Chapter 9. Multi-sector

Multi-sector adaptation and sector-wide implications

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Contents

1 Introduction

The previous chapters examine impacts and adaptation options on a sector-by-sector basis. While this provides information about a core set of options available to the land-based sectors, there are other options which were not identified by this approach. There is need to take a broader view and identify impacts and options that are common across the sectors, or involve the mixing of options from two or more sectors. For the most part these are much larger in scale and/or involve the integration of skills and knowledge from the different sectors. There are also secondary effects such as flow on to the broader economy, or environmental impacts which have not been core to the sector reviews, but warrant consideration. The options that are identified in this chapter tend to be more strategic or transformative in nature. The discussion on management innovations explores some emerging thinking on transformational change. General implications of this and the preceding sector based chapters are identified in Section 4.

2 Cross-sector impacts

The set of impacts reviewed in this chapter are the least well known, with relatively few examples or only limited depth of analysis in the available foundation studies. In some cases inferences can be made about impacts by direct interpretation, climate change projections, or from principles established in international studies. In other cases there is considerable uncertainty around the direction and magnitude of impacts, and/or local conditions in New Zealand mean that only very limited inferences can be made in the absence of local studies. In these cases, knowledge around impacts is in its infancy and the general statements made about impacts in this chapter should not be considered robust as new knowledge could change these assessments.

This relatively limited foundation knowledge is evident when compared with what is known about the direct production impacts documented in Chapters 3–7. In some examples – such as changes in nitrogen discharge risk under carbon dioxide fertilisation – the impacts flow on from the way in which production adaptation options are implemented. Table 9.1 provides a knowledge summary of the impacts identified, highlighting key foundation studies, and where knowledge has been inferred or based on international reviews. Further discussion is provided in the text below.

Table 9.1. Cross sector impact knowledge summary.

Impact	*Climate drivers*	*Magnitude and distribution*	*Foundation studies*
	Environmental impacts		
Increased erosion and sedimentation	Increasing rainfall and storm intensity Increased westerly wind flow	Highly localised Could to be concentrated in high exposure regions such as the Manawatu, Northland, Hawkes Bay, and parts of the East Coast	In principle, drivers and linkages well established General erosion risks well studied in New Zealand Few quantitative studies linking erosion and climate change risks
Increased nutrient risk	Increasing rainfall and storm intensity – sediment bonded phosphorous	As above	As above
	Carbon dioxide fertilisation – more nitrogen input	Highly localised	Limited knowledge Principle established but no New Zealand studies Key review by Stuart et al. (2011) for the United Kingdom

Biodiversity losses and gains in natural ecosystems	Temperature regime change Regional and local variability in rainfall	Rising temperature will drive change in natural ecosystems Habitat modification by rainfall change highly variable and uncertain Difficult to isolate climate change effects from other pressures in open ecosystems	Overview by McGlone et al. (2010)
Pests and diseases			
Changes to the abundance and distribution of harmful organisms	Increasing temperature drivers Habitat modification through secondary (biomass) effects of rainfall change	More southerly range for some pests 'Hot-spots' and outbreaks Decreased range for some pests	Principles of temperature change effects well established internationally New Zealand bioclimatic range studies available for some species Specific pest-host-environment studies not comprehensive for all pests
Changes to bio-control viability	Temperature, carbon dioxide concentrations, rainfall	Increases and decreases in bio-control efficacy Individual pests, bio-control agents and hosts have specific interactions	Key New Zealand review: Gerard et al. (2010)
Pressures on regional infrastructure			
Increases direct damage	Increasing rainfall and storm intensity Sea-level rise in some locations	Highly localised damage Impacts range from mild inconvenience to long term loss in viability Sector specific exposure levels	Key New Zealand reviews: - Rural Water Resources Infrastructure (MWH 2010) - Sector Infrastructure (AECOM 2011) - Transport (Gardiner et al. 2009a; 2009b)
Increases to maintenance and inventory costs	Cumulative multi-stress drivers	Difficult to detect without monitoring	
Socio-economic			
Positive flow on from temperature shifts and carbon dioxide fertilisation	Secondary impacts from climate driven production change	Opportunities for regional growth when exploiting production gains	Explored at national macro-economic level. Not at regional to sub –regional level. Key New Zealand modelling by Stroombergen (2010)
Negative impacts during periods of major drought	Rainfall and temperature drivers	Negative impacts on rural revenue with known flow on effects to the national economy	As above Cyclical effect well established in New Zealand and internationally
Economic multipliers from choosing to adapt	Secondary impact	Opportunities for growth in industry and labour markets, for example construction industries	Principle well established Specific economic analyses of climate change adaptation not available

2.1 Environmental impact

2.1.1 Erosion and sedimentation

There is a strong rationale for expecting increasing erosion risks under climate change. This is contingent on the temperature-driven changes to rainfall intensity described in more detail in Chapter 2. Such changes, in the order of a 6–8 per cent increase in rainfall intensity per degree temperature rise lead to upward pressure on the erosivity of landscapes. The linkage between rainfall intensity and erosion is well documented in past events (Marden 2004) and also from many years of theoretical and experimental work. It is difficult to assign formal probabilities for major erosive episodes linked to climate change. This is because the specific climate forcing events that lead to large erosive episodes are at the extreme high end of the rainfall distribution and are difficult to model (Chapter 2).

Wind erosion is also an important factor with linkages to climate change, particularly in parts of New Zealand that experience intense Foehn winds (Chapter 2). These linkages should be thought of as 'in-principle' as there have been no direct quantitative studies, due to limitations in climate projections for this variable (Mullan et al. 2011). The New Zealand Land Resource Inventory (NZLRI) shows contemporary wind erosion affecting 12.8 per cent of New Zealand, with quite different distribution patterns in the North Island and South Island (Figure 9.1). As described by Mullan et al. (2011), estimating the effects of climate changes on surface forcing winds is problematic, but indirect estimates of changes to synoptic patterns point to increases and overall intensification of the Foehn winds.

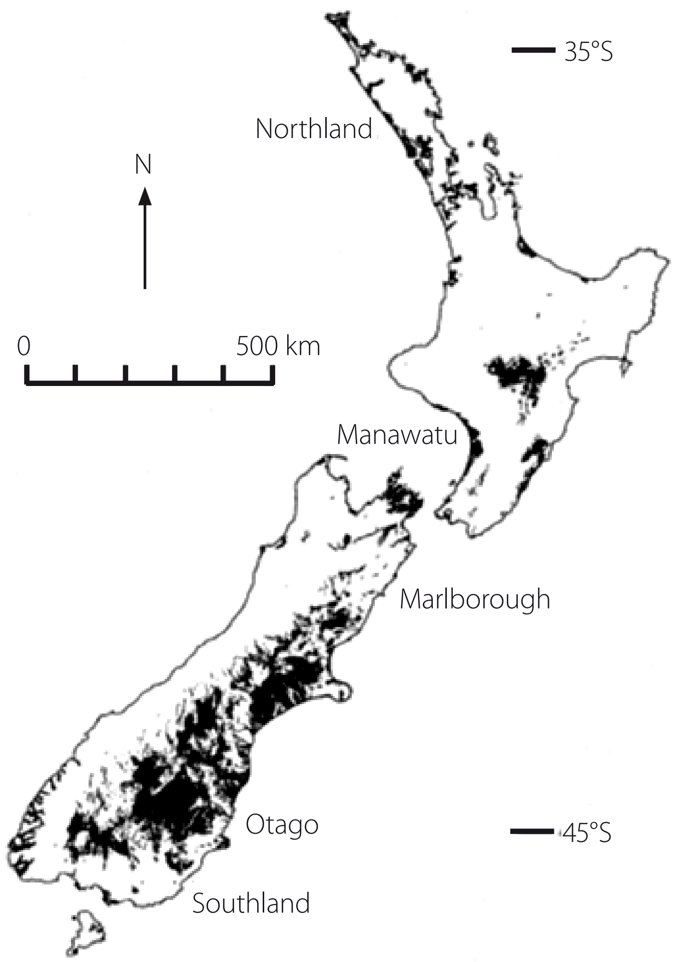

Figure 9.1. Contemporary wind erosion distribution in New Zealand, as mapped in the New Zealand Land Resource Inventory (LCR 2012). Shaded zones show areas of high exposure to wind erosion.

Climate properties are certainly not the only input to erosion risk, and in many cases can be considered secondary to landscape factors. Soil's physical and chemical properties, landscape factors (slope and shape given geological substrate), as well as vegetation cover all interact to give erosive potential. In New Zealand other geomorphic factors are also influence landscape erosivity, such as the role of earth movement in loosening sheer strength. Given these factors and process knowledge, good quantitative tools exist to explore erosion risk in New Zealand, particularly in erosion-prone hill country regions (for example McIvor et al. 2003; Dymond et al. 2006). Given these factors, the Land Resource Inventory (LCR 2012) identifies some high risk zones. These are listed in Table 9.2 along with a general appraisal of the relevant climate changes that are expected.

Table 9.2. General appraisal of climate changes expected in zones ranked 'high' to 'very high' in erosion risk according to the National Land Resource Inventory. Climate change projections and processes described in Chapter 2.

Region	***Expected climate change***
Northland	Reduced average rainfall: -5 to -15% Increased risk of sub-tropical storms
East Cape	Reduced average rainfall: -5 to -15% Increased risk of sub-tropical storms
Manawatu	Increased average rainfall: -2 to + 15% Increased risk of westerly storms
Coastal Wairarapa	Increases and decreases in average rainfall: -10 to +10%
Nelson-Marlborough Hinterland	Increases in average rainfall: +5 to +10%
Central South Island	Increases and decreases in average rainfall Uncertainty due to mountain spill over effect
Otago	Increases in average rainfall +1 to +7% Rainfall uncertainty high in this district

It is important to read Table 9.2 as a very broad brush appraisal of risks, and it is inappropriate to extend this to estimates of instream water quality. In most circumstances there are highly localised factors which will affect erosion and stream sedimentation. A good example is the study of Parkyn et al. (2006) who found quite different responses to changes in vegetation cover in geologically similar and adjacent catchments on the East Cape of New Zealand.

The lack of quantitative estimates of changes to erosion risk under climate change is a function of the uncertainties in climate scenarios that have been made available to landscape specialists. In the past, climate projections from models have only been available on a mean monthly basis. However, these are not suitable for erosion estimation. As described in Chapter 2, emerging regional scale climate projection techniques are starting to address this issue and provide estimates at a daily or even sub-daily time step with improved treatment of variability. There are opportunities to improve estimates of erosion risk in the short term for New Zealand, by coupling projections like the Primary Sector Adaptation Scenarios (PSAS) with existing physically based erosion models.

2.1.2 Nutrient risks

Using the landscape for primary production brings with it changes to the risk of nutrients entering and affecting water bodies. Some of these risks have been described in more detail in Chapter 8, along with the current suite of initiatives to improve environmental management through the Land and Water Resources Forum (LAWF). Generally two major pathways are of concern in New Zealand, the entry of sediment boded phosphorous and the entry of free-draining nitrogen into waterways under land used for primary production.

In general, the direct influences of climate change have not been studied specifically for these environmental risks in the New Zealand context. However, the 'in-principle' assessments made above can be directly extended to sediment bonded phosphorus – the expected changes to rainfall intensity in a warming climate would increase the risk of steam discharge – but detailed consideration of local factors is required in order to build robustness into this assessment.

There have been few studies of the effects of climate change on diffuse source nitrogen pathways – both in New Zealand and internationally. This was a key observation in a recent review by Stuart et al. (2011), who noted that the implications for the rate of nitrate leaching to groundwater as a result of climate changes are not yet fully understood. The available predictions suggest that leaching rate may increase under future climate scenarios. At present, the extension of the predictions cited from international studies in the New Zealand context rests on the direct interpretation of climate change projections.

As with nutrient and sediment risks these is need to be cautious about this extension, as local factors can have a large influence on the movement of nitrate between surface, subsoil and groundwater systems. This is highlighted by the general impact pathway in Figure 9.2. There are complex locally varying interactions between the climate change, nitrogen source term as well as behaviour of the soil and geological substrate.

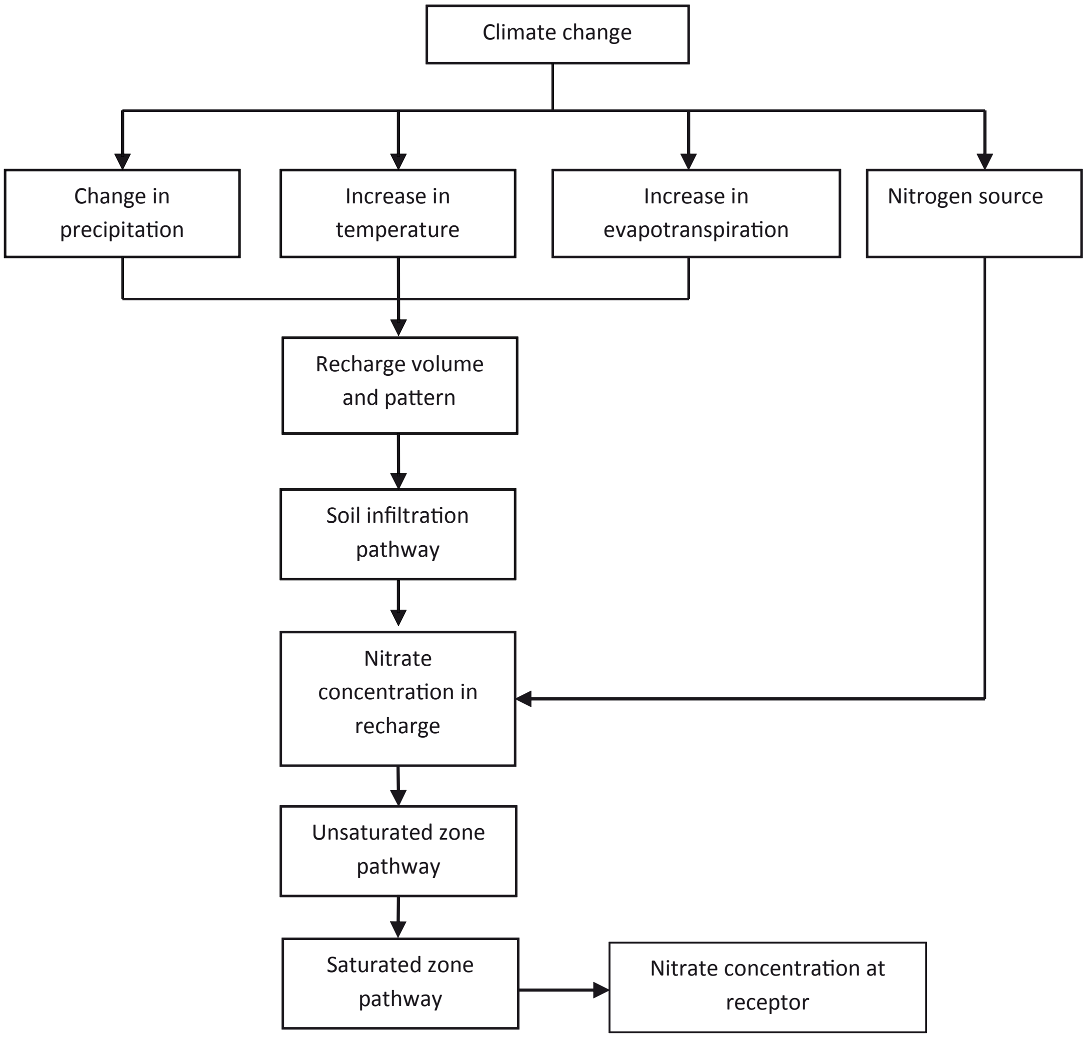

Figure 9.2. The impact pathway for nitrogen risk under climate change. Adapted from Stuart et al. (2011).

Of relevance are the recent research findings on CO_2 fertilisation reported in Chapters 3–7. The availability of nitrogen is a critical factor in determining the strength of growth responses in CO_2-sensitive crops and pastures. The environmental demand is created to boost nitrogen applications in managed agro-ecosystems, thereby modifying the nitrogen source term along with climate change in Figure 9.2. This factor was also highlighted by Stuart et al. (2011) noting the lack of process and modelling studies to explore specific thresholds and complex interactions. As described in Section 3.1 of this chapter, there may also be opportunities to exploit this effect, and to use crops and pastures more effectively to turn nitrogen over from soluble leachate form into plant material.

2.1.3 Natural systems

There are numerous case studies and documented examples from field monitoring of biotic changes, and responses by flora and fauna under observed climate change. McGlone et al. (2010) concluded that on balance New Zealand has experienced little observed biodiversity change under observed warming. There have been much larger changes which can be attributed to more direct modifications to habitat than to anthropogenic warming. This may be due to the relatively mild exposure profile experience in New Zealand in comparison to regions like the northern Arctic where biodiversity impacts have been found with a high degree of certainty. It may also be a function of the local monitoring networks. A summary of biodiversity responses under key New Zealand habitats is provided in Table 9.3.

Table 9.3. Summary of expected biodiversity and natural system responses under climate change. Adapted from McGlone et al. (2010).

Impact area	*Climate drivers*	*Magnitude and distribution*
Coastal ecosystems	Rising temperatures Sea-level rise Extreme warm events Altered sea conditions	• Ecological boundaries of coastal ecosystems will move • Erosion of soft shore lines • Sea-level rise affecting dunes, estuaries, and a range of saline, brackish and freshwater lagoons, shallow lakes and marshes will be most affected by sea-level rise • Loss of productive estuarine habitats likely to accelerate • Warming could extend potential range of mangroves, but threaten biologically important seagrass meadow habitats • Potential impacts on sea and shore birds through altered abundance of marine food and access to it
Alpine ecosystems	Rising temperatures	• Ecological boundaries of alpine ecosystems will move, with potential loss of alpine environment • Increasing shrubby growth and loss of herbaceous taxa • The effect on alpine organisms is unclear
Freshwater ecosystems	Rising temperatures	• Little known about temperature threshold responses in aquatic ecosystems • Only two species of fish have low temperature tolerance, others have a wide range • Fish kills can start to happen when water temperatures are over 25°C • High resilience to floods
Weeds	Rising temperatures	• Highly likely that there will be changes in the abundance of weeds as climate warms • Uncertainty as to whether new weeds will dominate or be subspecies in natural ecosystems • Very difficult to manage and impossible to eradicate once established
Range shifts in phenology	Rising temperatures	• ‘In principle’ changes in reproduction and development due to rising temperatures well established by international studies • Landscape complexity and maritime climate of New Zealand may limit this effect

2.2 Pests and diseases

Rising temperatures will strongly affect the abundance and distribution of pests, as well as the viability of controls. General assessments suggest that warming will create more favourable climates for some pests and they will expand their southerly range However, for other pests, increased temperatures will decrease their range. Initially this will occur as a series of ‘hot spots’ given the very specific host and population factors that govern pest distributions.

A sector-specific consideration of pest impacts can be found in Chapter 7 (Forestry), while the pastoral sectors and broad acre cropping provide some information on pests specific to each sector (see Chapters 3–5). Due to the complex interactions between pests and hosts, and their relative impacts, pest risks are difficult to evaluate. A comprehensive bank of information does not exist under current climatic conditions, let alone those for climate change. Studies, by necessity, are species specific which mean there are caveats around generalised assessments of climate change impacts on pests and diseases.

Complex pest-host-predator (control agent) relationships and ecological population dynamics need further study. Climate change may also bring some benefits: for example, the direct suppression of some pests like Alligator weed and the European leaf mite, as they do not reproduce effectively in high temperatures. Warmer temperatures may also boost the effectiveness of some bio-control agents, like St Johns Wort beetle in southern locations. Some adaptive responses to climate change can unintentionally increase pest risks: planting lucerne as a safeguard against drought offers more habitat to the *Microctonus aethiopoides,* a predator of beneficial native insects. Rising temperatures could also activate some 'sleeper pests' – organisms already present, but not problematic under current climate.

The implications of rising temperatures on animal bacterial/viral diseases and pathogens have not been given much attention in New Zealand. In principle, both positive and negative impacts are possible, depending on the specific biology and transmission risk factors. As described in Chapter 3, different breeds of production animal are more or less susceptible under the more tropical type environment created by climate change in New Zealand. Black et al. (2010) suggest that European breeds (e.g., meat sheep for fat lamb production), are likely to be disadvantaged, not only by the more subtropical climate, but also by their greater susceptibility, in comparison with more tropical breeds, to a range of vector-borne diseases. Higher temperatures can increase the rate of development of certain pathogens or parasites that have one or more stages of their life cycle outside an animal host. Temperature changes can also modify the risk of a range of animal and zoonotic diseases Black et al. (2010). Other complex interacting factors include:

- the molecular biology of the pathogen
- vectors that control the rate and range of spreading (if any)
- farming practice and land use
- zoological and environmental factors
- emergence of new micro-environments and micro-climates.

As with all pest risk analyses, one of the largest uncertainties are the role of micro-climatic environments. These create a niche for specific pests and diseases – significantly affecting rates of survival and establishment. Detailed pest risk assessment is highly non-linear, in that small changes in difficult to quantify factors can have a large effect on final outcomes. As described in Chapter 2, even the very best set of current climatic projections tells us very little about change at this micro-climatic level. This makes forecasting and prediction of disease and pests risks complex and difficult.

2.3 Regional infrastructure

The primary sectors are an integrated supply chain, with processing, value adding operations and market access beyond the farm gate being critical for all sectors. Impacts on processing and transport infrastructure are therefore critical to the long term future of the sectors. A review of climate change impacts on water resources infrastructure is provided by MWH (2010), with discussion in Chapter 8. Linkages with stock movement, fodder movement infrastructure, and adaptation activities in the sheep and beef sector are identified in Chapter 4.

Gardiner et al. (2009a) undertook an extensive gap analysis of New Zealand's transport infrastructure under climate change. Although their analysis focussed on all rural and urban areas, many of the findings are directly applicable to this sector-based overview. They reported extensive gaps in understanding of regional change, but were able to make some interpretations of impact, based on climate knowledge and a detailed risk assessment framework. To guide the development of future impact assessments, a prioritisation of climate change risks for the New Zealand transport sector was undertaken (Table 9.4). Hazards to coastal shipping are critical because these provide an essential link to overseas markets for land based products.

Table 9.4. Prioritisation of climate change effects for high risks to land transport networks. Gardiner et al. (2009a).

Climate change effect category	***Risk***	***Additional factors***	***Priority***
Coastal flooding (sea-level rise and storm surge)	High risk to all three modes	• 'Top five' risks to coastal shipping • Only some coastal locations affected • Significant costs likely for response options • Particularly important for assets with a long design life	✓✓✓✓
Inland flooding	High risk to all three modes	• 'Top five' risk to road • Significant costs likely for reinstatement or rebuilding • Particularly important for assets with a long design life	✓✓✓✓
Rainfall	High risk to road and rail	• 'Top five' risk to road and rail • Significant costs likely for reinstatement or rebuilding • Particularly important for assets with a long design life	✓✓✓✓
Inland erosion and instability	High risk to rail	• 'Top five' risk to road • Significant costs likely for reinstatement or rebuilding	✓✓✓✓
High temperature	High risk to all three transport modes	• 'Top five' risk to rail • Rail has a long design life • Forward planning is required to allow staged replacement of at-risk rail, and to ensure new designs are adequate	✓✓✓✓
Storminess	High risk to all three transport modes	• Aggregate effects (extreme rainfall and high winds) are top risks for all modes and recommended priorities to progress • Potentially widespread distribution of effects	✓✓✓
Coastal erosion	High risk to road and coastal shipping	• Not a top five risk • Only some coastal locations affected • Significant costs likely for response options • Particularly important for assets with a long design life.	✓✓✓
High winds	High risk to road and coastal shipping	• 'Top five' risk to coastal shipping • Most high risks can be mitigated at short notice; • however, protecting ports may be difficult	✓✓✓

✓✓✓✓ = Top priority; ✓✓✓ = High priority

AECOM (2011) undertook an overview analysis of damage risks specifically for infrastructure and operations past the farm gate that support the land-based primary production. The work is broken down into a sector-by-sector analysis. Examples highlighting on the priority findings were presented, and are reproduced here in Table 9.5. These highlight different exposure profiles between the different sectors, given their reliance of different transport modes, networks and energy sources.

Table 9.5. Example of infrastructure impacts on a sector basis, source: AECOM (2011).

Sector	*Impact*
Arable	Around half the arable processing facilities are located within regions expected to experience a decrease in rainfall. This will have a potential impact on the availability and costs of water for their processing facilities.
Dairy	The dairy sector is more energy intensive in processing and will require more energy for activities such as cooling and general plant operations. This will potentially place the dairy sector at higher risk as a result of increasing temperatures.
Forestry	The forestry sector is at risk from flooding and washout of unsealed (temporary) roads which would prevent access to remote areas.
Horticulture	Pipfruit and kiwifruit are energy-intensive in processing and will require more energy for activities such as cooling and general plant operation. This will potentially place them at higher risk as a result of increasing temperatures.
Meat	Sectors that produce perishable goods such as meat are potentially more vulnerable to disruption and outages due to climate change impacts.
Wool	Approximately one- third of the wool sector is located within regions expected to experience increases in rainfall. Wool processing and transport facilities could be at risk from increased flooding.

Increasing prospects of repair and maintenance costs for infrastructure under climate change were identified by Gardiner et al. (2009a), AECOM (2011) and MWH (2010). But it is difficult to go beyond a general broad brush assessment to a specific set of recommendations for regions and sites. One study that took this step is a case study for the Hamilton region reported by Jollands et al. (2005). The analysis found a 4 per cent to 9 per cent increase in maintenance costs for a mid-range climate scenario in 2050, translating to NZ$2000 to NZ$3000 per month for the regional transport network. Incremental change and the need to assess climate change impacts at a high level of detail were noted, along with understanding the importance of considering the interconnectedness of systems. Energy and transport networks have greater flow on effects across communities and the sectors, than site-specific impacts.

A common theme in all the available reviews of infrastructural impacts is the uncertainty and lack of regional to local specificity in available information. The work of Gardiner et al. (2009a), although completed in the context of transport infrastructure, provides a succinct summary of this issue that is common across all infrastructure classes. The common important features are:

- uncertainty in regional climate change predictions and in downscaling for projected changes in extreme events as required for determining impacts on transport networks at the regional level
- lack of readily accessible specific infrastructure datasets and design standards for each of the territorial local and regional authorities.

2.4 Socio-economic effects

The available economic modelling indicates that the flow-on effect on New Zealand's GDP of mid-century climate change is about around 0.1 per cent increase (EcoClimate 2008 cited in Stroombergen 2010). This general level assessment has substantial caveats as the effects are not linear, are based on 'on-average' shifts in soil water as a proxy for production output, and do not include estimates of extreme events. The analysis includes an approximation of export prices, where New Zealand's products command a higher return given international impacts.

When broken down to the regional level, and examining New Zealand's primary sector in isolation, there was a small negative effect (minus 2 per cent) on regional agricultural GDP, reflecting a total reduction in agricultural output under climate change. The estimate does not include the increased output expected under CO_2 fertilisation reported in Chapters 3–7. This contrasts to the global impacts reported by Cline (2007) of a 23.1 per cent fall in agricultural GDP averaged across countries without CO_2 fertilisation, to a fall of 12.1 per cent, when CO_2 fertilisation is factored in to production output levels. Modest agricultural damage is expected globally if carbon dioxide fertilisation fails to manifest itself. The damages are disproportionally concentrated in developing countries (Cline 2007).

Moving beyond the on average estimates of climate change reported above, there is a well-established cyclical effect associated with major drought in New Zealand. For example, the widespread rainfall deficit spanning late 2007 to the end of autumn 2008 was estimated to have cost the New Zealand economy around NZ$2.8 billion (MAF 2009), mainly from negative on-farm impacts, but also from smaller but detectable negative impacts on regional economies.

3 Cross-sector adaptation

This set of adaptation options require a cross-sector response, or instilling a multi-sector approach to the management of an individual land unit. Many of these responses are already well known in New Zealand, with its strong history in the use of trees in the farm landscape and of risk management. Some high level information is identified for these particular options, but it is likely that there is more in-depth and locally specific information available through industry organisations and within the community of land management professionals. Other forms of adaptation, such as some aspects of the process of transformational change will be relatively new, as they are currently being developed as an emerging form of climate change adaptation. At this point we return to some of the general management theory that was described in Chapter 1, examining innovation in management as a form of adaptation in itself.

3.1 Environmental management

The increased rainfall intensity projected under climate change provides an in-principle rationale to improve measures around erosion and sedimentation discharge. In the land-based sectors (excluding forestry), farm-level environmental management usually takes the form of Whole Farm Planning (WFP). WFP has traditionally involved firstly a resource inventory, a form of 'biophysical assessment' of a farm unit examining vegetation, landscape (soil and geomorphology) and drainage design. Secondly, one seeks to identify interventions – new landscape designs such as planting riparian zones, vegetation, and location/ design of soil conservation works – to minimise landscape instability, sediment transport to streams, and localised erosion. Whole farm plans take many forms in New Zealand. Some examples include:

- Horizons Sustainable Land Use Initiative (SLUI), where WFP are a key vehicle to deliver future proofing assistance to the region's land owners. The plans focus on resource conservation (soils, land, water, vegetation) and sediment management, but also extend into enterprise development in recognition that the environment and farm business cannot be treated separately (Mackay 2007). Services and resources are available to facilitate the plans, such as farm mapping and business risk analysis. Mackay (2007) provides a general description of protocols.

- DairyNZ (2008) farm environmental assessment provides a protocol and checklist for understanding farm resources, and potential interventions such as riparian planting. This is a self-assessment tool designed to rapidly build landholder knowledge of environmental risks on-farm.

- Beef and Lamb (2008) have a farm and environmental planning toolkit. This is a combination of risk assessment and mapping, with options for developing plans at three different level of (increasing) detail.

These resource kits and protocols are examples of the many forms and contexts in which the general WFP approach has been applied. Their general effectiveness in terms of erosion control is well established. For example, Dymond & Shepherd (2006) used modelling to evaluate a realistic scenario for the Manawatu, a well-known high risk region for stream erosion. They study used a scenario of 10 per cent adoption of WFP plans across the region. That is, 500 farm units in on the highest priority zones fully implementing WFP. They found potential for a 50 per cent reduction in the mean sediment discharge of the Manawatu River. Farm case studies highlight similar levels of effectiveness (MAF 2010).

Blaschke & Ngapo (2003) carried out a widespread evaluation of WFP in New Zealand. They found that WFP is widespread, across many sectors and there is evidence of their effectiveness through many individual case studies. However, there is often a lag in taking the actions identified in the planning phase to tangible actions that are implemented on the ground. This is because WFP have a traditional focus on land capability assessment and soils, but there is scope to integrate them with other aspects of land-based business, particularly business planning. This would be particularly useful in managing the implementation costs and bottom-line advantages to farmers.

Similar observations could be made about the integration of WFP and climate risk assessment. At present, there is limited information upon which to make comments about the inclusion or not of climate variability and change in WFP. For example, whether extreme-value analysis and subsequent changes to storm intensity are (or could be) factored in to the WFP process. This will be an important consideration if one of the goals of future WFP in New Zealand is to future proof sectors to the direct physical-environmental impacts of climate change.

The 'in principle' interpretation about nitrogen dynamics under CO_2 fertilisation (Section 2.1.2) provides a rationale to examine nutrient use efficiency as a tactical and strategic adaptation response. Current efforts, through farm systems management and targeted nutrient budgeting, seek to use pasture, crops and other on-farm vegetation to uptake of all of the available nitrogen. This removes it from the leaching zone, preferably at critical times of the year like winter where infiltration is high. These practices are well described in industry technical and training material (e.g., Dexcel 2006). Hence, the 'in principle' implications of CO_2 fertilisation for nutrient management are both a challenge and opportunity. On one hand there may be need to supply more mineral nitrogen in the form of mineral or organic fertiliser to capture increased growth opportunities. On the other, some crops and pastures will be able to assimilate more nitrogen, possibly at faster rates, making them more effective as nutrient management tools.

3.1.1 Ecosystem services

Ecosystem services have been identified as a type of transformational climate adaptation internationally (Stokes & Howden 2010; Cullen et al. 2004). At a simple level ecosystem services involves creating a monetary value (market) for the environmental activities undertaken by landholders, thereby creating a new alternative industry. Rutledge et al. (2010) undertook a pilot analysis of the potential value of ecosystems services to regions of New Zealand. Benefits for soil conservation, carbon sequestration, and water yield of new *Pinus radiata* afforestation ranged from greater than NZ$150 /ha/yr to NZ$50 /ha/yr.

At a more complex level, one definition of ecosystem services is given by Baker et al. (2011, p 2) as: *'an engineered or designed ecosystem is one that has been extensively modified by humans to explicitly provide a set of ecosystem goods and services including more fresh water, trees, and food products and fewer floods and pollutants. These modified landscapes provide a range of ecosystem goods and services, particularly food production as farmers seek to maximize commercial gain from land use.'* This is just one of many emerging definitions of the option.

In reality, the creation of ecosystems services is a complex activity and the subject of open debate. As described by Rutledge et al. (2010) it would represent a large paradigm shift in primary industry management. The option is in its infancy in open market based agricultural economies. At present it has limited utility as a policy option (Baker et al. 2011). Consistent with many forms of transformational change it is some way from being a reality in terms of on-ground implementation. There are many open questions that surround difficulties in quantifying costs and benefits, as well as other approaches to valuation of ecosystem services in economic and non-economic terms. New Zealand is in the early stages of discussion around this option, as evidenced by a recent forum paper from the national academy of science (Baker et al. 2011).

3.2 Pest and disease management

A more detailed appraisal of specific pests and disease adaptation options is available in the Forestry chapter (Chapter 7), as well as chapters on the horticulture, broad acre crop and pastoral sectors (Chapters 3–6). Given that pest and disease management can be controlled locally within an individual land unit, but also has cross landscape and sector aspects, it is worthwhile outlining some of the general approaches in this chapter.

As described in Section 2.2, it is essential to have a detailed understanding of pest and disease dynamics in order to accurately estimate current and future risks. This includes a detailed understanding of pest-host-predator (control agent) population dynamics, and specific knowledge of thresholds and how these function in a range of niche micro-climates. More accurate assessments and a detailed understanding of these complex interactions also support the identification of a suite of adaptation options (Table 9.6).

Table 9.6. Adaptation options identified for bio-control and pest risk management. Adapted from Gerard et al. (2010) with additions from Chapter 3–7.

Tactical	*Strategic*	*Transformational*
Building refuge habitats	Risk management for Integrated Pest Management systems with new bi-control agents	Development of new industries, crops and distribution networks
Pre-emptive action against sleeper pests	Increased genetic diversity	Retiring at-risk industries and regions
Pesticides/bio pesticides	New information systems involving monitoring and modelling	
Selecting resistant cultivars	Improved grower awareness, monitoring and reporting	
Use of endophytes	Breeding for resistance	
	Pasture renewal and break crops	

Gerard et al. (2010) provide the most complete review of climate change adaptation options focussed on pest risk management in New Zealand. They identify some specific adaptation options relating to domestic biosecurity:

- Maintaining and/or increasing the capacity of work teams to carry out operational assessment and inspection.
- Focussing on control in low incidence areas and an increased emphasis on biological controls, and increases ecological restoration of corridors.
- Strengthening regulation of internal borders, especially relating to garden plants.
- Cleaning of machinery.
- A need for clear guidance for local authorities, particularly relating to siting of new subdivisions and corridor plantings of natives, with clear information on both unsuitable and suitable plant species.
- Explicitly considering climate change and adaptation when the Regional Pest Management Strategy comes up for review. This should include addressing the apparent gap between potential threats and resources to monitor them.
- Implementing a comprehensive plant species recording database. This is a matter of both regional and national significance.

3.3 Multiple forms of production

In the context of managing climate variability, increasing production diversity on an individual holding is a strategic response to reduce exposure to negative impacts. This hinges on exploiting the differences in seasonality and timing of impacts experienced by different forms of production. For example, at a time when a pastoral unit is experiencing negative impacts from drought an irrigated lucerne may have high production and with fodder being sold at a premium. At a biophysical level there are also positive effects from integrating two different forms of that can be exploited, such as shelter from trees providing a wind refuge for stock, helping to keep their condition high at critical times in the reproductive cycle. There is considerable experience and information relating to these types diversification options at the local and regional level in New Zealand. This section describes some broad considerations relating to climate management, but does not provide a comprehensive synthesis of this knowledge.

New Zealand has a long history of integrating production forests into its farming operations (Mead 2003). While it can be identified as a form of strategic adaptation to climate change, there are also a number of co-benefits not directly related to climate associated with this option. Those relating to managing climate are: the provision of shelter for animals given changes to wind and increased heat stress; management of environmental impacts like increasing wind and water erosion (Olaughlan 2006); having a dual income stream, one which is responsive to the highs and lows of seasonal variation and another which has less variability with steadier inter annual returns (West et al. 2011). There are also a number of production trade-offs that are made in agro-forestry systems. For example, through impacts on light and moisture availability, pasture productivity within the integrated system is lower than in a pasture only system (Peri et al. 2001).

Sinclair & Dotterer (2010) completed a study exploring the linkages between the Dairy and Beef industries. They described them as an identifiable linked value chain. There are knowledge synergies between the sectors such as in genetics and supply infrastructure. There are also more direct linkages, such as pastoral farmers creating income by overwintering dairy cattle. Another example is the integration of arable cropping with a pastoral farming system – for example the adaptation of producing more animal feed on-farm is described in some detail in the Dairy chapter (Chapter 3). Although it is difficult to obtain up to date figures, integrated dairy and arable systems are being developed on the Canterbury plains.

The general strategy of looking to diversify the production and by extension income of a rural business is not new to New Zealand, and has been a part of normal risk management for some time. This has been primarily focussed on management of market-based risks, with variability in prices driven by both international and domestic (supply) pressures (Nartea & Webster 2008). But the core strategic principles are the same for managing climate and price variability. The options used most commonly are farm-focussed, looking at production diversity. But other viable off-farm sources of income – such as investment in financial assets – are available but not adapted as widely (Nartea & Webster 2008), perhaps because these were not perceived as particularly efficient strategies for managing risk (Martin (1996) cited in Nartea & Webster (2008)).

3.4 Regional infrastructure

A critical first step in addressing climate change impacts on supporting infrastructure is information development (Gardener et al. 2009a, Gardiner et al. 2009b; MWH 2010; AECOM 2011). Most of the options available to reduce risk are transformational in nature, and involve either changing localities, re-routing, investing more in upgrades, or retiring at-risk infrastructure. Investment in new infrastructure needs to future proof itself against the risks of climate change identified in Section 2.3. For this reason, the available reports, considering the availability and depth of information to date, recommend a phase of information development to start initial responses. Table 9.7 outlines these recommendations, broken down to a sector level in order to reflect the different exposure levels for infrastructure in the land-based sectors (AECOM 2011).

Table 9.7. Examples of sector-specific adaptation options to reduce risk to key processing infrastructure. Source: AECOM (2011).

Sector	***Adaptation action***
Arable	Undertake a cost-benefit analysis to determine the most appropriate water security adaptation measures for the arable sector
Dairy	Undertake a cost-benefit analysis to determine the viability of alternative fuel and water resources for the dairy sector
Forestry	Identify critical locations where unsealed roads are higher at higher risk of washout, and implement road construction methodologies that enhance flood resilience into these areas with a view to expanding to all new unsealed roads
Horticulture	Undertake a cost-benefit analysis to determine the viability of alternative fuel and water resources for the horticulture and viticulture sectors
Meat	Ensure back-up power is available at critical meat processing plants and storage facilities
Wool	Undertake a detailed sector-specific flood risk assessment of wool processing and storage facilities

3.5 Institutional change

It is increasingly recognised that effective institutions are central to adaptive capacity.

Dixit et al. (2012) developed a framework to systematically assess institutional strengths and weaknesses around a core set of functions that underpin adaptation. These are:

- ability to deliver *assessments* that guide tangible decision making
- ability to *prioritise* information development and delivery (for example targeting the most exposed areas)
- *co-ordination* to achieve cross-institutional outcomes including sharing of resources and information
- *information management* including the collection and synthesis and dissemination of resources
- *development* of a risk management process and culture.

Pilot assessments presented by Dixit et al. (2012) indicate that there can be a wide range of institutional capacity between and also within countries. The framework is an analysis of 'barriers' or 'organisational factors', but gives little guidance around what actions could be taken to ameliorate barriers. As described in more detail in the Water Resources chapter (Chapter 8), New Zealand is currently engaged in key water resource management reforms that are in part aimed at identifying and addressing these types of institutional barriers.

3.6 Innovation in management

It is recognised that innovation in management is in itself a form of climate change adaptation. Chapter 1 describes much of the basis for management approaches to adaptation at a generic level, including some of the key innovations. To recap on the material presented in Chapter 1 briefly, management for adaptation calls for greater emphasis on viewing it as a process, rather than a tangible identifiable action. Three main approaches are identified:

- ***Adaptive management*** – otherwise known as 'learning by doing', or 'continuous improvement' – follows a cycle of monitoring, review, planning, and implementation. It is particularly useful as a way of reducing uncertainty over time.
- ***Decision making that explicitly deals with uncertainty*** is a strong theme in climate change adaptation. Decision making seeks to find 'win-win' strategies that work across the range of future conditions is a useful first step. This helps ensure that adaptation decisions are robust to uncertainties in climate change, many of which have been identified in Chapters 3–8. For instance the range in climate scenarios, lack of process knowledge, or limitations in quantifying impacts.
- ***Risk management*** is a process to assess how a business or production system can achieve specific outcomes given information about the likelihood of an external event, like climate change. Events such as droughts are examined to see how they impact a business, as well as how likely they are to occur. Management responses are developed to reduce any negative effects or capture any opportunities that arise from these events. It is important to view risk management as broad activity as there is sometimes the tendency to just isolate it to the analysis stage. It involves assessing context, analysis of risk, monitoring, building awareness through communication and evaluating and taking actions that reduce threats or maximise opportunities (AS/NZS ISO 13001 (2009); Clark (2001)).

Transformational change has been identified in this review as one level of adaptation that land managers can implement. Chapters 3–8 identify a number of –transformational change options for their sectors. These tend to be 'technological' focussing on the research and innovation activities that drive the leading edge of land-based management. Recent surveys of transformational change highlight a number of innovative practices in its management (Kates et al. 2012). These focus on the underlying process rather than the tangible outcomes that form on-ground action. They are relevant when smaller incremental changes do not address climate change risks. This emerging knowledge is summarised as a set of practices and processes (Kates et al. 2012):

- Recognising that adaptations will form around focussing events such as drought or floods. It is difficult to 'force' adaptation options without the focus provided by experiencing these events directly.

- Supporting social and organisational contexts are needed to create incentives and deliver resources.
- For adaptation to progress to on ground action there needs to be common agreement that it is an opportunity to make a fresh start and move toward a more attractive future.
- The use of broad based participatory problem solving that blends analysis (such as 'what-if scenarios') with consultation and stakeholder ownership of problems provides a sound platform for taking action.
- A commitment to reducing uncertainty over time and framing decision timetables accordingly.
- Broadening risk management to include transformational change as a response option.
- Arrangements that share costs and benefits of adapting usually underpin successful implementation programs. This can be done by (such as job creation in adaptation activities) by source (Government and Industry), or by time (shifting to the future or equalised between generations).
- Sustained leadership over the timeframe of transformational change. This is usually a distributed form of leadership as opposed to hierarchical.

Describing management innovations at this generic level lacks the practical information needed to guide implementation. Case studies are useful for this purpose and illustrate the generic approaches. These are usually a blend or apply only a subset of the generic factors described above. Kates et al. (2012) identify numerous international examples where elements of transformational change are evident, for example: The Thames Estuary 2100 Plan; the creation of drought resilient crops in Mozambique and planning for sea-level rise in California. Table 9.8 identifies a range of examples from New Zealand land-based sectors. These draw from past and more recent experience, highlighting that there are working models of transformational change in New Zealand. They re-enforce an observation made by Kates et al. (2012), that transformational change need not be expensive or prohibitive, and in many respects can be a normal aspect of management.

Table 9.8. Case study examples of transformational changes in New Zealand land-based sectors.

Example	***Description***
	Past tangible actions and technologies
Aerial topdressing	Aerial application of phosphate fertiliser created an expansion in land use in New Zealand. It boosted the productivity of otherwise marginal land increasing total unit output. It is now a common practice in the pastoral and forest sectors.
Artificial insemination	In the dairy and sheep and beef sectors introduction of this technology lifted farm output and improved the rate at which genetic gains can be expressed in the production herd and flock. The year on year gains made by these sectors today rely upon this and some other breeding and reproductive technologies.
Overcoming trace element deficiencies (e.g., cobalt, selenium)	Careful identification of trace element deficiencies and creating fertiliser mixes that addressed them opened up new land to forest and pastoral enterprises and boosted productivity.
Genetic improvements in pasture and timber (density)	Have led to strong production and efficiency gains in the forest and pastoral sectors. In the case of timber density new products have been developed based on this innovation.
	Change as a longer term process
Forest management	Long term management and planning underpin the forest sector, and processes applied here have direct relevance for transformational change. This experiential knowledge provides a model to consider when looking at transformational change. These are described in more detail in Chapter 8.
Farm level innovation in Marlborough	A detailed case study of sustained innovation, leading to significant farming system change is documented for a pastoral holding in Marlborough (Collins et al. 2009). The farm boosted productivity, profitability and environmental performance during a significant long term decline in rainfall. This has been one documented example of sustained leadership, high levels of collaboration and transformational change on an individual farm.
Land and Water Reform	Changes around the institutions and regulatory environment governing water are identified as key adaptation areas internationally (Kates et al. 2012). New Zealand is currently engaged in a process of Land and Water Reform, which is a transformational process. This is described in more detail in Chapter 8.

4 Implications across all sectors

Chapters 1–8 and the first three sections of this chapter provide a comprehensive review of knowledge about impacts and adaptation options available to New Zealand's land-based sectors. There are a number of implications that arise from this review, that provide some useful steps for the next phases of adaptation. These are condensed into eight concrete implications for the land-based sectors:

1. A changing climate is both an opportunity and a challenge for land sectors.

   There are many of 'win-win' strategic and tactical adaptation options available to manage shifts in production variability in the immediate future. This level of change can be made now because there are no sunken costs associated with their implementation. There is good evidence that they yield production and economic benefits no matter what level of climate change arises over the coming decade. They have the added benefit of building more climate resilience into production systems over the long term. Potentially, these options not only reduce the negative impacts from climatic change in factors like drought, but also capture the opportunities from increased plant growth that arise from higher rainfall, increasing temperature and carbon dioxide fertilisation.

2. A key decision will be when to act.

   A core management problem is the trade-off between acting now or delaying adaptation until some point in the future. On one hand continually delaying adaptation builds exposure to climate change over time. On the other hand, investing now in expensive adaptation options comes at a cost. In the face of this challenge there is a natural tendency to maintain existing approaches to management. The identification of 'win-win' tactical adaptation options as well as a sensible planned approach to strategic and transformational options provides the land-based sectors with the solutions to this problem.

3. There is no 'one size fits all' approach to adaptation.

   The impacts depend on the production system, management choices, local climate conditions, as well as the rate and extent of the changing climate. This report has identified a range of impacts and adaptation options along a continuum of tactical, strategic, and transformational action. Some options may be tactical in one production system but strategic in another. Results in each sector review show that what works for one region or land unit cannot be readily applied in another without modification. However, all options have one thing in common – they will build more resilience to a changing climate on the ground.

4. Land managers and professionals will determine the success of the adaptation options used.

   Although adaptation options have been identified it is clear that some grounding is needed for successful implementation. Decisions from the fine tuning necessary to adapt under local conditions, through to providing knowledge and financial analysis to support strategic land management decisions will need to be climate proofed and checked with local experience. Implementing the tactical and strategic adaptation solutions identified in this report is within normal risk management practices, and there are considerable opportunities in acting now.

5. In the longer term, more impacts may emerge from severe or uncertain climate changes.

   This could present a different set of challenges and opportunities, including multiple stressors and cumulative impacts over many seasons, as well as changes to extreme events and impacts on infrastructure. Other risks, such as market or consumer preferences, are also difficult to anticipate but will also affect business decisions such as how best to respond to a changing climate.

6. The greater the change in climate, or the impacts of that change, then the more likely that transformational options will be required.

   In New Zealand transformational changes have been developed and implemented in the past, such as aerial topdressing, artificial insemination, overcoming trace element deficiencies (e.g., cobalt, selenium), as well as genetic improvements in pasture and timber density. Forest sector management, water reform, and innovation at the farm level provide other examples. The main lesson from these experiences is that implementing transformational adaptation need not be expensive or prohibitive.

7. **Action can be taken now to expand our range of options to prepare for the future, no matter what climate scenario eventuates.**

   Although a number of options can be identified it is prudent to continue to expand the range of options that are available, particularly targeting those that are 'win-win'. This is a key element of transformational change. This involves keeping a 'watching brief' on the latest information; staging action to manage costs; getting involved and shaping longer term planning at a regional level; initiating practical actions that reduce important uncertainties like monitoring or improving asset inventories; and innovating to expand the range of solutions that are available. Sustained leadership to harness the creative and innovative drive of the land-based sectors is a critical ingredient to success.

8. **Adaptation is a way of future proofing land-based sectors and the New Zealand economy to a changing climate.**

   This report identifies practical adaptation activities that are or can be part of day-to-day business, as well as those that build on the innovative drive of the land-based sectors. It is up to land managers to take up the challenge and translate this into on the ground action. These have flow on effects to regional economy through land use, job creation and bringing in investment. There are also opportunities to improve the broader sustainability of the sectors as part of adaptation response.

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