their situation.

6.2 Economic Returns, Investment & Risk

As with most businesses, farm system change, and adaption will require a positive return on investment and economic profitability for it to be a considered option. Most primary industries have bench marking data, via the industry good organisations, to show the annual returns and costs involved with the business as well as many of the initial investment capital costs and often the return on that investment. DairyNZ also include the environmental impact through their benchmarking database.

Many of these returns or costs are presented in a per hectare, per stock unit or per tray type calculation providing the opportunity for interested parties to understand what their own returns may be if they were to adopt or change part or all of their system to a different enterprise.

Any system change comes with an element of risk, be it financial, physical or emotional and every individual has a differing level of appetite for risk. The economic returns generally show that high risk and high investment requirements equal high returns with the corresponding situation of low risk and investment requirements resulting in lower returns. Individuals at the forefront of change and adoption, our innovators and early adopters, have a higher appetite for risk than those that fall into early followers, late followers or laggards.

These are important factors to consider for farmers when looking to engage them in a new idea or topic, it needs to be financially rewarding at the appropriate risk level for them to start the process.

6.3 Strong Markets and Market Requirements

Any new enterprise being considered also needs to be accompanied with an understanding and knowledge of the final market and its ongoing security of demand, its current level of supply and the main competing countries or products.

[73] Beef + Lamb New Zealand – Knowledge Hub Climate Change search https://beeflambnz.com/knowledge-hub/search?term=climate+change&field_topics=All&type=All
[74] DairyNZ Climate Change - https://www.dairynz.co.nz/environment/climate-change/
[75] Foundation for Arable Research – Greenhouse Gas https://www.far.org.nz/articles/tags/164/greenhouse-gas
[76] Horticulture NZ – Climate https://www.hortnz.co.nz/environment/national-policy/climate/

It is important to know the market before producing the product. What does the end consumer do with the product, how do they like to receive it, when do they want the product, how much of the product do they want, what is their price point and the resulting payment to the grower/supplier. How long is the market chain, as the producer how many hands does it pass through before getting to the consumer. As a producer, the closer you can be in the value chain to your end consumer, the stronger your returns are and the more dynamic you can be to consumer demands and changes, relationships in the value chain are important for ongoing security of market access.

New Zealand produce is generally well positioned in current markets and ensuring we maintain the quality of the product in those markets generally ensures our ability to continue trading within them. Many of our markets now require compliance with industry standards such as Global Gap in the horticulture industry to maintain high quality products and traceability. While these can seem onerous at the time for the business to complete and maintain they must be considered when any change is being made to a system as they enable New Zealand's continued relationship in particular markets. If a business is not willing to undertake the regulatory requirements the benefits of making the change will not be realised.

6.4 What Works Elsewhere

Case studies of enterprises that are successful in other regions of New Zealand as well as other countries that have a warmer climate than Mid Canterbury could be one opportunity to demonstrate what may be possible as our climatic environment changes.

Countries such as Australia who also produce a high level of primary produce provide New Zealand with insight as to what we could potentially grow and how to do it in a cost-effective way and supply into existing markets. This also provides a demonstration of what works successfully. In the literature review it was identified that farmers like to see other farmers succeed before trying new ideas themselves, they have the chance to learn what to do and what not to do to be efficient early in the change.

Case studies can be presented in several different formats from written through to live streaming and webinars. The technology available to connect with farmers around the world can make understanding more about their business and how adaptable it may be much easier than trying to understand through written articles, stories or documents. Seeing and hearing from respected sources in the industry can be a strong influencer in decision making.

The fields of influence model by Stephen Covey, figure 2 below, makes us think about what we can control and what we can influence throughout the decision-making process. The outer Circle of Concern is the space where we consider all ideas, thoughts and plans that will impact the process. Refining those by selecting ones we can control brings those particular thoughts or plans into the circle of control. Those remaining generally fall into the space in-between of the Circle of Influence, meaning you may well be able to influence the outcome or impact they might have on your final decision.

Taking the time to identify these with the key people who will be involved in the business is important to ensuring all concerns will be considered. Many farming businesses involve husband and wife partnerships or parents and children where everyone needs to have an understanding and input to the decision making, everyone will have a slightly different perspective.

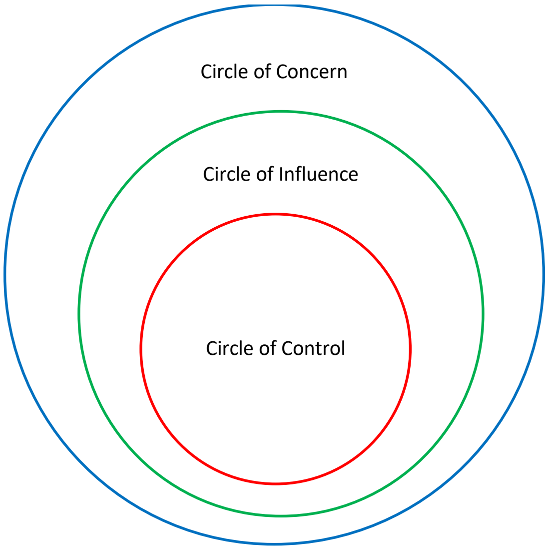

Figure 4 Steven Covey Circles of Influence

6.5 Repetition

Hearing and seeing things multiple times and in various forms, from different sources at different times is often needed to enable behaviour change. It provides people with confidence that the new idea, behaviour or process is the right thing to do and will work in their particular system. Change of a system can take a long period of time and seeing that change through a whole cycle is often needed to ensure they have the knowledge to confidently make the change. Repeatedly visiting a new system in differing environments at different stages can build confidence that a business can or cannot make the transition.

Our experience with Red Meat Profit Partnership Action Groups (RMPP AG) often saw groups of farmers look at one part of a system multiple times in different environments to help the decision-making process. An example of this is a legume-based group that visited dryland lucerne and irrigated lucerne systems on both flat and rolling hill country to decide if lucerne was a tool they could utilise in their farming system or how to make it work better. Each of the farms visited utilised and incorporated lucerne in different ways providing members of the group with variations that may fit in their own systems.

6.6 Group Think, Learning and Drivers

The major driver of the RMPP AG process was the formation of groups of farmers to come together to learn more about a specific topic, farm system or management process. Farmers working together and learning from one another is a powerful tool in building confidence to make changes in their businesses.

A key element of the group think and learning process was the farmer involvement in the driving of the goals and objectives for the group that fed into the activities the group would undertake. Having input from the beginning from everyone involved was critical to getting farmers to ‘buy in’ to the concept and the idea, the program then became more about how does each particular group activity impact or influence each individual farm system.

In an environment where farmers are comfortable, and they are supported by people they are comfortable with; they question one another very well on the positives and negatives of a particular system or management technique. The objective is to learn from and challenge one another and understand why it is done the way it is. Support from other farmers also taking on the same challenges of new ideas or techniques is known to be a catalyst for change.

Understanding the four core styles of learning, visual, auditory, read/write and kinesthetics were important from a facilitation perspective during the RMPP AG program to ensure every member of the group was able to take on board the information in their most suited form. Activities were always conversational based with visits to specific sites to see and hear what need to be shared. Written notes were taken and shared after the activity for members to continue the learning process with reading further and reminding themselves what they saw on the day. For the kinesthetics learners who learn by doing, often seeing a peer having done the activity or management practice is enough to kick start the opportunity to have a go themselves.

6.7 Trusted Advisors and Continued Support

Farmers regularly use advisors in business decision making. Ensuring that the advisors are knowledgeable and well respected amongst their peers will give the farmer confidence that the information they are passing on is accurate. The farming community in Mid Canterbury is small and details of advisors who know their content and topic very well spreads quickly and confidently.

Ongoing support and regular engagement from advisors and peers ensures that farmers can maintain progress and have access to relevant and up to date information. Having the support of an advisor or a mentor checking in with a farmer on a regular basis gives that farmer the opportunity to ask questions or get clarity around a challenge they have. Often when left to go it alone motivation levels decrease over time or when obstacles are encountered and change may not happen at the pace that is required.

When embarking on a system change or introducing a new behaviour it is important to know what support is available within the industry, how accessible it is and what the cost of the support is in order to make the change with confidence and that when you need support it is available.