Climate Change Effects on the Land Transport Network Volume One: Literature Review and Gap Analysis

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Executive summary

Introduction

Transport networks are essential to the operation and wellbeing of our economy and communities. Transport infrastructure is designed and positioned to be resilient to natural weather hazards. While it is generally accepted that climate change will have impacts on the land transport networks, the future effects of climate variability involving more frequent and/or more intense natural hazard events are uncertain.

The purpose of this project is to identify and assess the impacts climate change may have on New Zealand's land transport networks (road, rail, ports and coastal shipping), and to provide recommendations, including adaptation options, to address identified information gaps and risks. The research findings are intended to inform land transport infrastructure providers and policy makers with information needed in terms of adapting the design, operation and maintenance of critical assets to the effects of anthropogenic climate change.

This report is the first stage of a two-part project. Stage One (Volume One) involves a literature review and gap analysis and is concerned with reviewing the current situation, identifying gaps in the state of knowledge and prioritising what aspects need further research. This study was carried out in 2008 and comprised the following aspects:

- an online stakeholder questionnaire for selected network operators, central and local government authorities and research institutions on their research needs, adaptation responses and perceived barriers to how land transport networks are planned, designed, operated and maintained to address the effects of climate change;
- a literature review on the effects of climate change and adaptation measures for land transport networks (road, rail and ports) internationally and by New Zealand's central government agencies, local government, crown research institutes, universities and private agencies;
- a climate change review summarising the likely effects for New Zealand, drawing on findings from analysis of the IPCC Fourth Assessment Report;
- a legislation & policy review of climate change on national land transport networks;
- a risk assessment of the land transport networks from changing weather under climate change, including identification and prioritisation of risks to each mode;
- a modal review (road, rail and ports) using the risk assessment findings to provide an analysis of key climate variables with potential for impacting design or operation;
- an initial assessment of regional climate change impacts on land transport networks;
- a gap analysis of information, knowledge or practice (covering climate science, policy and individual modes), and prioritisation of further work required to enable risks of climate change on the land transport network to be better understood.

A summary of the findings from each of these aspects is given below.

Stakeholder summary

The survey of stakeholders indicated the following key points:

- Land transport network operators, central agencies and researchers have a good general awareness of potential effects of climate change on land transport networks.
- About half the 29 respondents are preparing for the effects of climate change; steps include inter-agency collaboration, investigation of frequency/severity of effects, developing adaptation responses and preparing guidance.
- Less than half the respondents indicated a knowledge gap – the main issue reported is uncertainty on the nature, timing and scale of regional climate change effects, with the current response being to keep a 'watching brief'.
- One knowledge gap identified was the need for more specific information to assist operators to prepare for climate change. However, one exception was noted: no New Zealand research was reported on the effects of climate change on road, rail or ports.
- No comment was made on concerns about the capacity of infrastructure to cope with effects of climate change; some infrastructure providers require assets' design life to take account of climate change.
- A small proportion of stakeholders mistook the effects of climate change to mean the effects of transport greenhouse gas emissions on climate patterns. A smaller number questioned the likelihood of predicted climate change effects occurring.
- Funding, uncertainty of climate effects, their likelihood and/or consequence, and institutional capacity were the key barriers to limiting the ability of the industry to address the adverse effects of climate change on land transport networks.

Literature review

Aspects from the various New Zealand studies reviewed in the literature which have particular relevance to the current project were as follows:

- Substantial literature has been produced documenting the potential effects of climate change, notably by the National Institute of Water and Atmospheric Research (NIWA); given inherent uncertainty in the predicted effects of climate change, a key implication is that further refinement of the climate change models is needed to reduce uncertainty in regional analysis of impacts on the land transport network.
- Techniques to analyse historical data on effects of severe weather events (as opposed to climate change) for the state highway network are reportedly well documented, although our research was unable to identify a clear link between such analysis and consequential changes in land transport network design and operation; evaluating the use of natural disaster models as a platform for identifying future flood risk from longer term climate changes may be beneficial.
- The state highway system is the only section of the land transport network that has published an assessment of the risk and potential costs of climate change; the implication is that work to assess climate change risks in the rail and port networks, and to plan and act accordingly in all three modes, is at an early stage.

- High level New Zealand-specific guidance about the potential effects of climate change and risk assessment methodologies provide useful starting blocks for those involved with the planning, design, operation and management of land transport network infrastructure to determine potential effects.

Reviewing the international literature revealed the following:

- A significant diversity of multidisciplinary inputs is required to assess the effects of climate change on transport networks, and to develop robust adaptation strategies covering the planning, design, operation and maintenance of such services.
- Climate change factors need to be incorporated into infrastructure design and maintenance on an ongoing basis.
- Risk analysis tools help define the thresholds and standards of transport service to guide transport planning, engineering and future investment in order to account for the inherent uncertainties with incorporating climate related factors into the decision making process.
- Recommendations have been made by many international studies to calculate the costs of climate change effects, including the cost of disruption and emergency works, and the implications of adapting transport systems to address climate change risks.
- The need for contingency planning to enable rapid recovery of the transport system in the event of natural hazards is identified by some international studies.
- The use of early warning systems is an important part of minimising the impacts of climate change related damage and disruption to transport systems.

International studies also identified the need for climate change adaptation to be built into long-term capital improvement programmes.

Climate change review

New Zealand's climate change variables for 2040 and 2090 that are of relevance to such networks are summarised in Table XS1. The most significant effects of climate change on land transport networks are likely to be caused by climate extremes (e.g. heat stress, flood, storm surges) rather than a change in mean climate conditions.

Table XS1 Main features of New Zealand climate change projections for 2040 and 2090.

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 (*).
Daily temperature extremes	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 in Northland, Auckland, Gisborne and Hawkes 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 Hawkes 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 (***).
Wind (average)	Increase in the annual mean westerly component of windflow across New Zealand (**).	About a 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 (>10 m/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 (****).	–
Waves	Increased frequency of heavy swells in regions exposed to prevailing westerlies (**).	–	–
Storm surge	Assume storm tide elevation will rise at the same rate as **mean** sea level rise (**).	–	–

**** = *Very confident*: at least 9 out of 10 chance of being correct (very confident means that it is considered 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 the change.

* = *Low confidence*, but the best estimate possible at present from the most recent information (such estimates could be revised considerably in the future).

Over time, climate change effects are not expected to occur in a linear fashion. Periods of cooling or extreme events may occur beyond predictions. Therefore, operators should treat climate change scenarios as the likely or potential trends that transport networks will be exposed to during the broad 20-year scenarios based around 2040 and 2090.

The main issues identified by the gap analysis in terms of climate research are the need for:

- better models for predicting key climate parameters that may affect transport infrastructure networks, e.g. solar radiation models for determining potentially adverse effects on transport components (such as ultraviolet damage or radiation heat gain) do not adequately account for cloud cover;
- higher resolution models of relevant effects to enable detailed analysis of spatial and temporal distribution of climate change effects. This is a vital input into any risk analysis of transportation infrastructure at the local and regional level;
- calculation of the combined effects of climatic factors affected by climate change on transportation (e.g. combined effects of sea level rise, storm surge, tides and high winds for coastal areas; the combined effects of wind and rainfall on inland storm patterns); and
- clearer definition of the trigger points or relationships between key climate parameters and transport infrastructure, e.g. the relationship between ambient temperature, solar radiation and the level to which rails are resilient to these conditions such as maximum temperature and the number of antecedent hot or cool days.

Legislation and policy

The main legislation and policy issues identified by the gap analysis are the lack of:

- overall integration of land transport (road, rail and coastal shipping) planning with land use planning;
- explicit recognition in legislation and requirements to consider climate change effects as part of transport asset and network management responsibilities;
- explicit recognition in strategic land transport policy and requirements to consider climate change effects as part of transport asset and network management responsibilities, with a focus on asset managers taking action now to understand and prepare their networks better for potential risks from climate change;
- clarity on appropriate planning timeframes to ensure transport-related decision making, including funding priorities, is projecting far enough into the future to take account of projected climate change effects;
- definition of responsibility for dealing with climate change in terms of national and regional interests and local infrastructure providers, including the private sector's role; and
- audit processes for monitoring adaptation policies and associated progress at national, regional and local levels.

Risk assessment and modal review of climate change effects

A risk assessment was conducted to identify and prioritise the dominant risks to road, rail and ports/coastal shipping networks from climate change using the risk matrix method. The results are in general agreement with similar studies overseas (if differences in climate are accounted for). Prioritisation of climate change effects (high priority and above) for high risks to land transport networks are summarised in Table XS2.

Table XS2 Prioritisation of climate change effects for high risks to land transport networks.

Climate change effect category	Risk	Additional factors	Priority
Coastal flooding (sea level rise and storm surge)	High risk to all three modes	• Top five risk 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 road and rail	• Top five risk to road. • Significant costs likely for reinstatement or rebuilding.	✓✓✓✓
High temperature	High risk to rail	• 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 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

In summary, the top priority risks relate to:

- coastal inundation from sea level rise combined with storm surge (ports but also coastal land transport corridors potentially at risk),
- inland flooding (all modes),
- high rainfall and inland erosion/instability (road and rail), and
- prolonged high temperatures (heat stress leading to rail buckling in particular).

Each modal review further considered current weather-related vulnerability, high priority climate change risks and response options. The principal needs in response to these identified gaps are summarised below:

For the **road network:**

- specific mapping of areas at risk of coastal flooding/inundation caused by sea level rise and storm surge;
- nationwide asset performance assessment of existing drainage, culvert and bridge structures, and associated improvements/upgrading required to cope with increased flows caused by climate change;
- translation of projected increased rainfall intensity and frequency on inland erosion and slips, and identification of areas and regions that are vulnerable to these effects and are at risk of operational effects or adaptation requirements.

For the **rail network:**

- clarification of the relationship between solar radiation, air temperature and rail temperature to assist in determining the stability of the rail track associated with buckling at increasingly frequent higher temperatures;
- nationwide assessment of rail track levels in relation to mean sea level and associated prediction in sea level rise and storm surge;
- translation of projected increased rainfall intensity and frequency on inland erosion and slips, and identification of areas and regions that are vulnerable to these effects and are at risk of operational effects or adaptation requirements.
- assessment of existing drainage culvert and bridge structures, and associated improvements/upgrading required to cope with increased flows;
- changes in groundwater levels in relation to foundation design and ballast stability.

For **ports and coastal shipping networks:**

- land contours and other infrastructure topographic levels, their relativity to wharf and port infrastructure levels, and the projected sea level rise and storm surge effects of climate change;
- operational range limits (level and grade) for roll-on roll-off ramps and passenger gangways;
- land stability and the extent of coastal protection works required to protect port areas from increased storm, wave and surge impacts, and sea level rise; and
- harbour entrance studies (tidal prism effects) for current and future flow changes; and
- effect of river flood levels and frequency coinciding with high spring tides at river ports.

Regional implications

The study identified two primary barriers to the detailed regional assessment of climate change impacts on land transport networks in New Zealand:

- 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; and
- lack of readily accessible specific transport infrastructure datasets and design standards for each of the territorial local and regional authorities, and other transport mode owners and operators.

Based on available spatial patterns of climate change predictions, the following broad conclusions were drawn on where regional effects may occur on the land transport network:

- sea level rise/storm surge: increasing threat nationally to ports and low-lying coastal transport networks with a higher risk likely on the western seaboard;
- extreme temperature: potential for increased heat buckling on the rail network (highest risks predicted for the northern part of the North Island);
- stronger winds: higher risk to roads and ports in eastern coastal areas of the North and South Islands, and on the Canterbury Plains in the lee of the Southern Alps.

Regional patterns could not be determined for flood, erosion and slip risk because of a lack of detail on regional differences in the frequency/intensity of extreme rainfall, and a lack of information about where transport networks are currently disrupted by such events.

Recommendations for Stage Two

Stage One identified two specific themes that are important to all modes and the general issue of how climate change affects the land transport sector:

- the temporal and regional manifestations of climate change effects on land transport infrastructure, and
- adaptation measures (planning, design, operation, maintenance or replacement)

The prioritisation of which regions of the network are at risk and when these risks are likely to emerge under different scenarios (the 'where' and 'when' of climate change) is seen as a key issue; it is recommended that this be developed further in Stage Two, to the extent that existing information gaps in transport databases permit.

A national risk profiling approach is therefore recommended for development and application in Stage Two to determine likely regional effects. Based on their prioritisation in Stage One as high priority risks to the national land transport network, the national profile should target the following three aspects:

- **Rail heat stress study:** assess specific impact scenarios for the national rail network associated with rail buckling from high temperatures/heat wave events.
- **Coastal inundation risk study:** identify low-lying coastal land transport infrastructure (road, rail and ports) that are potentially more at risk from coastal flooding from sea level rise and storm surge.

- **Inland flood risk study:** identify sections of the state highway and rail networks currently at risk of (or prone to) inland flooding as a basis for estimating the likely flood risk of these areas under different climate change scenarios.

The national profiles should be based on regional Graphical Information System maps using current climate change predictions and, subject to availability of transport data, identify the likely regional impacts for each mode. Scenarios should be developed for current (nominally ten-year) and future (50-year and 100-year) timeframes. The focus should be on defining the probable effects on the physical assets/infrastructure of land transport systems and the adaptation measures required to counter these effects.

Abstract

This two-stage project (undertaken in 2008/2009) aims to identify and assess the impacts climate change may have on New Zealand's land transport networks (road, rail, ports and coastal shipping), and provides recommendations, including adaptation options, to address identified information gaps and risks. Stage One includes a review of research in New Zealand and overseas on climate change risks and adaptation responses for land transport. A stakeholder survey was used to determine work being carried out by local, regional and central government agencies, crown research institutes and universities. Key climate change risks and knowledge gaps for each mode, and prioritised aspects requiring further research, were identified by climate science, planning and transport engineering experts in a risk assessment workshop. The report summarises findings from the literature review and gap analysis in the context of potential trends in climate change in New Zealand over the next 50 and 100 years. Gaps in climate research, policy and legislation, and individual transport modes are described alongside recommendations for areas needing further research. These include three national transport profiling studies (inland flooding, coastal inundation and rail heat stress) that were taken forward in the second stage of the project.

1 Introduction

1.1 Background

Transport networks are essential to the operation and wellbeing of our economy and communities. Transport infrastructure providers design and position transport assets to be resilient to natural hazards. The future effects of climate variability and change are uncertain, so it is not clear how to prepare road, rail, ports and coastal shipping networks for the effects of changing climatic conditions and more frequent natural hazard events.

The intent of this project is to determine the extent to which land transport infrastructure providers and policy makers need additional information to adapt road, rail, ports and coastal shipping asset design, operation and maintenance practices for weather patterns associated with human-induced (anthropogenic) climate change.

While it is now generally agreed that anthropogenic climate change effects exist, considerable uncertainty remains regarding the severity of these changes and the potential effect these changes may have on transport systems in particular. In this context of high uncertainty, we have little alternative but to take a risk-based approach in making decisions about appropriate actions to be taken.

The first stage of this project is all about establishing common understandings about the likely effects of anthropogenic climate change; the assessment of these in terms of risk to New Zealand's road, rail and coastal shipping networks; and to identify any significant gaps in current knowledge which could seriously impair decisions about appropriate levels of action required to ensure sustainable transport networks.

Limited detailed information is available to assist land transport network operators to understand how climate change may affect specific assets at a regional or local scale. As a result, assessing the potential effects of climate change on land transport networks at this stage of the project has focused on the general conditions for road, rail, ports and coastal shipping networks nationally. A focused approach to identify risk to network assets in specific regional contexts is recommended.

The assessment of climate change risks used in this study is based on the commonly used 'Risk Matrix' approach and was designed to be consistent with recognised good practice and the requirements of the Risk Management Standard AS/NZS 4360:2004, which states:

> *Risk management is the term applied to a logical and systematic method of establishing the context, identifying, analysing, evaluating, treating, monitoring and communicating risks associated with any activity, function or process in a way that will enable organisations to minimise losses and maximise*

opportunities. Risk management is as much about identifying opportunities as avoiding or mitigating losses.

Risk in this context can be seen to be a combination of:

- the likelihood that a hazardous event or stressor (associated with anthropogenic climate change) of specified magnitude occurs;
- the probability that transport networks are damaged or fail to meet a need as a result of this event or stressor[1]; and
- the social, economic, environmental and possibly cultural impacts that result.

The first of these is a function of the nature, scale and timing of climate change effects. These matters are addressed in Chapter 3 of this report. The second relates to the resilience (or vulnerability) of transport networks to these changes. Network and asset vulnerabilities for road, rail and ports/coastal shipping networks are considered in Chapters 6, 7 and 8, respectively.

The third factor relates to the consequences of the network failing to perform as it was intended. The consequences of these failures could be defined in various ways, such as using the four wellbeings or levels of service requirements. An assessment of the potential impacts of disruption when networks are disrupted or fail was not undertaken at this stage. Quantifying such impacts is an important component of a risk assessment that should be completed at an appropriate scale.

While much detailed information on transport systems is routinely gathered, it is collected for other purposes and is therefore not directly usable to quantify impacts. For example, national topographic Land Information New Zealand (LINZ) data exist but the contour intervals are such that it is difficult to ascertain flood-prone parts of networks with any great accuracy. More accurate Light Detection and Ranging (LiDAR[2]) data only exist for specific areas where obtaining accurate information has been necessary. LiDAR data are costly to obtain and are often not freely available, even where they do exist. These difficulties, as well as the uncertainties of regional predictions for climate change, will limit the ability of subsequent research to assess detailed impacts on land transport infrastructure at the regional or national scale.

[1] A distinction is made here between events such as storms ,which are short-term and described as having an associated return period (e.g. a 100-year flood), and stressors which relate to increasing temperature, rainfall, etc.

[2] A method of detecting objects and determining their position, velocity or other characteristics by analysis of pulsed laser light reflected from their surfaces.

In determining the risk from anthropogenic climate change, we are not concerned with network failures associated with normal climate variation, e.g. failures associated with events and stressors that are within design limits and at current levels of frequency. We are concerned about additive effects that compromise current design expectations. This distinction is, however, somewhat academic because in reality, it is difficult to determine unequivocally whether individual network components would or would not have failed, in any particular circumstance, in the absence of anthropogenic climate change. This is partially because future climate change effects are only statistically definable based on limited knowledge of the past and of the underlying science, and partially because asset design, condition and the ways they could fail are variable.

Risk assessment is used here to establish which (additional) climate change risks dominate and to identify gaps in the current state of knowledge. The findings from the risk assessment and other Stage One studies have been used to establish priorities for the second stage of the project, and to identify what can practically be achieved to advance the current state of knowledge as regards future-proofing transport networks against anthropogenic climate change effects.

1.2 Scope

Land Transport New Zealand (now the NZ Transport Agency or the NZTA) engaged MWH NZ Ltd in partnership with the National Institute of Water & Atmospheric Research Ltd (NIWA) to assist its understanding of how, where and to what extent climate change will affect the land transport network, and what policy options and adaptation measures should be adopted in response to this risk. The project has been divided into two consecutive stages:

Stage One (Volume One): literature review and gap analysis (this report) involves a review of the literature on climate change effects on the road, rail, ports and coastal shipping networks to determine the extent of research already carried out by central government agencies, local government, crown research institutes (CRIs), universities and private agencies. It includes an assessment of how adequately existing literature identifies the potential trends in climate change in New Zealand, and the implications for the operation and management of these land transport networks, as well as identification and prioritisation of gaps in knowledge. This research was carried out in 2008.

Stage Two (Volume Two): approach to risk management deals with a broad assessment of potential climate change scenarios as they relate to land transport networks at the national level across a range of time horizons and geographic scales, and the formulation of recommendations for appropriate adaptation measures to enable more effective management of climate change risks with an indicative assessment of cost implications. Such measures are to be prioritised and categorised by type, such as:

- design issues, where changes in the design of the land transport network are proposed;
- operational issues, where changes in the operation of the land transport network are proposed;
- research issues, where detailed recommendations are not possible at this time and further research is required; and
- policy issues, where recommendations would affect current policies.

1.3 Limitations and assumptions

In preparing our methodology, we have made the following assumptions about the scope of the project:

- The wider effects of transport, such as how greenhouse gas emissions affect climate change, will not be addressed in this research. This topic is extensively addressed elsewhere in policy and research. Policies and trends to reduce greenhouse gas emissions from transport and associated effects on land transport network patterns of use are not directly addressed in our research. However, they form an important policy context that may influence the consequences of climate change on land transport networks. We recognise this context in our climate science, risk assessment and gap analysis methodologies.
- Indirect effects of climate change on the land transport network are not considered in our methodology. Thus changes in land use and potential impacts on the use or demand for land transport networks are considered outside the scope of this study.
- Conditions resulting from climate change that affect the capacity of transport networks to meet the requirements of the Resource Management Act (RMA) 1991 (New Zealand Government 1991) are also deemed to be outside of this project's scope. The capacity of land transport networks to meet RMA requirements relating to air quality, water quality and pest management in adverse conditions exacerbated by climate change have therefore not been considered in this research project.

One of the key challenges for this research involves defining the linkage between the engineering performance criteria for transport infrastructure assets and the corresponding climate change parameters that need to be modelled under future scenarios. Where possible, we have identified determining factors and their critical values or trigger points at which significant changes will be required in land transport infrastructure design or operation to maintain functionality in the face of climate change effects.

A final note is that transportation networks will require ongoing maintenance, development and redevelopment even if no climate change effects occur, principally because of population growth, as well as economic and technology changes.

1.4 Methodology

In conducting this research, we have completed several interlinked phases of work to combine the latest knowledge relating to the effects and risks associated with climate change and the land transport network in New Zealand. We have analysed the available material to identify and prioritise gaps in knowledge and practice that need further study in order to address the potential risks associated with climate change in the design, operation and maintenance of land transport networks.

Our methodology for each phase of work is described briefly below:

- **Literature review:** The project team conducted a literature review of published and unpublished material to identify the relevant effects of climate variability and change; gaps in knowledge; and responses to climate change effects on the design, construction, operation and maintenance of roads, rail, ports and coastal shipping operations in New Zealand and internationally.
- **Questionnaire:** We invited selected land transport network operators and contractors, central and local government authorities and research institutions to complete an online questionnaire regarding climate change issues; the survey provided feedback on their research needs, adaptation responses, and perceived barriers to how land transport networks are planned, designed, operated and maintained to address the effects of climate change.
- **Climate review:** NIWA summarised available information about the likely effects of climate change for New Zealand, predominantly using information based on the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) (Houghton et al. 2001) but also including the latest findings from analysis of the IPCC Fourth Assessment Report (AR4) (IPCC 2007).
- **Legislation and policy review:** We analysed the extent to which the effects of climate change on land transport networks are addressed in New Zealand's policy and legislation. A review of published draft or operative legislation and policy was conducted to identify guidance regarding the effects of climate change on land transport networks. Relevant responses from questionnaire recipients were also taken into account.

  Our review focused on central government guidance, and was not a detailed assessment of how these are being translated into local policies and plans (e.g. Long-Term Council Community Plans (LTCCPs), Regional Land Transport Strategies (RLTSs) and local codes of practice).
- **Risk analysis:** Using a risk matrix approach, climate change effects and their risks to road, rail, ports and coastal shipping operations have been identified and prioritised by technical mode specialists. An initial assessment was made to define climate-related trigger points that would render land transport networks inoperable, along with

appropriate response measures. Gaps in current practice and industry knowledge have been identified.

- **Modal review (road, rail and ports/coastal shipping networks):** The risk assessment findings were used to provide an initial analysis of climate change effects on how key climate variables can potentially affect the design or operation of these land transport networks. Regional considerations are discussed where broad spatial patterns of predicted climate change effects have been identified.
- **Gap analysis:** Key gaps in information, knowledge or practice (covering climate science, policy and individual modes), and the potential responses to address them have been prioritised based on the implications and value of so doing.

2 Setting the scene

2.1 Introduction

As a key component of Stage One, and as a means to set the scene regarding the project team's current understanding and knowledge of research on climate change impacts on land transport networks, we conducted two tasks early in the project:

- the stakeholder questionnaire, and
- the literature review (New Zealand and internationally).

We surveyed groups of stakeholders regarding climate change issues, research needs, adaptation responses, and perceived barriers as to how land transport networks are planned, designed, operated and maintained to address the effects of climate change. The literature review included published literature and material available online relating to climate change effects and land transport networks. Details of the findings from both tasks are described in this chapter.

2.2 Stakeholder questionnaire

2.2.1 Introduction

The NZTA sought guidance about the extent of relevant research that is or has already been carried out by central government agencies, local government, CRIs, universities and private agencies. The methodology for developing and conducting the survey, and a detailed analysis of the findings, are provided in Appendix C.

Of the 70 questionnaires distributed, 29 responses were received, representing a response rate of 43%, although it is noted that returns were obtained from all of the critical respondents. Seven of the 29 responses were not included in our analysis as these responses referred to matters outside the scope of this study, such as the effects of greenhouse gas emissions from transport, or the implications of changes of land use and transport choices on the land transport network caused by climate change. The responses from the remaining 22 organisations are analysed in the following sections.

It should be noted that the responses received may be biased towards those organisations that are aware of, and those that may have made preparations for, the effects of climate change on land transport networks.

2.2.2 Preparing for the effects of climate change

The questionnaire revealed that just over half of the 29 respondents indicated preparations are being made for the effects of climate change on land transport networks. All groups of questionnaire recipients are preparing for the effects of climate change. All central government agencies and crown entities stated that their organisation had made preparations for the effects of climate change, while the response from other organisations was mixed.

Respondents identified the types of action being taken to prepare for the effects of climate change including policy, planning, decision making criteria, design, funding, operation and management of transport assets. These responses included investigating the frequency and severity of impacts, adaptation to possible impacts, preparing guidance documents for central and local government, and incorporating climate change responses into local and regional documents.

With regard to existing and proposed adaptive changes, most respondents were concerned about the cost implications that are and will be involved with responding to the effects of climate change on land transport networks. Territorial local authorities (TLAs) indicated minimal responses have been made to respond to the effects of climate change for locally managed land transport networks.

2.2.3 Organisational co-ordination and collaboration

Two out of three respondents are co-ordinating with other organisations with regard to responding to the effects of climate change. Again, all the central government and crown entity organisations are co-ordinating with other organisations, while the response from all other groups was mixed. Those that were collaborating with other organisations are doing so via joint working groups on climate change adaptation, and by discussing and co-ordinating actions amongst themselves.

2.2.4 Climate change and transport systems

The questionnaire demonstrated that most organisations had identified the effects of climate change as an issue for land transport networks. Only one respondent, a TLA, stated that they have limited knowledge on the detailed effects of climate change on their networks. Most respondents identified the adverse effects of heavy rainfall and storms on transport networks, with particular reference to coastal areas. A range of other effects were described.

2.2.5 Sources of information

Most respondents noted that they use a range of information sources and other organisations, both nationally and internationally, to assess the effect of climate change on land transport networks. These information sources include central government organisations, local and regional councils, clients, guidelines, technical reports, scientific journals, published information, information and data on the internet, and media reports. One respondent noted that they receive informal information through monitoring.

2.2.6 Information and research gaps

Less than half of the questionnaire respondents stated that their organisation has identified gaps in knowledge about the effects of climate change on land transport networks. Where gaps are identified, these included general uncertainty about the exact nature, timing and scale of effects, and the inability to predict the nature and timing of localised climate change effects accurately.

When asked what their organisation is doing about the identified gaps in knowledge, most respondents indicated a 'watching brief' on the issue. No respondents have commissioned or done research on the likely implications of climate change on road, rail or ports and coastal shipping, although one crown agency referred to two relevant international publications. These are discussed below.

2.2.7 Barriers to responding to climate change

The questionnaire revealed that 83% of respondents' organisations perceived barriers in addressing the adverse impacts of climate change on land transport networks. The three biggest barriers identified were:

- funding,
- uncertainty of climate effects, their likelihood and/or consequence, and
- institutional capacity.

Other barriers identified included complacency, lack of public transport and low emissions vehicles, a lack of national or local leadership, and finding the balance between avoidance and adaptation.

2.2.8 Summary of stakeholder feedback

A survey of land transport network operators and contractors, central and local government authorities, and research institutions about the effects of climate change for road, rail, ports and coastal shipping networks provided a timely overview of the current state of knowledge about climate change effects for land transport networks.

In summary, our survey of stakeholders indicated the following:

- Land transport network operators, central agencies and researchers have a good general awareness of the potential effects of climate change for land transport networks; some are making preparation to investigate and address effects. Local government respondents indicated minimal response had been made to the issue.
- A small proportion of stakeholders mistook the effects of climate change to mean the resultant effects of transport greenhouse gas emissions on climate patterns. A small

number of stakeholders questioned the likelihood of predicted climate change effects occurring.
- The need for more specific information to assist operators to prepare for climate change effects was identified as a gap in knowledge. No specific research is underway to fill this or other related gaps in knowledge.
- Funding, uncertainty of climate effects, their likelihood and/or consequence, and institutional capacity were the key barriers to limiting the ability of the industry to address the adverse effects of climate change on land transport networks in New Zealand.

2.3 Literature review

2.3.1 Introduction

National and international literature relating to the effects of climate change and adaptation for transportation infrastructure has been reviewed in order to assess the nature of guidance and the current state of knowledge about the impacts of climate change on land transport networks. Given the worldwide interest in climate change, a large number of studies have been completed and many more are in the process of being published, hence the review has focused on key studies rather than being exhaustive.

The following is a summary of relevant literature in New Zealand and internationally, and draws out the salient matters for this project.

2.3.2 New Zealand

The IPCC, in its special report concerning Australasia (Watson et al. 1998), highlights the importance of transport in New Zealand:

> *Australia and New Zealand are particularly dependent on efficient, reliable transport within their relatively sparse domestic markets and for international trade. Impacts on transport services therefore could affect tourism and exports, in addition to the direct effects on transport safety and costs.*

Over the last few years (particularly since 2004), a series of guidance materials has been produced by the Climate Change Office and Quality Planning of the Ministry for the Environment (MfE) to help local government understand the legislative environment and assess and plan for climate change impacts. The most relevant publications include:

- *Preparing for Climate Change: A Guide for Local Government in New Zealand* (MfE 2004a) helps councils across New Zealand assess the likely effects of projected climate change during the 21st century and plan appropriate responses where necessary. It includes a framework for a risk-based assessment of how local government should respond to climate change.

- *Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand* (first and second editions) (MfE 2004b; MfE 2008) provides guidance on identifying and assessing likely future regional and local effects of climate change across New Zealand. It is designed to help local government identify and quantify the opportunities and hazards which climate change poses for their functions, responsibilities and infrastructure, particularly infrastructure and developments that will need to cope with climate conditions in 50 to 100 years' time. It also includes a generic risk assessment framework, and provides guidance on decision making and the legislative context (outlined in the policy sections of this report), as well as guidance on how to incorporate that knowledge into council planning.
- *Making Good Decisions – Climate Change Effects* (MfE 2007b) identifies activities that are particularly sensitive to the impacts of climate change (including bridges, roads, port facilities and coastal protection works), and discusses statutory provisions and gives examples of provisions currently made in regional and district plans.
- The *Quality Planning Climate Change Guidance Note* (Schofield & Lyons 2008) aims to provide best practice information on how to assess the significance of the effects of climate change, and how to respond to them, if necessary, with a particular focus on how climate risk assessment can be incorporated into local government regulatory, assessment and planning processes across all council functions and responsibilities, as well as giving advice on methods for considering and addressing climate change effects under the RMA. It also gives good examples of how local authorities have incorporated consideration of the effects of climate change into existing council decisions, activities and plans.

Guidance manuals have also been developed for specific areas. Of most relevance to this project are:

- *Coastal Hazards and Climate Change: A Guidance Manual for Local Government in New Zealand* (MfE 2004c),
- *A Methodology to Assess the Impacts of Climate Change on Flood Risk* (MfE 2005a),
- *Changes in Drought Risk with Climate Change* (MfE 2005b), and
- *Incorporating Climate Change into Stormwater Design – Why and How?* (Shaw et al. 2005).

These manuals provide information on the effects of climate change on coastal hazards and how to handle the possible impact of climate change when addressing flood and drought risk, and stormwater planning.

Kouvelis (2007) provides more specific guidance for incorporating climate change considerations into activity management planning and engineering design Codes of Practice, with some suggestions on how climate change predictions can be incorporated into 'engineering best practice' across New Zealand.

In addition to guidance which relates specifically to climate change, several reports which provide guidance on natural hazard risk management, which has many similarities and can be applied to climate change. The following reports provide guidance specifically developed for road networks and state highways:

- *Natural Hazard Road Risk Management Part I: Risk Management Strategies, Part II: Implementation Strategies, Part III: Performance Criteria* (Brabhaharan et al. 2001, Brabhaharan et al. 2006, Brabhaharan & Moynihan 2002) describe guidelines and case studies of risk management strategies for road networks in response to natural hazards, methods for implementing natural hazard risk management, a framework to determine performance criteria of a road network during times of emergency, and methodologies for assessing the risk of natural hazards to road links. Climate change considerations are not specifically mentioned.
- *Developing a Hazard Risk Assessment Framework for the New Zealand State Highway Network* (Seville & Metcalfe 2005) provides a risk management framework for networked systems regarding the probabilistic analysis of total risk applicable to any type of hazard event with the potential to cause road closures, recommending the Geographical Information System (GIS) as the most appropriate platform on which to base a risk assessment. In addition, the report provides a summary of relevant hazard data available. Climate change considerations are not specifically mentioned.

One of the more comprehensive research reports on natural hazard management is the *Natural Hazard Management Research Report* (MfE 2006c). It is a stand-alone technical research report on the key aspects of natural hazard management. The report includes a 'toolbox' of generic management approaches and treatment options available for managing natural hazards, and a comprehensive overview of the planning and legal framework (including case law), as well as a discussion on best practice within New Zealand. Physical and numerical modelling is referenced as a technique for determining the behaviour of various hazards, such as climate change.

The importance of undertaking more detailed localised study is illustrated by the Climate Long-Term Impact on New Zealand Infrastructure (CLINZI) project (Jollands et al. 2007), which found that many of Hamilton City's infrastructure sectors demonstrated greater responsiveness to population changes than changes in gradual climate change. This is because climate change effects will vary throughout the country, with some areas being more (or less) vulnerable than others.

Wratt (2002) states that a cautious approach to designing new infrastructure is desirable, particularly regarding development in areas that are already under threat. Literature on the occurrence and cost of historical weather related events may be useful for determining those areas at greatest risk. For example, *Preparing for and Adapting to Climate Change* (MfE 2007a) includes the costs of the top 13 weather related disasters in New Zealand from 1968 to 2006; similar studies, such as *The Waikato Weather Bomb: Understanding the Impact* (MfE 2004d), may be useful in determining the potential impacts of weather related events, which are predicted to become more frequent because of climate change.

Aside from the studies already mentioned, in the context of the current project, very little climate change research has been conducted for the land transport sector. Indeed, this NZTA project is the first study of its kind in New Zealand.

The closest precursor to this study is research carried out by Kinsella & McGuire (2005), who studied the climate change impacts on New Zealand's state highway assets and justified closer investigation of assets with a long intended life, namely major culverts and bridges. The authors found that rising sea level, storm surges, and increased frequency and intensity of heavy rainfall are the most relevant to state highway assets. They concluded that bridges (and culverts with a design life of over 25 years) may not have been adequately protected by policy and practice from the potential impacts of climate change. This finding resulted in the Transit[3] Bridge Manual (Transit New Zealand 2003) being amended to include relevant climate change effects as a design factor (this is discussed in the policy section of this report). The report considered the cost implications of climate change effects on emergency works, assuming that current annual costs ($18M) will double, with a linear cumulative increase to $711M in 2080. The cost of installing extra bridge spans to adapt bridges in areas affected by greater projected increases in mean rainfall was assessed at $295M. The cost increase to accommodate predicted climate change effects in new bridge design was calculated at 1%.

An Environment Canterbury report (O'Donnell 2007) considers the effects of climate change on Canterbury and opportunities to respond to these effects in the regional policy statement. The report highlights the opportunities available within the regional policy statement to ensure consideration of climate change effects when locations and designs of strategic infrastructure such as land transport networks are being developed. The influence of settlement patterns is acknowledged as a major contributing factor to sustainable demand for and use of transport corridors. The report notes the influence of the regional policy statement considering the life of assets and the relationship of asset life to climate change effect projections (see Section 2.3.3.2).

[3] Transit New Zealand was merged with Land Transport New Zealand (LTNZ) in August 2008 to become the NZTA.

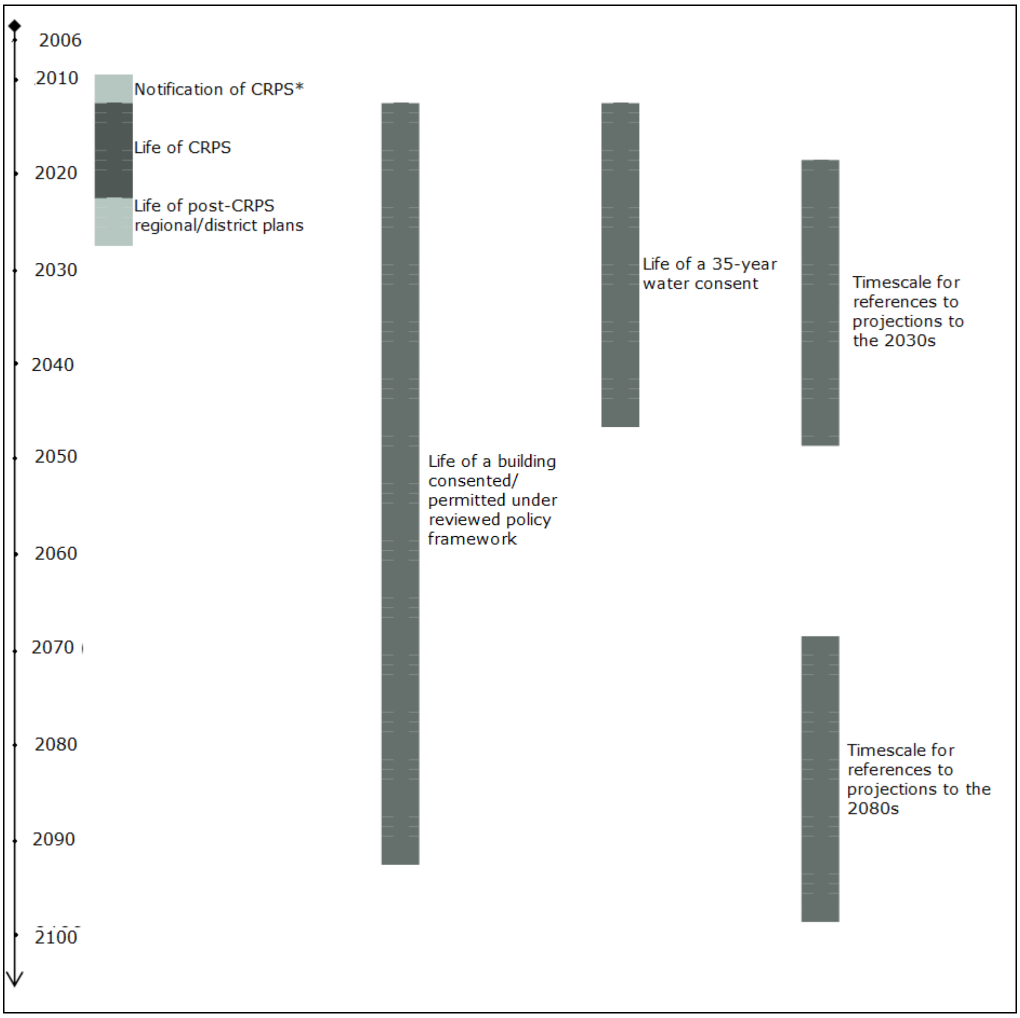

Figure 2.1 Timing of regional policy statements and influence over the life of assets in relation to predicted climate change effects timeframes. (Source: O'Donnell 2007).

*CRPS: Canterbury Regional Policy Statement

2.3.3 International perspective

2.3.3.1 General

A number of studies, summarised below, provide examples of how other countries have assessed climate change may affect transportation networks. These risk assessment studies tend to follow the same basic approach, which validates the methodology followed in this report.

Many of the publications acknowledge that the need for action is now starting to be more widely recognised by transport and other authorities. For example, the Highways Agency in the UK has begun a programme of research to understand the impacts of climate change, and is planning revisions to standards, specifications and operating procedures.

2.3.3.2 Australian studies

Austroads (2004) and the Federal Department of Transport and Regional Services (DOTARS) engaged the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Australian Road Research Board (ARRB) Transport Research, the Monash University Centre for Population and Urban Research, and the Australian Bureau of Agricultural and Resource Economics (ABARE) to undertake a project to examine likely future climate change and population scenarios for the whole of Australia during the 21st century. The aim was to investigate the effects of climate change on major road infrastructure, as represented by the Australian National Highway network. The study compared pavement maintenance and rehabilitation costs for a year 2100 climate projection and found a 0–3% increase required in the annual pavement maintenance and rehabilitation budget to account for climate change effects. The annual pavement maintenance and rehabilitation budget was estimated to increase by around 30% (considering the influence of climate change and transport demand changes).

In Victoria, Australia, CSIRO (Holper et al. 2007) conducted a risk assessment of different infrastructure types and found that transport ranked fourth in terms of risk from climate change (the five types, in order of risk, are water, power, telecommunications, transport and building infrastructure). The study describes the effects of climate change induced weather patterns on the design and operation of road, rail, airport and port infrastructure in Victoria.

2.3.3.3 USA studies

In the USA, several studies have been undertaken that focus on different aspects of the effect of climate change on transportation and infrastructure, including winter road maintenance, safety and operations (Sato & Robeson 2006; Pisano et al 2002). These include an assessment of the effects of flooding on the performance of urban transport network in the Boston metropolitan area (Suarez et al. 2005).

A study of the potential impacts of climate change on U.S. transportation (National Research Council 2008) focuses on their consequences for the infrastructure and operation of road, rail, air (which is not included in this study) and shipping. The report provides a tabular summary of five key climate change effects and their impact (both positive and negative) on operations and infrastructure, and also broadly discusses the geographical locations affected. Its primary objective is to provide guidance for transportation decision makers on how best to proceed, by identifying adaptation options and offering recommendations for research and actions that can be taken. The report notes that prudent choices today could avoid some of the costs by diminishing near-term maintenance expenditures and reducing the risk of catastrophic failure, with its toll on human life and economic activity. It provides a six-step decision framework for transportation professionals to address the effects of climate change on transportation infrastructure:

1. assess the likely impact,
2. inventory essential infrastructure,
3. analyse adaptation options,
4. determine investment priorities,
5. implement a programme of adaptation strategies, and
6. assess their effectiveness.

A Gulf Coast study (Savonis et al. 2008) assessed the impacts of climate change and variability on transportation systems and infrastructure in the Gulf Coast, concluding that even temporary flooding may have significant economic, safety and social ramifications in a transport system that already is under stress from congestion, and with people and freight haulers becoming increasingly dependent on just-in-time delivery.

2.3.3.4 UK studies

A study in the UK published by Thornes & Davis (1992) gives a clear picture of the effect of all extreme weather events on each transport sector and on infrastructure, and an evaluation of the costs deriving from delays and disruption in the service.

Another UK study (Arkell & Darch 2006) analyses the effect of climate change on London's transport network, including infrastructure and users, and how to plan ahead to adapt. The report notes the implications for rail in a hot year (2003) with 5.5 times as many 'delay minutes' nationally compared with a cooler year (2004) and more buckled rails at an estimated cost of at least £0.75M. The report identifies three key actions: monitoring, taking account of climate throughout the design life of new infrastructure and assessing the risk posed by climate change to existing infrastructure.

A study of possible effects on the Scottish road network (Galbraith et al. 2005) addresses road impacts and network management issues by presenting historical events with discussion on how they will increase in magnitude and frequency in the future based on the climate change predictions. The report assesses the effect of climate related factors in detail and identifies several climate-related trigger points that can damage road infrastructure or disrupt operations:

- Certain design mix asphalts may be liable to deformation at surface temperatures of 45°C.
- Wind gusts of over 20 m/sec have the potential to make high-sided vehicles unstable.

Priority recommendations are presented in terms of design, operation, research and policy issues, and assigned in the short- and long-term. Priority recommendations include:

- revision of design storm parameters used in surface water drainage design,
- identification and assessment of locations where flooding has occurred,
- pre-emptive clearing of detritus from channels and watercourse structures, and
- the need to undertake research into catchment runoff estimation parameters.

The report also includes risk-based design approaches, including cost/benefit analysis to evaluate alternative options, as well as giving consideration for using Variable Messaging Systems to provide a greater level of locally-relevant information to road users.

2.3.3.5 Other studies

A Finnish study (Saarelainen 2006) states that adaptation can be seen as a risk and safety assessment considering:

- contingency planning (emergency planning and warning);
- structural improvements to limit and prevent damage and to preserve the service level in existing transport infrastructure;
- improving design criteria for new constructions (e.g. to account for design wind speeds, flood levels, etc.); and
- improving building regulations, guidelines and recommendations.

The Finnish study is concise, descriptive and purely qualitative, using historical events to illustrate the current lack of preparation for climate change and similar events as examples when discussing the potential cost of future damage with indicative adaptation measures.

In their report of the state of knowledge about climate change and its impacts (Parry et al. 2007), the IPCC concluded that adaptation must be far more extensive than is currently occurring to reduce vulnerability to future climate changes.

2.3.4 Implications of literature review findings for this project: summary

2.3.4.1 New Zealand

The following list summarises some of the aspects reviewed in the literature which have particular relevance to this report.

- In New Zealand, substantial literature has been produced documenting the potential effects of climate change. NIWA, in particular, has produced considerable information on this subject; the most recent predictions, along with discussions on uncertainty, are presented elsewhere in this report. Given the inherent uncertainty in the predicted effects of climate change, the literature in this area is continually evolving. A key implication is that further refinement of the climate change models is needed to reduce uncertainty in regional analysis of impacts on the land transport network.
- Techniques to analyse historical information about the effects of current severe weather events (as opposed to climate changes) are well recorded (e.g. Brabhaharan et al. 2001), although our research was unable to identify a clear link between such analysis and consequential changes in land transport network design and operation. Given that some climate change effects are simply more extreme manifestations of current weather events (e.g. extreme rainfall), it could be useful to evaluate the use of such natural disaster models as a platform for identifying future flood risk from longer term climate changes (e.g. scaling up using 100-year average recurrence interval (ARI) 24-hour rainfall predictions).
- New Zealand's state highway system is the only section of the land transport network that has published an assessment of the risk and potential costs of climate change (Kinsella & McGuire 2005). The implication of this limited research base is that work to

assess climate change risk in the rail and port networks, and to plan and act accordingly in all three modes, is at an early stage.

- High level New Zealand-specific guidance about potential effects of climate change and risk assessment methodologies provide useful starting blocks for those involved with the planning, design, operation and management of land transport network infrastructure to determine potential effects.

2.3.4.2 International literature

Key conclusions drawn from the international literature identify:

- **the significant diversity of multidisciplinary inputs required to assess the effects of climate change** on transport networks, and to develop robust adaptation strategies covering the planning, design, operation and maintenance of such services;
- **the need for climate change factors to be incorporated into infrastructure design and maintenance** on an ongoing basis, e.g. by revising design storm calculations, revising pavement specifications to account for extreme and increasing temperatures, and accounting for revised design wind speeds;
- **the value of risk analysis tools to help define the thresholds and standards of transport service** to guide transport planning, engineering and future investment in order to account for the inherent uncertainties with incorporating climate related factors into the decision making process;
- **the range and quality of information requirements** for studies similar to the current project, including:
  - higher resolution of climate models to enable regional studies;
  - historical information about weather related events;
  - better understanding of climate related processes that damage transport infrastructure;
  - inventories of critical transport links in light of climate change projections to determine whether, when and where projected climate changes might be consequential;
  - updated flood zone maps that account for sea level rise (incorporating land subsidence);
- **recommendations by many international studies to calculate the costs of climate change** effects, including the cost of disruption and emergency works, and the implications of adapting transport systems to address climate change risks. Investment analysis techniques are recommended to account for the costs of adaptation in light of the economic costs of failure caused by climate change related weather patterns;
- **the need for contingency planning** to enable rapid recovery of the transport system in the event of natural hazards is identified by some international studies. New Zealand's systems, in this case, are well established;

- **the use of early warning systems in some studies** is an important part of minimising the impacts of climate change related damage and disruption to transport systems, for example by highlighting pending infrastructure failure or identifying the likelihood of severe natural hazards occurring.

International studies also identified the need for climate change adaptation to be built into long-term capital improvement programmes. On this note, New Zealand's RMA framework ensures climate change is taken into account in planning new transport infrastructure. However, the financial implications of adapting new and existing land transport network infrastructure to address climate change have yet to be determined.

3 Climate review

3.1 Introduction

The potential trends in climate change in New Zealand are set out in this chapter. Historical information is considered to distinguish natural variability from longer-term patterns relating to climate change.

A description of the natural greenhouse gas effect, the effect of increased greenhouse gas concentrations, and techniques used by NIWA to downscale global climate change models for New Zealand conditions are detailed in Appendix B.

3.2 New Zealand climate model considerations

NIWA has downscaled global climate change models to prepare New Zealand climate change scenarios for two periods: the 20-year period centred on 2040 (2030–2049) and the 20-year period centred on 2090 (2080–2099) (MfE 2008). A third timescale is proposed for analysis in Stage Two of this project. A 2010 scenario will also be used in Stage Two to describe likely climate change effects in the immediate term. Climate impacts for 2101 will be assessed through a projection of current trends present in New Zealand climate data over the last 50 years.

NIWA undertook statistical downscaling from twelve different Atmosphere–Ocean Global Climate Models or AOGCMs (an AOGCM uses greenhouse gas emission and aerosol concentration scenarios to predict future climate variations) for each of the two periods for a mid-range greenhouse gases emission scenario (referred to as A1B – see Figure B3 in Appendix B). The methodology is described in more detail in Appendix B. Optimistic and pessimistic greenhouse gas emission scenarios will be analysed in Stage Two of this project for the three future time horizons.

As recommended by IPCC, NIWA did not indicate a ‘most likely value’ from within these ranges of projections. It should be noted that the extreme ends of the range may be slightly less likely than the central values, as extreme values reflect the outcomes of a climate model which gives the most extreme projection rather than reflecting agreement between a number of models. NIWA also notes changes may occur outside of the scenario range because of the uncertainties in regional climate modelling. With an understanding of how to interpret global climate change predictions as they may apply to New Zealand, these scenarios are a useful tool for infrastructure operators to identify potential scenarios that they may face as a result of climate change.

3.3 Natural variability and climate change

3.3.1 General remarks

In considering future climate change and its effect, it is important to remember that seasonal and natural year-to-year variations in climate and in the frequency of extremes will continue to occur. For example, climate models vary considerably in describing the climate change related trends and events in summer; however, modelling of winter effects show the least variability.

Over the coming century, New Zealand will have to deal with the combination of a shift in the underlying mean climate caused by global warming and natural variations. As part of NIWA's climate modelling methodology, long-term warming trends are superimposed on the natural decadal climate variations described below. For example, as described in MfE (2008), the effects of a negative phase of the Inter-decadal Pacific Oscillation (IPO) would generate more La Niña activity that is likely to result in weaker westerlies across New Zealand, particularly in the South Island, with a consequence of lower rainfall totals in the west of the country (as seen in 2007/08). The wind and rainfall effects of climate change may therefore be countered or enhanced by natural climatic variability, although the temperature and sea level rise would still be experienced.

3.3.2 El Niño Southern Oscillation Index

In New Zealand and the South Pacific, the El Niño Southern Oscillation (ENSO) is a significant source of seasonal and year-to-year climate variability (Nicholls, 1993). The Southern Oscillation Index (SOI) explains up to 40% of year-to-year air temperature variations in the tropical Pacific. Although El Niño is an important influence on New Zealand's climate, it accounts for less than 25% of the year-to-year variance in seasonal rainfall and temperature at most New Zealand measurement sites. ENSO is also a significant source of seasonal and year-to-year variability in sea level.

In El Niño years, New Zealand tends to experience stronger or more frequent winds from the west in summer, leading to drought in east coast areas and more rain in the west. In winter, the winds tend to be more from the south, bringing colder conditions to both the land and the surrounding ocean. In spring and autumn, southwesterlies tend to be stronger or more frequent, providing a mix of the summer and winter effects.

La Niña events, which occur at the opposite extreme of the SOI cycle, have weaker impacts on New Zealand's climate. New Zealand tends to experience more northeasterly winds, which bring moister, rainier conditions to the northeast parts of the North Island and less rainfall than usual to the southwest parts of the South Island.

3.3.3 Decadal climate variability

NIWA scientists recently identified a long-lasting ‘shift’ in New Zealand’s climate that occurred around 1977 (Salinger & Mullan 1999). The shift is characterised by more persistent westerlies onto central New Zealand since 1977, resulting in the west and south of the South Island being about 10% wetter and 5% cloudier, and with more damaging floods. The north and east of the North Island have, on average, been 10% drier and 5% sunnier, compared to 1951–76 data. This change point of 1977 coincided with an eastward movement in the longitude of the South Pacific Convergence Zone, and more frequent El Niño events in the recent record. This shift is probably caused mainly by Pacific-wide natural fluctuation called the IPO (Mantua et al. 1997), which exhibits phase reversals about once every 20–30 years.

3.4 Regional climate change effects in New Zealand

3.4.1 Aspects considered

Some of the most significant effects of climate change for land transport networks might be caused by changes in climate extremes (for example extreme rainfall, strong winds and storm surges), rather than just changes in mean climate conditions. Unfortunately, estimates of likely changes in regional climate extremes are generally less certain than projections of likely changes in mean conditions.

The following sections describe possible changes to mean and extreme climate conditions in two time scenarios with reference to the spatial (regional) distribution of effects. See the latest local government guidance manual (MfE 2008) for more details. Implications for land transport networks are discussed in Chapter 9.

3.4.2 Mean and extreme temperatures

New Zealand's mean temperatures are expected to increase by about 1°C in the 2040 scenario (Figure 3.1) and by 2°C by 2090 (Figure 3.2).

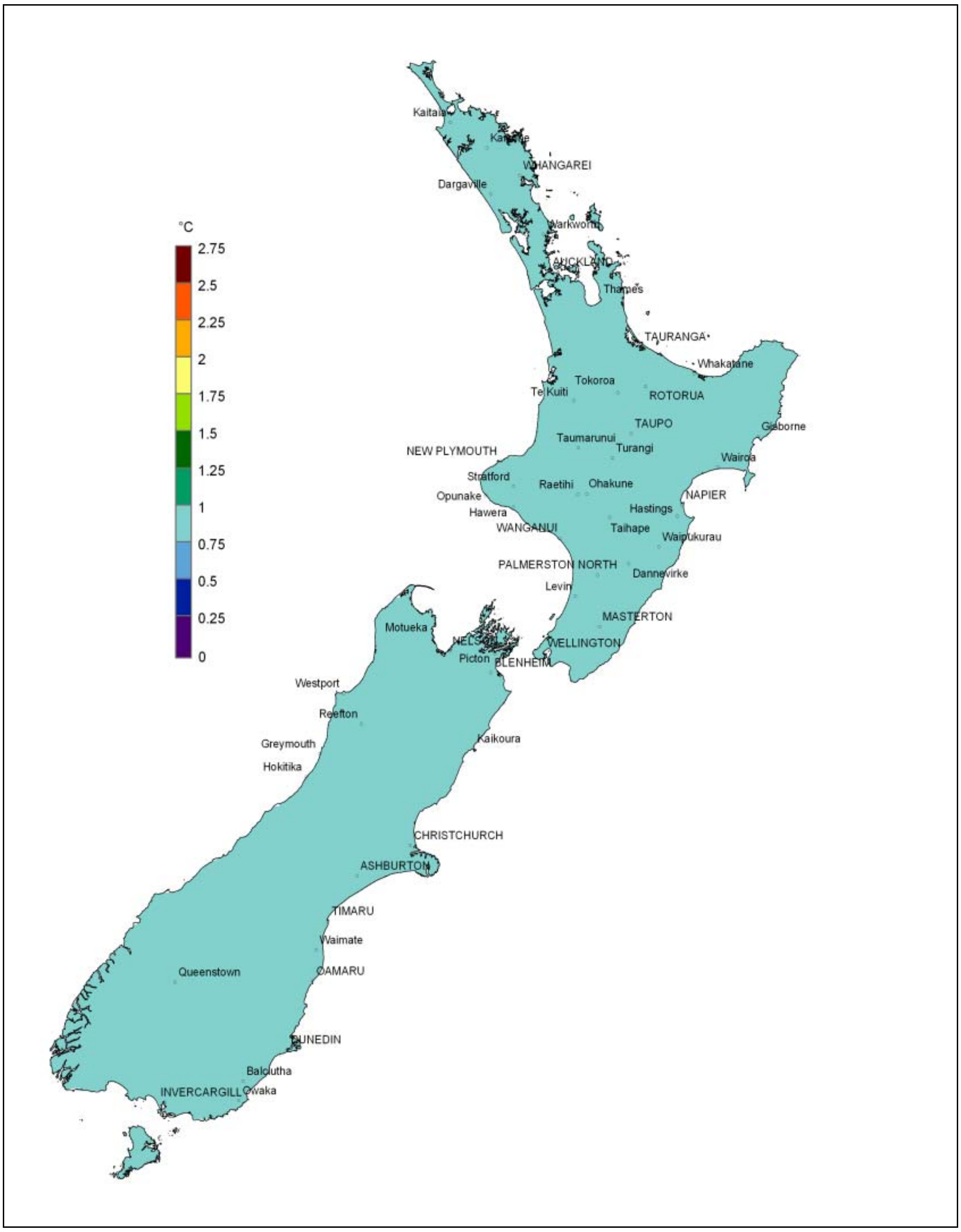

Figure 3.1 New Zealand's projected changes in annual temperature (in °C) to 2040 relative to 1990.

Note: This projection was based on a twelve-model average of projections and for the A1B emission scenario.

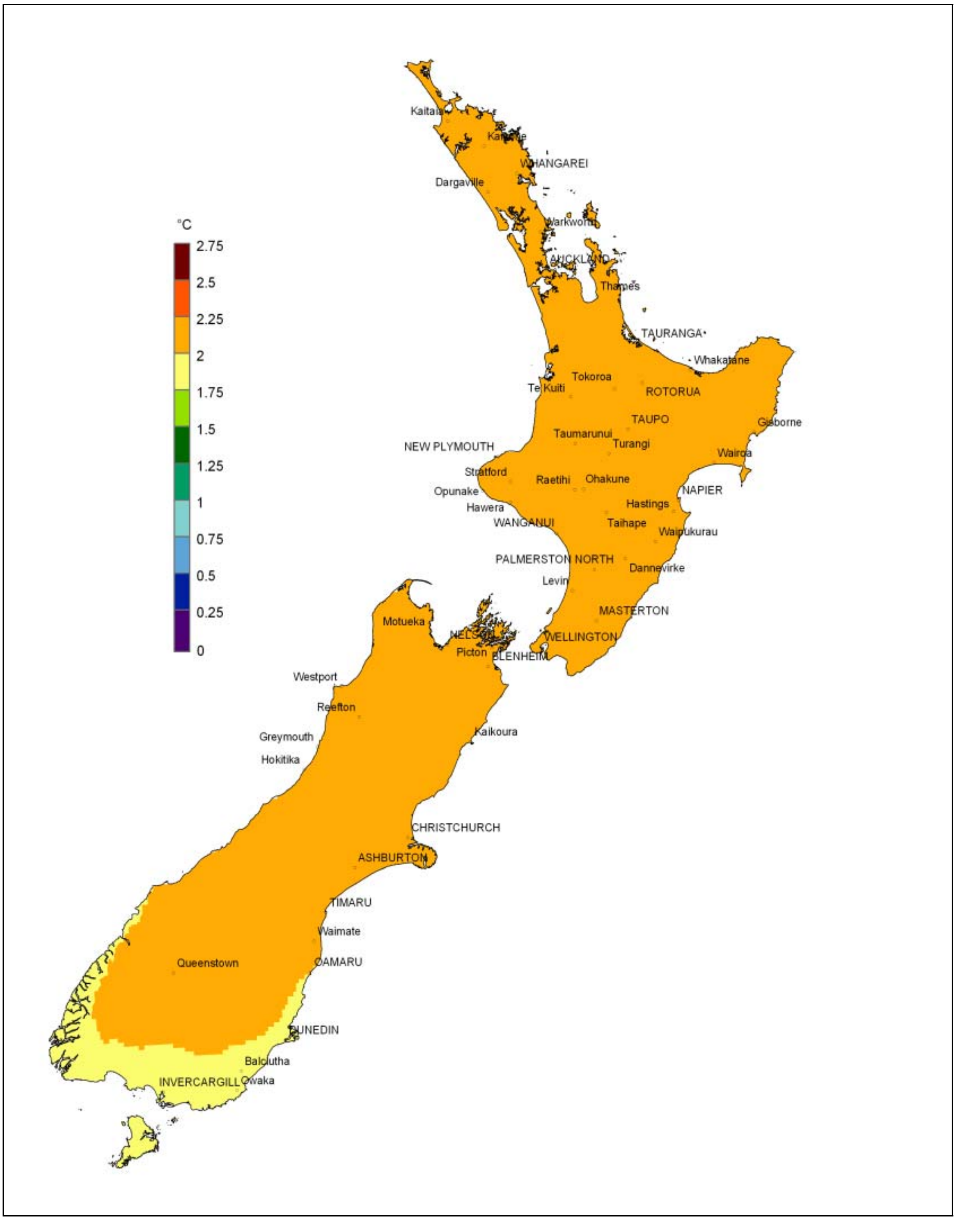

Figure 3.2 New Zealand's projected change in annual temperature (in °C) to 2090, relative to 1990.

Note: This projection was based on a twelve-model average of projections and for the A1B emission scenario.

An increase in mean temperature is expected to affect temperature extremes by increasing the frequency of 'hot days' in areas that currently experience them. In the example shown, a 'hot day' is defined as a day which exceeds 25°C. The figure shows that for a 2°C increase in the mean temperature (which is consistent with the twelve-model average temperature change projection for New Zealand to 2090; see Figure 3.3) the number of hot days is projected to increase by as much as 50 days, with the largest increases occurring in the Bay of Plenty, Waikato, Auckland and Northland regions.

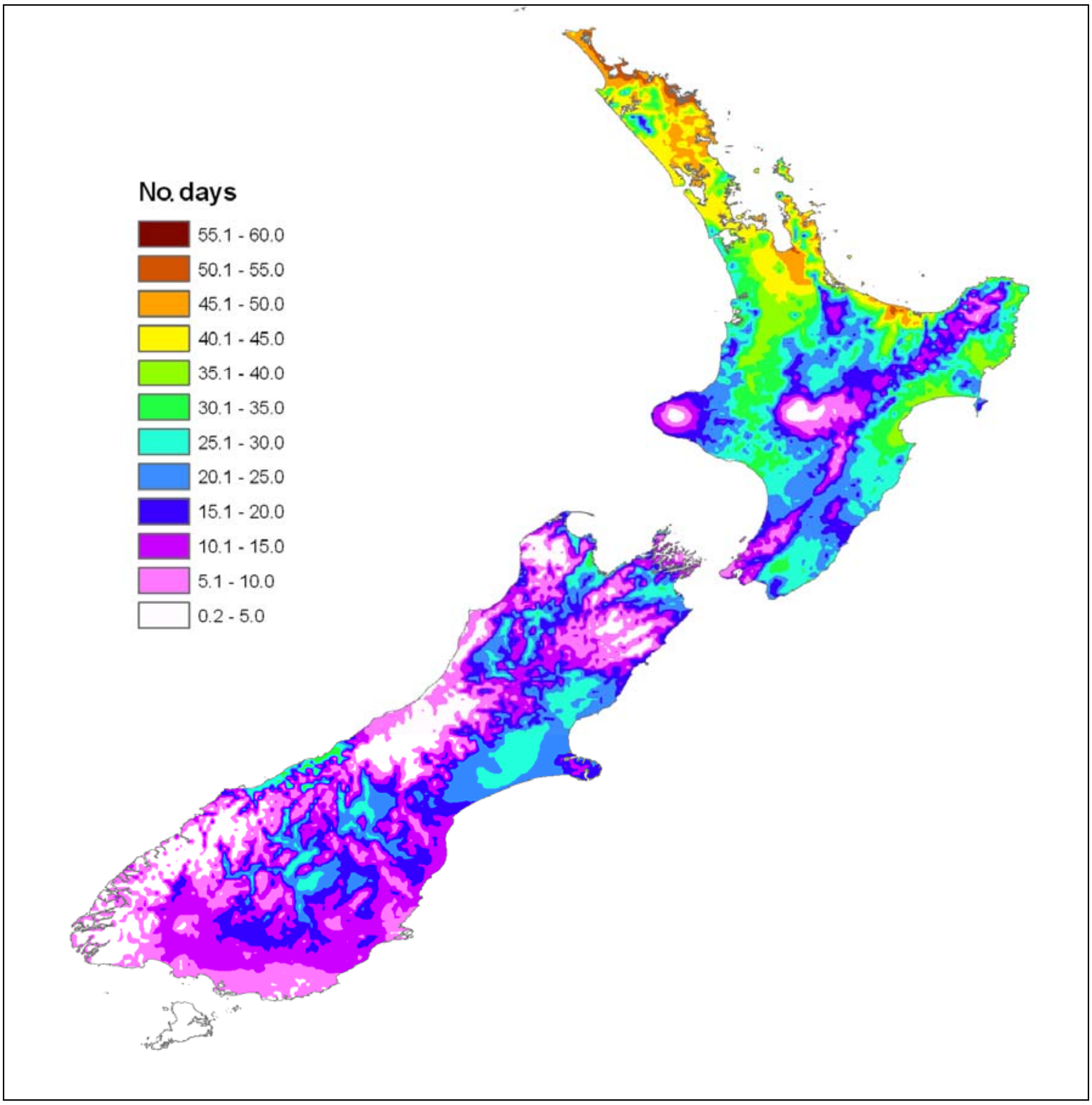

Figure 3.3 Predicted increase in the number of days with a maximum air temperature greater than 25°C associated with a 2°C warming in the mean temperature.

Note: This increase in the mean temperature is consistent with the twelve-model average temperature change projection for New Zealand to 2090 (see Figure 3.2).

3.4.3 Mean and extreme rainfall

For annual rainfall, the projections (Figure 3.4 and Figure 3.5) indicate a strong southwest to northeast gradient. This occurs because many of the models project an increase in the frequency or magnitude of airflow across the country from the southwest or west, which tends to bring rain to the West Coast and the main mountain chains, and less to the northeast.

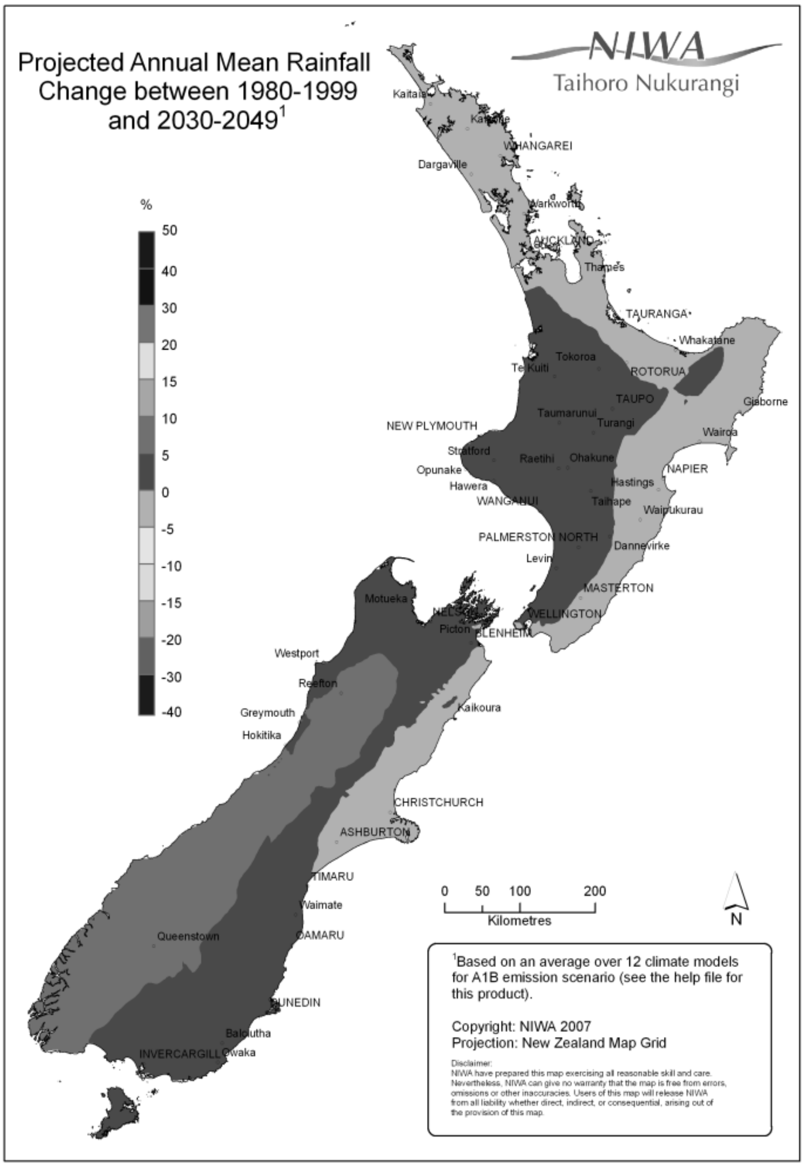

Figure 3.4 New Zealand projected changes in annual rainfall (in %) to 2040, relative to 1990.

Note: This projection was based on a twelve-model average of projections and for the A1B emission scenario.

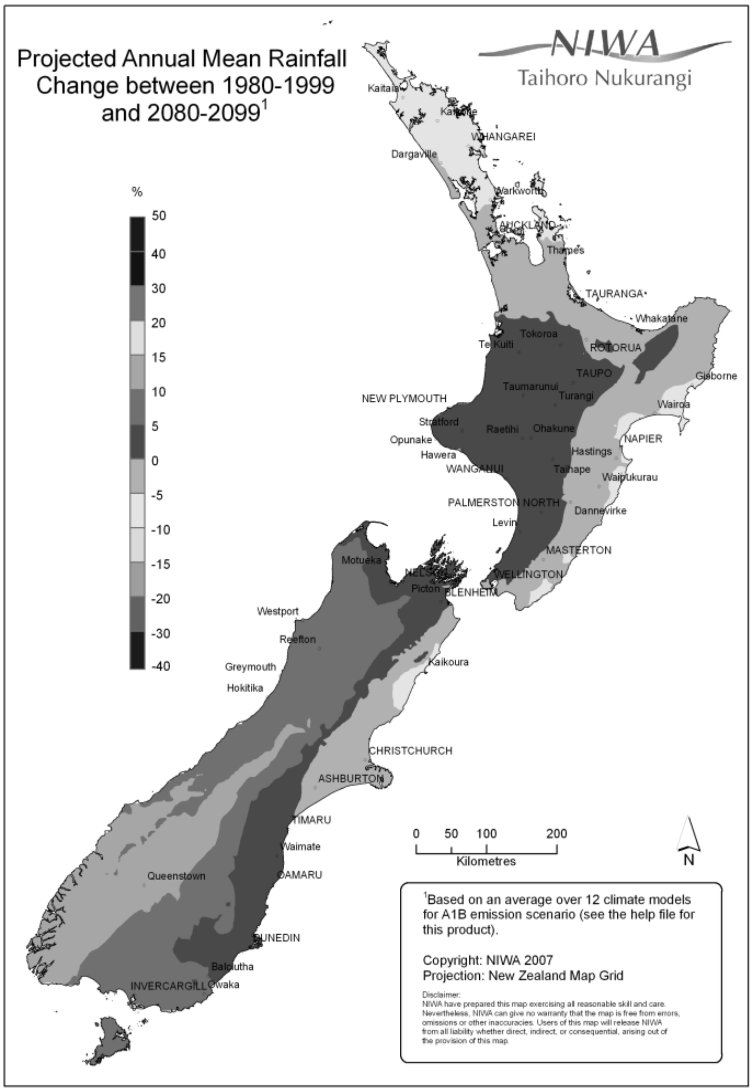

Figure 3.5 New Zealand projected changes in annual rainfall (in %) to 2090, relative to 1990.

Note: This projection was based on a twelve-model average of projections and for the A1B emission scenario.

Models vary considerably: for some locations, even the sign of the change cannot be stated with any confidence. However, for 2090, annual mean rainfall, the regions of Taranaki, Manawatu-Wanganui, West Coast, inland Otago and Southland tend to show increased rainfall for all scenarios, compared to Hawkes Bay and Gisborne, which show rainfall decreases. Seasonally, the largest projected percentage decreases are for the north and east of the North Island in winter and spring. (A note of caution: a significant amount of inter-model variability exists, particularly in the projections of seasonal rainfall. This uncertainty, which is masked when merely considering the twelve-model average, is taken fully into account in the risk-based assessment framework applied in this research).

A warmer atmosphere can hold more moisture (about 8% more for every 1°C increase in temperature), so the potential for heavier rainfall certainly exists. Figure 3.6 shows the impact of this increased moisture holding capacity on the 24-hour 100-year ARI (return period) rainfall map, given a 2°C warming (consistent with the twelve-model average temperature change projection for New Zealand to 2090; see Figure 3.2). The figure shows that for broad areas of New Zealand, the 24-hour rainfall total expected once in 100 years will increase by 20–30 mm. For mountainous locations, the total may increase by more than 100 mm.

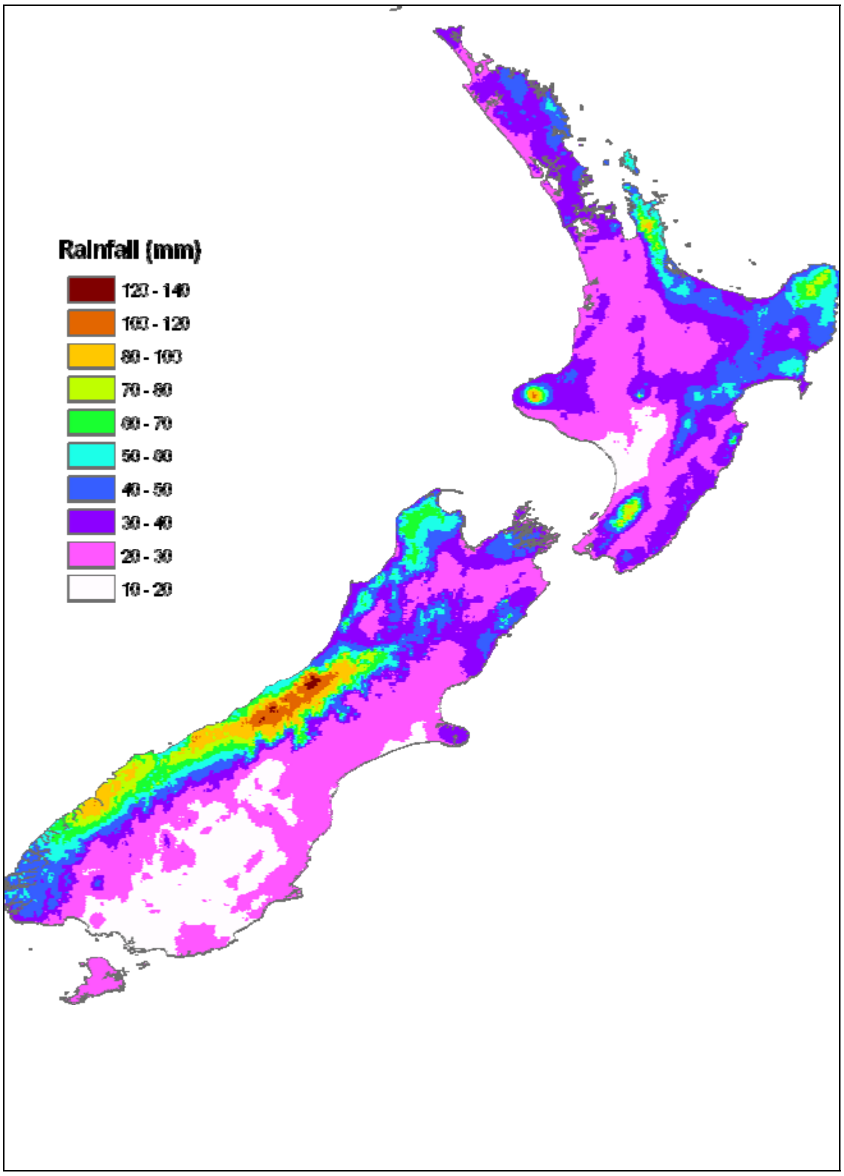

Figure 3.6 Predicted increase in the 24-hour 100-year ARI (Average Recurrence Interval) rainfall total associated with a 2°C warming in the mean temperature.

The IPCC (2001) has declared that more intense rainfall events are 'very likely over many areas'. Various modelling studies suggest that heavy rainfall will occur more frequently in New Zealand over the coming century, but the likely size of this change is uncertain. In broad terms, what is an extreme rainfall in the current climate might occur about twice as often by the end of the 21st century under a mid-range climate change scenario. For high temperature changes, an extreme rainfall in the current climate might occur 3–4 times as often by the end of the 21st century.

NIWA has provided some further guidance on extreme rainfall scenarios which can be used in preliminary 'what-if' analyses of, for example, possible implications for stormwater drainage systems (MfE 2008).

MfE (2005b) recommends using rainfall predictions in warmer conditions as a screening tool to assess the likely change in flood risk as a result of climate change. To complete more detailed analysis, weather and rainfall-to-river flow models are recommended to take account of the complex rainfall and river processes that affect flooding.

As the effects of climate change on cyclones and storms are not well known, more modelling is required to better understand the effects of storms on mean and intense rainfall conditions.

3.4.4 Drought

NIWA (Mullan et al. 2005) developed drought risk projections for a range of climate change scenarios based on the IPCC TAR, corresponding to approximately the middle 75% of the IPCC global temperature change projection range. Under both the 'low-medium' and the 'medium-high' scenarios (which bracketed this 75% range), the drought risk was projected to increase in frequency during the coming century for all areas that are currently drought prone.

Under the 'low-medium' scenario, by the 2080s, severe droughts (defined for the study as the current one-in-twenty year drought) are projected to occur at least twice as often as currently in the following areas: inland and northern parts of Otago, eastern parts of Canterbury and Marlborough, parts of Hawkes Bay, parts of the Bay of Plenty and parts of Northland.

Under the 'medium-high' scenario, severe droughts are projected to occur more than four times as often by the 2080s in the following regions: eastern parts of North Otago, Canterbury and Marlborough; much of the Wairarapa, Bay of Plenty and Coromandel; most of Gisborne; and much of Northland.

3.4.5 Snowfall and snowline

NIWA (MfE 2008) predict with confidence a shortened duration of seasonal snow lying. A rise in snowline is reasonably likely, and it is unlikely that climate change will lead to a decrease in snowfall events. NIWA (Tait, pers. comm.) expect that snow will continue to fall to sea level in parts of New Zealand; however, the potential impact of climate change on the frequency and intensity of snowfall is uncertain. However, confounding issues arise. Warmer air holds more moisture, so during winter this moisture could be precipitated as snow at high altitudes. Thus warming does not rule out increased winter snowfall, although the duration of seasonal snow cover could be shortened.

3.4.6 Mean and extreme wind

Global climate models suggest that for mid-range temperature change projections, the mean westerly wind component across New Zealand will increase by approximately 10% of its current value in the next 50 years (Mullan et al. 2001). The implications of this for strong winds are uncertain, but preliminary results from a single run of NIWA's regional climate model (see Figure 3.7 below) suggest only small changes (~2% increase) to extreme winds may occur on average for New Zealand, with slightly higher changes (~10% increase) possible in some locations (e.g. on the Canterbury Plains in the lee of the Southern Alps caused by an increase in the strength of downslope winds).

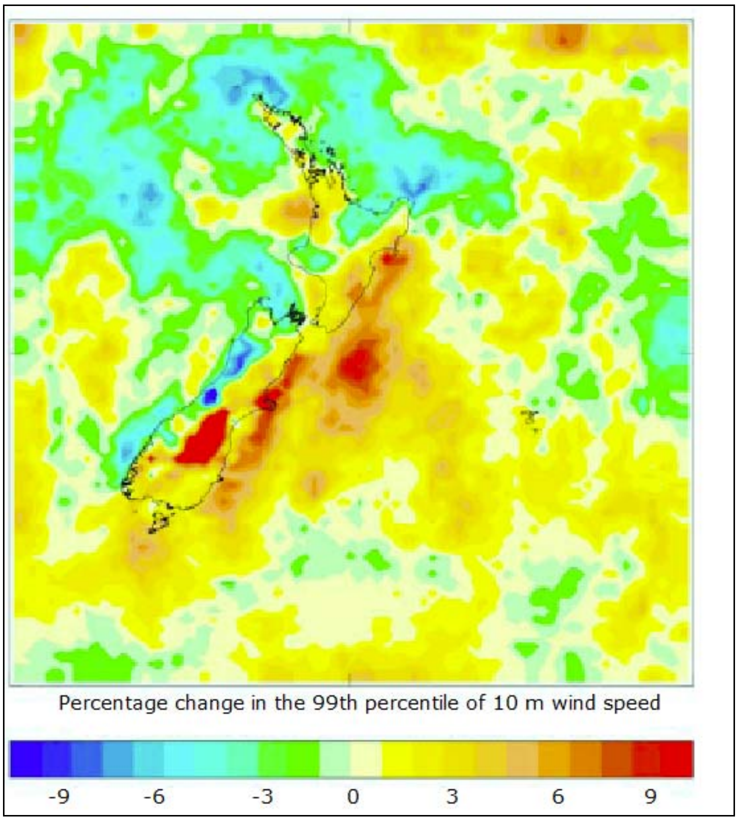

Figure 3.7 Change (in %) in the 99th percentile wind speed in the winter season between a control run (1980–1999) and a climate simulation under the A2 scenario for 2080–2099 (Adapted from MfE (2008)).

3.4.7 Ex-tropical cyclones and mid-latitude storms

Projections for these events are also an area of considerable uncertainty. Current knowledge suggests the most likely outcomes over the coming century for New Zealand are that ex-tropical cyclones might be slightly less likely to reach New Zealand, but if they do, their impact might be greater. The intensity or frequency of mid-latitude storms might also increase somewhat in our region. However, NIWA's level of confidence in these projections is low.

3.4.8 Sea level rise

The rise of relative sea level around New Zealand is likely to be similar to the global projections of sea level rise in the IPCC TAR. (The word 'relative' is used to exclude vertical land movement – uplift or subsidence of land or coastal seabed – that may occur, for example, as a result of earthquake activity). This is based on similarities between the New Zealand average and the global average over last century of around 1.8 mm/year. Sea level rise will not be a temporary aberration, but will continue for several centuries even if greenhouse gas concentrations are reduced.

Using the same approach as for global temperature change, the IPCC TAR projects that global mean sea level will rise between 9 and 88 cm between 1990 and 2100 in the full range of the Special Report on Emissions Scenarios (SRES) scenarios. A guidance manual on coastal hazards and climate change produced for the Climate Change Office by NIWA (MfE 2004c) suggests using a mid-range sea level rise projection of 0.2 m by 2050 and 0.5 m by 2100 for planning and design purposes until updated projections become available. Transport infrastructure operators should note that the upper limit of sea level rise predictions is very uncertain. The projected increase in westerlies may also influence the ocean wave climate that impacts on New Zealand. In particular, coastal regions exposed to the prevailing winds may be subject to an increase in the frequency of heavy swells that would add to the effects of higher sea levels.

3.4.9 Summary of climate change projections for New Zealand

Much of the climate change scenario material described above is summarised in a table for the Local Government Guidance Note prepared by NIWA (MfE 2008), reproduced here as Table 3.1.

Over time, climate change effects are not expected to occur in a linear fashion. Periods of cooling or extreme events may occur beyond predictions. Therefore operators should treat climate change scenarios as the likely or potential trends that transport networks will be exposed to during the broad 20-year scenarios based around 2040 and 2090.

Table 3.1 Main features of New Zealand climate change projections for 2040 and 2090 (from MfE 2008).

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 (*).
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 in Northland, Auckland, Gisborne and Hawkes 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 Hawkes 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 seasonal snow lying (***); rise in snowline (**); decrease in snowfall events (*).	–	–
Glaciers	Continuing long-term reduction in ice volume and glacier length (***).	–	Reductions delayed for glaciers exposed to increasing westerlies.
Wind (average)	Increase in the annual mean westerly component of windflow across New Zealand (**).	About a 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 (>10 m/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 (****).	–
Waves	Increased frequency of heavy swells in regions exposed to prevailing westerlies (**).	–	–
Storm surge	Assume storm tide elevation will rise at the same rate as mean sea level rise (**).	–	–
Ocean currents	Various changes plausible, but little research or modelling yet done.	–	–
Ocean temperature	Increase (****).	Similar to increases in mean air temperature.	Patterns close to the coast will be affected by winds and upwelling and ocean current changes (**).

Notes to Table 3.1:
All estimates represent the best current scientific estimate of the direction and magnitude of change. The degree of confidence placed by NIWA scientists on the projections is indicated by the number of stars in brackets:

- **** = *Very confident*: at least 9 out of 10 chance of being correct (very confident means that it is considered 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 the change;
- * = *Low confidence*, but the best estimate possible at present from the most recent information (such estimates could be revised considerably in the future).

3.5 Gaps in knowledge

A summary of the key gaps in knowledge relating to climate change science relevant to this project is given below.

Clouds and solar radiation: Key climate parameters such as clouds and solar radiation have not been examined in depth but may have a bearing on the operation of transport networks and infrastructure. An improved understanding of the physics behind cloud formation and cloud interactions with warming temperatures would assist in calculating the complex interactions that contribute to rainfall averages and extremes. The relationship between climate change, solar radiation and temperatures will refine assessment of transport asset vulnerabilities to heat-related effects (e.g. track buckling).

Model resolution: Higher resolution models would enable the detailed effects of climate change to be applied to local contexts. A close assessment of site specific factors should also take account of non-natural climate related factors such as urban heat islands and their effects on surrounding infrastructure.

Uncertainty in greenhouse gas emissions: A major problem associated with projecting future climate conditions in New Zealand is the inability to predict greenhouse gas emissions, because these depend so strongly on social, economic and political decisions yet to be made. Even if future emissions were known exactly, different global climate models will vary in the way they simulate climate feedback; this leads to different global average temperature changes. Such model differences are amplified at small regional scales, such as over the New Zealand landmass.

Uncertainty in regional climate change predictions: The national review of potential impacts on United States transportation (National Research Council 2008) highlights that professionals often lack sufficiently detailed data on which to modify design or operational plans to account for climate change. This is because transport professionals require data at the local and regional level, whereas climate change projections are undertaken at the global level. This type of information gap is commonly observed in climate change risk analysis in New Zealand and around the world. While scaling methods (including temporal scaling e.g. from monthly mean changes to a time series of daily values) may suffice – indeed, they may be the only option in some cases - they introduce additional uncertainty. Closing this information gap is an important goal of this study and a key area for innovation.

Scaling methods: Choice of the best scaling methods to use is a key knowledge gap that must be identified at this stage of the study. Appropriate choice is highly dependent upon the questions being addressed. For example, if risk assessment is being carried out for extreme events (such as a 1 in 100 year flood or rainfall event), different techniques are required from those used for analysing the impacts of mean changes. In addition, the input requirements of an impact model (such as the engineering design of a road) will govern the choice of scaling methodology and determine if additional statistical analysis of climate variables is required.

Uncertainty in downscaling for extreme events: NIWA's current process of downscaling the global projections to the New Zealand scale has a statistical error which may limit its use in studies of extreme events for transport design and planning. Typical values of the explained variance of seasonal mean temperature and precipitation at the climate station locations used are around 50–70% (temperature) and 20–50% (precipitation) (Mullan et al. 2001). Thus a significant proportion of the variance is unexplained by the regression equations used.

The levels of confidence shown in Table 3.1 attempt to sum up all the potential sources of model uncertainties. Typically, the 'direction of change' (i.e. increasing, decreasing or staying the same) is described with higher confidence than the 'magnitude of change'. For example, confidence is very high that the New Zealand mean temperature will increase, but is only medium that the change for a mid-range emissions scenario will be 0.9°C by 2040 and between 2.1°C by 2090. Projected changes to extreme events such as the frequency and/or intensity of heavy rainfall, high winds and storms have the lowest confidence. This is a major limitation for predicting detailed regional impacts on land transport infrastructure.

Uncertainty in climate step change: The current global projections describe climate change as a relatively gradual process over the next 50 to 100 years. However, it is unlikely that the human component of climate change, which is the driver of the projections, will be experienced as a smooth transition. Natural background variability will amplify change in some years, reflecting in potentially sudden and dramatic changes of the local and regional climate and weather. Rapid shifts in broad scale systems are also likely as the global system reaches critical thresholds. Understanding of such processes is not well developed, and they are not included in the current suite of AOGCMs.

Short-term (ten-year) predictions: One of the major limitations in climate change science is that it is not possible to forecast the nature of the coming decade, yet this information may be of most value to those making critical transport planning and investment decisions now.

Regarding closure of these uncertainties, current research around the globe and in New Zealand is focusing on enhancing the degree of confidence with which scenarios can be applied. At NIWA, scenarios of changes in temperature and precipitation generated for the IPCC's 2007 report from twelve global climate models have been downloaded and downscaled for New Zealand. Concurrently, NIWA continues to develop the only regional climate model for New Zealand (this is based on and nested within the UK Hadley Centre global climate model, but is run at a higher spatial resolution for the New Zealand area). Analyses of the regional climate model will enable significant improvements to be made in the understanding of climate change on New Zealand climate, particularly on extreme events, which have the most bearing on impacts on transport infrastructure.

While models differ and will continue to differ regarding climate change projections for New Zealand (and indeed for anywhere in the world), the improvement and increase in the number of models mean that the data can now be analysed probabilistically rather than using a low, middle and high projection range.

Probabilities of exceeding certain critical ‘trigger’ thresholds (e.g. the temperature at which bituminous pavements becomes viscous) are an important part of a climate change and land transport risk assessment process that needs further elaboration in future.

4 New Zealand transport and climate change legislation and policy

4.1 Overview

This chapter identifies aspects in New Zealand legislation and policy dealing with climate change and transport where gaps have been identified. It also considers aspects where progress has been made, or where an existing legislative or policy framework provides the potential for an appropriate response in terms of the land transport system (e.g. if given adequate information). Appendix D summarises key legislation while Appendix E summarises key central agency policies.

The review of New Zealand's legislation and policy relating to climate change and land transport sought to identify what guidance is available to land transport asset providers, planners, regulators and scientists about the effects of climate change on land transport networks.

Generally, relevant legislation relates to modes specifically, or guides the overall planning and regulatory responsibilities of other parties such as local government or the supplementary requirements of transport infrastructure providers. Examples of the former include the Land Transport Management Act 2003 (LTMA) (New Zealand Government 2003) and the Maritime Transport Act 1994 (New Zealand Government 1994). Examples of the latter include the RMA, the Local Government Act 2002 (LGA) (New Zealand Government 2002a), and the Civil Defence Emergency Management Act 2002 (CDEMA) (New Zealand Government 2002b).

In legislation, climate change effects on land transport networks are required to have particular regard given to them by applicants and regulators under the RMA. Road network and natural hazard management legislation allows for climate change effects to be considered as part of sustainable land transport systems and hazard readiness plans. However, climate change effects are not specifically referred to or required to be considered. Ports and (until the establishment of ONTRACK in 2004) the rail system have operated in an unregulated system; therefore no legislative mandate specific to those modes identify climate change adaptation as a strategic issue for consideration.

The poor integration of transport and land use planning is being increasingly recognised (e.g. Hunter et al. 2008). Efforts are currently underway through legislative (for example, elements of the Local Government (Auckland) Amendment Act 2004) (New Zealand Government 2004c) and other central government activity (for example, through the multi-sectoral Integrated Approach to Planning project currently being led by the Ministry of Transport (MoT)) to compel or at least facilitate a more integrated approach to land use and transport planning.

In the consideration of climate change effects, material is available to assist local government authorities to consider the potential effects of global warming on coastal settlements (MfE 2004c). In doing so, local government can integrate risk assessment and response across land use and transport considerations through planning instruments such as regional policy statements, as described in O'Donnell (2007).

In practice, the legislative framework and operational practice makes local government, multi-sectoral agencies, and mode operators such as ports, rail and road controlling authorities responsible for policy and planning responsibilities at the level at which climate change adaptation or response is most effectively considered and provided for. Regional Policy Statements and District Plans under the RMA, RLTSs under the LTMA, and LTCCPs under the LGA are all key elements in the overall statutory and central policy framework that have a bearing on the potential future effects of climate change on the land transport network. Mode operators' own policies are covered in Sections 6, 7 and 8, where relevant policies have been identified as part of this research.

Central government policy agencies have put considerable effort into strategies and guidance to advance adaptation to the effects of climate change. Land transport network managers are key audiences for material relevant to local government and the engineering fraternity. Guidance is necessarily general in relation to broad patterns of climate change effects and infrastructure vulnerability. Methodologies for risk assessment are comprehensive and advocate regular reassessment of climate change risks to reflect the availability of updated climate science, and appropriate infrastructure standards and practices.

Government research investment strategies clearly identify updated climate science, multi-disciplinary research and end-user focused information as being key to preparing transport infrastructure for the effects of climate change. Overarching transport and hazard management strategies provide existing frameworks to make clear and consistent references to climate change adaptation as a priority.

4.2 Gaps

4.2.1 Legislation

Local government in particular is faced with legislative responsibilities for planning for the future of areas and communities under relatively generic legislation. They are responsible for the provision, maintenance and/or control of community infrastructure, including key elements of the land transport system.

Key elements involving gaps are:

- **A lack of overall integration of land transport planning and land transport integration with land use planning.** This is a complex issue, but in brief, land use change is frequently driven in the private sector with little thought for or evaluation of impacts on transport systems. Climate change considerations need to be built into integrated thinking and planning for the future of transport and land use as one element. The relatively recent introduction of the effects of climate change as a matter to which particular regard must be had under the RMA can be seen as an attempt to fill the gap – but that will have little benefit until overall integration of land use and transport system planning is more effectively delivered.
- **Lack of explicit recognition of potential climate change issues in legislation.** The RMA now explicitly mentions climate change. Therefore, new activities that require assessment under the RMA trigger an assessment of climate change effects. However, other key planning and regulatory legislation does not. 'Sustainability' is a common thread in most new legislation that could allow for climate change considerations. However, it is left up to local authorities or similar agencies to recognise and determine how important climate change effects are in an overall assessment of sustainability when preparing policy and/or plans, and making decisions. It is still possible to overlook climate change effects without more guidance about 'sustainability'.
- **Timeframe issues.** Climate change effects are aspects of the future which are recognised as requiring action in the present if significant consequences are to be avoided, particularly for existing or new transport assets that are vulnerable to potential effects. However, the legislation provides for preparation and review of plans on a relatively short-term horizon (ten years for RMA plans prior to review, ten years for LTCCPs with three-year and annual updates through Annual Plans). The legislation largely leaves those responsible for planning to determine the appropriate period. Even the Building Act (New Zealand Government 2004), which formerly applied a 50-year lifetime to buildings, now provides no indication of the planning life for a building or structure.

  Asset Management Plans likewise have a planning life to be determined as part of the plan. Public transport funding decisions apply discount rates that imply a much shorter lifetime, e.g. the NZTA's Economic Evaluation Manual (LTNZ 2007), which requires an assessment period of 25 years.

By default, and in the absence of any other guidance, RMA case law has begun to apply a 100-year planning period for decisions that involve climate change, including the life of a building.

Guidance or determination in legislation of the expected (or planning) life of assets would provide a valuable context for appropriate decisions in terms of transport infrastructure and enable long-term costs (in terms of maintenance and/or replacement and/or modification) to be built into decision making.

- **Scale issues – what requires local response and what requires national response?** The RMA contains explicit provisions that exclude local government from making direct decisions on activities with regard to greenhouse gas emissions, but simultaneously encourages planning that would limit greenhouse emissions through a sustainable management mandate. This is a distinction that local government finds helpful (and is derived from a central government policy approach that seeks to deal with emissions using a market-based approach). The RMA also provides the potential for a national policy statement on climate change effects.

  However, other legislation does not provide any guidance on scale and response (Reisinger 2002). In dealing with land transport systems, such guidance in legislation could be helpful – for example the need for protection and performance of a national land transport network under climate change effects which put the networks at risk of vulnerability.

- **Monitoring / auditing of effectiveness.** Most of the legislation investigated is weak in terms of reviewing and auditing of effectiveness. Where auditing is implied or required, it is poorly scoped and not subject to clear processes, responses or responsibilities.

  Review and auditing of effectiveness/adaptability of policies, plans and outcomes in terms of climate trends could be one way of ensuring that climate change is taken into account more robustly in future. However, this gap highlights a more general issue rather than just a climate change issue for the transport system.

4.2.2 Policy

No specific drivers in central policy frameworks compel infrastructure operators to consider the effects of climate change and consequential adaptation strategies for their existing assets, unless works are assessed under the RMA for the potential effects of climate change.

Land transport programmes required under the LTMA (2003) are influenced by national and regional land transport strategies as required by the LTA (1998), which account for regional policy statements and plans, and therefore national policy statements under the RMA. Our literature review identified regional council investigations of how adaptation to the effects of climate change can be incorporated into regional policy and planning documents (O'Donnell 2007).

Given the national spread of climate change effects and a broad range of impacts on community assets and infrastructure throughout the country, a national policy instrument such as a national policy statement in the RMA may provide the strategic driver for considering adaptation in significant assets such as transport.

4.3 Issues adequately addressed

4.3.1 Legislation

Despite the gaps identified above, two aspects are noted as being adequately addressed:

- **Mainstreaming of climate change as part of sustainability and natural hazard considerations.** Almost by default, or perhaps driven by guidance from local government, those charged with performing under-developed legislation are starting to recognise and provide for the effects of climate change in planning and decision making.

  While, as noted above, climate change is not explicitly recognised in most legislation, and such recognition is considered to be a gap, it is not a fatal gap. Guidance and advice from central to local government has begun to fill the gap, aided by legislative wording encompassing 'sustainable' considerations. Legislation effectively drives hazard management strategies, so this existing framework could be strengthened to require analysis of the potential effects of climate change as factors to include in natural hazard assessment and preparedness.

- **Regional and local agencies should provide for targeted responses.** A positive aspect of the legislative framework is that it does leave decisions to be made at a level that may match the nature and extent of climate change effects. New Zealand's geography indicates that climate change effects, coupled with consideration of topography and geology, may best be addressed at regional and local levels. As noted earlier, legislation allows for this.

  However, the risk is that an uneven response with significant social and economic consequences will emerge in the longer term if no national overview of performance exists, and little or no national mandate requires performance.

4.3.2 Policy

Land transport network operators have reasonable climate science and risk assessment guidance available to them and clear hazard management responsibilities within existing policy frameworks. This study has not undertaken a close investigation of how effectively these frameworks are being implemented in practice.

The December 2007 discussion paper *Sustainable Transport: Update of the New Zealand Transport Strategy* (MoT 2007) notes the importance of transport system resilience, and the likely impact of climate change on the frequency and severity of extreme weather events.

The effects of climate change are acknowledged as factors affecting predictable travel time and access to facilities, two of the proposed targets for the New Zealand transport system.

Aspects of policy that are noted as being adequately addressed are:

- **Availability of good general guidance.** Central government policy agencies have put considerable effort into strategies and guidance to advance adaptation to the effects of climate change. Land transport network managers are key audiences for material relevant to local government and the engineering fraternity. Guidance is necessarily general in relation to broad patterns of climate change effects and infrastructure vulnerability. Methodologies for risk assessment are comprehensive and advocate regular reassessment of climate change risks to better reflect updated climate science, and appropriate infrastructure standards and practices.
- **Targeted information gathering and sharing framework.** Government research investment strategies clearly identify updated climate science, multi-disciplinary research and dissemination of end-user focused information as key to preparing transport infrastructure for the effects of climate change.

5 Risk assessment

5.1 Methodology

The focus of the risk assessment in Stage One of this project has been to attempt to identify and prioritise the dominant risks to road, rail, ports and coastal shipping networks from the effects of climate change. The widely-used risk matrix method has been employed in this study to characterise such risks.

In this method, risk is defined in terms of the severity of potential undesirable events or outcomes (the 'consequences') and the likelihood (probability or frequency) that these consequences occur, as scored on a five-point scale. These consequence and likelihood scores are then multiplied to give a measure of risk, ranging from a score of 1 (least risk) to a maximum score of 25 (greatest risk). Scores of 1 to 4 have then been rated as low risk, 5 to 9 as moderate and 10 to 25 as high. Broadly, high risks are considered in detail in this chapter and moderate risks are noted, but low risks are not progressed any further.

For the purposes of this study, climate change effect categories have been defined, and specific hazard events (threats) have been identified and assigned to the relevant category. This allows an understanding of the important climate change effects (which require further study) and the nature of the highest risk events themselves. The distinction between categories was made in part by considering how climate change effects would be modelled and studied. For example, even though rainfall and flooding overlap somewhat, modelling of flooding is significantly more complex than modelling of rainfall alone.

A more detailed description of the methodology and a schematic of the risk matrix method are given in Appendices F and G, respectively.

The consequences of interest are those that significantly impinge transport systems. The likelihood that such effects occur will depend on whether climate change effects are as severe and as frequent as predicted and, given this to be the case, the likelihood that the effect on transport systems is significant in any given situation.

In considering the risks, climate scientists from NIWA were asked to assess the current level of certainty in climate change projections for each climate change effect. The level of uncertainty for each source of risk was categorised as 'very high', 'high', 'medium' or 'low', and the following determinations applied to the risk:

- If the level of certainty was deemed to be 'low' then the risk was automatically set to 'high'.
- If the level of certainty was deemed to 'medium' then the risk was set to at least 'moderate'.

- If the level of certainty was deemed to be 'high' or 'very high' then the risk was not adjusted.

This is consistent with the general principle of taking a precautionary approach in the face of uncertainty.

The outcome of this process was a combined risk register for the three transport modes identifying the most significant risks. Mode specialists considered the adequacy of land transport network operators' ability to anticipate the climate change effects and consequences. Finally, gaps in knowledge were identified. In addition to determining risk, the process assessed, where possible, specific design and operational 'trigger points' or tolerance thresholds at which climate effects adversely affect the operation of transport networks.

The risks and gaps in knowledge identified by the risk assessment as they relate to the individual transport modes are discussed Chapters 6, 7 and 8, and a summary of the findings is given below. A copy of the risk register from which they are derived is given in Appendix G.

5.2 Risk assessment findings

The risks rated 'high' are ranked and compared across the three modes in Figure 5.1; the risk event descriptions are given in the risk register (Appendix G).

Figure 5.1 shows that highest risks from climate change are associated with roads (maximum score of 25 out of 25), followed by ports and coastal shipping (maximum score 20 out of 25), and rail (maximum score 16 out of 25).

The number of high risks attributed to each mode followed the same pattern, with 22 high risks identified for roads, followed by rail with 21, and coastal shipping with 10. This suggests that road networks may be the most vulnerable to climate change, being subject to the most significant risks and a large number of high risks. A wider range of potential risks from climate change were identified in relation to the road and rail networks, while ports may be exposed to a relatively narrower portfolio of effects.

Figure 5.1 shows that high risks associated with climate change could occur across all modes as a result of flooding, coastal flooding and fog and humidity. Road and rail are vulnerable to inland erosion and instability, rainfall, storms, wildfire and lightning. Road networks, ports and coastal shipping are all vulnerable to coastal erosion and wind. Roads alone are vulnerable to snow; only rail is vulnerable to high temperature.

The findings show that the highest risk identified for **roads** is being washed away by inland erosion and instability, leading to parts of the country being cut off (scored the maximum of 25 out of 25). This is followed by high intensity rainfall leading to an increase in the number of washouts; flooding causing bridges to be washed away, higher and faster river flows leading to washouts, and an increased number of washouts caused by high intensity falls (each scored 20 out of 25).

The identified highest risks to **rail** are rainfall raising water tables and soil moisture causing ground instability, and slope failure or instability; and high temperatures leading to buckling and permanent damage of railway lines (each scored 16 out of 25).

The highest risks to **ports and coastal shipping** were identified to be from coastal flooding, with wharf levels being too low during sea level rise and storm surge, and sea level rise resulting in port areas being permanently underwater (each scored 20 out of 25).

Road

Ref	Climate change effect category	Risk score
RD26	Inland erosion & instability	
RD7	Rainfall	
RD18	Flooding	
RD19	Flooding	
RD11	Rainfall	
RD17	Flooding	
RD12	Rainfall	
RD5	Rainfall	
RD8	Rainfall	
RD9	Rainfall	
RD24	Inland erosion & instability	
RD25	Inland erosion & instability	
RD41	Coastal erosion	
RD44	Coastal flooding	
RD40	Coastal erosion	
RD33	Wind	
RD29	Storms	
RD30	Snow	
RD39	Fog & humidity	
RD45	Wildfire	
RD46	Wildfire	
RD47	Lightning	

Rail

Ref	Climate change effect category	Risk score
RL48	Rainfall	
RL18	High temperature	
RL45	Rainfall	
RL46	Rainfall	
RL47	Rainfall	
RL30	Inland erosion & instability	
RL11	Flooding	
RL9	Flooding	
RL61	Wildfire	
RL63	Wildfire	
RL62	Wildfire	
RL57	Storms	
RL58	Storms	
RL59	Storms	
RL38	Lightning	
RL36	Lightning	
RL37	Lightning	
RL19	High temperature	
RL16	Fog & humidity	
RL17	Fog & humidity	
RL4	Coastal flooding	

Coastal shipping

Ref	Climate change effect category	Risk score
CS27	Coastal flooding	
CS32	Coastal flooding	
CS11	Flooding	
CS23	Wind	
CS24	Wind	
CS13	Flooding	
CS31	Coastal flooding	
CS34	Coastal erosion	
CS26	Fog & humidity	
CS25	Fog & humidity	

Figure 5.1 High risks to road, rail and coastal shipping networks in New Zealand from climate change (adjusted to take account of the level of certainty in climate change projections).

Key: Low risk (pale grey); moderate risk (medium grey); high risk (dark grey).

In order to understand more clearly how these risk results were influenced by the level of certainty in climate change predictions, Figure 5.2 shows the difference between the final risk ratings and the 'raw' ratings, which do not take account of the level of certainty in climate change projections. Figure 5.2 shows that when the risk scores were adjusted to account for the level of certainty in climate change projections, half of the risks rated low were promoted to moderate or high.

This highlights the importance of climate science knowledge and the increased level of certainty it brings. For example, if a risk assessment did not take the uncertainty of climate change effects predictions into account, fog and humidity would score low across all modes but future changes to fog and humidity are uncertain and are not well known. To be conservative in the face of this uncertainty, they are scored as high across all modes even though this high risk score may not represent the 'true' risk posed by these climate change effects.

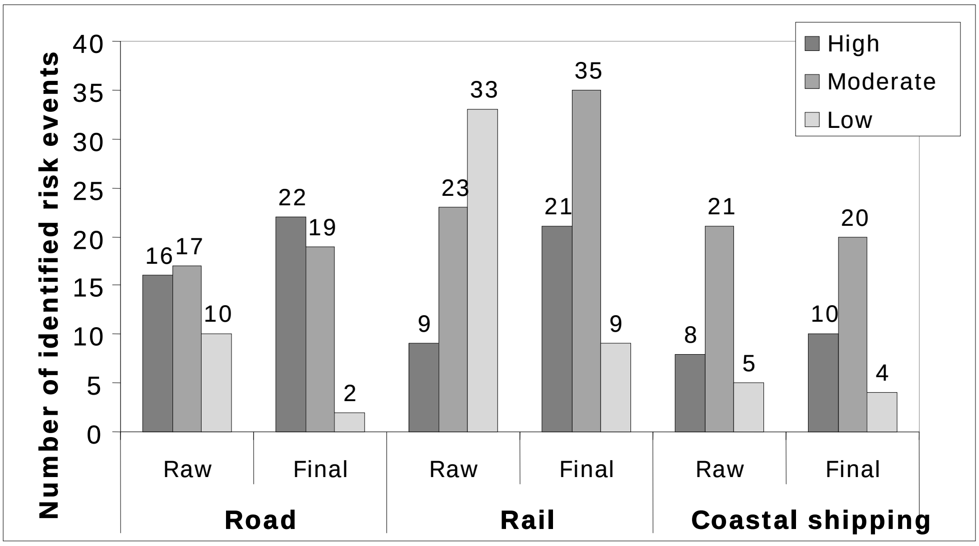

Figure 5.2 Change in risk when adjusted from raw to final rating (taking account of the level of certainty in climate change projections).

In order to gain a better understanding of the nature of the identified risks, the raw likelihood and consequence scores (i.e. before being modified to take account for certainty) have been plotted in Table 5.1.

Table 5.1 shows that the most events identified were of moderate consequence and very likely probability of occurrence. Few unlikely events were identified. We did not make further investigations into other potential unlikely events, given our focus on the most significant adverse effects. As explained in the notes to Table 5.1, 13 of the 18 highest risks affect roads.

During the risk assessment process, it was recognised that the impacts, and especially the appropriate actions to be taken, are different for design and planning for new infrastructure (where the latest knowledge can be used), as compared to the operation and maintenance of existing infrastructure (which will not have been designed to take account of climate change).

Table 5.1 Distribution of risk scores in the results matrix prior to adjusting for the level of certainty in climate change projections.

Likelihood score	Consequence score				
	Minor (1)	Moderate (2)	Major (3)	Severe (4)	Catastrophic (5)
Almost certain (5)	3	2	6[a]	2[b]	1[c]
Very likely (4)	1	24	10	5[d]	3[e]
Likely (3)	7	21	8	3	1[f]
Possible (2)	16	19	3	0	0
Unlikely (1)	1	2	3	0	2

Notes to Table 5.1 (see Appendix G for an explanation of the risk reference numbers):
a Road – rainfall (RD12, RD5, RD 8 and RD9) and road – inland erosion (RD24 and RD25);
b Road – rainfall (RD7) and road – flooding (RD19);
c Road – inland erosion and instability (RD26);
d Road – rainfall (RD11), road – flooding (RD17), rail – rainfall (RL48), rail – high temperatures (RL18) and coastal shipping – flooding (CS11);
e Road – flooding (RD18) and coastal shipping – coastal flooding (CS27 and CS32);
f Road – costal erosion (RD41).

In order to explore such differences, events with likelihood and consequence scores rated 'high' in the preliminary assessment were re-evaluated separately within each climate change effect category. The results for new and existing infrastructure are given in Tables 5.2 and 5.3, respectively, for the raw risk (derived by considering consequence and likelihood, and not modified to account for the level of certainty).

Table 5.2 shows that for new assets, flooding is a high risk across all modes, rainfall and inland erosion and instability are high for road and rail, and coastal flooding and coastal erosion are high for road and coastal shipping. Extreme high temperature is a 'high' risk only for rail.

Table 5.3 is a summary of the most significant climate change risks for existing assets. Drought and lightning are the only climate change effects to remain the same as for new assets, scoring low across all modes.

Existing roads are vulnerable to more climate change effects than new roads (i.e. more effects are considered high risk). Rail follows the same pattern, but it is less marked (although some low risks are promoted to moderate, the number of high risks is unchanged). Interestingly, new ports and coastal shipping have more moderate risks than existing ports and coastal shipping, which have more high and low risks. Flooding, coastal flooding and coastal erosion all become high risks for new port and coastal shipping assets.

It is worth noting that the mode specialists identified some climate change effects which could have a positive benefit or realise an opportunity. These included, for example, reduced cold weather working for road and rail (particularly in the southern regions of New Zealand), and reduced maintenance of under-keel draft for ports caused by rising sea level. However, these benefits were considered minor in comparison to the risks involved and are not pursued further in this study.

Table 5.2 Summary of the most significant climate change risks by mode for design and planning of new assets (not modified to account for the level of certainty in climate change projections).

Climate change effect category	Raw risk (Consequence x likelihood)		
	Road	**Rail**	**Ports & coastal shipping**
Extreme high temperature (including air and ground temperature)	Moderate	High	Low
Rainfall (including high intensity falls, and changes to average rainfall, groundwater and soil moisture)	High	High	Low
Flooding (including river and surface flooding)	High	High	High
Drought (including low river flows)	Low	Low	Low
Inland erosion and instability (including soil erosion and landslips)	High	High	Moderate
Reduced snow and ice events	Low	Low	Low
Fewer low temperature episodes	Moderate	Moderate	No threats identified
High winds	Moderate	Moderate	Moderate
Fog and humidity	Low	Low	Low
Coastal flooding (including sea level rise and storm surge)	High	Moderate	High
Coastal erosion	High	Moderate	High
Wildfire	Low	Low	Low
Lightning	Low	Low	Low

Table 5.3 Summary of most significant climate change risks by mode for the operation and maintenance of existing assets (not modified to account for the level of certainty in climate change projections).

Climate change effect category	Raw risk (consequence x likelihood) event based		
	Road	Rail	Ports & coastal shipping
Extreme high temperature (including air and ground temperature)	Low	High	Moderate
Rainfall (including high intensity falls, and changes to average rainfall, groundwater and soil moisture)	High	High	Moderate
Flooding (including river and surface flooding)	High	High	Moderate
Drought (including low river flows)	Low	Low	Low
Inland erosion and instability (including soil erosion and landslips)	High	High	Low
Reduced snow and ice events	High (benefit)	Low	Low
Fewer low temperature episodes	Moderate	Moderate	No threats identified
High winds	High	Moderate	High
Fog and humidity	Moderate	Moderate	Moderate
Coastal flooding (including sea level rise and storm surge)	High	Moderate	Moderate
Coastal erosion	High	Moderate	Moderate
Wildfire	Low	Moderate	Low
Lightning	Low	Low	Low

In order to help prioritise actions to address the gaps in knowledge associated with risks of climate change effects to land transport networks, we have further rationalised the large number of identified 'high risk' effects. The outcome of this analysis is summarised in Table 5.4.

Table 5.4 Prioritisation of climate change effect categories in relation to high risks to land transport networks.

Climate change effect category	Risk	Possible 'true' risk (raw risk)	Additional factors	Priority
Coastal flooding (sea level rise and storm surge)	High risk to all three modes	Rail risk may reduce to moderate	• Top five risk to coastal shipping. • Only some coastal locations affected. • Significant costs likely for response options. • Particularly important for assets with a long design life.	✓✓✓✓
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 road and rail	–	• Top five risk to road. • Significant costs likely for reinstatement or rebuilding.	✓✓✓✓
High temperature	High risk to rail	–	• 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 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.	✓✓✓
Wildfire	High risk to rail	Rail risk may reduce to moderate	• Not a top five risk. • Wildfire is related to drought risk, which is expected to worsen significantly. Further consideration is warranted even though the 'true' risk may be moderate.	✓✓
Fog and humidity	High risk to all three modes	Risk may reduce to moderate	• Not a top five risk. • Risk can be mitigated within short time frame with little infrastructure investment required. • Little information for climate change projections is available.	✓
Snow and ice	High risk to road and rail	Risks may reduce to moderate	• Not a top five risk. • Vegetation control to mitigate rail risk (trees falling on lines) can be done at short notice and therefore forward planning is not required. • Actions in relation to large snow and ice events (blizzards) will generally be limited to maintenance (snow clearing, etc.). • More storminess is possible but little information for climate change projections is available.	✓
Lightning	High risk to rail	Risks may reduce to low	• Not a top five risk. • More storminess is possible but little information for climate change projections is available. • Electrical storms are uncommon so a large increase would be required before it would become a significant problem.	✓
Drought	No high risks identified	–	–	×
Low temperature	No high risks identified	–	–	×

✓✓✓✓ Highest priority
✓✓✓ High priority
✓✓ Moderate priority
✓ Low priority
× Not a priority

5.3 Comments on the risk assessment process

Attempts were made to simplify the initial evaluation of risk by identifying levels of impact or climate-related 'trigger points' at which transport infrastructure operation is disrupted or design standards exceeded. This was not wholly successful because only a few measurable trigger points were identified, for example:

- the greater risk of non-continuous welded rail track buckling in air temperatures >36°C,
- stopbank designs to meet 1 in 400 year rain and flooding events, and
- bridge designs to allow a 1 in 100 year flood to pass without significant damage.

We were unable to identify additional trigger points nor elaborate on those identified for several reasons:

- Details of infrastructure design standards and weather-related vulnerabilities were not readily available. For example, we identified the potential impact of extreme winds on the deflection capacity of cranes in ports, although manufacturers' design standards were not able to be identified within the scope of Stage One of this research.
- Design standards for short-life infrastructure such as bituminous road pavements vary according to local conditions and were considered to be adaptable to the predicted climate change induced conditions through regular revisions of design standards. Replacement costs if design standards failed were considered relatively low by industry leaders such as the NZTA.
- Climate change effects are predicted as long-term trends involving short-term variances. For example, mean temperatures are likely to gradually increase, although cooler years are also likely to occur within a long-term trend towards warming. Many of the predicted climate change effects are within the range of current climate variability, particularly in the short to medium term, and transport systems already have a degree of resilience to climate change effects.

Despite these difficulties, the concept of trigger points is considered to be an important link between asset resilience and weather stress, and a useful means of quantifying the scale of climate change effects. This concept will prove more useful when considering impacts at a more detailed level for different types of transport infrastructure in Stage Two or in future research.

While it was originally intended to assess risks at different time horizons (10, 50 and 100 years), in reality, the mode specialists felt that it was only possible to make subjective judgements of risk on the basis of the long-term effect perceived to be most likely, nominally 100 years in the future. They felt that the impacts in the near term would generally be contained within the current variability of climate, while in the medium term, the effects would be similar but scaled down from those anticipated in the long term.

The judgements on risk by the mode specialists were made by considering the impact over the whole network nationally. Where regional climate change trends are available, more detailed analysis could be undertaken to take account of regional and situational effects, and the variation in different infrastructure component designs, subject to the necessary data being available. An initial appraisal of the regional implications of climate change on the land transport network is given in Chapter 9. This is an aspect that will be explored further in Stage Two of this study.

5.4 Risk summary

The risk assessment, using a structured formalised methodology, gave results that were very similar to what might be expected intuitively. The findings are also in general agreement with similar studies overseas (if differences in climate are accounted for) with no 'new' or unexpected high risks.

In summary, the highest priority risks relate to:

- coastal inundation from sea level rise combined with storm surge (ports but also coastal land transport corridors potentially at risk),
- flooding (all modes),
- high rainfall and inland erosion/instability (road and rail), and
- prolonged high temperatures (an issue for continuous welded railway lines in particular).

As an outcome of the prioritisation process (see Table 5.4), changes in fog and humidity, snow and ice, and lightning triggered by climate change were identified as low priority to land transport networks, while low temperature and drought were identified as being of no consequence.

This risk assessment has identified which transport infrastructure modes are most vulnerable to different climate change effects and has prioritised areas for further assessment in Stage Two. A key aspect will be to determine the regional and temporal distribution of climate change impacts so as to gain a better understanding of how individual transport networks are affected and to determine the basis for formulating adaptation measures.

6 Road networks and climate change

6.1 Road network background

The New Zealand road network consists of approximately 94 000 kilometres of roads. The state highway network is 10 894 kilometres long with a replacement value of $12.5 billion. Its primary function is to provide strategic national links that enable the inter-regional mobility of people and goods. The NZTA is responsible for managing and operating the state highway network and related assets.

New Zealand's local road network is made up of approximately 83 000 kilometres of local roads, owned by local communities and managed on their behalf by 74 territorial authorities. The primary purpose of local roads is to provide access and connectivity for communities, and to link with the state highways. Based on 2007 figures, approximately 21% of the local road network is located in urban areas, with the remaining 79% being rural.

While state highways make up only 11.5% by length of New Zealand's roads, they carry 46% of the 34 billion vehicle-kilometres travelled each year. Breakdowns in the level of service of a state highway can potentially have significant effects on communities and the economy. A reduction in the level of service on local roads can also have a major impact on local economies.

Climate change impacts present a real risk to road assets and to the combined local road and state highway network.

In the 2000/2001 financial year, $1.8 billion was spent nationally on road construction and maintenance. Approximately half of the funding for the total road network comes from taxes, namely petrol excise and heavy vehicle road user charges. The balance of funding is generated from local authority rates.

6.2 Road network design and weather-related vulnerability

6.2.1 Introduction

Weather conditions have a significant bearing on the road network's ability to operate. Transit New Zealand's 2005/2006 annual report (Transit New Zealand 2006) stated that state highway lanes closed on over 150 occasions owing to weather related incidents that year. The weather extremes of 2005/2006 were also noted:

- May 2006: Rainfall 200% over normal levels in Northland, Auckland and Canterbury.
- July 2006: Coldest on record since 1972.
- July 2006: Rainfall of 200% over normal levels in the Wairarapa, Wanganui and Hawkes Bay.
- July 2006: The wettest year experienced by the Wairarapa in 30 years.

State highway standards tend to be used by local road managers as a de facto standard, whether for signage, bridge design or road construction. Standards vary around the country, however, depending on local priorities and funding availability.

State highway and Austroads standards are updated regularly to introduce new techniques and specifications for the design and maintenance of a range of road assets, from aggregate, sub-base and basecourse specifications to drainage improvements, roadside signage and vegetation management.

6.2.2 Bridges

New Zealand's roads have more than 15 000 bridges, 4000 of which are part of the state highway network.

Bridges generally have a 100-year design life. The NZTA uses an ARI of 100 years to determine the design flood to be passed without significant damage to bridges.

Many bridges are lost prematurely in small-scale events because of the cumulative effects of events beyond NTZA's control gradually weakening infrastructure. The rate of premature loss will not necessarily be reduced by design standards developed solely to manage climate change impacts. For example, a scour-screening procedure could be developed (Coleman & Melville 2001).

Bridges and culverts are conservatively designed and engineered to accommodate site-specific factors including weather patterns. Regular inspections are carried out to ensure not only structural integrity but also potential scouring. Inspections are carried out over different timeframes depending on the road controlling authority.

The NZTA calculated a rough estimate of possible design changes to adapt to increased waterway depth anticipated as a result of climate change. Design changes would result in an estimated additional 10% increase in cost resulting from extended foundation heights.

Increasing water temperatures and sea level rise may lead to saline incursion at coastal bridges and therefore advance material deterioration.

6.2.3 Culverts, drainage and flood protection

An unknown number of culverts form part of the New Zealand roading network, from small diameter circular pipes under driveways to larger box-shaped concrete structures under roads. Many of these structures have been in place for a number of years and are only likely to be replaced if they fail.

State highway drainage systems are designed for local conditions. Transit assesses its current practice as sufficient, and believes improvement works will be able to cope when exacerbated rainfall and flooding conditions apply.

The 1978 Ministry of Works and Development Culvert Manual (MWD 1978) is still in use for the design of culverts and is still a valid methodology. Regular inspections of culverts are carried out to ensure that they continue to be fit for their purpose.

Around New Zealand, roads that have been built in flood-prone areas may have had that taken into consideration by either being built on a flood bank or having temporary bridge diversions available, as in the Wairarapa.

6.2.4 Pavement surface

Roads generally have a lifespan of 30 to 40 years, although they will be resurfaced several times within that period depending on wear, which is directly related to traffic volume, which continues to increase.

Chipseal and asphaltic concrete are the main pavement surfaces in New Zealand. Climatic factors are taken into account as part of the surface design as a variety of conditions nationwide, from hot and humid weather to regular freezing, can damage a surface. Hot weather can cause the surface to bleed; freezing conditions can quickly lead to cracking and water ingress, causing further damage.

The NZ-dTMS pavement deterioration model has been practised in New Zealand for the last ten years to provide a robust method of predicting the maintenance requirements of roading networks. Mean temperature and total rainfall are monitored along with traffic demand as part of pavement performance monitoring.

6.2.5 Land stabilisation

Because many roads follow old alignments, they tend to run alongside rivers or around hills, meaning that a large number of roads are cut into embankments. These locations are much more prone to slips, either uphill, with the risk of road closure while debris is cleared, or downhill, with the risk that part of the road collapses.

Known slip sites on the state highway network are identified and monitored as part of network maintenance contracts. Preventative maintenance works are carried out on slopes and batters in sensitive, slip-prone areas to ensure that the road remains open.

Some roads have been built on unstable land, such as sections of State Highway 35 in the East Cape and State Highway 1 north of Dunedin, and, as a result, require increased maintenance costs.

6.3 Climate change risks to the road network

Using the risk methodology described in Chapter 5, the potential effects of climate change to the national road network have been assessed and are summarised in Table 6.1. This is a broad assessment of potential effects that does not consider specific regions or sites.

Table 6.1 Potential effects of climate change on national road network.

Climate change effect category	Risk ranking	Main road asset or operations affected by climate related effect	Gaps in practice, knowledge and information
Inland erosion and instability (including soil erosion and landslips)	High	• Slope and batter slips cause disruption to the operation of roads owing to blockages. • Roads alongside rivers at increased risk of washouts and slips.	• Geotechnical assessment of existing and potential slip sites; • Need to identify the location of at-risk roads.
Rainfall (including high intensity falls, and changes to average rainfall, groundwater and soil moisture)	High	• Reduced surface friction and risk of 'loss-of-control' accidents; • Potential for basecourse and sub-base degradation.	• Other surface designs available at higher cost; • Need to identify areas at risk.
Flooding (including river and surface flooding)	High	• Disruption to the operation of roads; • Damage to drainage, culvert and bridge infrastructure from increased waterway flows and debris.	• Bridge design standards to take account of projected climate change effects; • Scour assessment intervals may need to be reduced.
Coastal flooding (including sea level rise and storm surge)	High	• Coastal roads at risk from storm surges and rise in sea level; • Moderate risk of reduced structure lifespan caused by corrosion.	• At-risk sections identified; • Need to identify new sections that may be at risk in the future.
Coastal erosion	High	• Road washout; • Erosion of coastal defences.	• Need to identify sections of road that may be at risk in the future.

Table 6.1 (cont.) Potential effects of climate change on national road network.

Climate change effect category	Risk ranking	Main road asset or operations affected by climate related effect	Gaps in practice, knowledge and information
High winds	High	• High risk of vehicles being blown off roads in exposed areas; • Moderate risk of damage to structures, and temporary road closure and bridge restrictions.	• Location and intensity of winds in relation to the national road network.
Fog and humidity	High but 'true' risk may be moderate	• Moderate risk of increases in fog-related crashes increases to High when the level of certainty in climate change projections is taken into account.	• Driver behaviour; • Fog monitoring and warning signs available.
Snow and ice	High but 'true' risk may be low	• Increased exposure to sudden events - blizzard, hailstorm; • Increased snowmelt contributes to flooding issues.	• Flooding issues considered under 'Flooding'.
Wildfire	High but 'true' risk may be low	• Roadside fires cause damage to equipment and vegetation. • Roadside fires disrupt traffic.	• Rural nature of network means fires can get out of control before being attended to.
Lightning	High but 'true' risk may be low	• Roadside fires in dry conditions.	• Rural nature of network means fires can get out of control before being attended to.
Extreme high temperature (including air and ground temperature)	Moderate	• Pavement surface bleeding; • Increased dust from unsealed roads.	• Surface design standards for warmer climate; • How to reduce dust using environmentally sound methods.
Drought (including low river flows)	Moderate	• Increased dust from unsealed roads.	• How to reduce dust using environmentally sound methods.
Fewer low temperature episodes	Moderate	• If an increase in freeze-thaw cycles occurs, an increase in the number of surface defects is likely to occur.	• Can be designed for to some extent.

6.4 High priority climate change risks to roads

6.4.1 Scope

In this section, predicted climate change effects that have been identified (in Table 5.4) as high priority risks to the road network are discussed in more detail. Other effects that were assessed as lower priorities have not been addressed in detail here.

6.4.2 Increased rainfall intensity and duration causing slips and flooding

Heavier and/or more frequent extreme rainfall across New Zealand is predicted with moderate confidence, especially in areas where the mean rainfall is predicted to increase, such as Tasman, West Coast, Otago and Southland (see Figures 3.4 and 3.5, and Appendix A).

The effects of extreme rainfall on slopes and batters are already identified as major disruptions to roads. The effect of rain on skid resistance, and the link between heavy rainfall and flooding events are currently major concerns to road managers without the added effects of climate change. Road assets and operations are at high risk of disruption from a number of weather-related effects:

- An increase in 100-year rain events, increased soil moisture and groundwater tables, and/or increases in mean rainfall cause more landslides requiring extensive repairs and causing closure of roads for short or extended periods. Potential consequences include damage to road assets, road users and road freight. Some regions of New Zealand have large inventories of known slip sites e.g. Northland and Manawatu.
- Floodwaters and debris may affect roads and bridges, thus requiring more frequent inspections, repairs and potential road closures during washouts. Increased scour of bridge piers, river bank protection works etc. will require extensive repairs.
- Surface water may lead to increased 'loss of control' crashes caused by longer periods of reduced grip.
- Culvert failure in the event of inadequate drainage may lead to road washout and closure to enable extensive repairs.

6.4.3 Coastal roads at risk from coastal flooding and erosion

The effects of coastal inundation and erosion on coastal roads are already difficult hazards to prepare for because of the complexity of climate factors at work and the uncertainty of future expressions of coastal weather conditions (Bell 2007). Advice from MfE suggests that climate change will not introduce any new types of coastal hazards, but will affect existing coastal hazards by changing some coastal conditions such as sea levels, storm tides, waves and swells.

In general, areas that are currently subject to occasional coastal hazards are likely to suffer increased risks with a warming climate, while areas that are currently in a delicate balance may begin to experience more damaging coastal hazards in future. MfE (2004c) advises that the mean sea level could reach up to 0.25 m above the average sea level in any given month, although this is most likely to occur during La Niña episodes in decades when the 20- to 30-year IPO cycle is in its negative phase (the current La Niña episode appears to have started in 1998 and may last until 2020–2030).

The average westerly wind component across New Zealand may increase by approximately 10% in the next 50 years. As a result, the frequency of heavy seas and swell along western and southern coasts would increase, and so could higher extreme waves during more intense ex-tropical cyclones and mid-latitude storms.

As a result of climate change, road infrastructure in the coastal zone is likely to be exposed to greater risks from inundation and coastal erosion:

- High waves and stormy conditions may wash away roads, disrupting access and requiring major repairs to restore road links. Potential for injury/death to road users exists.
- Coastal inundation and increased sea level rise may increase erosion of coastal structures, requiring more frequent inspection and repairs, and causing potential disruption.
- Increased saline incursion at coastal bridges may lead to accelerated material deterioration.

The extent of the entire road network within the coastal zone is not known. The predominant form of urban settlement patterns within coastal areas suggests that a significant section of the national road network is at risk, depending on the road elevation and vulnerability or resilience to coastal flooding effects.

6.4.4 High winds

A possible increase in strong winds >10 m/s, top 1 percentile) by up to 10% is predicted by 2090. Strong winds are associated with intense convection (expected to increase in a warmer climate) and with intense low-pressure systems, which might also become more common.

Figure 3.7 shows the potential distribution of wind strength increases, with the greatest potential increases distributed on the east coast of both the North and South Islands.

High winds have the potential to:

- blow vehicles off the road in exposed places, with resulting risk of injury or death;
- damage signs and infrastructure; and
- require temporary road closure and imposition of bridge restrictions.

6.5 Risk response for the road network

6.5.1 Current responses

New Zealand's Fourth National Communication to the United Nations Framework Convention on Climate Change (MfE 2006d) noted various regional studies have identified potential impacts of changing climate on stormwater drainage, flood risk to roads, bridges and structures, and coastal development.

Bell (2007) refers to an example of combined climate change effects being considered as part of a scheme assessment for a motorway project. Options for levels of serviceability were considered in respect of pedestrian safety and vehicle speeds in response to wave overtopping combined with sea level rise.

Transit (now the NZTA) issued advice to Bridge Manual holders in July 2005 (Transit New Zealand 2005) advising bridge designers of the potential rainfall and sea level rise effects of climate change, and the need to seek specialist site-specific assessment of potential climate change effects for new bridge designs. In 2004, Transit investigated the implications of retrofitting bridges with spans that were inadequate to withstand increased water flows during extreme rainfall, specifically 763 bridges in western regions at greater potential to be affected by climate change. Kinsella & McGuire (2005) found that the $295 million cost to improve at-risk bridges was significant and opted to repair bridge and culvert stock when a specific loss or need became evident. For shorter life assets, Transit found its current maintenance practice to be flexible enough to adapt to future impacts of climate change. Kinsella & McGuire (2005) also list current design practices and analyse whether these are sufficient to meet climate change effects (see Table 6.2).

Table 6.2 Assessment of climate change effects on the state highway network (source: Kinsella & McGuire 2005).

Asset type	Climate change parameter affecting the state highway network by 2080	Level of uncertainty[a]	Design life (estimated years)	Current practice[b]
Bridges	• Increased mean annual rainfall in western New Zealand.	Medium	100	**Minor changes to current practice required.** Bridges are designed for a 5% probability that the design criteria will be exceeded (e.g. by flooding) in any one year. A reduction in flood return periods constitutes a heightened risk to bridge stock.
	• Increased intensity and/or frequency of heavy rainfall throughout New Zealand (leading to flooding, soil saturation and slips).	Low		
	• Sea level rise (for costal bridges).	High		
Culverts (in waterways)	• Increased mean annual rainfall in western New Zealand.	Medium	20–100	**Minor changes to current practice required.** See 'Bridges' row above for longer life culverts (30+ years). See 'Drainage' row below for shorter life culverts.
	• Increased intensity and/or frequency of heavy rainfall throughout New Zealand (leading to flooding, soil saturation and slips).	Low		
	• Sea level rise (for costal culverts).	High		
Causeways and low-lying costal roads	• Sea level rise combined with increased frequency and intensity of storm surges	High Low	20–100	**Current practice sufficient.** Pavement maintenance will allow for pavement levels to rise. Improvement works to cope with changes in climate can be undertaken as part of periodic reconstruction when the effect occurs.
Pavement surfaces	• Increased mean annual temperature	High	10–25	**Current practice sufficient.** Bitumen, chipseal and asphalt specifications take temperature ranges into account. Because resealing is relatively frequent, changes to specifications do not to need to be altered until the effect occurs.
Drainage (surface)	• Increased intensity and/or frequency of heavy rainfall throughout New Zealand (leading to flooding, soil saturation and slips)	Low	20	**Current practice sufficient.** Drainage systems are designed for local conditions. Improvement works to cope with changes in climate can be undertaken as part of periodic reconstruction when the effect occurs.
Slopes and batters	• Increased mean annual rainfall in western New Zealand	Medium	N/A	**Current practice sufficient.** Monitoring and preventative maintenance works are carried out on some slopes and batters in sensitive slip-prone areas. Despite this, hillside slips are still unpredictable.
	• Increased intensity and/or frequency of heavy rainfall throughout New Zealand (leading to flooding, soil saturation and slips)	Low		

Notes to Table 6.2:

a NIWA has calculated confidence intervals for climate change data. These relate to the level of certainty that the predicted change will occur within the timeframe specified. Current predictions for climate change impacts to occur are to 2030 or 2080.

b These criteria refer to the capacity/flexibility of current management practice to encompass any changes to the state highway network caused by climate change. Assets that have a shorter lifespan than 30 years are expected to become obsolete and be replaced before the climate change impacts manifest.

A review by Environment Canterbury of the CRPS with regards to the effects of climate change identified a focus on the causes of climate change rather than the effects, as required by the RMA. A key issue relating to the adaptation of transport infrastructure to the effects of climate change was identified as a matter to consider in future reviews of the CRPS: constraints on the location and layout of strategic infrastructure to avoid climate change effects, such as constraints on development in areas susceptible to flooding or inundation.

In 2004, the Ministry for the Environment released *Preparing for Climate Change – A Guide for Local Government in New Zealand* (MfE 2004a). This publication was aimed at local government planners and managers with the intent of helping councils to identify, scope and respond to climate change in their respective areas (see second edition released in May 2008 – MfE 2008).

6.5.2 Gaps in knowledge or practice

The main gaps in knowledge relate to site-specific assessments of the vulnerabilities of road assets to the range of high risk climate change effects. In particular, information on the following is lacking:

- the location of areas susceptible to coastal flooding/inundation;
- the extent of increases in river flows, and impacts on structures and earthworks;
- the ability of existing drainage structures to cope with increased water flows; and
- design standards required to cope with identified climate change factors given the uncertainty of how severe those changes will be.

In order to analyse road assets at risk from climate change, some basic road asset datasets will need to be improved and/or developed, such as proximity of roads to water bodies, elevations above sea level and fine-scale topological references.

6.5.3 Response options

A variety of information sets are required to identify at-risk sections of roads. Local knowledge should provide a good starting point for currently susceptible areas. The difficulty arises in then identifying the areas that are in a delicate balance that may begin to suffer with climate change.

While, to some extent, slow deterioration can be dealt with, the highest risk to the road network is in sudden events that cause major damage such as a combined storm surge and high tide damaging an important coastal road, or a major rain event leading to increased river flows and saturated embankments, thus causing a road to be washed out.

The primary task therefore is to identify these at-risk areas. As described previously, this will entail collecting data on the proximity of a road or area to the coast, and the elevation above current and projected sea levels. Existing coastal defences will need to be recorded.

In inland areas, data regarding slopes and embankments such as slip angle, material and water content may need to be recorded, as well as proximity to bodies of water. The extent of increases in individual river flows may need to be calculated to determine at-risk bridges or sections of road.

A bridge risk assessment may then need to be carried out to identify those most at risk from increased flows, scour or debris. More frequent inspections may also need to be programmed in the future.

The ability of existing drainage structures to cope with expected flow increases will need to be calculated, and a risk assessment carried out regarding the consequences of failure.

All road controlling authorities should be aware of the sections of their roads that are most at risk from future climate change effects. With that knowledge, improvements or remedial work may be able to be carried out as part of future routine maintenance prior to possible events happening, thus saving money, ensuring no disruption to the level of service and retaining community links.

7 Rail network and climate change

7.1 Rail network background

The length of the New Zealand national rail network totals approximately 4000 km (in addition to a number of privately owned lines and sidings). The network includes approximately 2200 bridges and viaducts, either on or over the rail corridor, along with 150 tunnels and 12 000 culverts.

ONTRACK is responsible for managing and operating the national rail network and related assets, including rail tracks, structures (such as tunnels, bridges, culverts, retaining walls), electric traction and signalling, train control and track maintenance operations.

The following are identified by ONTRACK as key rail routes because of high passenger numbers and value of freight movements:

- Auckland and Wellington suburban passenger networks,
- Auckland/Hamilton/Mt Maunganui (20% of freight between these centres travels by rail),
- South Island coal route: Midland & Stillwater Westport Lines,
- North Island milk route: Oringi to Whareroa (seasonal),
- North Island Main Trunk (NIMT), and
- South Island Main Trunk.

The national rail network is valued at $10.6 billion. The rail operator, Toll Rail, reported revenue from rail operations of $725.8M in 2006.

Each week, ONTRACK's train control operations manage 900 freight trains, 52 intercity passenger services, 2200 suburban passenger services in Wellington and 1300 suburban passenger services in Auckland. On a tonnage basis, rail transports 13% of New Zealand's land freight (21% on a tonne-km basis).

7.2 Rail network design and weather-related vulnerability

7.2.1 Introduction

Rail asset standards have changed over time. Significant numbers of culverts, bridges and associated drainage systems are substandard compared to current design criteria. Similarly, although new track construction has been standardised, historically, a wide variety of material and construction standards have been used across the network, and maintenance standards have varied relative to tonnages and importance of the line. ONTRACK adopts a route-based planning approach to balance costs and value of services provided, based on the needs of passenger and freight users on each line.

The majority of the network is single track and very few alternative routes are available. This leaves the operation extremely vulnerable to weather-related events which result in line closure or reductions in operating speed.

The depreciable life of the rail assets varies from 20 years for signalling and communications, to 40 years for track and ballast, and 80 years for tunnels and bridges.

7.2.2 Drainage and bridges

Most of the New Zealand rail network was constructed in the early 1900s, with progressive upgrades of culverts, bridge waterways, drainage systems, river protection works and founding of bridge piers generally only occurring following failures, or when sections of line were upgraded (e.g. NIMT electrification and Kaimai Tunnel deviation). ONTRACK has reviewed the capacity of culverts and associated drainage and has identified the assets not meeting current design standards. A similar study of potential scour at bridge piers identified some with non-standard founding depth.

Substandard and/or poorly maintained drainage systems have resulted in numerous localised failures of the sub-base formation, and subsequent fouling and pumping of the ballast. This leads to geometric track exceedances, ongoing maintenance requirement and potential for derailment if not treated appropriately.

7.2.3 Flood protection

System-wide, a number of locations are identified as ‘at risk’ from river inundation and flooding of the permanent way, resulting in disruption to services. Because of natural and man-made constraints, and practical limitations in horizontal/vertical railway alignments, achieving flood capacity to contemporary design standards is a challenge.

7.2.4 Land stabilisation

Historically, detailed geotechnical assessment of land instability affecting the rail network has been limited. Movement within the ‘young geology’ has been accepted and mitigated as it occurs. In the last four years, ONTRACK has been undertaking ‘Weather Proofing Studies’ aimed at identifying and ranking land stability risks. A very high correlation exists between water management (by way of drains, culverts, etc.) and land instability. Considerable funding has been applied to the most at-risk areas of the network. The outcomes have been very beneficial to the overall robustness of the parts of the network treated.

7.2.5 Temperature and track stability

Rail track is at risk of buckling at higher temperatures if the stability of the track structure is not sufficient to constrain the expansion of the rail. This can lead to trains derailing, resulting in damage to freight, equipment and infrastructure, and potential harm to personnel and passengers.

Over the last couple of decades, concerted efforts have been made to weld the jointed track into continuous welded rail (CWR) and de-stress the track. The effectiveness of CWR track deteriorates over time as a result of maintenance activities, natural deterioration of the track components and quality control of CWR-related activities being variable.

Over the last decade, much effort has gone into identifying and stabilising these at-risk sites. Untreated at-risk CWR track lengths are subject to 40 km/hr speed restrictions whenever risk temperature thresholds are exceeded during the summer months. (Conversely, some of the same sites are subject to disruptions from weld failures, joint pull-apart and rail breaks through the winter months when the rail contracts).

7.3 Climate change risks to the rail network

Using the risk methodology described in Chapter 5, the effects of climate change on the national rail network have been assessed and are summarised in Table 7.1 below. This is a broad assessment of potential effects that does not consider specific regions or sites.

Table 7.1 Potential effects of climate change on the national rail network.

Climate change effect category	Risk ranking	Main rail asset or operations affected by climate related effect	Gaps in practice, knowledge and information
Rainfall (including high intensity falls, and changes to average rainfall, groundwater and soil moisture)	High	• Track movement; • Line closure; • Reduced operating speeds.	• Effect of increase in mean and extreme rainfall events on groundwater tables.
Extreme high temperature (including air and ground temperature)	High	• Track buckling; • Line closure; • Reduced operating speeds.	• Relationship between rail temperature and climate factors such as air temperature, solar radiation and antecedent hot days; • Location of at-risk track sections in relation to predicted occurrence of high temperatures; • Stability of track at higher temperatures than currently experienced.
Flooding (including river and surface flooding)	High	• Track washout; • Line closure; • Reduced operating speeds.	• Existing and likely track sections with under-capacity drainage infrastructure considering 2040 and 2090 climate factors; • Bridge scour assessment.
Inland erosion and instability (including soil erosion and landslips)	High	• Disruptions from blockages; • Decrease in track condition.	• Geotechnical assessment of existing and potential slip sites; • Effect of increase in mean and extreme rainfall on slips.
Coastal flooding (including sea level rise and storm surge)	High but 'true' risk may be moderate	• Salt water corrosion; • Overtopping causes line closures.	• Assessment of combined effect of sea level rise and storm surge on low-lying rail assets.
High winds	High but 'true' risk may be moderate	• Vehicle stability; • Moderate risk of equipment and freight damage, and reduced operating speeds.	• Location and intensity of gales at high wind sites in relation to the national rail network.
Snow and ice	High but 'true' risk may be moderate	• Blocked lines from trees; • Snow clearances and inspections.	–
Wildfire	High but 'true' risk may be moderate	• Trackside fires cause damage to equipment and vegetation.	–

Table 7.1 (cont) Potential effects of climate change on the national rail network.

Climate change effect category	Risk ranking	Main rail asset or operations affected by climate related effect	Gaps in practice, knowledge and information
Lightning	High but 'true' risk may be low	• Risk to line workers; • Power outages; • Damage to infrastructure.	–
Fog and humidity	High but 'true' risk may be moderate	• Arcing of conductors in humid conditions; • Reduced visibility below signal sighting distance; • Reduced operating speeds.	–
Coastal erosion-	Moderate	• Coastal erosion threatens lines; • Erosion of coastal defences.	• Scour rates in coastal areas.
Drought (including low river flows)	Moderate	• Settlement of structures and twist/top/cant exceedance; • Trackside fires cause damage to equipment and vegetation.	–
Fewer low temperature episodes	Moderate	• Frozen points.	–

7.4 High priority climate change risks to rail

7.4.1 Overview

In this section, the effects and consequences of predicted climate change effects that have been identified (in Table 5.4) as high priority risks to the rail network are detailed to describe the extent of potential effects. The scope of this project is high level. Consequently, we have not addressed other non-priority effects in detail, although these may be consequential issues for transport operators to consider.

Impacts on the infrastructure and rail operation depend upon the scale of the event. These include increased inspection and reduced operating speeds to mitigate the risk, and repairs and reinstatement following failure. The potential exists for consequential damage to freight and equipment, and harm to personnel/passengers in the event of a train derailment following the failure.

7.4.2 Extreme rainfall events causing slips and flooding

Heavier and/or more frequent extreme rainfall across New Zealand is predicted with moderate confidence, especially where mean rainfall increase is predicted, e.g. Tasman, West Coast, Otago and Southland (see Figures 3.4 and 3.5).

Extreme rainfall is already identified as a high-risk hazard to the railway network without the added effects of climate change. Railway assets and operations are at high risk of disruption from:

- culvert failure in the event of inadequate capacity, leading to track washout and shutdown of railways for extended periods to enable extensive repairs;

- increase in magnitude of 100-year rain events and/or cumulative rainfall that can cause more large landslides requiring extensive repairs and causing shutdown of railway for an extended period (significant sections of line are constructed across known slip faces);
- flash flood and debris effects on bridges and approaches requiring more frequent inspections and repairs, and causing shutdown of railway for an extended period;
- increased scour of bridge piers, approaches and river bank protection works etc., requiring more frequent inspections and extensive repairs, and causing shutdown of railway for an extended period;
- inadequate drainage/minor slips causing failure of the formation and fouling of ballast, resulting in twist/top/cant exceedances; these result in more frequent repairs, reduced operating speeds and potential (if not corrected) for consequential damage to freight and equipment, and harm to personnel/passengers.

7.4.3 Average annual rainfall causing slips

Increases in annual mean rainfall in Tasman, the West Coast and the west of the North Island are likely to exacerbate adverse effects of rainfall on the structure and operation of railway operations. These could result in:

- raised water tables and/or increased soil moisture causing ground instability, leading to failure of hillsides, requiring extensive repairs and causing shutdown of railway for an extended period (significant sections of line are constructed across known slip faces);
- raised water tables and/or soil moisture causing ground instability, leading to localised slips/debris onto the track and/or embankment failure or dropout, and requiring increased inspections and frequent repairs; this would result in reduced operating speeds or cause shutdown of the railway for short periods.

7.4.4 Mean and extreme high temperature

A likely increase in mean temperatures of 0.9°C by 2040 and 2.1°C by 2090, and more high temperature episodes increase the already high risks to the operation of railway networks and integrity of railway assets:

- Rail track is at risk of buckling at higher temperatures if the stability of the track structure is not sufficient to constrain the expansion of the rail. This can lead to trains derailing, resulting in major damage to freight, equipment and infrastructure, and potential harm to personnel and passengers.
- More frequent high temperatures exceeding the temperature thresholds for imposing ‘Heat 40’ speed restrictions will result in increased delays to services and increased frequency of inspections.

7.4.5 Coastal rail network at risk from coastal flooding and erosion

The effects of coastal inundation and erosion on the coastal rail network are already difficult hazards to prepare for because of the complexity of climate factors at work and the uncertainty of future expressions of coastal weather conditions (Bell 2007). Advice from MfE suggests that climate change will not introduce any new types of coastal hazards, but will affect existing coastal hazards by changing some coastal conditions such as sea levels, storm tides, waves and swells.

In general, localities that are currently subject to occasional coastal hazards are likely to suffer increased risks with a warming climate, while areas that are currently in a delicate balance may begin to experience more damaging coastal hazards in future. MfE (2004c) advises that the mean sea level could reach up to 0.25 m above the average sea level in any given month, although this is most likely to occur during La Niña episodes in decades when the 20- to 30-year IPO cycle is in its negative phase (the current La Niña episode appears to have started in 1998 and may last until 2020 to 2030).

The average westerly wind component across New Zealand may increase by approximately 10% in the next 50 years. As a result, the frequency of heavy seas and swell along western and southern coasts would also increase, and so could higher extreme waves during more intense ex-tropical cyclones and mid-latitude storms.

As a result of climate change, rail infrastructure in the coastal zone is likely to be exposed to greater risks from inundation and coastal erosion such as:

- increased salt water corrosion and accelerated material deterioration from floods and sea spray, and saline incursion at coastal bridges;
- high waves and stormy conditions possibly overtopping coastal defences, leading to scour and washout, and consequent line closures or service disruption during inspections;
- coastal inundation and increased sea level rise accelerating erosion of coastal structures requiring more frequent inspection, repairs and potential disruption.

The extent of the entire rail network within the coastal zone is not known. However, railway lines tend to be located further inland than adjacent roads so it is not expected to be as exposed as the road network. However, the rail network will be vulnerable to corrosion from salt water.

7.5 Risk response for the rail network

7.5.1 Current responses

To respond to sections of the rail network known to be vulnerable to current climate conditions, the more immediate at-risk sites are recorded on an 'Essential Features List' for inspectors. Flood warning arrangements are in place with some regional councils, e.g. Waikato/Waipa river systems, Horizons Regional Council and Environment Canterbury.

ONTRACK has developed matrices to assess and rank the stability of track sections in terms of ground movement and rail buckling. Rail thermometers are located at sites identified as 'at risk' to track buckling; a regime of speed restrictions is imposed once temperature thresholds are exceeded.

Special inspections are conducted during extreme weather events. Annual inspections seek to identify progressive changing of risk and these are supplemented by detailed engineering inspections. Inspection reports, risk factors and adaptation efforts are recorded in an Asset Database.

ONTRACK has undertaken various studies to determine the current status of culvert capacity, bridge founding etc. Overall, little provision has been made to prepare or extend these provisions for the likely effects of climate change.

7.5.2 Gaps in knowledge or practice

A gap exists in the understanding of the scale of impacts from climate change and the effects on the rail network. ONTRACK expects the change in risk on the rail network from general warming, wetting and drying to be low. Based on our study of the predicted distribution and intensity of climate change effects in relation to the national rail network, we have identified high priority risks to the national rail network particularly relating to the effects of climate change on rainfall and temperature as described in Table 7.1.

ONTRACK and its predecessors have had a philosophy of low-key works and ongoing inspection and maintenance rather than heavily-engineered major capital works. This approach relies heavily on regular inspection and follow-up corrective action. Under-investment during the 1990s has left a backlog of corrective actions required. ONTRACK is progressively intensifying efforts to make the asset more robust.

Following asset failures and consequent pressures to reopen the line, the opportunity to undertake a well-engineered design is often lacking. After the initial asset recovery, often permanent works are required to bring the repairs up to an acceptable standard.

A gap exists in the technical capacity of rail infrastructure to cope with compounding effects e.g. sea level rise coupled with storm surge, and increased mean and extreme rainfall events.

ONTRACK is currently mapping their entire network. Currently, no correlation has been found between network mapping and climate change data, e.g. possible inundation from sea during storm surges.

7.5.3 Response options

Scour ratings are only available for part of the network, and the consistency and application of such ratings is dubious. Best practice would require screening the entire bridge stock using current methodologies and knowledge of bridge scour. To date, this has not been a priority, as the immediate need is to treat assets that are on the verge of becoming unfit for their purpose (for example track and structures assets where the primary load-bearing elements have reached the end of their serviceable life).

ONTRACK may need to review its rail stressing regime should climate change increase the temperature range experienced by the track. Internationally, rail systems already operate in wider temperature ranges than are currently experienced in New Zealand.

A possible response is the extension of existing asset management practices (e.g. increased frequency of inspection regimes) to take account of increased frequency and intensity of weather events expected from climate change.

A review of the design criteria for the capacity of culverts, drainage systems and bridge foundations etc. may also be required to take account of increased frequency and intensity of weather events expected from climate change.

A key response option that could be developed would involve incorporating the output of climate change science modelling into ONTRACK's system mapping.

8 Coastal ports/shipping networks and climate change

8.1 Coastal ports and shipping network background

New Zealand coastal shipping is engaged in moving passengers and freight from port to port and island to island, and providing links to and from national and international markets.

Fourteen ports service coastal shipping in New Zealand. Ports range from river ports such as Greymouth to export ports such as Auckland. Some have natural harbours; others are protected by man-made breakwaters, e.g. New Plymouth and Napier.

Ports compete to provide a transport hub that facilitates imports and exports into and out of New Zealand. Tonnages of freight handled at each port are shown in Figure 8.1. Domestic sea freight shipping routes are shown in Figure 8.2.

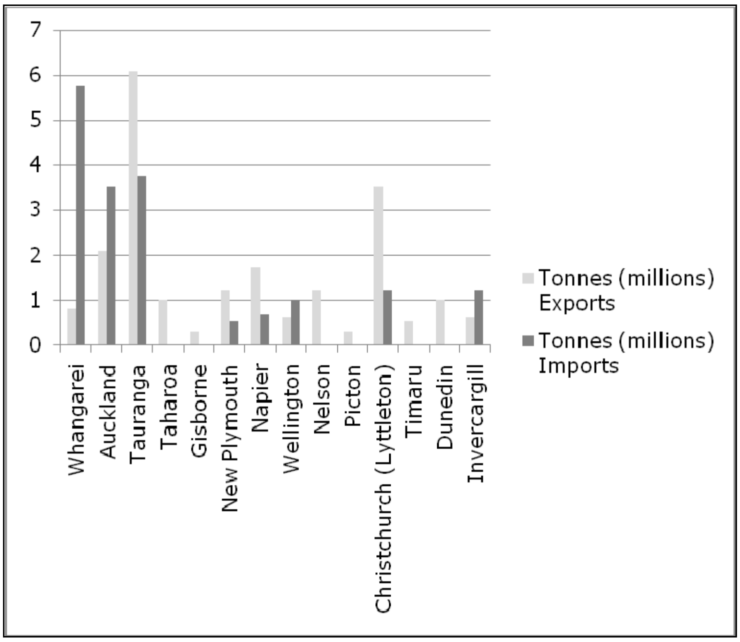

Figure 8.1 Imports and exports from New Zealand ports in 2007 (source: MoT 2008).

Ports are governed by regulations in the Port Companies Act 1988 (New Zealand Government 1988). Most are wholly or substantially owned subsidiary companies of local and registered authorities. Some are partly listed on the share market (e.g. Lyttelton), with the majority of shares held by regional authorities. The port owners are responsible for the operation, maintenance and development of the port and its assets, and are obliged to make financial returns to their shareholders.

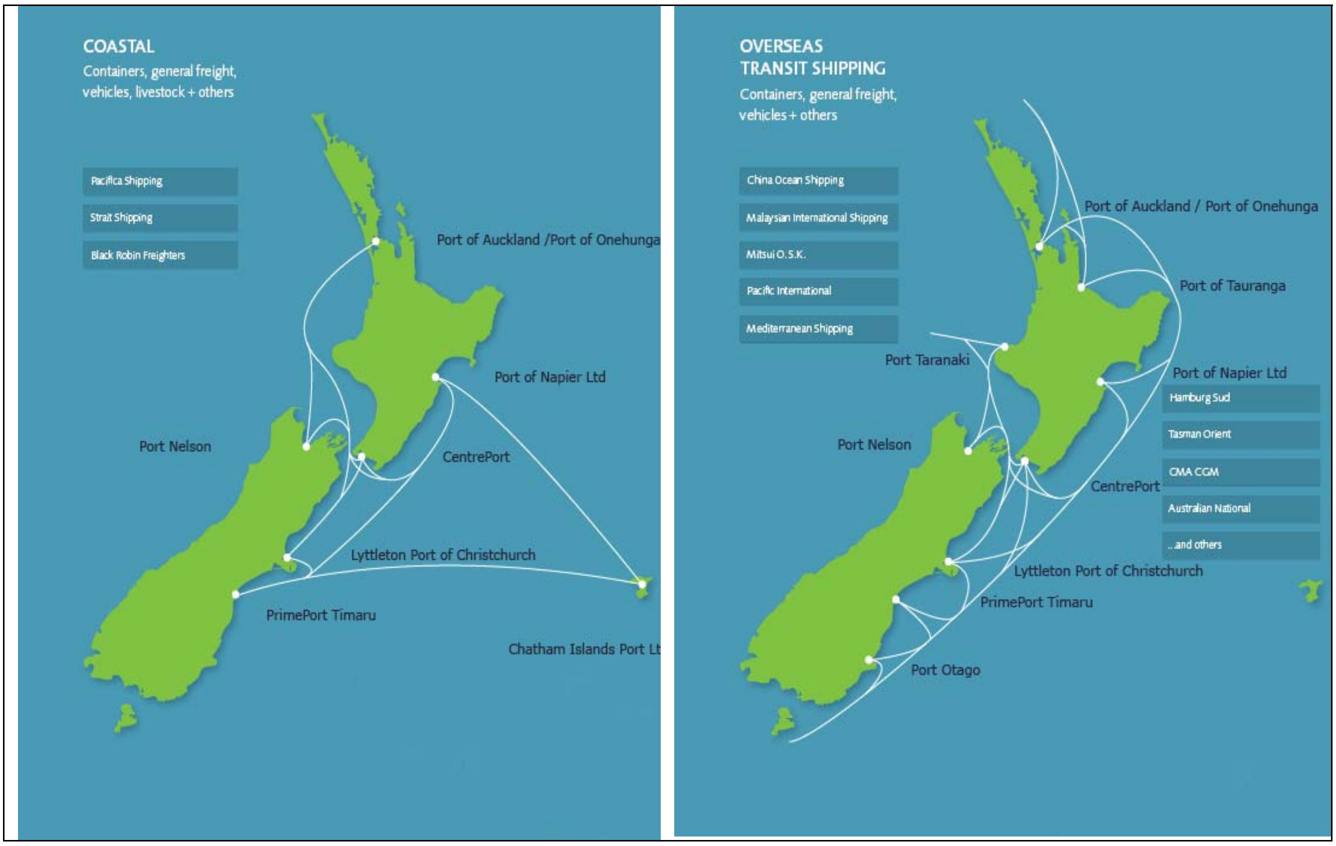

Figure 8.2 Domestic sea freight shipping routes within New Zealand (adapted from MoT 2008).

The New Zealand coastal shipping fleet is made up of thirteen coastal vessels comprising oil tankers, bulk cement carriers, rail passenger ferries, roll-on roll-off passenger vessels, roll-on roll-off freight vessels, conventional freight vessels and two research vessels. Five or six of these vessels are on the Cook Strait run. The only tug and barge freight operation on the New Zealand coast is Sea-tow Ltd. At present, this company only has one freight service, which carries bulk cement from Whangarei to Auckland. The rest of their fleet operates around Australia and the Pacific. In the past, their fleet carried commodities around the coast, e.g. coal from the West Coast; sand, gypsum and dolomite from Golden Bay and salt from Picton.

Fullers in the Auckland area move about 4 million passengers. Interislander and Bluebridge services carry approximately 1 million passengers a year across Cook Strait.

The government has set a target for domestic sea freight to be carrying at least 30% of all inter-regional domestic freight in New Zealand by 2040, effectively doubling the amount of domestic freight movement (four times as many freight tonne-kilometres as are transported now). The government’s motivation is a desire to encourage inter-modality and intelligent use of transport modes. Linkages also exist with other transport, energy and environmental initiatives.

The port network values have been taken from asset values shown from an internet search. Three minor ports do not publish their asset value, so rough estimates based on similar size ports were used to give an approximate value of $2.06 billion.

Ports in New Zealand range in age. A typical small port, Picton ran passenger and freight services from Wellington and Nelson in the early 1900s. Waitohi Wharf was built in 1912 for export vessels. This was extended in 1967 and received major maintenance repairs to the original structure in 1975. Road and rail berths were constructed in 1965 and 1972. Shakespeare Bay timber export berth was built in 2002. No. 1 ferry berth, with timber piles, has a 50-year life i.e. less than ten years remain before major reconstruction is due. No. 2 ferry berth has been designed to a 80–100-year life and is likely to exposed to the climate conditions predicted for 2090.

An online review indicated that some companies publish freight value but most do not. Typical information found for annual freight throughput is as follows:

- Auckland: $20.5 million,
- Tauranga: $10.6 million,
- Lyttelton: $ 4.6 million.

8.2 Port design and weather-related vulnerability

8.2.1 Introduction

Port assets are currently vulnerable to extreme weather events. Currently, some ports report wharf and breakwater facilities being overtopped in storm conditions. Climate changes are likely to exacerbate these events.

Port assets in the mid-size to large category are usually managed by professional engineers. They usually have a workforce to attend to maintenance and minor capital works.

8.2.2 Wharves

Wharves typically have a design life of 100 years. Most of the older wharves in New Zealand were built in the 1910s and therefore have limited life left. The process of rebuilding wharves is not being considered at the moment at most ports.

Wharves are designed with a 1–2m clearance of MHWS (Mean High Water Springs) sea level. Coastal ships other than roll-on roll-off vessels can usually load or unload at a great variety of deck levels.

Wharves are resilient to wind and mean rainfall, although extreme rainfall events may cause localised flooding, depending on catchment-specific flooding conditions, disrupting operations and potentially causing damage to personnel, assets, vessels, personnel and cargo.

8.2.3 Container cranes

Container cranes have a 20–30 year life. Cranes are vulnerable to the effects of high winds. Crane operators are restricted to operating cranes in wind speeds less than those specified by the manufacturer, depending on the nature of cargo being transported.

8.2.4 Breakwaters

Many ports in New Zealand rely on breakwaters to buffer port operations from the effects of high storm waves and storm swells.

Important ports such as New Plymouth, Napier and Timaru are at risk; so are secondary ports such as Oamaru. Breakwaters provide protection to other shoreline development, so the consequences if breakwaters are overtopped extend beyond port and coastal shipping operations.

8.2.5 Berths

The commercial port at Port Chalmers provides the only two fully-equipped deep draft container and multi-purpose berths in the lower South Island. In addition, it has two deep draft forestry berths.

At Dunedin, medium draft berths are available for handling general cargo, LPG and petroleum, and for deep-sea fishing boats.

Ravensbourne has a wharf used for unloading raw materials for fertiliser manufacturing. The deep draft berths are a critical factor in respect to the net return to the region's primary producers. These berths provide the means for container vessels, log carriers and woodchip vessels to depart fully laden from a single port of call.

Sediment transport from coastal and inland river systems require monitoring and removal to ensure the required draft is maintained to accommodate vessels. Nelson is an example of shallow draft holding up arrival and departure of some vessels using the port.

8.2.6 Vessels

New ships will need to be designed for the predicted wave climate. A report to PIANC (the International Navigation Association) notes the nature of modern vessels being more sensitive to wind, and the potential for passenger vessels subject to wind and wave operational criteria being at risk of more 'downtime'.

8.2.7 Accessibility for rail and road

Ports require a high level of accessibility by both roads and railways. Extreme events that affect road and rail networks throughout the rest of the country also apply to those inter-modal connections within port bounds.

Roll-on roll-off facilities such as those at Picton and Wellington provide inter-modal cargo exchange between road and/or rail with vessels. Facilities are designed to withstand limited vertical and horizontal movement, and are designed to allow for rolling and pitching in calm conditions. Most facilities in New Zealand are 30–40 years old and have a design life of 50–100 years.

8.3 Climate change risks to the port network

Using the risk methodology described in Chapter 5, the effects of climate change have been assessed for their potential risk to the national port and coastal shipping network (Table 8.3) below. This is a broad assessment of potential effects that does not consider specific regions or sites.

Table 8.3 Potential climate change effects on the national port and coastal shipping network.

Climate change effect category	Risk ranking	Main port or coastal shipping asset or operations affected by climate related effect	Gaps in practice, knowledge and information
Coastal flooding (including sea level rise and storm surge)	High	• Wharf levels being too low; • Tidal velocities; • Overtopping of breakwaters and excessive ship movement at berth; • Port infrastructure submerged; • Drainage problems; • Greater draft; • Less dredging; • Moderate effect on operational limits of roll-on, roll-off equipment affected; • Moderate navigation difficulties caused by current; • Moderate improvement to inland navigation prospects.	• Climate change effects on tidal velocities; • Combined effects of climate change related sea level rise and storm surge effects; • Vulnerable structures; • Accurate contour plans; • Maximum operating levels of roll-on, roll-off equipment; • Extra tidal prism and current effects; • Inland transport opportunities.
Flooding (including river and surface flooding)	High	• Navigation interruptions; • Surface flooding.	• Risk of increased flood frequency for each port; • Drainage standards required.
High winds	High	• Deflection on structures; • Loading and unloading delays. • Passage delays; • Ship handling difficulties.	• Structural integrity to stronger wind conditions.
Coastal erosion	High	• Loss of port land; • Moderate risk of sedimentation in ports and harbour entrances.	• Scour rates; • Vulnerable areas.
Fog and humidity	High but 'true' risk may be moderate	• Passage delays; • Collision.	–
Extreme high temperature (including air and ground temperature)	Moderate	• Corrosion; • Cargo fire risk; • Rail buckling; • Pavement seal bleeding; • Working conditions.	• Corrosion-proof asset coatings; • Effects on assets e.g. cranes, cargo, storage buildings; • Heat appropriate road pavement design; • Employer and union-agreed adaptation measures.

Table 8.3 (cont.) Potential climate change effects on the national port and coastal shipping network.

Climate change effect category	Risk ranking	Main port or coastal shipping asset or operations affected by climate related effect	Gaps in practice, knowledge and information
Rainfall (including high intensity falls, and changes to average rainfall, groundwater and soil moisture)	Moderate	• Loading, repairs and maintenance interruptions; • Navigation visibility.	• Assessment of effects.
Inland erosion and instability (including soil erosion and landslips)	Moderate	• Structure stability.	• Geotechnical assessment of revetment stability, slope stability and river and tributary bank stability.
Drought (including low river flows)	Moderate	• Water for washdown facilities.	–
Snow and ice	Low	• Loading rates.	–
Wildfire	Low	• Cargo fire risk; • Property damage.	–
Lightning	Low	• Risk to workers.	–
Fewer low temperature episodes	No threats identified	–	–

8.4 High priority climate change risks to ports

8.4.1 Scope

This section describes the effects and consequences of predicted climate change effects that have been identified (Table 5.4) as high priority risks to ports and the coastal shipping network. The scope of this project is high level and therefore we have not addressed non-priority lower ranked risks in detail, although they may be consequential issues for transport operators to consider.

8.4.2 High winds

A possible increase in strong winds (>10 m/s, top 1 percentile) by up to 10% is predicted by 2090. Strong winds are associated with intense convection (expected to increase in a warmer climate) and with intense low-pressure systems, which might also become more common.

Figure 3.7 shows the potential distribution of wind strength increases, with the greatest potential increases distributed on the east coast of both the North and South Islands.

High winds have potentially serious consequences for the operation of port infrastructure, particularly for exposed ports such as Wellington:

- Port buildings and crane infrastructure may suffer excessive deflection and structure failure, resulting in costly replacement and operational delays.
- Manoeuvring, berthing and loading operations delays in high strength winds conditions may result in reduced throughput and potential equipment damage.

8.4.3 Flooding

Flooding caused by heavier and/or more frequent extreme rainfall across New Zealand are predicted with moderate confidence, especially where mean rainfall increase is predicted, e.g. Tasman, West Coast, Otago and Southland (see Figures 3.4 and 3.5).

Port back-up land, used for cargo storage and port related industries, is naturally low-lying and therefore vulnerable to inland and coastal flooding. Port land relies on adequate up-catchment drainage management to detain or convey peak floods during rainfall events. Increased pressure on existing catchment drainage systems from climate change effects on rainfall therefore poses an increased risk of surface flooding on low-lying port areas.

The potential effects of flooding on port assets and operations include the following:

- Navigations may be interrupted in flood conditions in western ports such as Greymouth, Westport and Wanganui, causing delays.
- Navigations may be interrupted nationwide, particularly at river ports, during flood conditions because of the hazard of debris causing damage to vessels and port infrastructure.
- Surface flooding of port land may affect storage facilities and transfer of cargo onto other transport such as road and rail.

8.4.4 Coastal flooding

MfE (2004c) describes sea flooding as an acute event caused by a temporary increase of mean sea level (a 'storm surge') and energetic wave activity over and above the predicted high tide height. A storm surge is generated by a combination of adverse winds and low barometric pressure. Waves contribute to coastal inundation by a combination of wave set-up in water level and wave run-up, which may overtop low coastal barriers.

'Storm tide' is the term used to quantify the total height in sea level reached at the shore, combining tide, storm surge and wave set-up, to which wave run-up is added. The force of wave run-up and overtopping can cause damage to infrastructure. In some instances, sea flooding can occur during local fair weather when large swells from a distant storm ride in on the back of a very high tide.

Climate change will affect existing coastal hazards by changing some coastal conditions such as sea levels, storm tides, waves and swells. In general, localities that are currently subject to occasional coastal hazards are likely to suffer increased risks with a warming climate, while areas that are currently in a delicate balance may begin to experience more damaging coastal hazards in future.

MfE (2004b) advises that the mean level of the sea could reach up to 0.25 m above the average sea level in any given month, although this is most likely to occur during La Niña episodes in decades when the 20- to 30-year IPO cycle is in its negative phase (the current La Niña episode appears to have started in 1998 and may last until 2020 to 2030).

Climate change is likely to affect storms by increasing their intensity for a given return-period event (e.g. a 40-year return storm will be more intense than one with the same ARI now). The contributors to storm tides (wave, wind and barometric pressure) will also be increased. Climate change could potentially cause an increase in 'storminess' by producing a slight increase in the frequency of low-pressure troughs and depressions passing over New Zealand, although these projections have a low level of certainty. MfE (2004c) states that climate change modelling is unable to determine the effect of climate change on the frequency of ex-tropical storms reaching the northern and central regions of New Zealand.

The average westerly wind component across New Zealand may increase by approximately 10% in the next 50 years. As a result, the frequency of heavy seas and swell along western and southern coasts would also increase, and so could higher extreme waves during more intense ex-tropical cyclones and mid-latitude storms.

The potential effects of climate change on flooding and port assets and operations are as follows:

- Sea level rise will result in low level port areas (e.g. Greymouth, Westport, Wanganui and possibly Gisborne) being permanently underwater, causing wharves to be inoperable. The likelihood of the risk occurring will differ for each port, depending on the current sea level clearance of berth and wharf facilities. Protecting ports at risk by raising wharf levels, for example, will require major investment.
- Sea level rise and surge could exceed wharf levels, particularly during spring high tides, affecting berth facilities such as roll-on roll-off equipment. Roll-on roll-off vessels which have fixed hinge levels for their ramps and gangways, such as the Cook Strait ferries, could be affected when the maximum vertical range and gradients are increased if the vessels sit at higher levels. Reconstruction of approach ramps could be required to raise the hinge pin and the counterweight/hydraulic lifting system.
- Sea level rise and surge will cause overtopping of breakwaters and generate wave action in harbours, causing excessive ship movement at berth, and damage to ship and wharf structures and interrupting loading operations.
- Sea level rise could provide greater draft for ships in shallow harbours, reducing draft maintenance requirements for ports with draft restrictions such as Nelson, Timaru and Dunedin.

Risks from sea level rise on operational limits of roll-on roll-off equipment, and potential impacts of an increase in tidal area, water volumes and therefore tidal velocities were assessed as moderate risks to port infrastructure.

8.4.5 Coastal erosion

Coastal erosion and its effects on coastal infrastructure is a result of complex interactions between natural factors such as:

- weather (wind, waves and storm surge);
- oceanography (tides, offshore and alongshore currents);
- climate (seasonal, El Niño-Southern Oscillation, IPO, sea level rise, catchment runoff);
- geomorphology (type of beach/barrier system and how it responds, e.g. mixed gravel/sand versus sandy beach, stability of sandpits, inter-tidal estuary beaches, cliff erosion processes);
- sediment supply to the shore zone from cliffs, rivers, estuaries, winds and the offshore seabed; and
- seismic/tectonic factors (e.g. coastal uplift or subsidence, tsunami).

Global warming will affect sea level rise, alter rainfall and runoff patterns (which may cause a change in sediment supply to the coast), and may increase in the intensity of storms for a given return-period event, increasing the impacts of waves, wind and storm surge.

The rising sea level and surge will cause coastal erosion of soils previously above the reach of wave action. If these erodable soils are at the base of steep slopes, substantial land slips will result. This soil will eventually be re-distributed, if not cleared away, to cause seabed siltation – to some extent balancing the added depth of increasing sea level.

8.5 Risk response for the port network

8.5.1 Current responses

Ports currently use building code compliance, climate monitoring and operational responses to deal with extreme weather events.

One port confirmed in their questionnaire response to this project that climate change effects are taken into account in any changes to port assets. Other questionnaire respondents, and our industry knowledge and literature review, did not identify actions being made to prepare or extend existing weather management provisions in port operations for the likely effects of climate change.

8.5.2 Gaps in knowledge or practice

The following gaps in knowledge or practice were identified from the internal workshop in relation to adaptation responses by port owners/operators:

- land contours, infrastructure levels and their relationship to incremental high spring tide sea level rises;
- roll-on roll-off ramp operational range limits (level and grade) for road and rail related to ship levels at future high spring tides (this also affects passenger gangways);
- geological survey of land stability zones that may be affected by storm wave run-up at future high spring tides
- uncertainty in 'tidal prism[4]' – the increased volume resulting from greater spread of water across low land and resulting current velocity flows at the channel entrance;
- the effect of river flood levels and how often they will coincide with high spring tides at river ports;
- uncertainty whether any data exist regarding inundation from sea combined with storm surges;

4 The difference in the volume of water in a water body between high and low tides.

- lack of collation of coastal shipping data so that the effects of climate change on coastal shipping can be accessed with the various shipping companies.

8.5.3 Response options

The effect of climate change will vary considerably from port to port, as will the time when these issues materialise. Scope exists for studies to identify what the risks of the effects sea level rise and surge with flooding at individual ports are, where they will occur and what the likely trigger points are.

The main response option for ports is dictated by the magnitude of the in sea level associated with storm surge and the resultant risk of overtopping or inundation. More quantitative modelling studies are required to determine the combined effects of sea level rise and storm surge.

9 Regional implications of climate change to land transport networks

9.1 Introduction

Chapter 5 of this report identified and prioritised the dominant risks to road, rail, ports and coastal shipping networks from the effects of climate change from an overall risk perspective. Subsequent consideration of individual transport modes (Chapter 6 for road, Chapter 7 for rail, and Chapter 8 for ports and coastal shipping) provided further analysis of the high risks identified for each network, with a focus on the affected assets or operations, and gaps in knowledge or practice.

These considerations have provided a broad assessment of potential effects (i.e. what may happen and what are the consequences) but, with some exceptions, have not provided an assessment of which parts of the network are likely to be affected. The regional perspective is of prime importance as it provides a perspective of where and when such impacts may materialise, and the proportion and parts of the networks most at risk.

Some of the most significant effects of climate change for land transport networks might be caused by changes in climate extremes (for example, extreme rainfall, strong winds and storm surges), rather than just changes in mean climate conditions. Unfortunately, estimates of likely changes in regional climate extremes are generally less certain than projections of likely changes in mean conditions (see discussion in Sections 3.3 and 3.4). In addition, current gaps in knowledge for the national transport inventory limit the extent to which detailed comment can be made. These include lack of national datasets about where natural hazards currently disrupt land transport infrastructure.

Taking account of these limitations, this section provides an initial assessment of the likely regional patterns of climate change effects on road, rail and coastal shipping networks to the extent that existing models and data allow. It is expected that this initial analysis will set the basis for a broad high level regional profiling exercise to identify those parts of the network most at risk to climate change.

The regional distribution of climate changes that could affect surface land transport networks in North Island and South Island is illustrated by indicative maps in Appendix A, which show extreme temperatures (Figures A.1 and A.2) and extreme rainfall distributions (Figures A.3 and A.4) projected for the next 100 years. These maps show the national land transport networks (state highways, trunk rail and main ports) in order to provide the spatial context.

9.2 Regional impacts from extreme temperature, strong wind and sea level rise

9.2.1 General comments

The following sections provide an initial assessment of regional climate change impacts on specific land transport networks from extreme temperature (principally affecting rail), extreme wind (rail and ports) and sea level rise/storm surge effects of climate change (all modes). The selection of modes that are most significantly affected by each climate change category is based on the prioritisation of results from the risk assessment (Table 5.3).

9.2.2 Extreme temperature impacts on rail network

The regional distribution of extreme temperatures, as measured by the increase in number of days with a maximum temperature above 25°C (denoted 'hot days') for a 100-year scenario (which is associated with a 2°C warming in the mean temperature), is shown in Appendix A as Figure A.1 (North Island) and Figure A.2 (South Island). Table 3.1 indicates strong confidence in these predicted effects from climate change. Table 7.1 highlights the high risk rating attributed to the effects of high temperatures for rail.

The risk of high temperature to the rail transport network has a regional pattern mirrored by the distribution of hot days shown in these figures, with highest risks predominating at the northern part of North Island. Thus rail networks in the Bay of Plenty, Waikato, Auckland and Northland regions may face a greater exposure to high temperature conditions linked to rail buckling, with associated operational disruptions and damage to rails. Predicted adverse conditions could potentially occur in regions with key rail links, namely the Auckland suburban passenger network, Auckland/Hamilton/Mt Maunganui (20% of freight between these centres travels by rail) and northern sections of the NIMT line.

Not all sections of track in the area of more frequent extreme temperature would be at risk. Section 7.2.5 notes differing rail standards and vulnerabilities to high temperatures (e.g. unstressed CWR is more at risk in heat waves than jointed track). Within regions exposed to a significant increase in hot days, a subset of rail trunk lines within these at-risk regions may therefore be at greater risk to the effects of more frequent or more extreme heat waves as a result of climate change.

A gap in information is noted in Section 7.3 about the relationship between rail temperature, vulnerability to buckling and climate conditions. Defining this trigger point in detail would enable climate change effects on the rail network to be modelled, and therefore provide a more definitive regional and temporal risk map for the rail network in the north of the North Island. This aspect is proposed to be taken forward in Stage Two.

9.2.3 Higher risk from strong winds on road networks and port areas

Figure 3.7 illustrates the preliminary results from a single run of NIWA's regional climate model showing the 100-year change (%) in the 99th percentile of 10 m/s wind speed (i.e. daily wind speed that is exceeded only 1% of the time) for the whole of New Zealand.

The model suggests an increase in strong winds (exceeding 10 m/s) in eastern coastal areas of the North and South Islands, and on the Canterbury Plains in the lee of the Southern Alps.

Table 3.1 indicates low to moderate confidence in the predicted effects of climate change on average and strong wind conditions, and therefore these data are indicative.

Transposing these findings to national ports and the road network, the east coast ports (i.e. Gisborne, Napier, Lyttleton, Timaru and Otago) would potentially be at greatest risk from these effects. Likewise, the road network operators along the eastern side of New Zealand and in Central Otago may face higher risks of asset damage or disruption from strong winds caused by climate change effects.

Sections 6.4.4 and 8.4.2, respectively, describe the potential effects of high winds on road networks and port operations in more detail.

9.2.4 Sea level rise and storm surge

Coastal flooding as a result of sea level rise and storm surge poses a high risk to all land transport networks (see Table 7.1). To account for the predicted effects of climate change on sea level rise, NIWA suggests using a mid-range sea level rise projection of 0.2 m by 2050 and 0.5 m by 2100 for planning and design purposes until updated projections become available.

Climate change projections in Table 3.1 show, with a high degree of confidence, that storm tide elevation will rise at the same rate as mean sea level rise. During stormy conditions, the effects of heavy swells (linked to prevailing westerly wind patterns) are likely to compound sea level rise and storm tide elevations. With a projected increase in the annual mean westerly wind component, the overall regional effect of sea level rise and storm surge is likely to be greater on the western seaboard of New Zealand than the eastern coastline.

Determining regional transport infrastructure that is at risk relies on detailed studies of infrastructure elevations within the coastal margin and the resiliency of infrastructure to the effects of coastal flooding. Sections 6.4.3 and 7.4.5 note the potential vulnerabilities of coastal road and rail networks, respectively, to coastal flooding and (to a lesser degree for rail) the associated erosion/slip effects.

While the extent of the effects of flooding on road and rail networks situated in the coastal margins is not known, some broad indicative patterns can be identified, based on the proximity of these transport corridors to the sea. Thus in North Island, sea flooding and erosion/slips could potentially occur at low-lying parts in the following coastal locations:

- sections between Tauranga and Whakatane,
- sections between Gisborne and Napier,
- the coastal strip between Plimmerton and Paraparaumu, and
- parts of networks in reclaimed/low-lying areas (e.g. Wellington Harbour).

In the South Island, sea flooding and erosion/slips could potentially occur at low-lying parts in the following locations:

- sections between Marlborough to Kaikoura,
- sections between Westport, Greymouth and Hokitika,

- the flat coastal strip south of Christchurch, and
- the section between Timaru and Dunedin.

With respect to ports, Section 8.4.4 highlights the potentially extensive distribution of effects from sea level rise and storm surge around New Zealand. Potentially high risks from flooding and disruption to port assets and operations are notable at the following locations:

- low-level port areas, e.g. Greymouth, Westport, Wanganui and possibly Gisborne;
- ports with roll-on roll-off equipment such as the Cook Strait ferries' dock;
- ports and harbours with breakwater structures (that could generate adverse wave action) such as New Plymouth, Napier, Lyttleton, Timaru and Oamaru.

The locations listed above are illustrative and do not imply an actual risk of flooding or erosion/slips from climate change. Clearly, the relative elevations of coastal transport infrastructure regarding projected sea level rise, as well as existing sea protection measures, are critical aspects to assess before drawing up a definitive shortlist of those parts of the networks potentially at risk from sea inundation.

Within the limits of the data that are available, the regional impacts of sea level rise/storm surge for ports and coastal transport corridors are proposed to be explored at a regional/national level in Stage Two.

9.3 Other high risk climate change effects on surface transport

9.3.1 Scope

This section discusses climate change effects that could pose a high risk to surface transport networks but where the related regional climate change predictions are either not known, or where the consequent impact on infrastructure is a secondary effect that requires detailed local assessment (e.g. inland flood risk from extreme rainfall requires modelling using local topographical, land use and hydrological data).

The section covers flood, erosion and slip risk (from increased rainfall), and the effects of increased storminess. Because of the complex extensive nature of the effects or a lack of confidence in climate change predictions, descriptions of transport infrastructure at risk from these effects cannot be determined with any certainty at a regional level.

9.3.2 Flood, erosion and slip risk from increased frequency/intensity of extreme rainfall

It is not possible at this stage to determine regional impacts of extreme rainfall events on road, rail and ports caused by climate change. Predicted increases in extreme rainfall are not modelled well enough to be able to distinguish regional variations. MfE (2008) recommends the same changes to rainfall return periods be applied everywhere across New Zealand, with an 8% increase in 24-hour 100-year ARI rainfall for every 1°C increase in mean temperature. Future projections of regional variations may be possible if comprehensive modelling studies are completed.

The main effects of heavy rainfall events for land transport networks are floods, slips and erosion, identified as high and moderate risks for all modes in
Table 5.2 and Table 5.3.

Intuitively, where existing flood, slip and erosion risks currently affect land transport networks, the predicted increases in extreme rainfall events may be an important factor to consider when determining what parts of land transport networks are at risk.

Rainfall is only one factor contributing to flood, slip and erosion risks to land transport networks. Seville & Metcalfe (2005) note the two important parameters influencing flood risk assessment for the state highway network: the flood inundation level and the flood velocity. To determine these parameters, the influences on inundation level and the flow velocity of soil type and saturation, climatic conditions, vegetation cover, topography and rainfall patterns must be taken into account.

Seville & Metcalfe (2005) outline a methodology to determine the probability of floods affecting state highways, and they highlight rainfall flows as one of many factors to consider. If a similar methodology were applied to all road and rail networks and port areas, incorporating predicted climate change effects on rainfall flows for 2040 and 2090 timeframes, a comprehensive picture of the future risk of climate change-related flooding to the land transport network could be developed.

As a recommended starting point for future studies, current transport infrastructure vulnerability to weather effects, including a regional risk register of the locations prone to such effects should be identified and understood better. This will provide a basis from which to project the likely effects of climate change, e.g. based on a scaling of extreme rainfall. This aspect will be considered for inclusion in Stage Two.

9.3.3 Storminess

Climate change projections for New Zealand indicate that more storminess is possible but little information is available (see Table 3.1). Because of the low confidence in the predicted impacts of climate change on storminess and storm patterns in New Zealand (see Section 3.4.7), the regional implications of storms for land transport networks are not able to be evaluated.

The effects of increased storminess (either ex-tropical cyclones or mid-latitude storms) are likely to result in an increase in peak wind speeds and increase in extreme rainfall. Thus increased storminess is likely to exacerbate the regional effects of extreme rain and strong winds on land transport networks, as discussed in Section 9.2.

10 Gap analysis summary

10.1 Introduction

This section summarises the key gaps that have been discussed in earlier chapters of this report under the topics of climate research, legislation and policy, and the individual modes (road, rail and ports/coastal shipping). The list is not exhaustive but provides specific directions in which to prioritise research for further study.

Many gaps in knowledge about the effects of climate change are interdependent. Thus, imprecision in modelling climate change effects feeds through to uncertainties in predicting the magnitude of the resultant impacts on the transport networks as well as their regional and temporal characteristics. Conversely, lack of data on technical assets may affect the ability to transpose climate change predictions to allow regional risk analysis of effects on transport networks. For example, the lack of a high resolution elevation dataset for New Zealand does not support precise analysis of the risk of coastal flooding/inundation at the regional/national scale. For this reason, detailed climate change modelling studies are targeted at the local level using site-specific data where they are available.

A more fundamental type of gap in projecting future climate change conditions in New Zealand is the inability to predict future greenhouse gas emissions because these depend so much on social and economic factors, and policy decisions yet to be made. The current uncertainties regarding the timeframe for implementing an Emission Trading Scheme in New Zealand or the future price of fossil fuels are cases in point.

The following sections discuss the priority issues requiring further study concerning climate change issues that affect land transport networks, as well as the non-priority issues that are not considered to need additional study.

10.2 Priority issues

10.2.1 Main issues

Two specific themes that are important to all modes and the general issue of how climate change affects the transport sector are:

- the temporal and regional manifestations of climate change effects on land transport infrastructure, and
- adaptation measures (planning, design, operation, maintenance or replacement) required to counter these effects for the three transport modes.

Aside from these main issues, a number of topic-specific gaps need addressing as outlined below. This represents a ‘shopping list’ of issues for consideration by the NZTA. While some of these will be appropriate to take forward in Stage Two, the majority will need to be part of a wider NZTA research programme and/or taken up by other research funding agencies (e.g. Foundation for Research, Science and Technology (FRST)). Other identified issues will need to be given consideration by transport network operators, local and regional councils, and central government (policy and legislation).

10.2.2 Climate research

The main issues identified by the gap analysis in terms of climate research are the need for:

- better models for predicting key climate parameters that may affect transport infrastructure networks – e.g. solar radiation models for determining potentially adverse effects on transport components (such as ultraviolet damage or radiation heat gain) do not adequately account for cloud cover;
- higher resolution models of relevant effects to enable detailed analysis of spatial and temporal distribution of climate change effects. This is a vital input into any risk analysis of transportation infrastructure at the local and regional level;
- calculation of the combined effects of climatic factors affected by climate change on transportation (e.g. combined effects of sea level rise, storm surge, tides and high winds for coastal areas; the combined effects of wind and rainfall on inland storm patterns); and
- clearer definition of the trigger points or relationships between key climate parameters and transport infrastructure, e.g. the relationship between ambient temperature, solar radiation and the level to which rails are resilient to these conditions such as maximum temperature, and the number of antecedent hot or cool days.

10.2.3 Legislation and policy

The main issues identified by the gap analysis in terms of legislation and policy are the lack of:

- overall integration of land transport (road, rail and coastal shipping) planning with land use planning;
- explicit recognition in legislation and requirements to consider climate change effects as part of transport asset and network management responsibilities;
- explicit recognition in strategic land transport policy and requirements to consider climate change effects as part of transport asset and network management responsibilities, with a focus on asset managers taking action now to understand and prepare land transport networks better for potential climate change related risks;
- clarity on appropriate planning timeframes to ensure transport related decision making, including funding priorities, is projecting far enough into the future to take account of projected climate change effects;
- definition of responsibility for dealing with climate change effects in terms of national and regional interests and local infrastructure providers, including the role of the private sector; and
- audit processes for monitoring adaptation policies and associated progress at national, regional and local levels.

10.2.4 Road assets

The principal needs in response to identified gaps for road assets are as follows:

- specific mapping of areas at risk of coastal flooding/inundation caused by sea level rise and storm surge;
- nationwide asset performance assessment of existing drainage, culvert and bridge structures and associated improvements/upgrading required to cope with increased flows caused by climate change; and
- translation of projected increased rainfall intensity and frequency on inland erosion and slips, and identification of areas and regions vulnerable to these effects and at risk of operational effects or adaptation requirements.

10.2.5 Rail assets

The main needs in response to identified gaps for rail assets are as follows:

- clarification of the relationship between solar radiation, air temperature and rail temperature to assist in determining the stability of the New Zealand rail track associated with buckling at increasingly frequent higher temperatures, which are expected from climate change;
- nationwide assessment of rail track levels in relation to mean sea level and associated prediction in sea level rise and storm surge;
- translation of projected increased rainfall intensity and frequency on inland erosion and slips, and identification of areas and regions vulnerable to these effects and at risk of operational effects or adaptation requirements;

- rail network-wide assessment of existing drainage culvert and bridge structures, and associated improvements/upgrading required to cope with increased flows caused by climate change; and
- changes in groundwater levels in relation to foundation design and ballast stability.

10.2.6 Ports and coastal shipping assets

The principal needs in response to identified gaps for ports and coastal shipping assets are as follows:

- land contours and other infrastructure topographic levels, their relativity to wharf and port infrastructure levels, and the projected sea level rise and storm surge effects of climate change;
- operational range limits (level and grade) for roll-on roll-off ramps and passenger gangways;
- land stability and the extent of coastal protection works required to protect port areas from increased storm wave and surge impact and sea level rise associated with climate change; and
- harbour entrance studies for current and flow changes caused by climate change.

10.3 Non-priority issues

10.3.1 Aspects of non-priority issues

A requirement for the project included determining which climate change issues that affect land transport networks do not need additional study, either because these are adequately covered by existing research programmes or because they are of insufficient consequence to land transport networks. These aspects are covered separately below.

10.3.2 Aspects that are adequately covered in New Zealand

The Resource Management (Energy and Climate Change) Amendment Act (New Zealand Government 2004) that took effect in March 2004 directs decision-makers to ‘have particular regard to the effects of climate change’ when making decisions under the RMA. This is a comprehensive framework that ensures climate change effects are one of the contexts under which new transport infrastructure and modifications to existing infrastructure are considered. Robust decision making relies on the quality of data available to inform and test applicants’ designs and regulatory authorities’ decision making.

The responses from the stakeholder questionnaire (see Section 2.2 and Appendix C) and the literature review of research being conducted in New Zealand (see Section 2.3) indicate that research being undertaken on the effects of climate change on land transport is at a very early stage. (Conversely, much work is being undertaken on the reverse – the effects of land transport networks on climate change).

Substantial progress has been made in documenting the potential effects of climate change in New Zealand by NIWA, but outside of this project, very few studies have considered the effects on transportation in any detail. The gaps in climate change research identified in this project (Section 3.4) indicate that more research is needed in this area, particularly on predicting the climate extremes that have greatest potential for adverse effects on transportation networks.

Similarly to climate change science, considerable guidance material has been prepared for local government on adaptation to climate change, although, of necessity, this has been prepared on a broad cross-sectoral basis with only brief reference to transportation. The revised guidance manual for local authorities (MfE 2008) is a useful generic risk assessment framework, but lacks detailed guidance for land transport operators to prioritise their response to climate change issues, particularly in relation to where and when these risks will materialise. Other aspects of policy and legislation that are being adequately addressed are discussed in Section 4.3.

Given the early stage of research in New Zealand on climate change issues that affect land transport networks, we conclude that no aspects currently qualify as being adequately covered by existing programmes.

10.3.3 Aspects not requiring further consideration

These aspects have been identified by reviewing the findings of the risk assessment (Chapter 5) and the reader is referred to those issues marked in Table 5.4 as a low priority (or not a priority) to land transport networks from climate change. These are:

- fog and humidity,
- snow and ice,
- lightning,
- low temperatures, and
- drought.

11 Recommendations

11.1 Preamble

The Stage One study has identified the key climate change issues and the climate change parameters which will affect the New Zealand land transport infrastructure, network operations and maintenance.

As part of the study, gaps in knowledge for both the climate change predictions and the information databases associated with each of the modes have been identified. An initial assessment and ranking of climate change impacts on the land transport systems using a risk management approach has been undertaken.

As is evident from the findings of the literature review and gap analysis completed under Stage One, a large amount of investigation and study is required to produce a comprehensive New Zealand-wide climate change impact assessment for the land transport system across all modes.

The two primary barriers to the detailed regional assessment of climate change impacts on land transport networks in New Zealand are:

- the uncertainty both in regional climate change predictions and in downscaling for projected changes in extreme events, which is required for determining impacts on transport networks at the regional level; and
- the lack of readily accessible specific transport infrastructure datasets and design standards for each of the territorial local and regional authorities, and other transport mode owners and operators.

In light of these major issues, the Stage Two investigation must, of necessity, focus on outcomes that are achievable using existing climate modelling tools and data readily available from transport networks.

11.2 Selection criteria for scoping Stage Two

It is appropriate, at this stage, to reassess what would be most appropriate to take forward in Stage Two, given the findings to date. The selection criteria we have used are as follows:

- aspects to receive focus as described in our proposal,
- the NZTA's requirements for the Stage Two report (delivery outcomes of the project)
- key findings and priority gaps identified in the Stage One study, and
- what can be achieved in the project timeframe with available data and budget.

The focus of Stage Two, as described in our proposal, was as follows:

- prioritise areas for further spatial and technical analysis (with involvement of a reference group of transport sector, environmental and economic agency representatives),
- preparation of detailed climate change scenarios based on IPPC FAR (IPCC 2007),
- undertake a vulnerability assessment and risk analysis,
- formulate adaptation measures and strategies,
- identify additional research and studies to better characterise and more closely define the specific climate change impacts on New Zealand land transport systems and networks.

Some of the work for Stage Two has already been started or undertaken in Stage One. This includes a review of climate change issues concerning current legislation and policy, inclusion of climate change predictions that were released by MfE (2008), an initial assessment of the vulnerability and response options for each mode based on the risk assessment findings, and a preliminary assessment at the regional level (as far as modelling predictions allow). The gap analysis summary (Chapter 10) has also made an initial appraisal of additional research and study needs.

The prioritisation of which regions of the network are at risk and when these risks are likely to emerge under different scenarios (the 'where' and 'when' of climate change) is seen as a key issue and will be developed further in Stage Two, to the extent that existing information gaps in transport databases permit.

The required Stage Two report outcomes articulated in the project agreement are listed in Table 11.1 and reflect the Stage Two focus described above. These outcomes have been taken into account in developing the Stage Two scope.

Table 11.1 Required Stage Two report outcomes.

Outcome #	Stage Two outcomes*
1	Outcome of additional research and stakeholder feedback on climate change issues and methods to address them.
2	Methodology used and outcome of vulnerability assessment and risk analysis of issues for the land transport network.
3	Potential climate change scenarios as they relate to land transport networks across a range of time horizons and geographic scales, displayed visually on indicative maps.
4	Recommended mitigation (adaptation) options to address information gaps and risks to land transport networks, including a broad assessment of potential cost implications and value-for-money priorities.

* per Clause 6 (page 13) of project agreement

11.3 Proposed scope of work for Stage Two

The main objective of Stage Two will be to provide a better understanding of the temporal and regional manifestations of climate change effects on land transport infrastructure in New Zealand using a national/regional profiling approach to be developed for this project.

The focus will be on defining the probable effects on the physical assets/infrastructure of land transport systems. Adaptation measures (planning, design, operation and maintenance) required to counter these effects for the three transport modes will also be explored, as will a broad assessment of cost implications where appropriate.

We recommend liaising directly with relevant sector stakeholders in relation to particular tasks rather than co-ordinating a stakeholder reference group as originally proposed. We are confident from our contact with stakeholders that our proposals address the highest priority gaps identified in knowledge and practice.

The proposed scope of work for Stage Two is set out below and includes a cross-reference to the relevant Stage Two report outcomes (see Table 11.1).

- Develop regional GIS maps based on current understanding of climate change predictions and, subject to availability of transport data, identify the areas of high risk for each mode, as an output from Tasks 2, 3 and 4 (Outcome #3).
- Liaise with ONTRACK, collate national and international rail design standards in relation to temperature, and analyse asset databases to develop specific impact scenarios for the Northland/Auckland regional rail network relating to rail buckling from high temperatures under 10-, 50- and 100-year timeframes for heat waves (Outcomes #1, 2, 3, 4).
- Determine ports that are vulnerable to coastal flooding and liaise with selected port authorities to collate wharf and deck heights, and develop specific sea level rise/storm surge impact scenarios over 10- 50- and 100-year timeframes (Outcomes #1, 2, 3, 4).
- Liaise with rail and road controlling authorities to identify areas currently at risk of (or prone to) inland flooding as a basis for estimating parts of the networks that are likely to be affected by climate change projections using a scaling factor approach to model the likely impact of increased heavy rainfall events over 10- 50- and 100-year timeframes (Outcomes #1, 2, 3, 4).

The proposed scope of work for Stage Two, as set out above, has been formulated to align with the key findings and conclusions from the Stage One report (Volume One), and is generally in line with our proposal and the target objectives of the project, as set out in the Request For Proposal.

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Appendix A Spatial distribution of climate change effects in relation to land transport networks

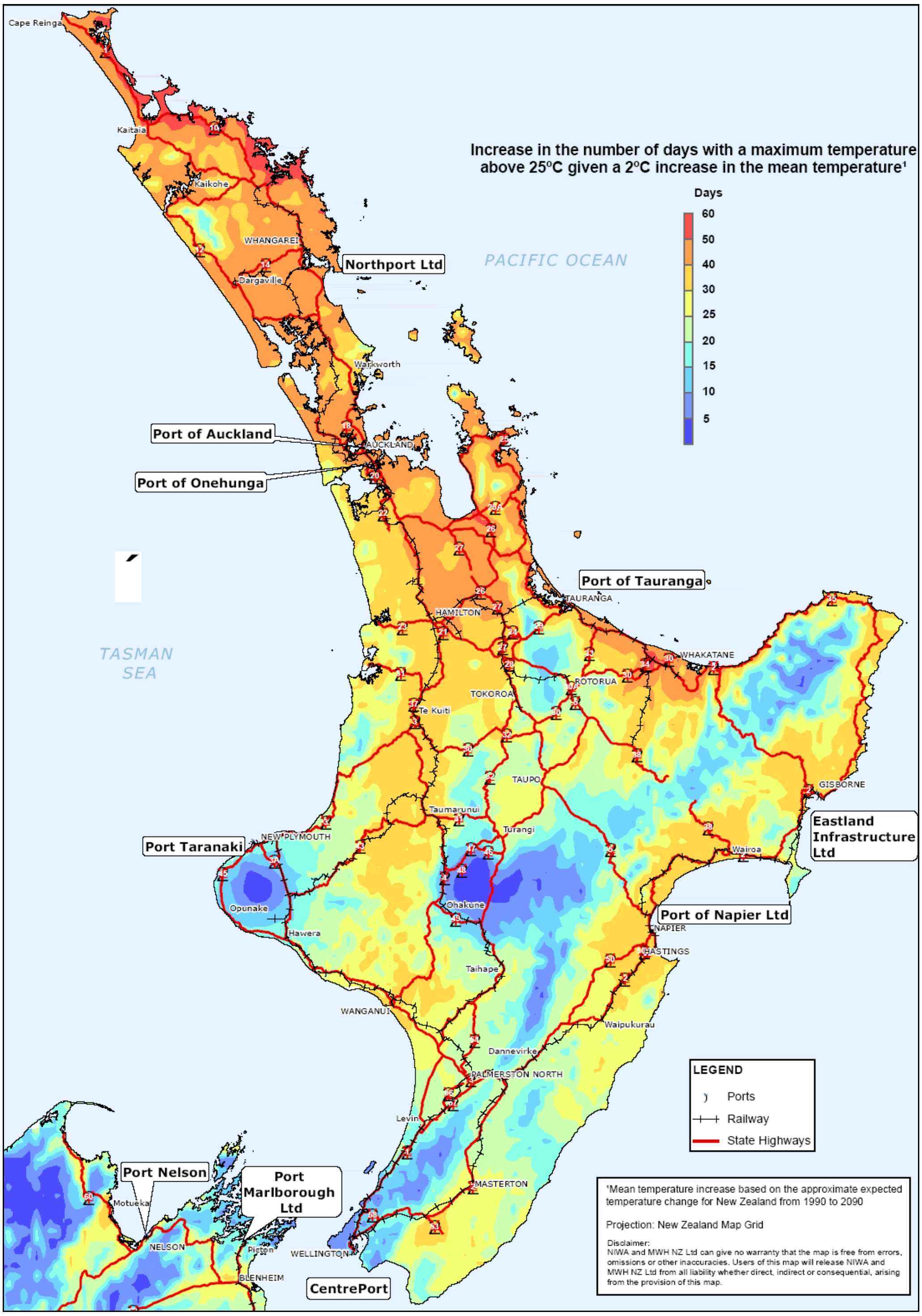

Figure A.1 Distribution of extreme temperature from climate change (100-year projection) in relation to land transport networks, North Island, New Zealand.

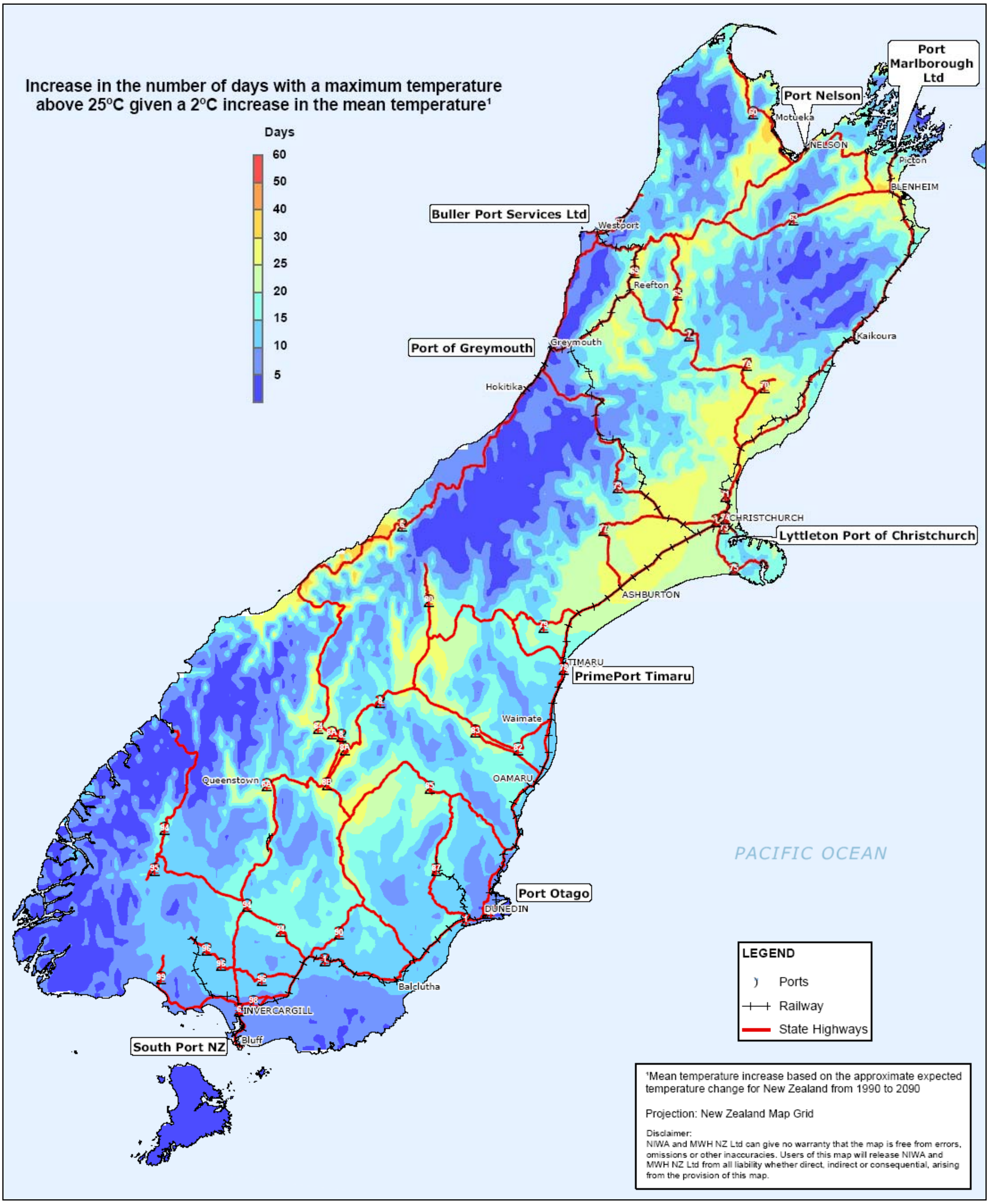

Figure A.2 Distribution of extreme temperature from climate change (100-year projection) in relation to land transport networks, South Island, New Zealand.

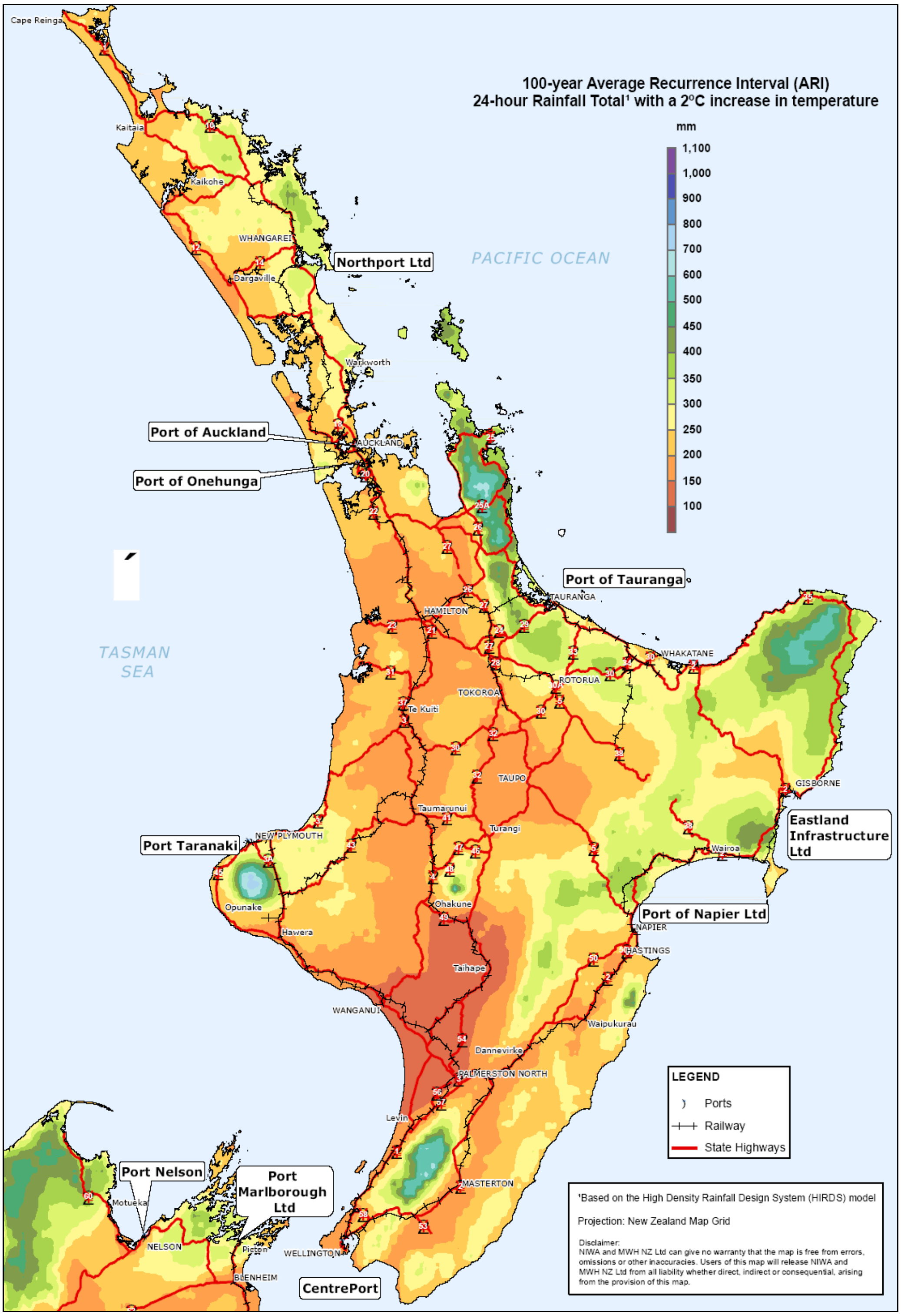

Figure A.3 Distribution of extreme rainfall under projected climate change conditions (100-year projection) in relation to land transport networks, North Island, New Zealand.

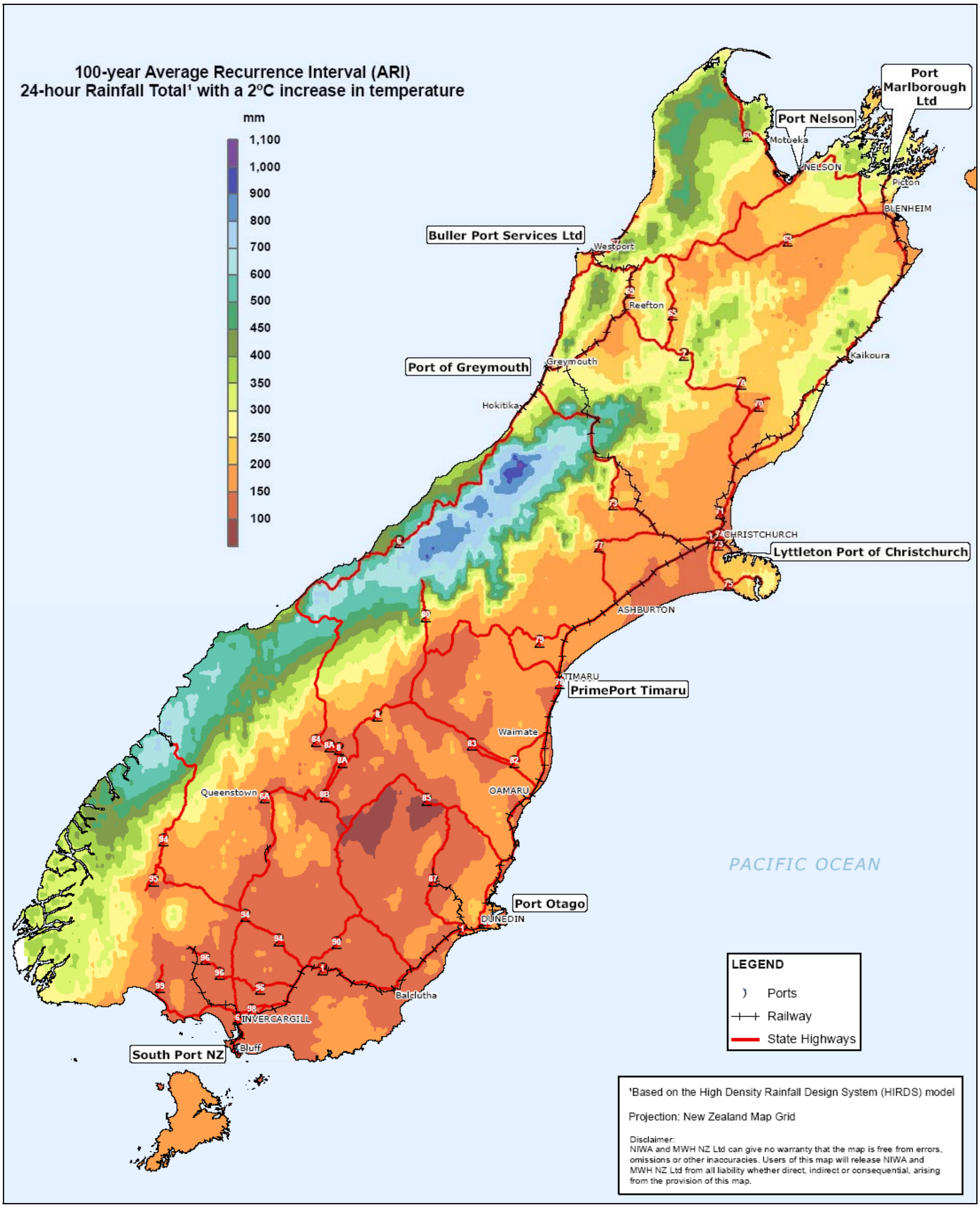

Figure A.4 Distribution of extreme rainfall under projected climate change conditions (100-year projection) in relation to land transport networks, South Island, New Zealand.

Appendix B Climate review

B1 The natural greenhouse effect

The greenhouse effect is a warming of the earth's surface and lower atmosphere caused by substances such as carbon dioxide (CO_2) and water vapour which let the sun's energy through to the ground but impede the passage of energy from the earth back into space.

Energy emitted from the sun ('solar radiation') is concentrated in a region of short wavelengths including visible light. Much of the shortwave solar radiation travels down through the Earth's atmosphere to the surface virtually unimpeded. Some of the solar radiation is reflected straight back into space by clouds and by the earth's surface. Much of the solar radiation is absorbed at the earth's surface, causing the surface and the lower parts of the atmosphere to warm (see Figure B1).

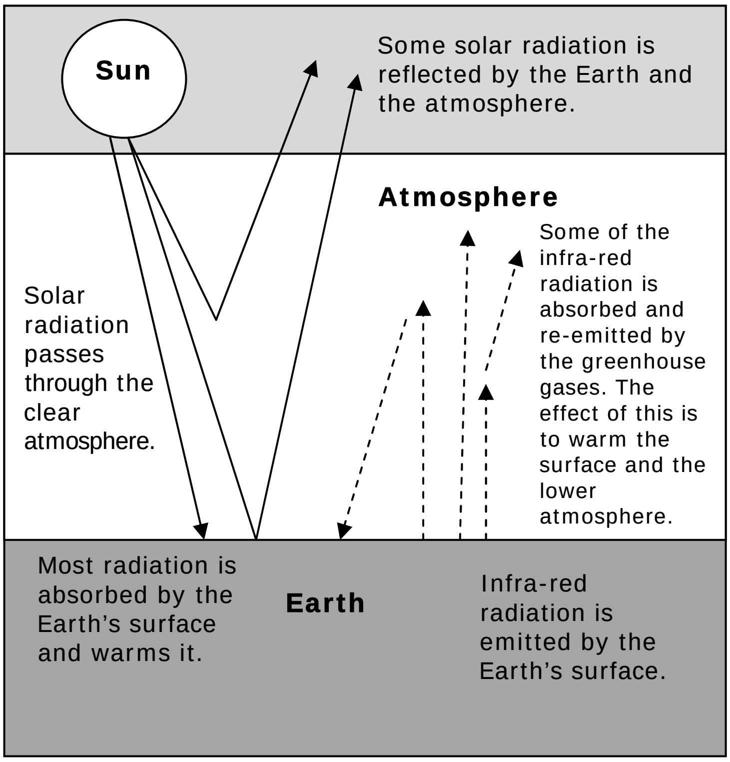

Figure B1 A simplified diagram illustrating the greenhouse effect (based on a figure in the 1990 IPCC Science Assessment (Houghton et al. 1990)).

The warmed Earth emits radiation upwards, just as a hot stove or bar heater radiates energy. In the absence of any atmosphere, the upward radiation from the Earth would balance the incoming energy absorbed from the Sun at a mean surface temperature of around -18°C, 33° colder than the observed mean surface temperature of the Earth. The presence of 'greenhouse' gases in the atmosphere accounts for the temperature difference. Heat (infra-red) radiation emitted by the Earth is concentrated at long wavelengths and is readily absorbed by greenhouse gases in the atmosphere, such as water vapour, CO_2 and methane. Absorption of heat causes the atmosphere to warm and emit its own infra-red radiation. The Earth's surface and lower atmosphere warm until they reach a temperature where the infra-red radiation emitted back into space, plus the directly reflected solar radiation, balances the absorbed energy coming in from the sun. As a result, the surface temperature of the globe is around 15°C on average, 33°C warmer than it would be if Earth had no atmosphere. This is called the natural greenhouse effect.

B2 The effect of increased greenhouse gas concentrations

If extra amounts of greenhouse gases are added to the atmosphere, e.g. from human activities, then they will absorb more of the infra-red radiation. The Earth's surface and the lower atmosphere will warm further until a balance of incoming and outgoing radiation is reached again (the emission of infra-red radiation increases as the temperature of the emitting body rises). This extra warming is called the enhanced greenhouse effect.

The magnitude of the enhanced greenhouse effect is influenced by various complex interactions in the earth–ocean–atmosphere system which are not included in the discussion above. For example, as the temperature of the earth's surface increases, more water vapour is evaporated. Since water vapour is itself a strong greenhouse gas, this is a positive feedback loop which will tend to amplify the warming effect of (for example) CO_2 emissions. Clouds tend both to cool the Earth because they reflect incoming sunlight, and to warm it by trapping outgoing infra-red radiation. The net result over the globe of clouds is a cooling, but it is still uncertain whether this overall cooling will increase or decrease as greenhouse gas concentrations increase. Heat is distributed vertically in the atmosphere by motion, turbulence, and evaporation and condensation of moist air, as well as by the radiation processes discussed above.

Thus many processes and feedback loops must be accounted for in order to predict climate changes resulting from particular greenhouse gas emission scenarios realistically (see Figure B.2). These complications are the source of much of the debate which has occurred about the likely magnitude and timing of climate changes caused by enhanced greenhouse gas emissions.

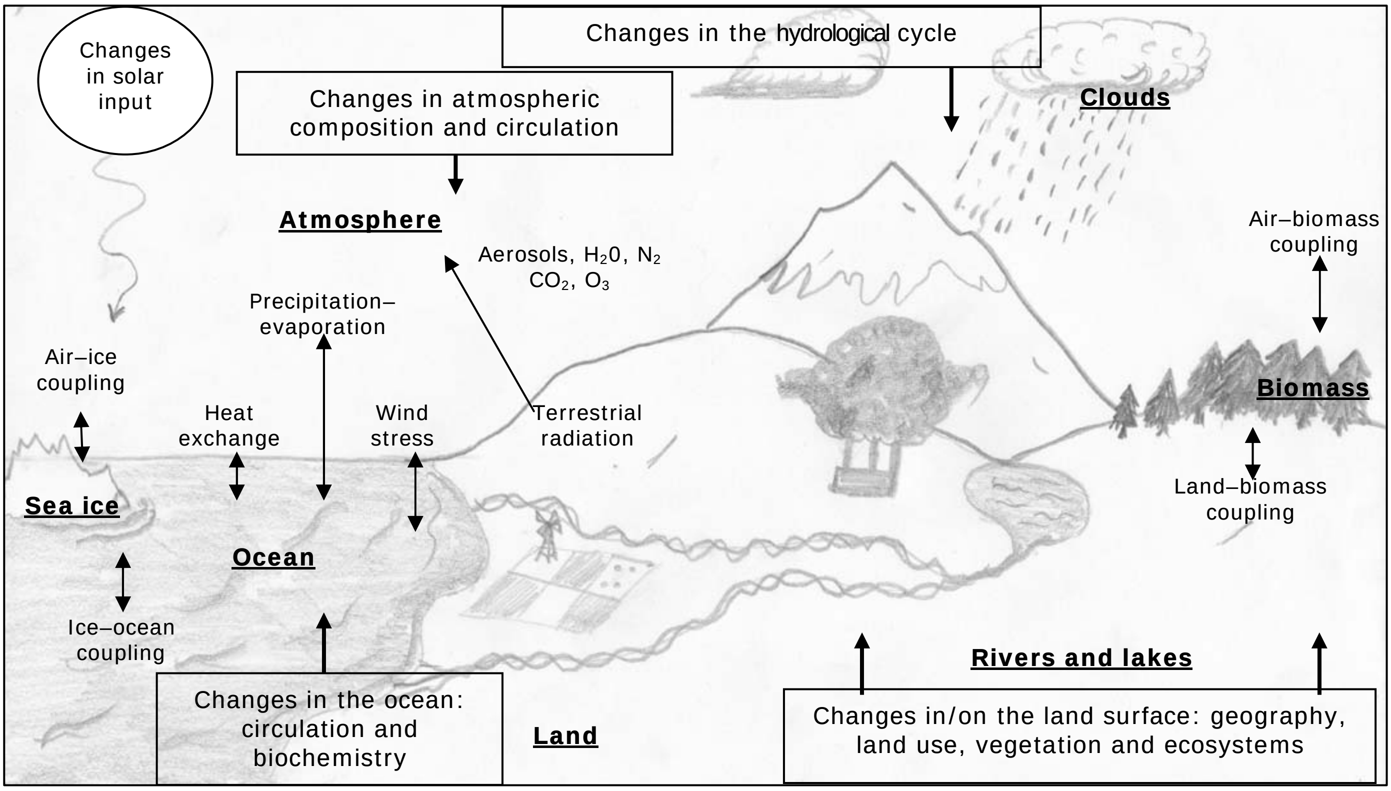

Figure B.2 A schematic view of many of the processes and interactions in the global climate system (based on Figure 1.1 of the 1995 IPCC Science Assessment (Houghton et al 1995)).

B3 Climate change scenarios for New Zealand

Predicting human-induced (anthropogenic) changes in climate over the next 100 years for a particular part of New Zealand requires:

- a prediction of global greenhouse gas and aerosol emissions for the next century;
- a global carbon cycle model to convert these emissions into changes in CO_2 concentrations (and similar models for calculating concentrations of other greenhouse gases and aerosols);
- A coupled AOGCM which uses the greenhouse gas and aerosol concentration information to predict future climate variations;
- downscaling of the AOGCM results through a procedure which takes account of the influence of New Zealand's topography on local climate. This can be done either statistically or with a high resolution regional climate model.

Given our current knowledge and modelling technology, each of these steps contains uncertainties. For example, emission predictions depend on the difficult task of predicting human behaviour, including predicting future greenhouse gas emissions. Our understanding of the carbon cycle, and of sources and sinks of non-carbon dioxide greenhouse gases, is still incomplete. Significant uncertainties also exist in current global climate model predictions, particularly at the regional level.

The climate change scenario approach recognises these uncertainties. A scenario is a scientifically–based projection of one plausible future climate for a region. For guidance on regional impacts of climate change, a range of scenarios is desirable. These can span credible estimates of future greenhouse gas emissions, and the uncertainty range in climate model predictions.

The IPCC developed 35 different emissions scenarios in its SRES (Nakicenovic & Swart 2000). These SRES scenarios cover a range of demographic, societal, economic and technical change 'storylines', and formed the basis for much of the climate projection work done for the IPCC's assessment reports. The SRES scenarios do not include specific initiatives to control greenhouse gas emissions, such as the Kyoto Protocol, but some of them (e.g. the B1 scenario) include the introduction of clean and resource-efficient technologies. Full AOGCMS were run for only some of these scenarios. A simpler globally-averaged model was then 'tuned' to these AOGCM runs and applied to all 35 SRES scenarios. The IPCC does not contend that any one SRES scenario is more likely than any other – it is as if they have provided a dice for predicting future conditions with 35 equally weighted sides.

Figure B3 (from the IPCC TAR (Houghton et al. 2001)) illustrates this approach.

- (a) shows the CO_2 emissions for six illustrative SRES scenarios along with the IS92a 'mid-range' scenario used in the Second Assessment Report.
- (b) shows projected CO_2 concentrations corresponding to these emissions.
- (c) shows projected anthropogenic sulphur dioxide emissions. The SRES also includes projections for other greenhouse gases and aerosols.
- (d) and (e) are the projected temperatures and sea levels resulting from the emission scenarios.

Figures (d) and (e) illustrate that even for a single emissions scenario, a range of temperature projections are possible, reflecting differences between climate models. Note that the real changes in global average temperature over the next century will not be as smooth as in this figure – irregular fluctuations caused by natural oscillations in the ocean–atmosphere system, volcanic eruptions and changes in solar activity will be superimposed.

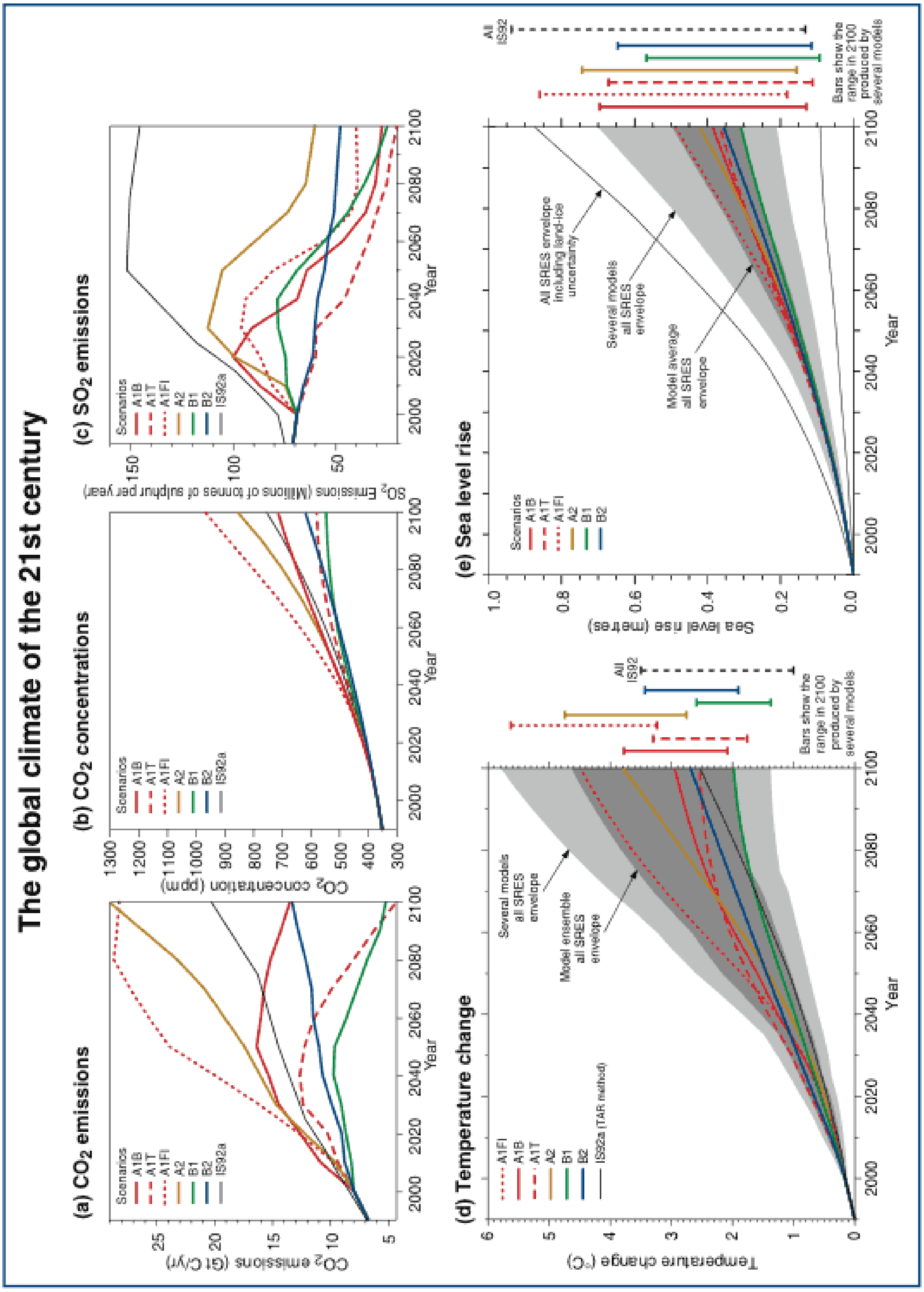

Figure B3 Global climate scenarios for the 21st century (from Figure 5 of the WGI Summary for Policymakers of the IPCC's TAR (Houghton et al. 2001).

B4 Downscaling to New Zealand

The global climate models predict trends in broad climate patterns across the Pacific, but do not take account of the effect of New Zealand's topography on the local climate. Approaches which can be taken to infer local changes corresponding to a particular global model simulation include:

- nesting a higher resolution regional climate model covering New Zealand and its surroundings within the global model simulations, and
- using statistical techniques based on present relationships between regional-scale climate patterns and local climate.

Most of the scenarios which have been used so far for assessing the likely impacts of climate change on New Zealand have used statistical downscaling. However, scientists are now evaluating the initial regional climate modelling results from a system implemented at NIWA using the UK Meteorological Office's unified climate model, with a view to using this to develop new scenarios.

Statistical downscaling starts with historical observations, and calculates 'downscaling relationships' between broad regional climate patterns and local climate observations. The downscaling relationships are then applied to the broad future regional climate patterns predicted by the global models, in order to provide more locally-detailed projections for New Zealand (e.g. Mullan et al. 2001). For the New Zealand scenarios used for Chapter 3, we undertook statistical downscaling for two periods: the 20-year period centred around 2040 (2030–2049) and the 20-year period centred around 2090 (2080–2099).

We undertook statistical downscaling from twelve different AOGCMs for each of the future periods for a mid-range greenhouse gases emission scenario (A1B – see Figure B3). Scaling factors based on the global average temperature projections shown in Figure B3 (d) can be used to assess the consequences of other emission scenarios.

Appendix C Questionnaire process and outcomes

C1 Questionnaire overview

C1.1 Scope and objective of the questionnaire

Part of the Stage One literature review and gap analysis involved a survey of central government agencies, infrastructure operators and research institutions to seek an overview of the current state of knowledge about the potential effects of climate change on ports, coastal shipping, road and rail networks in New Zealand. We also hoped to collect details about climate change issues, research, adaptation responses and perceived barriers that relate to how land transport networks are planned, designed, operated and maintained in response to direct climate change effects.

C1.2 Methodology

A draft questionnaire was peer-reviewed by an independent research specialist. The draft questionnaire was tested in three face-to-face surveys with stakeholder organisations. Their responses were recorded and analysed in our review of results. Once finalised, the questionnaires were distributed to 70 organisations and agencies associated either with climate change effects research, or operating ports, road, rail and coastal shipping networks. Follow-up phone calls were made before the due completion date of the questionnaire to encourage organisations to respond.

C1.3 Response rate and potential bias

Responses were received from 29 organisations, a response rate of 41%.

Six organisations' responses to the questionnaire related to the effects of transport greenhouse gas emissions as an anthropogenic cause of climate change. Respondents referred to carbon footprint calculation initiatives, emissions reductions, sustainable transport initiatives to reduce congestion, considerations about biofuels and emissions trading implications for their business. One respondent identified difficulties and constraints limiting the ability of the transport sector to meet biofuel targets owing to the availability of biofuel alternatives and the potential cost of conversion. A further constraint was identified as being the ability of the transportation sector to cope with increased patronage, given the investment timeframes for new rolling stock and the rail network limitations.

One organisation referred to the effects of climate change on land use and the consequent effects of changes in demand on transport systems. The response related to the importance of the land transport network in the supply chain for high value exports, and the ability of the transport system to adapt to changing regional patterns of horticulture and expanding demand for transport services. The greenhouse gas emission profile of transport systems was noted as a major contributor to the overall carbon footprint of New Zealand goods.

The responses from the remaining 22 organisations are analysed in the following sections. It should be noted that the responses received may be biased towards those organisations that are aware of and those that may have made preparations for the effects of climate change on land transport networks.

C2 Question 1: Please indicate the nature of your organisation

Figure C.1 illustrates the groups of organisations and how many questionnaire responses were received from each.

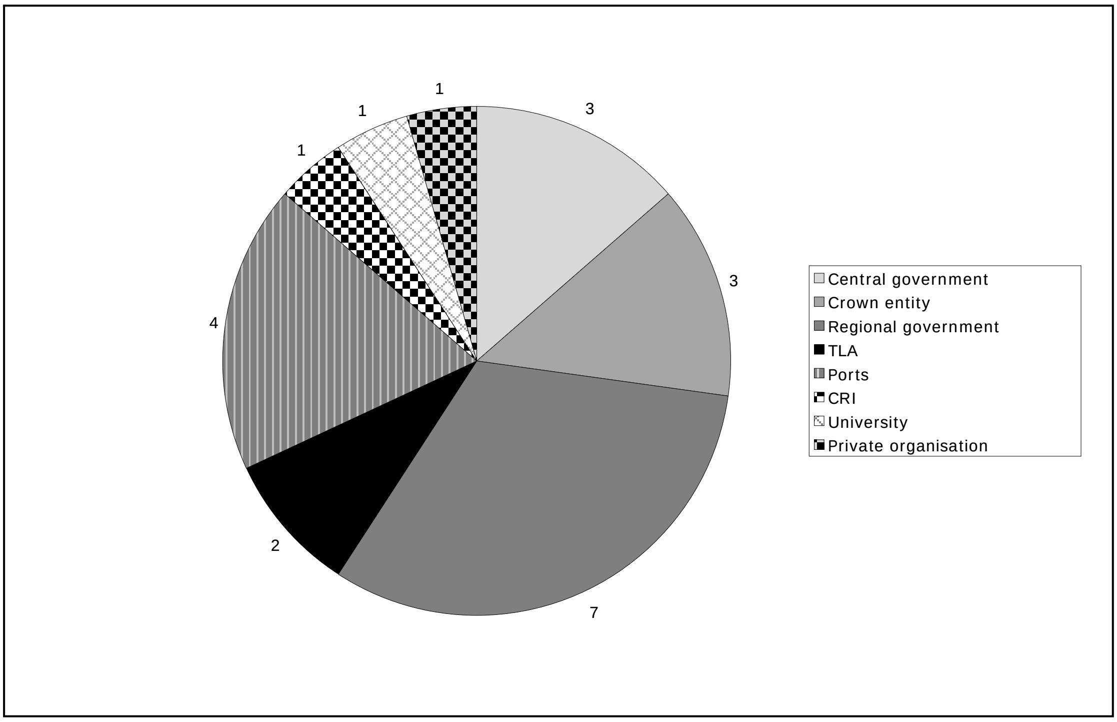

Figure C.1 Survey respondents by groups.

Regional council perspectives on the effects of climate change on land transport were well represented. Seven out of 13 regional councils and regional transport agencies invited to participate in the survey provided a response. We received 4 responses from 15 invitations to port operators around New Zealand.

Three out of four crown entities made a response to the survey: Land Transport NZ and Transit New Zealand (now combined to form the NZTA), and Maritime New Zealand. No formal questionnaire response was received from ONTRACK. Informal comments and technical guidance were received from ONTRACK and have been put into technical sections of the Stage One report.

MfE, MoT and the Ministry of Civil Defence provided a response to the questionnaire. No response was received from Treasury, the Ministry for Economic Development (MED) and the Ministry for Research, Science and Technology (MRST).

Nine local government bodies were invited to submit a response to the questionnaire. Two responses were received. Responses from Landcare and the University of Victoria represented research organisations involved in the study of the effects of climate change. A response from a road contractor provided a transportation industry-support perspective.

C3 Question 3: Has your organisation made any preparations?

C3.1 General comments

The full text of Question 3 was 'Has your organisation made any preparations for the effects of climate change on land transport networks? Please describe any responses in terms of policy, planning, decision making criteria, design, funding, operation, management or monitoring of transport assets (road, rail, ports and coastal shipping).'

Figure C.2 shows that over half of the groups surveyed are preparing land transport networks for the effects of climate change.

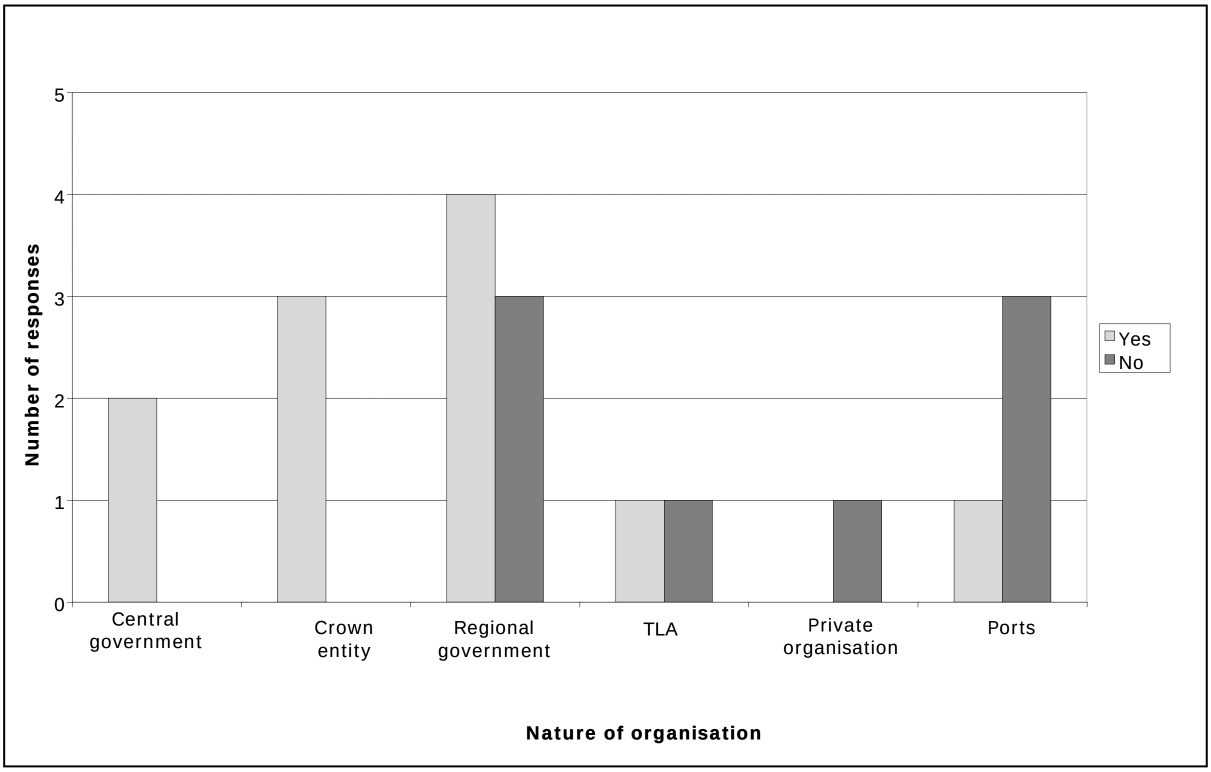

Figure C.2 Organisations' indication of preparations for the effects of climate change on land transport networks.

C3.2 Central government

While one central government organisation stated that they were just beginning to think about the response needed for the effects of climate change on land transport networks, a number have undertaken more comprehensive work on responding to the effects of climate change.

One central government organisation has considered the possible impacts on the scale and scope of emergencies that could arise as a result of climate change. It was noted that this, however, has primarily been focused on the frequency and severity of impacts, and not on the adaptation to possible impacts.

One respondent noted the main focus of their organisation on the mitigation of the effects of land transport networks on climate change, such as reducing greenhouse gas emissions via biofuels, vehicle technology, road pricing, and modal shift towards public transport, rail and shipping. It was noted that few adaptation initiatives had been undertaken in part because it is unclear how adaptation can be influenced from an agency working from a policy perspective rather than an operational agency that is involved in building infrastructure.

Several central government organisations noted that they had been involved in preparing documents to provide guidance on dealing with the effects of climate change. MfE has developed a climate change adaptation programme as part of New Zealand's whole-of-government climate change policy work programme. The Interdepartmental Group for Climate Change Adaptation (ICCA) has been established (one transport agency indicated it is a member of ICCA). Guidance manuals for local and central government have been prepared to help identify and quantify opportunities and hazards which climate change poses for their functions, responsibilities and infrastructure. A manual is available to help local authorities manage coastal hazards. *Flow Box* and *Flow Plan* are currently being prepared to assess the impacts of climate change on flooding in urban areas. Work has also been done on providing flood risk management advice for engineers, lifelines, insurers, local government, regional government and surveyors.

C3.3 Crown entities

The representatives from crown entities stated that their organisations had undertaken an assessment of the impacts of climate change on the roles and responsibilities of their organisation. The Maritime Authority referred to an assessment of the potential impacts of climate change on the maritime industry and environment followed by workshops on how these changes will affect the Maritime Authority's roles and responsibilities. This information has helped form a set of recommendations for future planning and project considerations, and become part of the overall strategic planning process for the organisation.

Transit New Zealand reviewed the direct effects of climate change, such as sea level rise and changing rainfall patterns, on the state highway network. The review identified the need for site-specific responses to climate change impacts and alternative remedial actions, in some cases, to mitigate potential climate change impacts. Transit recognised that it would be prudent to consider climate change in the design of all major long-life new infrastructure such as bridges and culverts that could be affected by climate change, particularly where provision for future retrofitting is not feasible or cost-effective. Transit subsequently amended its Bridge Manual (Transit 2003) to include climate change impacts as a design factor for consideration on a case-by-case basis.

The third crown entity stated that global warming was one of the many issues to be considered by the sector in identifying potential research proposals.

C3.4 Regional government

Two of the regional government organisations responded that they were in the process of investigating the effects of climate change for their areas or transport infrastructure specifically. One regional council incorporates climate change scenarios into regional planning documents and processes such as plan and strategy reviews, relevant consents, and river and flood management.

One respondent noted that they are in the process of developing a multi-party response to climate change for their area.

Three regional authorities noted no preparation for the effects of climate change for land transport networks, especially in documents such as the regional land transport strategy. One regional authority noted a high level investigation into the need to take account of climate change effects in regional planning documents.

C3.5 Territorial Local Authorities (TLAs)

One TLA noted that minor improvements had been made to seawalls during the process of routine renewals. Another TLA noted that no preparations for climate change are in place.

C3.6 Ports

One port indicated that the design height of a breakwater and the wharf deck level of a new berth were increased to take account of increased sea levels as a result of climate change. Another port indicated that most of their infrastructure is current and they will react to climate change effects when changes happen. This organisation also does some monitoring but note they do not have satisfactory information on which to base their monitoring assessment.

C3.7 Private organisations

One organisation noted that in terms of maintenance or upgrade projects (design and build), climate change issues do not have to be considered, unless this forms part of a consent application (the Assessment of Environmental Effects). Key clients do not require contractors to take the effects of climate change on transport infrastructure into account in their work.

C4 Question 4: Please comment on existing or proposed changes

C4.1 Full text

The full text of Question 4 was ‘Please comment on the existing or proposed adaptive changes (e.g. cost implications, implementation, difficulties, expected effectiveness etc.).’

C4.2 Central government

The Ministry of Civil Defence and Emergency Management expect their services to be required more frequently, so therefore they expect to experience increased costs associated with response and recovery in the community as a result of the impacts of climate change.

C4.3 Crown entities

The Maritime Authority stated that they were considering changes in accidents and incidents that will require emergency response, investigation and/or some kind of compliance action, and considering how training and publicity programmes may need to be adapted to mitigate the risks to vessel operations. They are also considering climate-specific impacts on the organisation and staffing into business continuity planning and succession planning, and are undertaking a review of the types of communication equipment installed in remote locations to ensure that they will be effective and robust under predicted changed weather patterns. The respondent noted that by building these considerations into the strategic planning process, additional costs will be met gradually over time.

Transit noted that an ongoing issue is the extent to which some decision makers and technical experts challenge the appropriateness of proposed adaptive changes, on the basis that current emergency events/hazard management practices consider climate change effects adequately. It can be a challenge for some people to accept that climate change effects cannot be predicted by referring to historical events. This organisation also has concerns about the reliability of data on climate change effects, which can limit the extent to which adaptive changes are incorporated into detailed design.

LTNZ stated that climate change will have some implications but these have yet to be quantified, hence the need for research.

C4.4 Regional government

One regional government organisation believed that the focus on adaptation to climate change effects is likely to be very low while the focus of mitigating the effects of greenhouse gas emissions is likely to be significant. Another regional government organisation noted that they are currently working with NIWA on a number of projects to address the issue of adaptive changes.

One regional council noted that while climate change effects for the region are not the only driver for one of their major roading projects, the project will have huge cost implications for their region, but will have benefits in terms of resiliency if other routes are affected by increased natural coastal hazards as a result of climate change. Another regional government organisation noted that current policy addresses maintenance of networks and the risk of natural hazards, but this is not specific to climate change. Changes are made as part of normal maintenance with consideration of the increased effects of climate change.

C4.5 TLAs

One TLA noted that improvements to date had been minor and no substantial future adaptations are planned.

C4.6 Ports and private organisations

Ports and private organisations emphasised the cost implications of responding to the effects of climate change. The cost implications include construction costs with regard to building breakwaters, and supply and placement of hydrocarbon based products such as bitumen for road surfaces. One port noted the potential for horrendous adaptation costs if climate change effects caused major implications, e.g. a 1.5–2 m increase in sea level. One respondent noted that transport infrastructure providers were not recognising the need to future-proof assets and were not making allowance for the costs of adaptation.

C5 Question 5 (part 1): Is your organisation co-ordinating with other organisations?

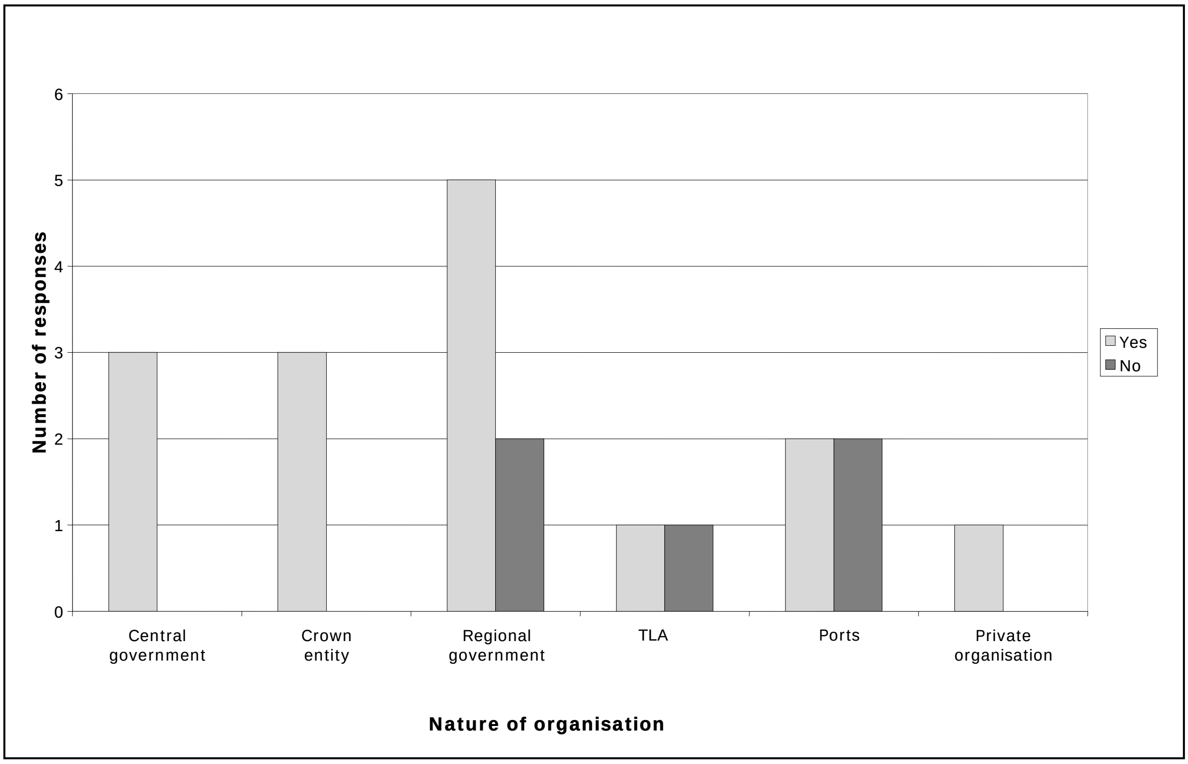

Figure C.3 Co-ordination across organisations to address the effects of climate change on the land transport network.

Of the 22 responses received, 15 (68%) said that their organisation is co-ordinating with other organisations (Figure C.3). All of the central government and crown entity organisations that responded to the survey stated that their organisation was co-ordinating with other organisations. Seven (23.33%) respondents said that their organisation was not co-ordinating with other organisations. A mixed response was received from regional government, TLA, private and ‘other’ organisations, with a number of organisations co-ordinating with other organisations and a number not doing so.

C6 Question 5 (part 2): Please describe any collaboration

C6.1 Central government

One of the central government organisations stated that they collaborate with TLAs to factor potential climate change impacts into readiness and response plans. MfE referred to the establishment of the ICCA joint working group, which has representatives from various agencies. One transport agency noted their action in the group has been limited so far because the organisation's role is somewhat unclear. A further central government organisation is collaborating with the Ministry for Agriculture and Forestry (MAF) to engage key sectors through an adaptation technical group. This organisation also stated that they have been working with a number of other organisations; the nature of this collaboration was not outlined, however.

Another central government organisation has been working with MAF to engage key sectors through an adaptation technical group. They are also working with MRST, FRST and the Ministry of Health. For example, work is being done with engineers who have been asked 'What would you need to do to consider impacts of climate change, in your advice?' IPENZ workshops were held on the science and worked examples, and aimed to have engineers imbed climate change into design.

MfE noted that it is focusing on how to present a high-level approach to adaptation to all of New Zealand and engage with those sectors not already engaged. They have the aim of understanding and assisting with adapting to climate change through sector-based visions, using, for example, a flexible, user control-based website. The focus would be on coping with the physical impacts and opportunities of climate change.

Sectors could include:

- civil defence,
- engineers,
- local government,
- business,
- lifelines utilities,
- non-governmental organisations,
- education/training,
- health,
- conservation,
- fisheries.

C6.2 Crown entities

One crown entity described a good working relationship with several organisations. They believe these relationships are important to ensure that timely and accurate data to inform decisions on adaptation are available, and to ensure that climate information and research are closely aligned with end-user requirements. This organisation is also considering greater collaboration with regional councils on catchment management, and considers that ongoing inter-agency collaboration is critical to the improved understanding and management of climate change effects. As such, they are very willing to participate in future collaborations.

Another crown entity noted that they had been collaborating to prioritise research for the transport sector.

C6.3 Regional government

Regional government representatives identified various forms of collaboration including co-ordinating the actions of organisations and agencies, and discussing climate change issues with local authorities and the NZTA.

Other regional government organisations simply listed the organisations they have collaborated with. These included MAF, MfE, NIWA, local authorities, research bodies, the Ministry of Economic Development, the NZTA and MoT.

One regional government organisation stated that they had established a Regional Climate Change Working Group involving staff from TLAs, central government departments and key stakeholders.

C6.4 TLAs

One TLA noted that they were in collaboration with a regional authority in provision and funding of public transport.

C6.5 Private organisations

One private organisation is working with Roading NZ to advocate issues to clients.

C6.6 Ports

One port company runs an Environmental Consultative Committee of stakeholders and consults with the local authority regarding road planning issues. Another port company works in collaboration with their regional authority in regards to the effects of climate change on the port.

C7 Question 6: Please describe the climate change effects

C7.1 General comments

The full text of Question 6 was 'Please describe the climate change effects identified by your organisation as an issue for land transport networks and describe what parts are affected (e.g. locations, assets, operational or maintenance activities).'

Some respondents described areas of road, rail and port/coastal shipping networks at risk of effects of climate change, particularly sea level rise, storm surge and heavy rainfall, and the consequences of these for coastal erosion, inland slips and flooding. Other organisations described climate change effects that were relevant to transport networks. One organisation indicated knowledge about potential climate change effects for their area was limited.

C7.2 Central government

A central government organisation stated that they expect transport networks to be disrupted more frequently by weather-related events such as flooding and slips that require increased effort in reinstating the network and repair. However, the costs associated with this would fall on the NZTA and TLAs.

Another central government organisation noted that people are generally aware of the effects of climate change on the transport network (e.g. additional risks in relation to flooding, sea level rise, severe weather events, etc.). One organisation has identified the following as possible effects of climate change on the land transport network:

- closures caused by flooding (rivers or tidal),
- damage by flooding,
- landslides, creeping damage to bridges and structures,
- higher tides and flood levels,
- possible effects from higher/lower/more variable water tables, and
- rerouting corridors.

The effect of climate change on coastal shipping was identified by a central government organisation. This includes the effects on ports (e.g. ships may have to stay off the coast during stormy weather) and sediment delivery to the coast.

In terms of the rail network, spray from seas and the effects on transmission lines and erosion were identified by a central government organisation as being exacerbated by the effects of climate change.

C7.3 Crown entities

One crown entity described six climate change effects identified by their organisation. Those described with a direct impact on transport infrastructure are:

- the potential for increased storm severity and incidence of severe weather events;
- a combination of sea level increase and storms leading to increased coastal erosion and potential for impacts to navigation aids and port infrastructure;
- heavy rainfall events increasing the likelihood of flooding and loss of land infrastructure (relevant for business continuity) as well as potential for changes to river bars and port access.

Indirect effects described included impacts on fish stocks and increased duration of fishing times for fishing vessels, and socio-economic changes in developing countries, which may affect availability of qualified seafarers and increased stress on marine ecosystems.

A detailed description of the potential impacts of climate change on the state highway network is included in Kinsella & McGuire (2005).

C7.4 Regional government

Regional government organisations identified an increase in landslides, particularly in coastal locations. Indirect effects of climate change on transport systems were also noted, such as potential changes in quantum, nature and timing of freight travel demand as agriculture industry adapts to changes in climate, e.g. a decline in dairying and an increase in cropping.

Further effects identified include an increased likelihood of climate variability and climate change resulting in sea level rise, inundation of low-lying infrastructure, accelerated aging of built structures, disruption caused by extreme events e.g. localised flooding, storm surge, storms, rockfall (and susceptibility to this), and rising sea levels and severity of storms affecting strategic links and infrastructure, including state highway bridges.

One regional government organisation stated that identifying the effects of climate change on land transport networks, was too detailed for them, and noted that the NZTA and TLAs would have identified the impacts.

C7.5 TLAs

One TLA stated that they have limited knowledge on the detailed effect of climate change on their networks, while another stated that the effects would be on access, maintenance and flood damage costs.

C7.6 Universities and CRIs

A university representative noted that the role of the university is focused on helping infrastructure providers. Therefore, coastlines, road susceptibility to landslips, flooding, ports affected by storms, storminess, sea level rise and rivers releasing into ports were considered as issues for land transport networks. The impacts of increased frequency of heavy rainfall and overtopping were identified by a CRI.

C7.7 Ports

Ports identified increased sea levels relative to the wharf and breakwater structures as being the main effect of climate change on ports and coastal shipping. One port identified the potential benefit of increased sea level on reduced maintenance costs from reduced dredging to maintain sufficient under-keel draft.

C8 Question 7: information sources

C8.1 Full text

The full text of Question 7 was 'What information sources/other organisations does your organisation use to assess climate change effects on land transport networks?'

C8.2 Central government

One central government organisation stated that they use sources such as IPCC reports to keep informed. Other sources of information that were mentioned by central government organisations were Geological Nuclear Sciences (GNS), NIWA, Met Service and MfE.

C8.3 Crown entities

Crown entities identified IPCC, MfE, the Australian Climate Change Office, the internet and scientific journals as sources of information. It was noted that for site-specific case studies for individual projects, NIWA meteorological datasets are used.

One crown entity stated that national consistency in assessing climate change effects is limited. This issue has been raised by Transit in recent submissions on the proposed New Zealand Standard for Flood Hazard Risk Management and the proposed New Zealand Coastal Policy Statement 2008.

C8.4 Regional government

Regional government organisations identified a number of information sources including the Regional Land Transport Committee, central government, CRIs such as NIWA, reports from consent applications, coastal consultant reports, published information, councils and reports and data on the internet.

One regional government noted that they are eagerly awaiting the results of several FRST research programmes to identify risk profiles for all types of infrastructure including built, ecological and community.

C8.5 TLAs

TLAs stated that they use media reports, MfE guidelines and occasional technical reports as information sources.

C8.6 CRIs and universities

One CRI stated that they use council data relating to asset operations and repairs, while another noted that climate change effects are not something they explicitly assessed.

A representative from a university responded by stating that they source climate-related information from global and national sources. NIWA are the source for local information. Statistics NZ provide census data, LINZ databases provide the physical context. They note that the quality of information is good.

C8.7 Ports

The port companies noted that conferences, seminars, NIWA and the New Zealand Business Council for Sustainable Development updates were their source of information for assessing the effects of climate change. Regional councils, MfE and IPENZ were also sources of information.

C9 Question 8: gaps in knowledge

C9.1 Overview

The full text of this question was 'Has your organisation identified any gaps in knowledge about the effects of climate change on land transport networks? If yes, please list the top three in order of priority.'

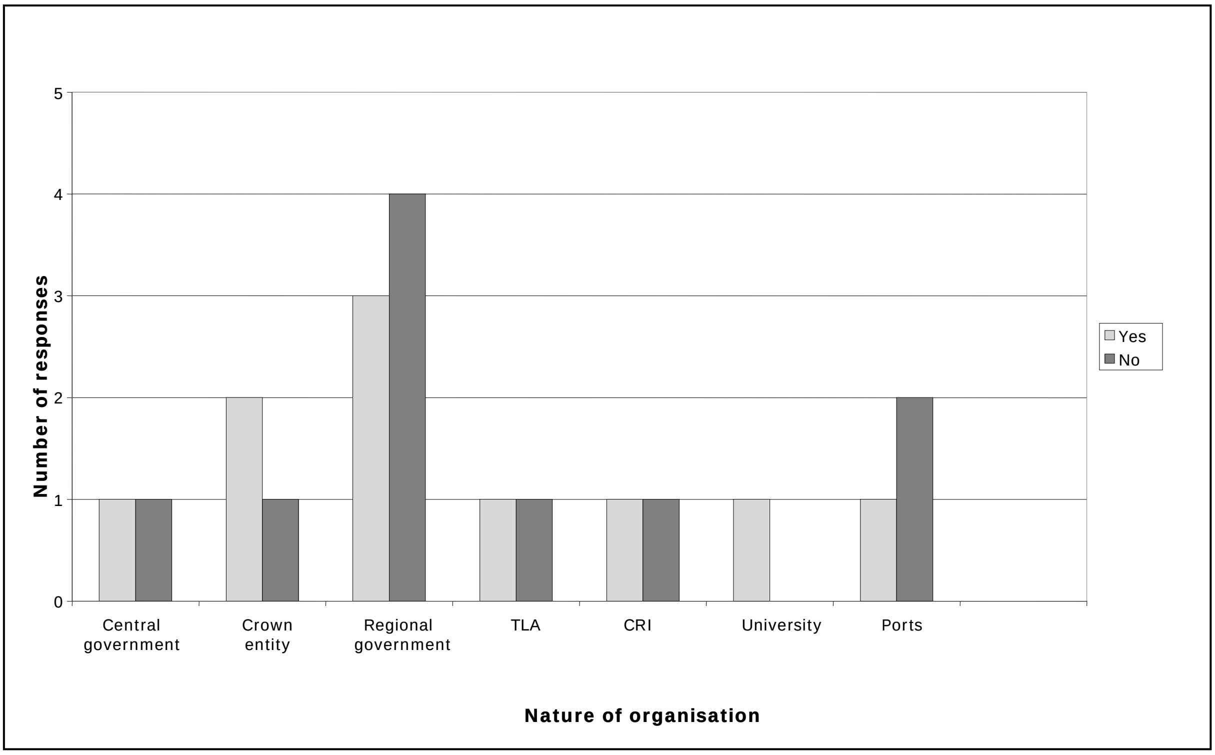

Figure C.4 Stakeholder groups' perception of gaps in knowledge about the effects of climate change on land transport networks.

Of the 22 responses received, 10 (45%) stated that their organisation had identified gaps in knowledge about the effects of climate change on land transport networks (Figure C.4).

C9.2 Central government

Within central government, one organisation stated that it is unclear where the effects will actually happen or be more severe (where, what type of infrastructure, how to respond), although they are generally aware that some areas will be affected more than others. Other central government organisations identified the following as gaps in knowledge about the effects of climate change on land transport networks:

- Where and how important are the existing problems?
- What level of incremental change can be expected?
- What provision is needed for step change (as opposed to incremental response) on a funding or decision basis?

C9.3 Crown entities

The following are gaps identified by crown entities about the impacts of climate change on land transport networks:

- general uncertainty about the exact nature, scale and timing of impacts;
- inability to predict the nature and timing of localised climate change effects accurately; and
- differing levels of knowledge/understanding about climate change effects among decision makers and technical experts, which creates potential for localised/regional inconsistencies in addressing these effects.

C9.4 Regional government

Key information gaps identified by regional councils were:

- local implications of climate change effects for regions,
- lack of leadership from government agencies about the level of risk to plan for, and
- the time horizons for which decisions should be made

One council noted the danger of duplicating effort, and inconsistencies in the approaches being adopted by different regions and agencies.

C9.5 TLAs

One TLA noted that they are at a very early stage of knowledge and not yet in a position to identify or prioritise knowledge gaps in detail.

C9.6 CRIs and universities

The knowledge gaps identified by CRIs about the impacts of climate change on land transport systems include:

- quantification of the impacts of heavy rainfall and possibly other climatic phenomena (e.g. extended dry periods) on road repair costs in New Zealand;
- quantification of land slips/instability costs to land transport infrastructure, and
- assessment and possibly quantification of impacts on ports and coastal roads from sea level rise.

The knowledge gaps identified by universities about the impacts of climate change on land transport systems include:

- The quality of socio-economic analysis is not good.
- The implications of changing hazard risks are not readily available - GIS should be made available.
- The extent of climate change effects in future is not well known, and neither is the frequency of events. New climate change scenarios are due from NIWA. The shape of the distribution curve may change, not just the frequency or magnitude. The character of the distribution is critical for preparing for flooding events. The frequency of heatwaves is reasonably well known, but precipitation patterns are less well known.
- The demand for transport is driven by demand and energy issues. How will an emissions trading scheme play out?
- What about people's use of public transport – will they wait for electric vehicles?
- Climate change effects could have an enormous effect on personal transport and freight.
- The cost of energy and social behaviour are two big determinants. Social psychology and changing thinking in organisations and communities also play a role.

C9.7 Ports and private organisations.

Ports sought more information to fill gaps in knowledge about sea level rise and changes in wind. Identifying when to raise the need to future proof projects was an information gap from a contracting industry perspective.

C10 Question 9: what organisations are doing about knowledge gaps

C10.1 Full text

The full text of Question 9 was ‘If applicable, please provide a summary of what your organisation is doing about the identified gaps in knowledge.’

C10.2 Central government

One central government organisation responded to Question 9 stating that so far they have had no work programme.

C10.3 Crown entities

One crown entity organisation stated that they are keeping abreast of updated scientific information, particularly reports from IPCC. Another crown entity organisation acknowledged that they need to do more work in this area. Currently, they are developing collaborative relationships with regional councils to jointly understand the cumulative effects of state highways on ecosystems. They hope to extend this to climate change issues. This organisation has also recently advocated for nationally consistent guidance on managing climate change effects.

C10.4 Regional government

A regional government body noted that they are beginning to scope out future investigations and have undertaken preliminary assessments. Another body mentioned that they were beginning to initiate a process in council to raise awareness of effects, from which actions will be identified. Another regional council is undertaking an infrastructure stocktake. Another council indicated they are collaborating with FRST research providers.

C10.5 TLAs

One TLA stated that they have established a Climate Change Office to co-ordinate the organisation’s efforts in this area.

C10.6 CRI and universities

One CRI noted that they are attempting to develop statistical relationships between climate variables, especially rainfall, road repairs and landslip incidence. However, limited and inappropriate data are a very significant barrier.

The university that responded to the questionnaire is trying to bring the policy debate out into the open, so as to encourage broader thinking, particularly for energy supply technologies. They prompt people to consider whether the RMA is a useful tool and consider how people will react to policy, and how to make it effective. The university marshals its resources to do background research, for example about social behaviour, and what motivates people to create effective change and conduct tertiary research.

C10.7 Private organisation

One private organisation stated that they have undertaken a carbon footprint and sustainability review of their operations with a view to improving their understanding and knowledge in this area.

Another private organisation believed that this was not applicable to them because until something definitive and scientific is available, they can only keep it at the back of their minds.

C11 Question 10: research on the implications of climate change

The full text of Question 10 was ‘Has your organisation commissioned or done any research on the likely implications of climate change on road, rail, ports and coastal shipping, excluding anything you’ve already mentioned in earlier questions?’

No organisations indicated they have commissioned or conducted research themselves about the likely implication of climate change on road, rail, ports and coastal shipping. A crown entity referred to two research papers which are mentioned in the literature review. These were:

- *Impacts of Climate Variability and Change on Transportation Systems and Infrastructure – Gulf Coast Case Study* (CCSP 2008)
- *Vulnerability of Road Systems to Climate Changes – Analysis of Impacts Made in the United Kingdom*. (Richards 2007).

C12 Question 11: timeframes

C12.1 Full text

The full text of Question 11 was ‘What timeframes are your organisation using for planning, decision making, design or research in relation to the effects of climate change on land transport networks (e.g. risk assessment scenarios for 50- and 100-year horizons and/or greater conveyance or strength requirements for infrastructure of >50 year design life to account for climate change effects)?’

C12.2 Central government

One central government organisation stated that their planning timeframes are approximately ten years, although the timeframe for criteria used in providing guidance for detailed planning is longer. Likewise, a central government organisation commented that some councils are thinking strategically because of the price of fuel and looming peak oil, and trying to build that thinking into LTCCPs (ten-year period) and strategic level documents (50–100 years).

One central government organisation noted that in adaptation work, the timeframe goes out to 2040/50. Another central government organisation noted that return periods are considered in terms of 1 in 100 years and stopbanks are designed to 1 in 400-year standards. With regard to local government, this organisation is pushing for thinking beyond the three-year timeframe.

C12.3 Crown entities

Impacts are considered up to 50 years in advance for one crown entity, while strategic planning framework operates over several timeframes, up to five years ahead.

One crown entity stated that large culverts and bridges are designed to a 50- to 100-year life. Highways without large structures are designed from between 10–40 years and thus can be managed on a shorter timeframe. For large structures, the most critical element is the approach and associated roading elevations, which cost as much and frequently have greater restraints.

The third crown entity noted that currently activities are required to consider a 25-year evaluation period but infrastructure, especially bridges, are built to a longer life expectation, and have ongoing service provision through periodic maintenance and renewal.

C12.4 Regional government

Only one regional government organisation specified timeframes in relation to the effects of climate change on land transport networks. These timeframes range from 10–90 years. One council indicated they hoped to be able to outline appropriate timeframes for the effects of climate change and land transport network preparations as a result of work currently underway.

One regional government organisation stated that they do not do any long-term analysis beyond the LTCCP horizon, i.e. ten years. Three other regional government organisations noted that they are not taking account of climate change effects in particular timeframes.

C12.5 TLAs

The TLAs stated that timeframes to consider climate change effects should relate to the life of infrastructure. One TLA noted that the timeframe for transport network planning is 30 years.

C12.6 CRIs and universities.

One research institute recommends consideration of effects up to the 2030s to facilitate linkages to medium-term planning processes (e.g. LTCCP) but recognises that 50–100 year timeframes are more relevant in some cases.

The university representative stated that timeframes should start at 30 years to take account of known technology. Up to 100 years is when they imagine new technology could be feasible, as per timeframes recommended by the IPCC. It was noted that the university needs to spend time on near-time issues. This near timeframe is relevant to national market development and freight movements. No timeframes have been set beyond 100 years. Not much work is being done about national market development, trade models and climate change factors.

C12.7 Ports

Port operators indicated that climate change effects can be factored into the life of new infrastructure design, as port infrastructure generally has a lifetime of between 50 and 100 years.

C13 Question 12: Does your organisation perceive any barriers?

The full text of Question 12 was 'Does your organisation perceive any barriers in addressing the adverse impacts of climate change on land transport networks?'

Of the 20 responses to this question, 19 organisations indicated they have identified barriers to addressing the adverse impacts of climate change on land transport networks (Figure C5). One respondent from regional government did not perceive any barriers in addressing the adverse impacts of climate change on land transport networks. This respondent also believed that climate change will increase the risk of existing hazards, and should be addressed through asset maintenance and replacement programmes.

C14 Question 13: types of barriers

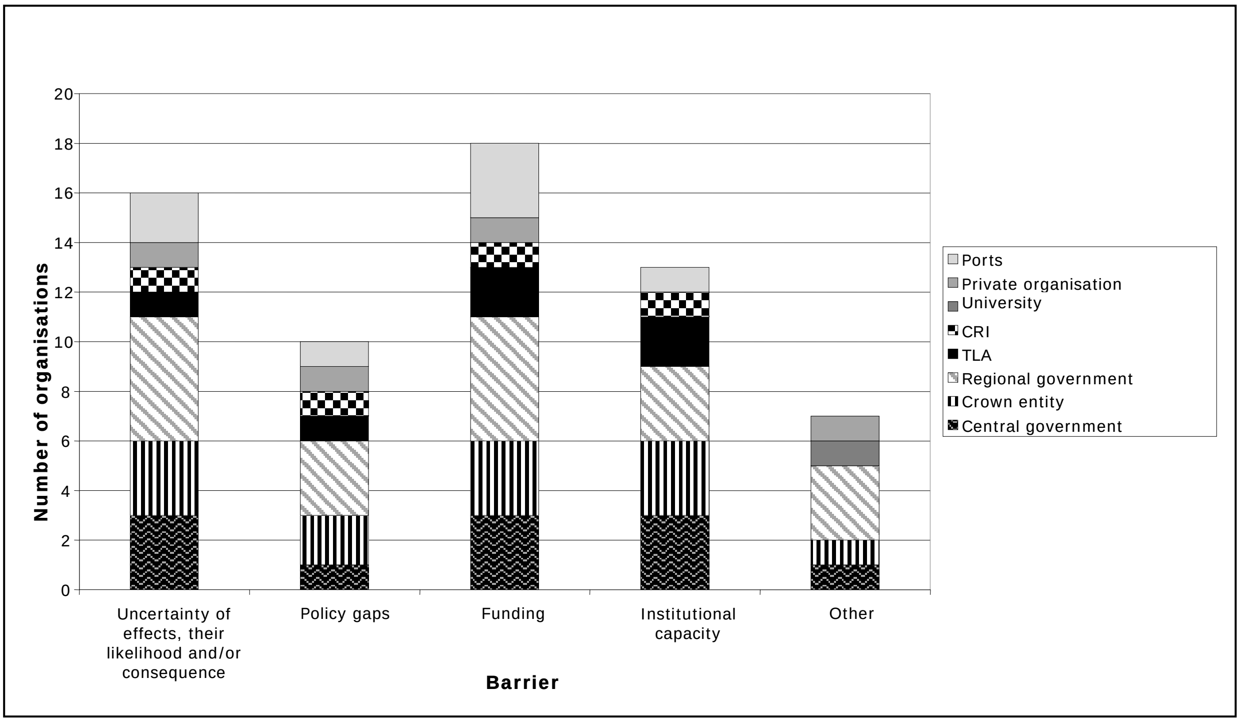

Figure C.5 Perceived barriers to addressing the adverse impacts of climate change on land transport networks.

Funding, the occurrence of climate change effects, and institutional capacity to prepare and respond to climate change were acknowledged by the most organisations as barriers to addressing the relevant effects. Other barriers identified are shown in Table C.1.

Table C.1 Barriers to addressing climate change effects identified by the organisations surveyed.

Organisation	Barrier identified
Central government	Complacency
Crown entities	Finding the balance between avoidance and adaptation, e.g. what kind of roads we will build for the vehicles of the future and how much effort should be spent trying to decrease greenhouse gas emissions; distinguishing between planning for hazard/emergency events and planning for climate change effects.
Regional government	No national and local leadership/drive; national issue.
Private organisation	Willingness of key clients to include in climate change effects in their decisions.

C15 Question 14: Details of barriers ticked in the previous question

C15.1 Central government

Adapting to the increasing risk will inevitably call for more investment by the owners and users of the networks. Some policy around how and if those costs are transferred will be needed. The public is complacent about the impact of climate change on transport networks, is judged as having little appetite for increased costs (from all aspects) and has low tolerance for disruptions caused by poor preparation.

One central government organisation stated that without knowing what role they could take in adaptation, its unclear whether policy gaps exist or if more funding is needed. The organisation noted that its institutional capacity is still relatively low, partly because of uncertainty about the organisation's role.

It was mentioned that uncertainty probably still exists regarding the effects (although at least in a general sense are aware of the effects). Another respondent noted ongoing uncertainty about the nature of the issue. Furthermore, it was noted that distinguishing between the effects of climate change and other effects is hard.

One central government organisation noted that awareness and understanding is lacking, particularly among councillors and developers, about the effects of climate change. Furthermore, one respondent noted that councils lack the expertise to consider the issues. The climate change specialists within councils tend to be in charge of all aspects of climate change and not just adaptation. Expertise is also lacking in the wider industry, such as economists and scientists. One respondent noted that economists and scientists often disagree.

A lack of money to run models and multiple future flow scenarios was identified as a barrier. One respondent suggested that school children need to be educated about climate change and that it should be included in school curricula.

Respondents felt a need to agree on terminology and definitions, and a need to encourage decision makers to read critically into the context in which 'experts' from both sides present information.

C15.2 Crown entities

One crown entity noted that historically, a co-ordinated, detailed policy based response to addressing climate change has been lacking. In part, this is because of institutional capacity constraints e.g. limited in-house skills or other time pressures/work priorities.

The discount rates currently specified in the NZTA's *Economic Evaluation Manual* (LTNZ 2007) (as stipulated by Treasury) limits the extent to which we are able to consider future benefits in investment decision making processes. This significantly limits our ability to recognise climate change benefits in decision making process.

One crown entity stated that barriers are not insurmountable. It is necessary to understand the risks then, with appropriate funding, they believe they can work through any other barriers such as industry capacity and capability, policy framework and community understanding.

C15.3 Regional government

One respondent noted that the scenarios at present are simplistic and doubtful. In order to commit investment seriously into change, their organisation must have better information. Every report/analysis that comes out suggests it is less of a direct risk than expected previously. The barriers are therefore knowledge of what will physically occur and what will the government do to adapt to climate change conditions.

Several regional government respondents noted that the barriers are all related to each other. The barrier in terms of policy gaps is that no requirement to develop a response policy exists. Furthermore, no policy to drive funding is in place. It was noted that no dedicated personnel are available to drive investigations and policy development, and no leadership is driving the investigations and policy development.

C16.4 TLA

One TLA stated that we are at the stage of 'not knowing what we don't know'. That particular TLA has just made a major commitment to becoming carbon neutral as a city by 2012, and has set up research and adaptation workstreams within their climate change office. Therefore, they are committed to developing the institutional capacity to address this issue.

One of the TLAs stated that they are struggling to fund basic maintenance and they do not have the human resources to assist in addressing the adverse impacts of climate change.

C16.5 CRIs and universities

One CRI noted that although global climate scenarios are relatively robust, the variability of climate scenarios at the regional scale (i.e. for different New Zealand regions) is very high. It was also noted that the understanding of climate change and use of tools (e.g. CLIMPACTS) within councils is variable and quite limited.

It was stated that climate change is being considered in individual plans by some councils. Even these councils might benefit from developing overarching policies for treating climate impacts (beyond just land transport infrastructure) within a risk management framework.

Funding of projects in this area is increasing but a funding gap exists for larger projects that would benefit from economies of scale (e.g. the whole of Auckland rather than one TLA). Furthermore, another respondent noted that funding is hard to secure, especially for uncertain effects observed over a long timeframe.

Research capacity in the area of integrated climate impact assessments is lacking. This ideally requires developing medium or large interdisciplinary, cross-organisational teams over years of sustained research effort. New Zealand research in this area has, to date, been carried out mainly by small ad hoc groupings assembled for short-term projects.

The university stated that uncertainty exists about the physical hazard risks, energy technologies and social uptake of alternatives. Research funding is less available here than in other countries and may be holding us back, but it is not a barrier. New Zealand has a lack of economic modelling expertise to be able to assess the implications of a shift in energy pricing and transport infrastructure requirements. This university has access to one economic model, which is not good at predicting the effect of change. Therefore, we need more sophistication and diversity in our economic models.

C16.6 Ports

Ports noted the following as barriers to addressing the effects of climate change:

- institutional capacity,
- a lack of policy from clients to drive changes through network operations, and
- financial barriers, including the willingness and ability to pay for adaptation.

One respondent suggested the country may have to merge port functions.

Appendix D Key legislation

D1 The RMA

D1.1 Purpose and relation to land transport of the RMA

The purpose of this Act is to promote the sustainable management of natural and physical resources.

Several sections under the RMA are directly or indirectly applicable to land transport. Regional councils, for instance, have a specific responsibility to integrate infrastructure with land use strategically through objectives, policies and methods (S30 (1 (g &b))). As regional and district plans have to give effect to Regional Policy Statements (Sections 67(3(c)) and 75(3(c))), considerable potential now exists for Regional Policy Statements to assume a significant role in promoting transport integration at regional level.

D1.2 Provisions of the RMA that are relevant to climate change

Part 2 7(i) of the RMA states specifically that:

> *In achieving the purpose of the Act, all persons exercising functions and powers under it, in relation to managing the use, development and protection of natural and physical resources, shall have particular regard to the effects of climate change.*

The Fourth Schedule of the Act also states that:

> *Matters that should be considered when preparing an assessment of effects on the environment. Any person preparing an assessment of the effects on the environment should consider any risk to the neighbourhood, the wider community, or the environment through natural hazards.*

Other provisions of the RMA relating to climate change are shown in Table D.1.

Table D1 Sections of the RMA that are relevant to climate change.

Section of the RMA	Details
S3	Definition of effect includes past, present and future effects; cumulative effects; and potential effects of high probability and of low probability that have high potential impact.
S30	Regional councils have a responsibility to control the use of land to achieve integrated management of resources of the region and for the avoidance or mitigation of natural hazards.
S31	Territorial authorities have a responsibility to control the effects of the use of land to achieve integrated management of resources as well as for the avoidance or mitigation of natural hazards.
S32	Specified persons must consider alternatives, benefits and costs of plans, and plan changes.
S35	General duty for local authorities to gather information and undertake monitoring; this applies to climate change.
S45	Preparation of National Policy Statements.
S59–S68	Preparation of regional plans in accordance with functions.
S72–S77D	Preparation of district plans in accordance with functions (includes avoidance or mitigation of natural hazards/climate change).
S79	Review of policy statements and plans.
S106	Subdivision consent can be refused or granted subject to conditions if land, structures or future uses are likely to be subject to natural hazards.
S108	Allows resource consents to be granted subject to conditions, including conditions relating to natural hazards.
S111	Use of financial contributions.
S220	Allows conditions to be placed on subdivision consents, including specific requirements.
S229	Purposes of esplanade reserves and esplanade strips to contribute to the protection of conservation values by providing for natural functioning and mitigating natural hazards.
S238	Vesting of roads.
S330–330B	Emergency works and power to take preventative or remedial action.

D1.3 Discussion on the application of the RMA

The Resource Management (Energy and Climate Change) Amendment Act that took effect in March 2004 directs decision-makers to 'have particular regard to the effects of climate change' when making decisions under the RMA (New Zealand Government 2004b).

In introducing objectives, policies, rules or other methods into a policy statement or plans, the RMA requires that a Section 32 analysis – consideration of alternatives, benefits and costs – of the provision must be undertaken. Councils must consider the implications of 'the risk of acting or not acting' if information about the subject matter of the provision is uncertain or insufficient.

This Act requires that adverse effects are avoided, remedied or mitigated.

The environment includes natural and physical resources, and social and cultural considerations.

S104E specifically excludes consideration of effects of greenhouse gas emissions on climate change when making decisions.

D2 The LGA

D2.1 Purpose and relation to land transport of the LGA

To define the purpose, roles and responsibilities of local government, the LGA provides a framework and powers for local authorities to determine the activities they undertake and the manner in which they undertake them.

The LGA outlines administrative and management responsibilities for regional and district councils, including land management, utility services, recreation assets, transportation and the associated provision of services.

The purpose of the LGA is to promote social, economic, environmental and cultural wellbeing of communities for the present and the future.

In relation to land transport, relevant components include:

- the requirement that councils prepare a LTCCP, including provisions for transport infrastructure and funding;
- the ability to prepare urban growth strategies;
- the ability to make bylaws;
- the ability to require developer contributions as opposed to financial contributions under the RMA;
- a process to stop legal roads under the tenth schedule of the LGA 1974.

Territorial authorities are also required to facilitate a process to identify the outcomes sought by the community on such matters as transport and land use, and to consult with the community about proposed programmes and projects.

The LGA requires stopped roads along the margins of the coast (along MHWS) to be vested in the council as esplanade reserves.

Section 650A1(i) of the Local Government Amendment (No 2) Act allows for district councils to undertake various works in the coastal environment including the erection and maintenance of: quays, docks, piers, wharves, jetties, launching ramps, and any other works for 'the improvement, protection, management or utilisation of waters within its district' (subject to the controls established by the RMA).

Community planning is a cornerstone of the LGA, with the requirement to prepare LTCCPs. Specific consultation is required when preparing these plans or bylaws under the Act. This has particular significance for coastal strategies or other management plans that are adopted as part of the response to coastal hazards, including climate-induced coastal hazards.

D2.2 Provisions of the LGA that are relevant to climate change

The sections of the LGA that are relevant to climate change are shown in Table D.2.

Table D.2 Sections of the LGA that make provision for climate change.

Section of the LGA	Details
S3	Purpose.
S10	Purpose of LGA.
S76–81	Decision making and requirements.
S82	Principles of consultation.
S90	Policy on significance The policy adopted under subsection (1) must list the assets considered by the local authority to be strategic assets.
S91–92	Identifying and reporting on community outcomes.
S93 & 95	LTCCP and annual plan.
S101 & 102	Financial management and funding policies.
S106	Policy on development or financial contributions.
S189	Power to acquire land.
S197-199	Development contributions
S201–204	Formulation of development contributions policy and use.
Schedule 10	Information to be included in council plans and reports.

D2.3 Discussion on the application of the LGA

Local authorities are responsible for a range of functions that may be affected by climate. Climate-related risks are not new to local government planners, resource managers, and/or hazard and emergency managers. The effects of floods, droughts, storms and other extreme weather events are already addressed by local government when planning and providing services (MfE 2004b).

Local authorities have both a social and legal obligation to take climate change effects into account in their community planning. Long-term planning functions therefore need to account for expected long-term shifts and changes in climate extremes and patterns to ensure future generations are adequately prepared for future climate conditions (MfE 2004b).

Local government is required to operate under a range of principles. Many of these principles are relevant when considering the possible effects of climate change. The concept of sustainable development is embedded with the LGA.

The LGA requires councils to prepare a number of plans – LTCCPs and annual plans. The annual plan must set out details of council asset administration and costings.

All plans provide a decision making framework, but beyond that, all council decisions must be made in a context that involves:

- each decision relating to a stated objective or community outcome;
- consideration of all reasonably practicable options, their benefits and costs, and their efficiency and integration with stated objectives;
- consideration of the implications of the decision in relation to present and future needs, and all statutory responsibilities;
- consideration of the views of affected people at varying stages of decision making through to consultative procedures; and

- consideration of prudent stewardship of the council's resources and of sustainable development (all to the extent which is in proportion to the significance of the decision (MfE 2004b)).

However, climate change is not explicitly referred to in the LGA, although this is implicit in the requirement that local government considers the foreseeable needs of future generations.

Community outcomes are to be reported on every three years (starting in 2009) but only financial outcomes are audited under the LGA.

D3 Local Government (Auckland) Amendment Act 2004

D3.1 Purpose and relation to land transport

The purpose of the Local Government (Auckland) Amendment Act 2004 (New Zealand Government 2004c) is to enable all public transport service assets and liabilities of the Auckland Regional Council (ARC) to be vested in the Auckland Regional Transport Authority (ARTA), and to provide for the better integration of transport and land use planning.

This Act made changes to transport governance, regulatory and funding proposal for the Auckland region. It established two new entities as subsidiaries of the ARC – ARTA and Auckland Regional Holdings. ARTA plans, funds and develops the Auckland regional land transport system, in co-ordination with the NZTA and ONTRACK. Auckland Regional Holdings manages assets and interests on behalf of the ARC.

Additionally, the Amendment Act required the ARC and seven constituent territorial authorities to prepare and publicly notify proposed land use changes to their planning documents that integrate land transport and land use provisions, consistent with the Auckland Regional Growth Strategy.

The Local Government (Auckland) Amendment Act has no specific provisions that are relevant to climate change.

D3.2 Discussion on the application

This specific legislation arose from the perceived lack of integration and co-ordination of transport and land use planning in the wider Auckland region.

It sets a clear mandate in place for ARTA to develop integrated responses to transport issues.

Climate change issues are included implicitly through the LGA connections and the sustainability responsibilities within the parent legislation.

D4 The LTMA

D4.1 Purpose and relation to land transport of the LTMA

The purpose of the LTMA is to contribute to the aim of achieving an integrated, safe, responsive and sustainable land transport system.

The LTMA came into force in November 2003 to give effect to the principles of the New Zealand Transport Strategy. The current Land Transport Amendment Bill is designed to maximise the performance of the government land transport sector, and its impact on the New Zealand economy and environment.

The legislation has a strong 'sustainability' thread, and endeavours to provide a framework to meet multiple objectives in determining funding.

The LTMA does cover environmental issues but climate change issues are not given any prominence.

D4.2 Provisions of the LTMA that are relevant to climate change

Several sections of the LTMA give the NZTA powers which can either directly or indirectly address the effects of climate change, as shown in Table D.3.

Table D.3 Provisions in the LTMA that give the NZTA powers to address the effects of climate change.

Section of the LTMA	Details
S12 & S19	Land transport programmes Any organisation preparing a land transport programme must take into account how each activity: • assists economic development, • assists safety and personal security, • improves access and mobility, • protects and promotes public health, and • ensures environmental sustainability.
S5 & S6	Approved organisations (including ARTA) must, in preparing a land transport programme, take into account any current national land transport strategy, the National Energy Efficiency and Conservation Strategy, and relevant regional land transport strategies.
S20	An activity/activity class must have the following to be gain approval: • the activity or activity class contributes to the Authority's objective, including its social and environmental responsibility, in an efficient and effective manner; and • the activity or activity class has, to the extent practicable, been assessed against other land transport options and alternatives. However, the Authority may, without complying with subsections (2) and (3), approve for payment from the national land transport account any activities and activity classes that, in the opinion of the Authority: • are in the urgent interests of public safety, or • are necessary to effect immediate or temporary repair of damage caused by a sudden and unexpected event.
Part 3, S68	Objective of the Authority. This section of the LTMA sets out the objective of the authority, which is to allocate resources and to undertake its functions in a way that contributes to an integrated, safe, responsive and sustainable land transport system. S68(2) also states that in meeting its objective, the Authority must exhibit a sense of social and environmental responsibility, which includes: • avoiding, to the extent reasonable in the circumstances, adverse effects on the environment; and • ensuring that persons/organisations preparing land transport programmes take the views of affected communities into account and give full consideration to land transport options and alternatives.

Table D.3 (cont.) Provisions in the LTMA that give the NZTA powers to address the effects of climate change.

Section of the LTMA	Details
S69	<u>Functions of Authority</u> • to promote land transport sustainability in New Zealand; • to review and revise the national land transport programme in accordance with its most recent performance agreement; • to promote safe transport on land in New Zealand; • to fund research, education, and training activities and activity classes; • to provide the Minister with any advice relating to the Authority's functions that the Minister may request; • to co-operate with, or to provide advice and assistance to any government agency or local government agency when requested to do so by the Minister.
Schedule 1(3)	<u>Provisions relating to programmes</u> Indicate the options and alternatives (including demand management) considered for the activities and activity classes.
Schedule 1(4)	<u>Objectives of activities and how they contribute to purpose of the Act</u> • State the objective or objectives to be achieved by each activity and each activity class. • State how each activity or activity class contributes to the purpose of this Act.
Schedule 1(7)	Steps for developing options and alternatives must include the steps the organisation intends to take in developing land transport options and alternatives.
Schedule 1(9)	<u>Policy directions</u> In the case of Transit and the Authority, include policy directions given under Part 3 of the Crown Entities Act 2004.

D4.3 Discussion on the application of the LTMA

This Act is the key national transport planning/funding legislation. It applies only if NZTA funding is to be sought for a project. Projects are funded based on three assessment criteria:

- seriousness and urgency;
- contribution to New Zealand Transport Strategy (NZTS) objectives:
  - assists in economic development
  - assists in safety and personal security,
  - improves access and mobility,
  - protects and promotes public health, and
  - ensures environmental sustainability; and
- economic efficiency.

Section 13 of the LTMA allows Road Controlling Authorities to consult through the LTCCP process – providing a direct linkage to the LGA.

D5 The Land Transport Act

D5.1 Purpose and relation to land transport

The purpose of the Land Transport Act (LTA) 1998 (New Zealand Government 1998) is:

- to promote safe road user behaviour and vehicle safety;
- to provide for a system of rules governing road user behaviour, the licensing of drivers, and technical aspects of land transport, and to recognise reciprocal obligations of persons involved;
- to consolidate and amend various enactments relating to road safety and land transport;
- to enable New Zealand to implement international agreements relating to road safety and land transport.

Part 13 of the LTA (as amended by the LTMA), is of relevance to RMA policies and plans as it provides the basis for land transport strategies. Specifically, it allows the Minister of Transport to prepare a national land transport strategy and for each regional council to prepare a regional land transport strategy. Section 175(3) also specifies that 'a regional land transport strategy may not be inconsistent with any regional policy statement or plan that is, for the time being, in force under the Resource Management Act 1991'.

D5.2 Provisions that are relevant to climate change

Sections of the LTA that specifically make provision for addressing climate change effects are shown in Table D.4.

Table D.4 Sections of the LTA that make provision for addressing climate change effects.

Section of the LTA	Details
Part 12 – The Crown and land transport	
S169	Objectives of Minister
S169A	Functions of Minister
Part 13* – Land transport strategies	
S170	National land transport strategy
S174	Effect of national land transport strategy
S175	Regional land transport strategies
S176	Currency of regional land transport strategies
S181	Effect of regional land transport strategies
S182	Annual reports on regional land transport strategy

*Part (c) (e) (3) particularly addresses climate change.

D5.3 Discussion on the application of the LTA

The LTA provides for the regulation of transport in New Zealand, including general requirements for participants in land transport system.

The LTA does not explicitly mention the need to consider the effects of climate change. However, climate change can be included when developing national and regional land transport strategies.

D6 Transit New Zealand Act

D6.1 Purpose and relation to land transport

The Transit New Zealand Act 1989 (New Zealand Government 1989) defines Transit NZ's functions and powers in relation to motorways and state highways.

Transit had the ability (as did councils under the provisions of the LGA 1974 that were not repealed) to declare and manage access to limited access roads. The LTMA expanded Transit NZ's functions and powers in 2003, and these passed to the NZTA in August 2008.

D6.2 Provisions that are relevant to climate change

The Transit New Zealand Act contained some provisions which are relevant to climate change. These are listed in Table D.5.

Table D.5 Provisions in the Transit New Zealand Act that are relevant to climate change.

Section	Details
S48	The Minister shall have power to do all things necessary to construct any road under the Minister's control and maintain it in good repair.
S60	Authority may declare state highways.
S61	Powers and duties of Authority in relation to state highways Subject to Section 62 of this Act, the Authority shall have the sole powers of control for all purposes, including construction and maintenance, of all state highways under this Act, and any such powers shall be exercised only under this Act.
S62(1)	All or any of the functions, duties, and powers of construction, maintenance and control conferred on the Authority by this Act with respect to any state highway or portion of a state highway may be delegated by the Authority to the territorial authority in whose district the state highway or portion of it is situated.
S67	The whole cost of construction and maintenance of state highways is to be paid out of the State Highways Account. The whole of the cost of construction and maintenance of the carriageway of any state highway (including any part of a state highway that is the subject of a delegation pursuant to Section 62 of this Act) in accordance with the standard prescribed by the Authority shall be provided by the Authority out of the State Highways Account.

D6.3 Discussion on the application

This Act provides important definitions including the following:

- A motorway:
  - means a motorway declared as such by the Governor General in Council under Section 138 of the Public Works Act 1981 or under Section 71 of this Act; and
  - includes all bridges, drains, culverts, or other structures or works forming part of any motorway so declared.
- A road means a public highway, carriageway, bridle path, or footpath, subject to specific provisions and limitations.

D7 The CDEMA

D7.1 Purpose and relation to land transport of the CDEMA

The CDEMA is intended to:

- promote sustainable management of hazards;
- encourage and enable communities to achieve acceptable levels of risk;
- provide for planning and preparation for emergencies, and for response and recovery;
- require local authorities through to regional groups to co-ordinate planning and activities;
- provide a basis for the integration of national and local civil defence emergency management;
- encourage co-ordination across a wide range of agencies, recognising that emergencies are multi-agency events; and
- focus on reduction, readiness, response and recovery.

The CDEMA relates to land transport specifically in Schedule 1 of that Act, which defines lifeline utilities. These include:

- the port company that carries out port related commercial activities at Auckland, Bluff, Port Chalmers, Gisborne, Lyttelton, Napier, Nelson, Picton, Port Taranaki, Tauranga, Timaru, Wellington, Westport or Whangarei;
- an entity that provides a road network (including state highways); and
- an entity that provides a rail network or service.

D7.2 Provisions of the CDEMA that are relevant to climate change

The CDEMA lists many definitions that are relevant to considering and addressing climate change effects.

An **emergency** means a situation that:

- is the result of any happening, whether natural or otherwise, including, without limitation, any:
  - explosion,
  - earthquake,
  - eruption,
  - tsunami,
  - land movement,
  - flood,
  - storm,
  - tornado,
  - cyclone,
  - serious fire,
  - leakage or spillage of any dangerous gas or substance,
  - technological failure,
  - infestation,
  - plague,
  - epidemic,
  - failure of or disruption to an emergency service or a lifeline utility, or
  - actual or imminent attack or warlike act; and

- causes or may cause loss of life, injury, illness or distress, or in any way endangers the safety of the public or property in New Zealand or any part of New Zealand; and
- cannot be dealt with by emergency services, or otherwise requires a significant and co-ordinated response under this Act.

A **hazard** means something that may cause or contribute substantially to the cause of an emergency.

National significance includes, without limitation, any case where the Minister or the Director considers that:

- public concern or interest is widespread;
- use of resources is likely to be significant;
- it is likely that the area of more than one Civil Defence Emergency Management Group will be affected;
- it affects or is likely to affect or is relevant to New Zealand's international obligations;
- it involves or is likely to involve technology, processes or methods that are new to New Zealand; or
- it results or is likely to result in or contribute to significant or irreversible changes to the environment (including the global environment).

The CDEMA also contains other provisions that relate to climate change; these are shown in Table D.6.

Table D.6 Provisions of the CDEMA that are relevant to climate change.

Section of the CDEMA	Details
S8	The functions of the Director for Civil Defence and emergency management includes identifying hazards and risks that the Director considers are of national significance; (2b) S9(d) covers research and investigations into matters relating to civil defence emergency management.
S12	Local Authorities are to establish Civil Defence Emergency Groups.
S17	As part of the function of a Civil Defence Emergency Group, the group is to (i) identify, assess and manage those hazards and risks; (ii) consult and communicate about risks and (iii) identify and implement cost-effective risk reduction.
S38	Matters relevant to development of civil defence emergency management plans must have regard to: • (a) the responsibility of people and communities to provide for their own wellbeing and the wellbeing of future generations; • (b) the benefits to be derived for people and communities from the management of hazards and risks; and • (c) New Zealand's international obligations.
S59	Departments and others to undertake civil defence emergency management functions and responsibilities. This is relevant to port and road network operators.
S60	Duties of lifeline utilities Every lifeline utility must: • (a) ensure that it is able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency; • (b) make available to the Director in writing, on request, its plan for functioning during and after an emergency; • (c) participate in the development of the national civil defence emergency management strategy and civil defence emergency management plans; • (d) provide, free of charge, any technical advice to any Civil Defence Emergency Management Group or the Director that may be reasonably required by that Group or the Director.
S65	Duties to consider alternatives, assess benefits and costs.

D7.3 Discussion on the application of the CDEMA

The CDEMA requires that a risk management approach be taken when dealing with hazards. In considering the risks associated with a particular hazard, both the likelihood of the event occurring and its consequences must be considered. The CDEMA is largely an enabling mechanism, which can complement both the Building Act and the RMA. In particular, integration between regional and district councils is achieved with the formation of Civil Defence and Emergency Management Groups comprising representatives from each of the TLAs and the regional council within a region. The CDEMA (Section 17(1)) outlines the functions of a Civil Defence and Emergency Management Group in relation to relevant hazards and risks. These include:

- identifying, assessing and managing those hazards and risks;
- consulting and communicating about risks; and
- identifying and implementing cost-effective risk reduction.

Section 48 provides that each Civil Defence and Emergency Management Group must provide a plan, which must state the hazards and risks to be managed by the Group and the actions necessary to do so. The CDEMA therefore anticipates that regional and territorial authorities will co-operate in the management of hazards and risk, including coastal hazards.

This legislation identifies the importance of land transport systems in emergency circumstances, and provides for forward planning of this role.

Risk reduction is a key element of the legislation, and lifeline utilities (including the land transport elements) have a responsibility to ensure they can function during and after an emergency, such as might be experienced increasingly as a result of climate change.

D8 Building Act 2004

D8.1 Purpose and relation to land transport of the Building Act

The purpose of the Building Act 2004 (New Zealand Government 2004a) is to provide for the regulation of building work, the establishment of a licensing regime for building practitioners, and the setting of performance standards for buildings to ensure that:

- people who use buildings can do so safely and without endangering their health; and
- buildings have attributes that contribute appropriately to the health, physical independence and wellbeing of the people who use them; and
- buildings are designed, constructed and able to be used in ways that promote sustainable development.

Key elements of the land transport system, such as bridges, culverts, wharves and jetties, require permits under the Building Act. An early amendment to the Act removed uncertainty about responsibilities for control over structures in the coastal marine area (i.e. outside district boundaries).

Less directly, the Building Act has some influence on urban development, intensification, etc., and thus on associated land transport requirements.

D8.2 Provisions of the Building Act that are relevant to climate change

In achieving the purpose of this Act, a person to whom this Section 4 (2) applies must take into account the following principles that are relevant to the performance of functions or duties imposed, or the exercise of powers conferred on that person:

- the need to ensure that any harmful effect on human health resulting from the use of particular building methods or products or of a particular building design, or from building work is prevented or minimised;
- the importance of ensuring that each building is durable for its intended use;
- the importance of standards of building design and construction in achieving compliance with the building code; and
- the importance of allowing for continuing innovation in methods of building design and construction.

Part 3 of the Building Act sets out the main functions, duties and powers of the chief executive, territorial authorities, building consent authorities and regional authorities under this Act.

According to Section 8(1), in this Act, unless the context otherwise requires, building means a temporary or permanent movable or immovable structure (including a structure intended for occupation by people, animals, machinery or chattels).

The building code covered by Section 16 prescribes functional requirements for buildings and the performance criteria with which buildings must comply in their intended use.

Section 35 states that a project information memorandum must include:

- land concerned, which:
  - means the land on which the proposed building work is to be carried out, and
  - includes any other land likely to affect or be affected by the building work;
- special features of the land concerned, which include, without limitation, potential natural hazards or the likely presence of hazardous contaminants that:
  - are likely to be relevant to the design and construction or alteration of the building or proposed building,
  - are known to the territorial authority, and
  - are not apparent from the district plan under the RMA.

According to Section 71, a building consent authority must refuse to grant a building consent for construction of a building, or major alterations to a building if:

- the land on which the building work is to be carried out is subject or is likely to be subject to one or more natural hazards; or
- the building work is likely to accelerate, worsen or result in a natural hazard on that land or any other property.

In Sections 71–74, 'natural hazard' means any of the following:

- erosion (including coastal erosion, bank erosion and sheet erosion),
- falling debris (including soil, rock, snow and ice),
- subsidence,
- inundation (including flooding, overland flow, storm surge, tidal effects and ponding), or
- slippage.

Section 212 states that a territorial authority must act as building consent authority for its district. A territorial authority must perform the functions of a building consent authority within its district and for any coastal marine area in relation to any application for a building consent made to the territorial authority, and any building consent granted under that application.

According to Schedule 1, a building consent is not required for the following building work:

- the construction of any motorway sign, stopbank, culvert for carrying water under or in association with a road, or other similar structure, that is a simple structure and is owned or controlled by a network utility operator or other similar organisation;
- construction of any retaining wall that retains not more than 1.5 metres depth of ground and that does not support any surcharge or any load additional to the load of that ground (for example, the load of vehicles on a road);
- (the construction of any platform, bridge or the like from which it is not possible for a person to fall more than 1 metre even if it collapses.

D8.3 Discussion on the application of the Building Act

The Building Act addresses building work in the interests of ensuring the safety and integrity of the structure through its construction and subsequent use.

Buildings require building consent under the Building Act. Where controls are imposed under both the RMA and the Building Act, both must be met with generally the practical effect that the more stringent control prevails. The Building Act raises questions of whether the land 'is likely to be subject to erosion, avulsion, alluvion, falling debris, subsidence, inundation or slippage'; or whether the works are likely to 'accelerate, worsen or result in erosion, avulsion, alluvion, falling debris, subsidence, inundation or slippage of that land or any other property'. Under Section 36 of the Building Act, the existence of these natural hazards can be noted on the title of a property.

Although district councils can exercise some judgement about whether to allow a subdivision or development, councils cannot avoid responsibility for avoiding or mitigating effects of natural hazards in favour of reliance on controls under the Building Act.

Because the RMA takes a long-term (intergenerational) view, RMA requirements can be more restrictive than those imposed under the Building Act – for example, standards based on 1 in 100 year events, rather than 1 in 50 years as under the Building Act. RMA plans are important, as they may determine whether a building can be sited in the relevant area in the first place. The Building Act (specifically Section 36) is particularly important where coastal (or other) hazards are discovered after titles have been created or even after development is already established.

D9 Railways Act 2005

D9.1 Purpose and relation to land transport

The purpose of the Railways Act 2005 (New Zealand Government 2005) is to:

- promote the safety of rail operations by:
  - stating the duty of rail participants to ensure safety,
  - authorising the Minister to make rules relating to rail activities, and
  - clarifying the nature of approved safety systems established by rail participants;
- restate and amend the law relating to the management of the railway corridor; and
- consolidate legislation relating to railways.

This legislation regulates the rail network and its components. It does not provide a planning framework, but does include elements relating to the protection and management of existing elements of the system.

D9.2 Provisions that are relevant to climate change

Section 28 covers the power of the Director to prohibit operation, impose conditions, or detain or immobilise rail vehicles or railway infrastructure. If the Director believes, on reasonable grounds, that the operation or use of a rail vehicle or class of rail vehicle or any railway infrastructure may endanger persons or property, and that prompt action is necessary to prevent the risk, the Director may prohibit or impose conditions on the operation or use of the rail vehicle or rail vehicles of that class or railway infrastructure. Without limiting the power to make ordinary rules under Section 49, ordinary rules may, according to Section 52:

- regulate the use of railway lines, and empower access providers to control, restrict and prohibit the use of a railway line, and to close railway lines in specified circumstances or on specified occasions;
- set out standards, specifications or codes of practice for the safety performance, design, construction, inspection, alteration, maintenance or use of railway infrastructure or railway premises;
- set out the standards and requirements for forming, surfacing and maintaining carriageways at level crossings;
- set out standards and requirements concerning rail vehicles, including, without limitation, their construction, mass and dimensions, emissions, environmental requirements, loading requirements, identification and fuel systems, and their repair, maintenance, modification and inspection; and
- set out procedures to verify compliance with standards and requirements of the rules.

Subject to the provisions of the RMA, for the purposes of protecting a railway, or preventing or lessening the risk of damage to any railway infrastructure or railway premises, a licensed access provider or railway premises owner may, under the provisions of Section 77:

- construct, maintain, alter or reconstruct an embankment, groyne or other protective work on any land or on the bank of a river or stream; or
- divert, dam or take away any part of the whole of the water of a river or stream, or alter the course of a river or stream.

Section 83 (Maintenance of crossings) specifies the following provisions:

- At a level crossing, the licensed access provider for the railway line concerned must form, surface and maintain the carriageway at the level crossing on the railway line, and the road controlling authority for the road concerned must form, surface and maintain the approaches to the level crossing.
- If a road crosses over a railway by means of a bridge, the road controlling authority for the road must maintain the bridge.
- If a railway line crosses over a road by means of a bridge, the licensed access provider for the railway line must maintain the bridge.
- If a road and railway line both use the same bridge, the relevant road controlling authority and the relevant licensed access provider must jointly maintain the bridge.
- The duties imposed by this section are subject to any agreement between the road controlling authority and the licensed access provider.

D9.3 Discussion on the application

The railway system is relatively loosely regulated in New Zealand. This specifically relates to the existing system and rolling stock, although the legislation also resolves aspects where road and rail networks intersect or overlap.

The legislation lacks any requirements of provisions for forward planning.

Any relevance of this legislation to climate change is limited to providing basic public use, safety and protection of existing assets.

D10 Maritime Transport Act 1994

D10.1 Purpose and relation to land transport

The purpose of the Maritime Transport Act 1994 (New Zealand Government 1994) is:

- to continue the Maritime Safety Authority of New Zealand,
- to enable the implementation of New Zealand's obligations under international maritime agreements,
- to ensure that participants in the maritime transport system are responsible for their actions,
- to consolidate and amend maritime transport law,
- to protect the marine environment, and
- to continue or enable the implementation of obligations on New Zealand under various international conventions relating to pollution of the marine environment.

This legislation primarily promotes maritime safety, and links New Zealand's shipping and port operations into the existing web of international maritime and shipping protocols, guidelines and regulations. However, the responsibilities of the Minister extend to integration with the objectives of other legislation in terms of an 'integrated, safe, responsive and sustainable transport system'.

D10.2 Provisions that are relevant to climate change

The Maritime Transport Act contains a definition of 'hazard' that is very useful when looking at climate change effects. According to the Maritime Transport Act, a hazard means an activity, arrangement, circumstance, event, occurrence, phenomenon, process, situation or substance (whether or not arising or caused on board a ship) that is an actual or potential cause or source of harm; 'hazardous' has a corresponding meaning.

Other provisions of the Maritime Transport Act relating to climate change are shown in Table D.7.

Table D.7 Provisions of the Maritime Transport Act relating to climate change.

Section and title	Details
S5: Objectives of Minister	The objectives of the Minister under this Act are: (a) to undertake the Minister's functions in a way that contributes to an integrated, safe, responsive and sustainable transport system; and (b) to ensure that New Zealand's obligations under the conventions are implemented.
S5A: Functions of Minister	The functions of the Minister under this Act are: • to promote safety in maritime transport; • to promote protection of the marine environment; • to administer New Zealand's participation in the conventions and any other international maritime or marine protection convention, agreement or understanding to which the Government of New Zealand is a party; • to ensure New Zealand's preparedness for and ability to respond to marine oil pollution spills; • to make maritime rules and marine protection rules under this Act.
S36: Maritime rules relating to other matters	The Minister may from time to time make maritime rules for all or any of the following purposes: • assisting economic development, • improving access and mobility, • protecting and promoting public health, and • ensuring environmental sustainability.
S39	Matters to be taken into account in making maritime rules include: • The level of risk existing to maritime safety in New Zealand in general; • the need to maintain and improve maritime safety and security, including (but not limited to) personal security; • whether the proposed rule: – assists economic development, – improves access and mobility, – promotes and protects public health, and – ensures environmental sustainability.

D10.3 Discussion on the application

The Maritime Transport Act provides a general framework within which ports and coastal shipping operate, and which also applies, to a certain extent, to the regulation of foreign vessels operating in New Zealand waters.

Risk management is a strong thread within the legislative responsibilities, including both maritime safety but also security (including biosecurity).

Any additional risks which might be associated with climate change are encompassed by the ability to make rules.

The legislation also sets in place administrative structures relating to oil spills and biosecurity management, both of which may require special consideration in terms of climate change effects.

While this legislation is focused on central government responsibilities, this inevitably affects land transport through direct effects of central government policy (such as final taxes and direct regulation of some activities which could extend to, for example, vehicle import regulations), and also indirectly through government departments' analysis of and action within areas of responsibility of local government and the private sector (for example, involvement in RMA policies and plans).

Mitigation and adaptation are important aspects of response to climate change within the Act, including through programmes for the transport sector. Spatial planning (most likely involving transport and land use) is noted as a means of adaptation to climate change.

D11 Climate Change Response Act 2002

D11.1 Purpose and relation to land transport

The purpose of the Climate Change Response Act 2002 (New Zealand Government 2002c) is to enable New Zealand to meet its international obligations under the Convention and the Kyoto Protocol, including, but not limited to, its obligation under Article 3.1 of the Protocol to retire units equal to the number of metric tonnes of CO_2 equivalent of anthropogenic greenhouse gases emitted from the sources listed in Annex A of the Kyoto Protocol (United Nations 1997) in New Zealand in the first commitment period.

Several sections of this act relate specifically to land transport:

- Under Article 4 commitments, New Zealand must:

  promote and co-operate in the development, application and diffusion, including transfer, of technologies, practices and processes that control, reduce or prevent anthropogenic emissions of greenhouse gases not controlled by the Montreal Protocol in all relevant sectors, including the transport…sectors.

- Under Article 2:

  (vii) Measures to limit and/or reduce emissions of greenhouse gases not controlled by the Montreal Protocol in the transport sector; (viii) Limitation and/or reduction of methane emissions through recovery and use in waste management, as well as in the production, transport and distribution of energy.

- Under Article 4 and 10, New Zealand has an obligation to:

  Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change...Such programmes would, inter alia, concern the energy, transport and industry sectors as well as agriculture, forestry and waste management. Furthermore, adaptation technologies and methods for improving spatial planning would improve adaptation to climate change.

D11.2 Provisions that are relevant to climate change

Article 2 states that the Act's objective is to achieve, in accordance with the relevant provisions of the Convention, stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

D12 Public Works Act 1981

D12.1 Purpose and relation to land transport

The purpose of the Public Works Act 1981 (New Zealand Government 1981) is to enable government and local authorities to acquire land (either by agreement or compulsion) for public works such as schools, hospitals, roads and airports.

The act provides the ability to take land to form new components of New Zealand's transport infrastructure.

D12.2 Provisions that are relevant to climate change

No specific provisions are made for climate change in the Public Works Act.

D12.3 Discussion on the application

This Act is only likely to be relevant if climate change effects result in the need to modify routes or acquire additional space for protection of existing assets.

Appendix E Key central agency policy

E1 Climate change policy

New Zealand's policies regarding climate change have been strongly focused on addressing anthropogenic activities to manage New Zealand's greenhouse gas emissions. New Zealand's first Climate Change Policy package, agreed by Cabinet in 2002, proposed a range of measures, including a carbon tax on energy, industrial and transport emissions. Adapting to the effects of climate change was identified as one of a range of foundation policies on which New Zealand's overall response to the issue of climate change must be based.

A Cabinet paper entitled *Climate Change IV: Adapting to Climate Change* (POL (02) 74) (MfE 2002) proposed three concurrent components for work on impacts and adaptation:

- an assessment of the economic impacts of climate change, linkages between sectors and immediate co-benefits from adaptation to potential future change. This assessment would initially focus on the effects of climate variability and extreme events such as droughts, floods and coastal storm surges, and link with programmes of the Ministry for Civil Defence and Emergency Management and MAF;
- a better definition of the roles of local and central government in dealing with environmental hazards arising from climate change, identification of vulnerabilities, development of options to assist local government planning, and provision of appropriate guidance for planning and decision making;
- facilitation of a greater awareness of business opportunities and risks arising from climate change effects, and making the best use of collaboration across sectors. This will require a better appreciation of the potential effects of climate change, both within New Zealand and overseas, across all sectors of society and the economy.

In June 2004, the New Zealand Climate Change Office released *Preparing for Climate Change: A Guide for Local Government in New Zealand* (MfE 2004a). The guide comprises three parts:

- Part One explains the general effects of projected global warming on New Zealand, current climate variability, projected future climate changes both nationally and regionally, and how climate change may change the frequency and intensity of extreme weather events such as floods and storms.
- Part Two explains councils' social and legal obligations to take climate change effects into account in their community planning, the key principles that need to be considered in responding to climate change and how to assess the impact of climate change on council functions. Checklists are provided to help ensure that climate change is considered in various plans.
- Part Three outlines how councils can integrate climate change into council decision making, and qualitatively and, if necessary, quantitatively, assess if/how climate change will affect specific council functions and services.

Table E.1 outlines how local government functions may be affected by climate change.

Table E.1 Local government functions and possible climate change effects (adapted from MfE 2004a).

Function	Affected assets or activities	Key climate influence	Possible effects	Sensitivity to effects
Roading	Road network and associated infrastructure.	Extreme rainfall, extreme winds.	• Disruption from flooding, landslides, fallen trees and lines; • Direct effects of wind exposure on heavy vehicles.	Drainage, natural hazards.
Transport	Management of public transport; provision of footpaths, cycleways etc.	Changes in temperature, wind and rainfall.	• Changed maintenance needs for public transport (road and rail) infrastructure; • Disruption from extreme events.	Drainage, natural hazards.

Adaptation to the effects of climate change was considered outside of the scope of a cross-departmental review of New Zealand's climate change policies in 2005. However, the review noted the importance of adaptation guidance documents that were already available. The review recognised the value these guidance documents have in helping stakeholders understand the likely changes in climate and to apply a sequential risk-assessment approach to evaluate whether these changes could materially affect operations.

The review emphasised the importance of a risk-based approach for long-lived infrastructure and assets that are exposed to climatic conditions in any way. The review notes the benefit of routine climate change risk assessments in planning processes by industry and local and central government to avoid lock-in of technologies and practices that are vulnerable to hazards that could be exacerbated by climate change. The report reflected current and future work relating to adaptation with a focus on:

- working with science organisations to increase the availability of appropriate research findings to central and local government and other sector groups;
- ongoing provision of basic information to decision makers on climate change impacts, adaptation options, and the potential costs and benefits of preparing for climate change; and
- partnering with stakeholders and helping them use this information as appropriate.

A cabinet paper, *Climate Change Policy – The Way Ahead* (MfE 2006a), outlines New Zealand's whole-of-government climate change policy work programme. A report about preparing for and adapting to climate change, detailing recommendations on priorities and needs was identified in the first stage of work to be done.

The resulting report, *Helping New Zealand Prepare for and Adapt to Climate Change* (MfE 2006b), identified the need for climate change research to underpin an adaptation strategy. Topic areas identified as priority research requirements included many relevant to land transport infrastructure:

- risks to transport;
- impacts of storms;
- improved coastal planning and hazard management;
- impacts of climate projections beyond 2100 for New Zealand;
- cost/benefit analysis of adaptation options (including consideration of social equity and fairness, different discount rates, incentives, delayed effects and inter-generational equity); and
- the likely spread of plant and animal pests, including the arrival of new pests.

In September 2006 a paper to the Cabinet Policy Committee (POL Min (06) 20/12 (MfE 2006b)) detailed the work already underway to adapt to the effects of climate change. Efforts to raise awareness about climate change impacts and adaptation had been aimed at local government and included assistance such as:

- guidance brochures (e.g. *Preparing for climate change - A guide for local government in New Zealand* (MfE 2004a), and *Local communities – planning for climate change* (MfE 2004e);
- the Quality Planning Guidance Note *The Effects of Climate Change under the Resource Management Act* (Quality Planning 2005) – a web-based guide for local government published in 2005;
- a number of technical reports (including droughts, agriculture, coastal hazards and flood risk);
- a number of workshops (e.g. International Adaptation Workshop (2004), numerous local government workshops on climate change impacts and adaptation (2002, 2004, 2006) and IPENZ seminars (2006)); and
- engagement with stakeholders (e.g. research providers, the public and professional bodies).

The paper recommended an effective adaptation work programme needed to build on the actions identified above and also:

- assist with filling any gaps in knowledge on climate change impacts;
- disseminate information in a form that is useful to its audience; and
- engage with decision makers to raise awareness, encourage action and enhance the capacity to adapt.

The September 2006 paper (MfE 2006b) noted officials' conclusions following preliminary consultation with government and external stakeholders:

- The basic research and science behind climate change predictions are in good shape (this will require ongoing investment to ensure that the information is kept up-to-date).
- Better information needs to be provided about climate scenarios for New Zealand, in an easily accessible format, to raise awareness and support improved decision making.
- Major effort is required to translate this information into technical performance requirements, design standards, planning information and financial/asset management tools.
- Information needs to be promoted to professional advisers (e.g. engineers, architects, planners, insurers and accountants), and decision makers such as councillors and boards of directors, through training, professional development and best practice codes/guidance.
- Better information needs to be provided about the likely spread of plant and animal pests, and the arrival of new pests (including in freshwaters).

- Better co-ordination and information sharing among central government agencies is necessary.

The paper identified the need for more effort by public and private sectors to prepare for and adapt to the impacts of climate change. The Cabinet Policy Committee agreed that the immediate focus of the climate change impacts and adaptation work programme should be on a range of issues, including the following, which are relevant to land transport networks:

- water and coastal (e.g. emergency and hazard management, such as Civil Defence and Emergency Management Group plans and Regional Council plans, flood and storm surge preparedness, and coastal management);
- infrastructure investment and maintenance (e.g. asset management, design and resilience); and
- biodiversity and biosecurity.

Partnerships with stakeholders were initiated by Ministry for the Environment officials with the following priority stakeholder groups:

- local government (including Local Government New Zealand), by looking into ways to develop existing (and possibly new) technical performance requirements, design standards, best practice codes/guidance, planning information and financial/asset management tools, and by training and professional development for both officials and councillors;
- IPENZ, by looking into ways to develop existing (and possibly new) engineering performance requirements and engineering design standards (e.g. bridge design and flood event probability); and
- the insurance industry through the Insurance Council of New Zealand and IAG New Zealand Ltd., by looking into current technical information, providing industry best practice codes and helping develop insurance packages.

In October 2007, the government announced a new package of climate change policies, including an adaptation work programme to help prepare for the physical impacts of climate change and to work in partnership with stakeholders from central government, local government and engineering sectors, among others.

E2 The NZTS

The NZTS (MoT 2002) outlines the vision and principles for New Zealand to achieve an affordable, integrated, safe, responsive and sustainable transport system by 2010. The NZTS reflects on the role of transport's fuel emissions and contributions to climate change. It does not specifically identify how to adapt the land transport network to the effects of climate change.

The NZTS commits government to being forward-looking, accountable, collaborative and evidence-based in the governance, management, administration and allocation of funds for land transport.

The NZTS states that in being forward-looking it will 'ensure that policy and funding reflect the government's strategic priorities and policy in areas such as economic and regional development, tourism, health and climate change.'

The December 2007 discussion paper *Sustainable Transport: Update of the New Zealand Transport Strategy* (MoT 2007) notes the importance of transport system resilience:

> *New Zealand is vulnerable to a range of natural disasters and extreme weather events and it is predicted that climate change will mean these are more frequent and severe. A common potential consequence is damage to transport infrastructure and disruption of all forms of transport – air, rail, road and sea. There may be risks to the safety of the travelling public and the predictability of journey times may be affected.*

The discussion paper proposes a series of high-level transport specific targets for 2040. One of the targets refers to 'Travel times by principal routes to be improved relative to 2007 for identified critical intra- and inter-regional connections, as determined with each region.'

E3 Maritime policy

One of the drivers for the government's interest in enhancing the role of coastal shipping in New Zealand's transport system is climate change and the reduced CO_2 emissions per tonne of freight moved by coastal shipping compared with other modes. *Sea Change* (MoT 2008) does not acknowledge adaptation to the effects of climate change as a issue facing the industry or an impediment to the 2040 target of a doubling of domestic sea freight's share of inter-regional freight movement.

Final Guidelines for Port and Harbour Risk Assessment and Safety Management Systems in New Zealand (Maritime Safety Authority 2004a) identifies a range of weather effects such as wind, storminess, swell and tidal effects affecting the navigational safety of harbour areas.

The Port and Harbour Marine Safety Code (Maritime Safety Authority 2004b) requires that safety management systems be based on risk assessment processes to systematically identify the hazards and consequences, which may occur or arise from the activities of harbours, including navigational, geographical, weather, operational and vessel-related activities.

The distribution of relevant navigational, tidal and weather information is identified as a typical objective to include in a Navigational Safety Policy

A report on the *Environmental Factors Affecting Safe Access and Operations within New Zealand Ports and Harbours* (Maritime Safety Authority 2005) details the environmental factors and decision making considerations for ports and harbours. It states the minimum considerations that should be factored into all port risk assessments and safety management systems.

The report recommends all ports should have certain minimum equipment requirements for the assessment of environmental conditions in order to operate at a minimum safety level. Individual ports may consider that, after careful risk and cost/benefit analysis, some of the equipment described in this report is not required for the particular circumstances at their port. In this case, an assessment should be made that the risks are acceptable or that risk reduction can be achieved by other means.

Climate factors such as wind, tide, waves, current and wave direction are identified as environmental considerations to be taken into account. The report refers to the rise in mean sea level and projected acceleration with increasing global temperatures, and recommends that exceedance curves for high and low tides for the next 50 or 100 years should be generated from tidal records for engineering design of port facilities and under-keel clearances.

The report notes the requirement to apply an accurate assessment of the relevant environmental phenomena in order to successfully operate ships into and out of ports and harbours.

E4 Rail policy

The *National Rail System Standard/4: Risk Management* (ONTRACK 2007) identifies environmental and force majeure events such as flooding as potential risk areas that rail personnel may need to judge as part of a project or change in operations.

The National Rail Strategy (MoT 2005) identifies the importance of ensuring key rail infrastructure, passengers, staff and freight are not unreasonably at risk from accidents, whether caused by rail system failures, spillage of hazardous goods, or natural disasters such as slips, flooding or earthquakes. Appropriate risk management is identified as an important part of civil defence emergency management requirements.

E5 Infrastructure policy

New Zealand's first nationwide infrastructure stocktake led by the MED in 2004 covered New Zealand's transport, energy, water and telecommunications networks. The concerns identified in the stocktake did not include identification of climate change effects as a risk to transport infrastructure.

E6 Science and research policy

MRST's *Environment Research Roadmap for Science* (MRST 2007) is one of a series designed to guide New Zealand's science and research activity. Roadmaps provide a broad context and represent the government's high-level directions to the CRIs including FRST.

The roadmap recognises the role of scientific information in dealing with natural hazards. The roadmap suggests flood risk management may become more dependent on climate modelling, which places increased pressure on climate change science to provide reliable predictions of the future.

The roadmap suggests a range of key research questions including how urban infrastructure can be planned/adapted to meet the challenges of climate change.

Three of the six environmental research areas identified in the roadmap relate to the adaptation of land transport networks to the effects of climate change:

- **Global environmental change:** this area requires better modelling to predict future climate change scenarios and enhanced international collaboration. A key challenge is taking an integrated science and socio-economic approach to work out how the country should best adapt to future climate change.
- **Land, water and coasts:** getting the most out of current research investments needs better integration of existing research programmes. Enhanced communication of relevant and user-friendly information to environmental managers is also needed. Data collection and management must be improved.
- **Urban design and hazards:** an urban research agenda that best suits New Zealand needs to be developed. The Ministry of Civil Defence and Emergency Management's 'all hazards' framework and

emphasis on risk reduction are increasingly reflected in research contracts. Work is needed in some areas to improve connections with end-users.

The government's view of how the priority issues need to be taken forward highlight the range of disciplinary capabilities required to gain greatest benefit from future research. These have been summarised as:

- integrated multidisciplinary research, maintaining effective long-term capabilities and international collaborations;
- ensuring the environmental management sector will benefit from and be transformed in the future by research, through greater transfer and uptake of research; and
- additional effort on environmental sensing networks and data.

Improving responses to climate change is one of the projected outcomes from the implementation of the *Environmental Research Roadmap for Science* (MRST 2007).

E7 Emergency management and civil defence policy

The National Civil Defence and Emergency Management Strategy 2007 (Department of Internal Affairs 2008) sets out the vision or goal for civil defence emergency management as being a 'resilient New Zealand, Aotearoa manahau; – communities understanding and managing their hazards'. The strategy encourages New Zealanders to understand the hazards they face, and to act routinely to reduce and avoid the consequences of hazards on the basis that they value the enduring social, economic, cultural and environmental benefits of doing so.

In order to attain the goal of a resilient New Zealand, the strategy is to be applied using of the 'Four Rs':

- risk reduction,
- readiness,
- response, and
- recovery.

Two objectives outlined in the National Civil Defence and Emergency Management Strategy of particular interest are:

- **Objective 2B: Developing a comprehensive understanding of New Zealand's hazardscape:** This seeks to clarify hazard risks in order to identify and prioritise risk reduction activities and inform readiness, response and recovery planning. Central and local government agencies are encouraged to work together with hazard monitoring agencies, emergency services and lifeline utilities to understand hazards and risks better, and to develop more efficient and effective approaches to managing them.
- **Objective 2C: Encouraging all Civil Defence and Emergency Management stakeholders to reduce the risks from hazards to acceptable levels:** This clarifies the role of all stakeholders to take actions to reduce the risks from hazards.

The *September 2007 National Hazardscape Report* (Officials' Committee for Domestic and External Co-ordination 2007) describes key geological, meteorological, biological, technological and social hazards in New Zealand. Climate variability and climate change are identified as important factors influencing hazards in New Zealand. The report anticipates the role of ongoing research leading to greater certainty about the possible impact of climate change, but notes the potential for significant uncertainty. The existing uncertainties are identified as contributing to the difficulties associated with reacting to climate change at a national level.

The report notes that policy makers recognise the importance of adaptation, as it is increasingly reflected in policy and strategic planning documents which deal with issues such as including climate change effects in stormwater system design.

The report notes the importance of demand management and reducing the reliance on land transport networks as part of any resiliency strategy.

The report also notes the aims of the Transport Emergency Management Co-ordination Group (led by the MoT) to co-ordinate responses to critical transport infrastructure failures. The report summarises the role of the group to support the transport sector to make rapid damage assessments, identify critical interdependencies and set regional transport infrastructure recovery priorities. Assessing and responding to climate change effects is not identified as a strategic matter for consideration by the group.

Appendix F Risk assessment methodology

F1 Methodology overview

The general process of risk management is represented in the Joint New Zealand and Australian Risk Management Standard AS/NZS 4360:2004 by the processes shown schematically in Figure F.1 below. This stage of work has proceeded as far as evaluating risk.

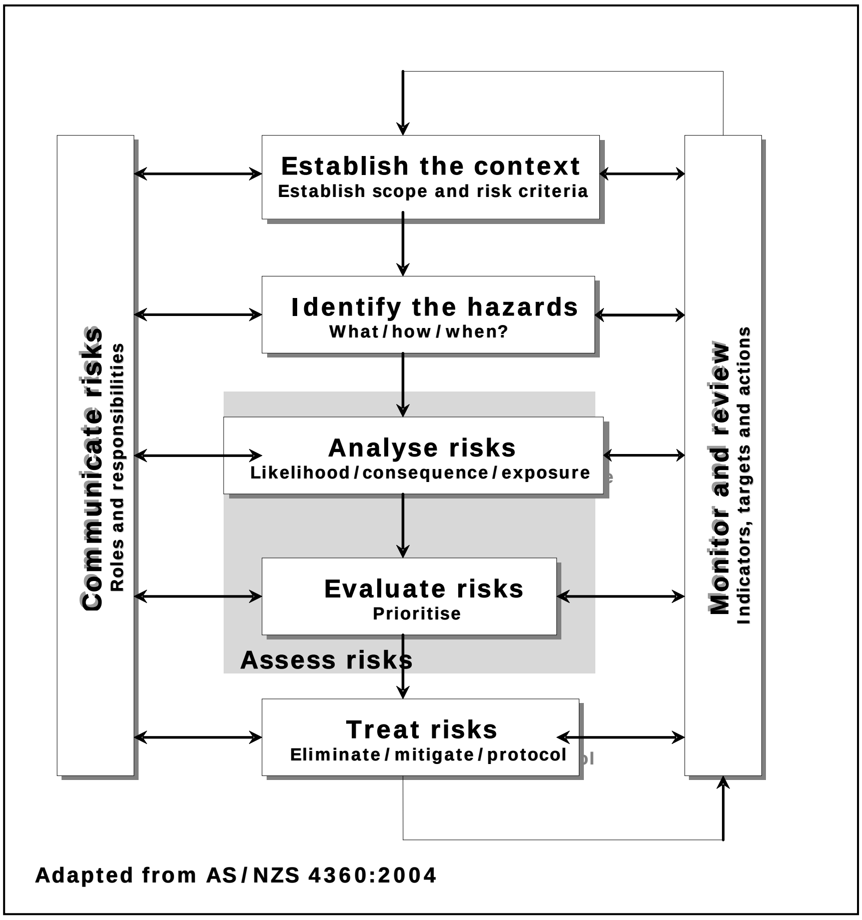

Figure F.1 Risk management framework (taken from AS/NZS 4360:2004).

The risk matrix method as described in Chapter 5 of this report is summarised in the schematic shown in Figure F.2.

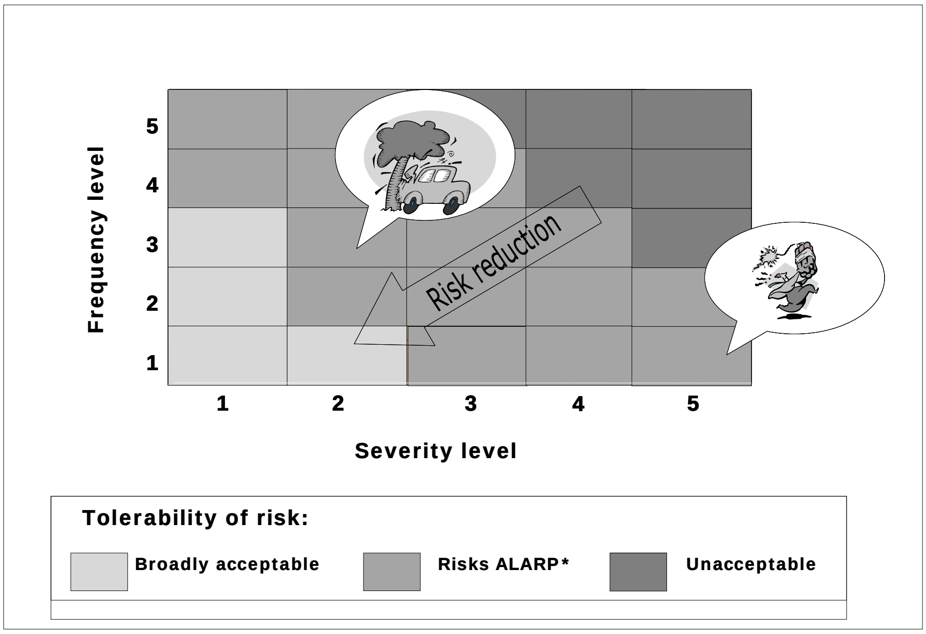

Figure F2 Schematic of risk matrix method used to assess hazards.

*(ALARP – As Low As Reasonably Practicable)

Using this basic risk matrix methodology, the hazards and risks to transport systems were identified and scored using the following broad steps:

1. The risk recording framework and 'scoring' schemes were devised in the form of a risk register template.
2. The mode specialists then populated the risk register using their industry knowledge concentrating on commonly known understandings, but augmented and corroborated by specifically targeted literature reviews.
3. A Risk Workshop was held, involving the mode specialists, climate change experts (NIWA) and others. The workshop focused on the most significant risks identified by the mode specialists and the gaps in the current state of knowledge. The workshop enabled cross-fertilisation among areas of expertise confirming and calibrating the most significant risks within a transport mode and across modes through discussion and agreement.
4. Mode specialists refined their evaluation of risks, taking account of the workshop findings, and with a particular emphasis on the most significant risks and gaps in knowledge.

F2 Risk framework development

The fundamental information sought principally from the mode specialists and recorded in a risk register, was as follows:

- a description of the various detrimental climate change effects on transport infrastructure,
- an assessment of the severity of the consequence of each defined effect,
- an assessment of the likelihood that the defined event and associated consequence occurs,
- a description of any specific trigger points at which fundamentally different actions might be taken to reduce the risk, and
- an assessment of the state of knowledge and hence gaps in that knowledge.

To aid the mode specialists in assigning likelihood and consequence scores, 'prompt lists' were provided that defined the five-point scales to be used. The prompt lists for likelihood and consequence are reproduced in Tables F.1 and F.2, respectively. The corresponding level of risk – 'high', 'moderate' or 'low' – was then determined according to the likelihood–consequence combinations shown in the risk matrix given in Table F.3.

Table F.1 Prompt list for assessing the likelihood scale.

Likelihood scale					
Level	Likelihood	Expectation period	80-year expectation	40-year expectation	Two-year expectation
5	Almost certain	Expected to happen within the next two years.	Certain (~100% chance) to happen within the next 80 years.	Almost certain (>99% chance) to happen within the next 40 years.	Expected (>95% chance) to happen within the next two years.
4	Quite likely	Expected to happen within the next 40 years.	Almost certain (>99% chance) to happen within the next 80 years.	Expected (>95% chance) to happen within the nex t40 years.	5% chance of happening within the next two years.
3	Likely	Expected to happen within the next 80 years.	Expected (>95% chance) to happen within the next 80 years.	50% chance of happening within the next 40 years.	3% chance of happening within the next two years.
2	Possible	Expected to happen within the next 240 years.	30% chance of happening within the next 80 years.	15% chance of happening within the next 40 years.	1% chance of happening within the next two years.
1	Unlikely	Expected to happen within the next 400 years.	20% chance of happening within the next 80 years.	10% chance of happening within the next 40 years.	Very unlikely (<1% chance) to happen within the next two years.

Table F.2 Prompt list for assessing the consequence scores.

Consequence scale							
Level	Consequence	Service delivery	Scope of impact	Economic		Reputation	Health and safety
				Direct cost	Indirect cost		
5	Catastrophic	Long-term shutdown of services (weeks) or extended period of disruption to services (months) where no reasonable alternative is available OR disruption to services for years with a reasonable alternative. Many people affected.	Major national effect	$250 million	$2.5 billion	Major concerns at an international media cover, significant media attention, impact on reputation of industry as a whole.	Many fatalities.
4	Severe	Medium-term shutdown of services (days) or long-term disruption to services (weeks) where no reasonable alternative is available, OR extended disruption to services (months) with a reasonable alternative any people affected.	Minor national effect or multiple major regional effects	$25 million	$250 million	Major concerns at a regional level, sustained national adverse media coverage, major implications within industry.	Many serious injuries and/or multiple fatalities.
3	Major	Short-term shutdown of services (hours) or medium-term disruption to services (days) where no reasonable alternative is available, OR long-term disruption to services (weeks) with a reasonable alternative. Many people affected.	Major regional effect or multiple minor regional effects.	$2.5 million	$25 million	Regional media cover or short-term national cover. Significant local concerns and opposition, and temporary loss of image.	Multiple serious injuries or a fatality.
2	Moderate	Short-term disruption to services (hours) where no reasonable alternative is available, OR medium-term disruption to services (days) with a reasonable alternative. Many people affected.	Minor regional effects or multiple major local effects.	$250,000	$2.5 million	Some local media cover; difficulties and concerns.	Serious injuries.
1	Minor	Little/no disruption to services OR few people affected; issue can be relatively easily overcome.	Major local effect or multiple minor local effects.	<$250,000	<$2.5 million	Possible local media cover. No significant issues regarding image, or cultural or spiritual aspects.	Minor injuries.

Table F.3 Risk matrix combining likelihood and consequence of possible hazards.

Likelihood	Consequence				
	Minor (1)	Moderate (2)	Major (3)	Severe (4)	Catastrophic (5)
Almost certain (5)	Low	Moderate	High	High	High
Very likely (4)	Low	Moderate	High	High	High
Likely (3)	Low	Moderate	Moderate	High	High
Possible (2)	Low	Low	Moderate	Moderate	High
Unlikely (1)	Low	Low	Moderate	Moderate	High

F3 Preliminary evaluation of risk

The mode specialists were asked to populate the risk register prior to the workshop because it was recognised that establishing likely effects would involve them in some significant up-front investigation. However, it was recognised that the mode specialists would have only limited knowledge of the likely severity of climate change effects at that stage. To assist them, NIWA put together a review document giving a collation of perceived understandings about likely climate change effects, with a focus on land transport.

The assessment of risk to transport systems from climate change was found to be particularly challenging because of the high levels of uncertainty involved. These uncertainties arise from:

- **Climate modelling uncertainty:** numerous models of climate change predict a wide range of climate change effects. These models differ principally through the different assumptions made about the future levels of control on emissions of climate changing pollutants.
- **Uncertainty associated with each climate model:** each attempts to predict many years into the future.
- **Uncertainty over the impact** that a specified change in climate will have on transport systems.
- **Uncertainty in the future demands on transport systems** from changes in behaviour resulting from, for example, fuel price rises and legislative instruments, such as tax incentives or disincentives designed to affect behaviour.

The original brief for the project was to consider climate change effects in the context of current transport system usage. Hence judgements by the mode specialists on risk are made on the basis that transport system demand will be broadly the same as today. However, recent evidence shows the effect that fuel prices, among other things, have on transport choice.

In an attempt to simplify the initial evaluation of risk, mode specialists were asked to align their thinking about risks with the level of impact that might result in a fundamental shift in how infrastructure might be designed or maintained, and identify these as 'trigger points'. It was felt that, having defined the level of impact in this way, it would be easier for the mode specialists to assign a likelihood that action would be required. The likelihood that climate change effects would be severe enough for the trigger points to be reached could then be determined separately by climate change experts.

In considering the risks, mode specialists were also asked to assess the current state of knowledge in terms of quantifying the impacts and risks from climate change. Where gaps appear in knowledge, uncertainty in the 'true' level of risk is likely. In these circumstances, mode specialists were asked to score these uncertain sources of risk conservatively. The level of uncertainty for each source of risk was categorised as 'high', 'medium' or 'low', and the following determinations were applied to the risk:

- If the uncertainty was deemed to be 'high' then the risk was automatically put to 'high'.
- If the level of uncertainty was deemed to be 'medium' then the risk was set to at least 'moderate'.

This is consistent with the general principle of taking a precautionary approach in the face of uncertainty.

F4 Risk workshop

A risk workshop was held on 19th May 2008 involving the transport-mode specialists, the project core team members and representatives from NIWA (see Table F.4).

Table F.4 Attendees at the workshop on climate change effects on land transport.

Name	Affiliation
Laurie Gardiner (Chair)	MWH environmental specialist
Brian Kouvelis	MWH local government & water specialist
David Wratt	NIWA climate science
Andrew Tait	NIWA climate science
Debbie Firestone	MWH environmental
Dennis Hynes	Railways mode specialist
Jerry Byfield	Roads mode specialist
John Smart	Coastal shipping mode specialist
Steve Oldfield (Facilitator)	MWH risk specialist
Nicole Mistal (Scribe)	MWH environmental

A short overview of the key principles on climate change for New Zealand was given at the beginning of the workshop to provide a common basis on which to evaluate risks to the transport networks. Thus a key function of the workshop was to 'calibrate' the preliminary risk ratings for different climate change effects and the three transport modes.

Prior to the workshop, the mode specialists identified 44 sources of risk for roads from climate change effects, 71 for railways and 40 for coastal shipping. These ranged from 'high' to 'low' risks but with an emphasis on the most significant. Of the risks identified, 23 of were deemed 'high' for roads, 7 'high' for railways and 11 'high' for coastal shipping. However, a number of these risks were rated as 'high' as a result of a low level of certainty in the actual risk involved. Further study could show that some of these risks may not be high in reality. At this stage, all risks rated as 'high' were retained for further consideration.

The most significant risks rated as 'high' in the preliminary assessment and issues of high uncertainty were the focus of discussions at the workshop. Both the risk ratings and levels of certainty were reviewed and adjusted to fit the climate change principles as presented and discussed at the workshop.

In discussing and re-evaluating the effects of climate change at the workshop, it became increasingly evident that the impacts, and especially the appropriate actions to be taken, were different for designing and planning new infrastructure compared to operating and maintaining existing infrastructure. As a result, the likelihood and consequence scores of each source of risk rated 'high' in the preliminary assessment were re-evaluated separately for new and existing infrastructure.

Following the discussions and deliberations, the number of risks rated as 'high' changed from 23 to 18 for roads, from 7 to 9 for railways and from 11 to 8 for coastal shipping. The majority of these risks arise from changes in rainfall, with sea level rise combined with storm surge being a potential issue for coastal shipping, and prolonged high temperatures being an issue for CWR railway lines in particular.

Details of the risks and gaps in knowledge identified are given Chapters 6, 7 and 8. A copy of the risk register from which they are derived is given in Appendix G.

It is worth noting that the mode specialists identified some climate change effects which could have a positive benefit or realise an opportunity. These included, for example, reduced cold weather working, particularly in the southern regions of New Zealand. However, these opportunities were considered small in comparison to the risks involved and were not pursued further in this study.

F5 Post-workshop considerations

Following the workshop, the risk register was calibrated to match the findings from the workshop, and the ‘high’ and ‘uncertain’ risks were short-listed for attention in future work. The main findings in terms of the high risks and gaps in knowledge for each road, rail and costal shipping are described in Chapters 6, 7 and 8, respectively.

Appendix G Risk register

G1 Threats and opportunities affecting the road network

Table G.1 Risk register of possible threats to the road network caused by climate change.

Aspect		Risk reference number					
		RD 26	RD7	RD18	RD19	RD11	RD17
Climate change effect category		Inland erosion and instability.	Rainfall	Flooding	Flooding	Rainfall	Flooding
Description of hazard, and its cause and effect		Roads washed away, cutting off parts of the country.	Increased number of washouts caused by high intensity falls.	Bridges washed away because of damage.	Increased washouts caused by higher and faster river flows.	Damage to bridge structures from higher river levels flows and increased debris.	Bridges damaged by higher water level and potential debris.
Level of certainty		Medium	Medium	Medium	Medium	Medium	Medium
Likelihood		Almost certain	Almost certain	Very likely	Almost certain	Very likely	Very likely
Consequence		Catastrophic	Severe	Catastrophic	Severe	Severe	Severe
Risk*		High	High	High	High	High	High
Risk modified by certainty		High	High	High	High	High	High
Locations**		Nationwide	Nationwide	Nationwide	Nationwide	Nationwide	Nationwide
Potential responses	Reinstate/status quo	N/A	Reinstate road if possible.	Replace	Reinstate road if possible.	Repair	Repair
	Protect	N/A	Protect steep banks.	Protect structure from future damage.	Protect steep banks.	Protect structure from future damage.	Protect structure from future damage; Monitor potential upriver debris.
	Modify	N/A	–	Modify profile/ design.	–	Modify profile/ design.	Modify profile/ design.
	Move/rebuild	Realignment at critical locations.	Realignment at critical locations.	Rebuild higher with increased protection. Consider alternative location or tunnel.	Realignment at critical locations.	Rebuild higher with increased protection. Consider tunnel.	Rebuild higher with increased protection. Consider tunnel.
Comments		–	–	Bridges generally have a 100-year design life, therefore all new bridges should account for predicted climate change effects.	–	Bridges generally have a 100-year design life, therefore all new bridges should account for predicted climate change effects.	Bridges generally have a 100-year design life, therefore all new bridges should account for predicted climate change effects.

* likelihood x consequence

** critical locations, factors which determine critical locations, geographical variation and comments

Table G.1 (cont.) **Risk register of possible threats to the road network caused by climate change.**

Aspect		**Risk reference number**					
		RD12	RD5	RD8	RD9	RD24	RD25
Climate change effect category		Rainfall	Rainfall	Rainfall	Rainfall	Inland erosion and instability	Inland erosion and instability
Description of hazard, and its cause and effect		Increased 'loss of control' crashed because of longer periods of reduced grip owing to surface water.	Increased flooding from high intensity falls.	Increased number of slips caused by high intensity falls and higher water table.	Increased road closures owing to slip debris.	Increased road closures owing to slip debris.	Increased road closures owing to washouts.
Level of certainty		Medium	Medium	Medium	Medium	Medium	Medium
Likelihood		Almost certain	Almost certain	Almost certain	Almost certain	Almost certain	Almost certain
Consequence		Major	Major	Major	Major	Major	Major
Risk*		High	High	High	High	High	High
Risk modified by certainty		High	High	High	High	High	High
Locations**		Nationwide	Nationwide	Nationwide	Nationwide	Nationwide	Nationwide
Potential responses	Reinstate/status quo	N/A	Clean up.	Clean up and reinstate if possible.	–	Clean up and reinstate if possible.	Reinstate road if possible.
	Protect	N/A	Improve flood protection where possible.	Remove/ protect steep banks.	Remove/ protect steep banks.	Remove/ protect steep banks.	Protect steep banks.
	Modify	Improve surface water drainage.	Improve drainage facilities.	–	–	–	–
	Move/rebuild	Rebuild with improved surface water damage.	Consider raising road.	Realignment at critical locations.	Realignment at critical locations.	Realignment at critical locations.	Realignment at critical locations.
Comments		–	–	–	–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.1 (cont.) **Risk register of possible threats to the road network caused by climate change.**

Aspect		**Risk reference number**					
		RD41	RD44	RD40	RD33	RD27	RD20
Climate change effect category		Costal flooding	Coastal flooding	Coastal erosion	Wind	Inland erosion and instability	Flooding
Description of hazard, and its cause and effect		Roads washed away, cutting off parts of the country.	Roads flooded, cutting off parts of the country.	Increased erosion causing damage to roads, or road closures.	Increased number of vehicles blown off road or overturned.	Flooding as a result of blocked culverts and ditches.	Increased hazardous driving conditions.
Level of certainty		Medium	Medium	Medium	Medium	Medium	Medium
Likelihood		Likely	Likely	Likely	Almost certain	Likely	Likely
Consequence		Catastrophic	Severe	Severe	Moderate	Major	Major
Risk*		High	High	High	High	Moderate	Moderate
Risk modified by certainty		High	High	High	High	Moderate	Moderate
Locations**		State Highway 1 north of Kaikoura and north of Dunedin susceptible.	State Highway 1 north of Kaikoura and north of Dunedin susceptible.	Coastal roads nationwide and those next to tidal rivers/harbours.	Nationwide, especially in exposed areas and those known to suffer from high winds.	Nationwide	Nationwide
Potential responses	Reinstate/status quo	Not status quo	Not status quo	Reinstate	N/A	Repair	N/A
	Protect	Erosion protection works.	Erosion protection works.	Erosion protection works.	Provide wind barriers at known locations.	N/A	N/A
	Modify	Modify coastal protection works.	Modify coastal protection works.	Modify coastal protection works.	N/A	Increase size of culverts.	Improve surface drainage.
	Move/rebuild	Realignment at critical locations.	Realignment at critical locations.	Realignment at critical locations.	Realignment at critical locations.	Rebuild for increased flows.	N/A
Comments		–	–	–	–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.1 (cont.) **Risk register of possible threats to the road network caused by climate change.**

Aspect		Risk reference number					
		RD36	RD38	RD1	RD10	RD15	RD42
Climate change effect category		Wind	Wind	High temperature	Rainfall	Rainfall	Coastal flooding
Description of hazard, and its cause and effect		Increased damage to signs and infrastructure (including bridges) by stronger winds.	Increase in extreme wind events such as tornadoes and cyclones.	Prolonged higher temperatures and/or higher average temperatures increasing incidence of bleeding and other surface defects.	Damage to culverts not designed for high flows.	Increased sediments blocking existing drainage features.	Increased salinity inland increasing corrosion of structures and leading to a shorter lifespan.
Level of certainty		Medium	Medium	Very high	Medium	Medium	Very high
Likelihood		Very likely	Very likely	Very likely	Very likely	Very likely	Very likely
Consequence		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Risk*		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Risk modified by certainty		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Locations**		Nationwide, particularly in exposed areas and those know to suffer from high winds.	Nationwide	Nationwide: Those locations that are currently exposed to high temperatures will be exposed for longer periods and/or to higher temperatures. Locations not exposed to high temperatures may become so.	Nationwide	Nationwide	River bridges near to the coast.
Potential responses	Reinstate/status quo	Reinstate	N/A	Repair and reinstate	Repair	Maintain	N/A
	Protect	N/A	Cannot protect asset but can warn users.	N/A	N/A	–	100-year design life negates need for protection.
	Modify	Improve design of signs and supports.	N/A	Change design standards to take account of increased temperatures and affect on road construction.	Increase size of culverts.	–	–
	Move/rebuild	Can be moved if required.	N/A	N/A	Rebuild for increased flows.	Alter future design standard.	Take account of possible changes for future construction.
Comments		–	–	New Zealand roads already suffer from bleeding and defects in warm weather. Better design for warmer climates should be considered for all future works notwithstanding 25-year design life.	–	–	–

* likelihood x consequence

** critical locations, factors which determine critical locations, geographical variation and comments

Table G.1 (cont.) **Risk register of possible threats to the road network caused by climate change.**

Aspect		**Risk reference number**					
		RD2	RD39	RD29	RD13	RD14	RD22
Climate change effect category		Low temperature	Fog and humidity	Storms	Rainfall	Rainfall	Drought
Description of hazard, and its cause and effect		Increased incidence of surface effects from an increase in freeze/ thaw cycles.	Increased fog reduces visibility, leading to an increase in vehicle crashes.	Increased exposure to sudden events, e.g. blizzards and hailstorms.	Increased runoff, causing environmental problems.	Faster deterioration of gravel road surfaces.	Increased risk of carcinogens released from increased oiling of gravel roads.
Level of certainty		High	Low	Low	Medium	Medium	Medium
Likelihood		Likely	Likely	Possible	Likely	Likely	Likely
Consequence		Moderate	Moderate	Major	Moderate	Moderate	Moderate
Risk*		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Risk modified by certainty		Moderate	High	High	Moderate	Moderate	Moderate
Locations**		Nationwide: Those locations that are currently exposed to freezing temperatures will experience more freeze/ thaw cycles owing to milder winters.	Nationwide	Nationwide, particularly at higher altitudes.	Nationwide	Nationwide	Nationwide
Potential responses	Reinstate/status quo	Repair and reinstate.	N/A	N/A	N/A	Reinstate surface.	Not status quo.
	Protect	N/A	N/A	N/A	N/A	N/A	N/A
	Modify	Change design standards to take account of increased freeze/thaw action.	Fog monitoring and variable message signs system.	N/A	Use of sinks.	Modify construction technique.	Modify treatment method.
	Move/rebuild	N/A	N/A	N/A	N/A	Over time, the number of unsealed roads will reduce.	Over time, the number of unsealed roads will reduce.
Comments		Specialised design and construction required. See Crown Range performance. Fluctuation in extreme damage that cause the problems, and the number of freeze/thaw cycles.	–	–	–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.1 (cont.) **Risk register of possible threats to the road network caused by climate change.**

Aspect		**Risk reference number**					
		RD34	RD35	RD16	RD30	RD47	RD45
Climate change effect category		Wind	Wind	Rainfall	Snow	Lightning	Wildfire
Description of hazard, and its cause and effect		Increased number of temporary closures caused by wind.	Increased number of bridge restrictions caused by wind.	Rivers realign themselves because of increased flow rates and increased volume.	Increased snowmelt contributes to flooding issues.	Roadside fires in dry conditions.	Roadside fires cause damage to equipment and vegetation.
Level of certainty		Medium	Medium	Medium	Unknown	Unknown	Low
Likelihood		Almost certain	Almost certain	Unlikely	Possible	Possible	Likely
Consequence		Minor	Minor	Catastrophic	Moderate	Minor	Minor
Risk*		Moderate	Moderate	Moderate	Low	Low	Low
Risk modified by certainty		Moderate	Moderate	Moderate	High	High	High
Locations**		Nationwide, particularly in exposed areas and those known to suffer from high winds.	Nationwide, particularly in exposed areas and those known to suffer from high winds.	Nationwide	Nationwide, particularly at higher altitudes.	–	–
Potential responses	Reinstate/status quo	N/A	N/A	N/A	N/A	–	–
	Protect	N/A	Provide wind barriers at known locations.	N/A	N/A	–	–
	Modify	N/A	Provide wind barriers at known locations.	N/A	N/A	–	–
	Move/rebuild	Realignment at critical locations.	Provide wind barriers at known locations.	N/A	N/A	–	–
Comments		–	–	Asset owners eventually have to accept the inevitable.	–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.1 (cont.) **Risk register of possible threats to the road network caused by climate change.**

Aspect	Risk reference number					
	RD46	RD6	RD3	RD21	RD37	RD4
Climate change effect category	Wildfire	Rainfall	High temperatures	Drought	Wind	High temperatures
Description of hazard, and its cause and effect	Roadside fires disrupt traffic.	Increased flooding owing to higher water tables.	Higher temperatures and drier atmosphere leading to increased dust pollution from gravel roads.	Increase in wandering stock, causing road safety issues.	Increased number of temporary road closured because of windblown sand in coastal areas.	Release of carcinogens from increased use of oil as a dust suppressant on gravel roads.
Level of certainty	Low	Medium	Very high	Medium	Medium	Very high
Likelihood	Likely	Possible	Very likely	Likely	Possible	Possible
Consequence	Minor	Moderate	Minor	Minor	Minor	Minor
Risk*	Low	Low	Low	Low	Low	Low
Risk modified by certainty	High	Moderate	Moderate	Moderate	Moderate	Low
Locations**	–	Nationwide	Nationwide	Nationwide	Nationwide coastal locations, particularly in exposed areas and those known to suffer from high winds.	Nationwide
Potential responses – Reinstate/status quo	–	Clean up	Do nothing	N/A	Clean up	Review method of dust suppression.
Potential responses – Protect	–	Improve flood protection where possible.	N/A	Better fencing alongside roads.	Protect sand deposits.	Review method of dust suppression.
Potential responses – Modify	–	Improve drainage facilities.	Some unsealed roads will become sealed over time.	Better fencing alongside roads.	Modify sand deposits.	Some unsealed roads will become sealed over time.
Potential responses – Move/rebuild	–	Consider raising road.	N/A	N/A	Realignment at critical locations.	N/A
Comments	–	–	Already an issue in some areas; will only increase with drier/warmer conditions.	–	–	Use of old engine oil as a dust suppressant is already a concern in some areas.

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.2 Risk register of possible opportunities to the road network caused by climate change.

Aspect		Risk reference number		
		RD28	RD31	RD32
Climate change effect category		Low temperatures	Low temperatures	Low temperatures
Description of hazard, and its cause and effect		Reduced frequency of road closures with shorter snow season.	Decrease in ice- and snow-related crashes because of an increase in mean winter temperatures.	Decrease in ice- and snow-related maintenance because of increase in mean winter temperatures.
Level of certainty		High	Very high	Very high
Likelihood		Very likely	Almost certain	Almost certain
Consequence		Major	Moderate	Moderate
Risk*		High	High	High
Risk modified by certainty		High	High	High
Locations**		Nationwide, particularly at higher altitudes.	–	–
Potential responses	Reinstate/status quo	Clean up	–	–
	Protect	N/A	–	–
	Modify	N/A	–	–
	Move/rebuild	N/A	–	–
Comments		–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

G2 Threats and opportunities affecting the rail network

Table G.3 Risk register of possible threats to the rail network caused by climate change.

Aspect		Risk reference number			
		RL48	RL18	RL45	RL30
Climate change effect category		Rainfall	High temperatures	Rainfall	Inland erosion and instability
Description of hazard, and its cause and effect		Raised water tables and/or soil moisture causing ground instability and leading to failure of hillsides, requiring extensive repairs and causing shutdown of railway for an extended period; potential for consequential damage to freight and equipment, and injury/ death to personnel/ passengers.	Railway lines buckle and are permanently damaged, requiring extensive repairs and causing shutdown of railway for an extended period; potential for consequential damage to freight and equipment, and injury/death to personnel/passengers.	Culvert failure/inadequate drainage leading to track washout requiring extensive repairs and causing shutdown of railway for an extended period; potential for consequential damage to freight and equipment, and injury/death to personnel/passengers.	Increase in magnitude of 100-year rain events and/or cumulative rainfall causes more large landslides requiring extensive repairs and causing shutdown of railway for an extended period; potential for consequential damage to freight and equipment, and injury/death to personnel/passengers.
Level of certainty		Medium	Very high	Medium	Medium
Likelihood		Very likely	Very likely	Very likely	Very likely
Consequence		Severe	Severe	Major	Major
Risk*		High	High	High	High
Risk modified by certainty		High	High	High	High
Locations**		Known slip planes.	System-wide: Rail track is generally designed for neutral temperature (36°C). Legacy of lower maintenance standards have exposed much of the system to risk from higher temperatures (especially areas of continuous welded rail (CWR) which has not yet been de-stressed).	System-wide	Geology of country is generally young with significant sections of line constructed across known slip faces.
Potential responses	Reinstate/ status quo	Inspection, temporary speed restrictions (TSR).	Rail temp >40°C; impose 'Heat 40 TSR' (unless section of track proven stable at higher temperatures).	Inspection, TSR	Inspection, monitoring, regular maintenance.
	Protect	Geotechnical assessments to identify at-risk sites; inspection and protection works.	Heat 40 TSR, increased rate of track stabilising/distressing.	–	–
	Modify	–	Raise standards for CWR installation, monitoring and maintenance. Upgrade materials. Trigger point will be safety, financial and/or service driven.	Upgrade substandard culverts and drainage.	Design/construct retaining measures, for sites with active movement and/or high risk sites. Triggers will be financial, service and safety driven.
	Move/rebuild	Relocate line to avoid at-risk site or retaining/dewatering work to lower risk.	–	New installations to new design criteria accounting for expected storm intensities/ return periods.	–
Comments		–	Internationally rail systems already operate in wider extremes of temperature than the New Zealand rail system. Assuming New Zealand adopts similar standards of infrastructure and maintenance, it could accommodate wider ranges than currently experienced.	Identified by ONTRACK (2007) as third highest risk, with 960 culverts & associated drainage rated 4or 5, and 600+ sites at risk of washout.	ONTRACK has commissioned system-wide studies to identify key erosion risk sites. Identified by ONTRACK as second highest risk, with 200 potential sites.

* likelihood x consequence

** critical locations, factors which determine critical locations, geographical variation and comments

Table G.3 (cont.) **Risk register of possible threats to the rail network caused by climate change.**

Aspect		**Risk reference number**			
		RL11	RL9	RL46	RL47
Climate change effect category		Flooding	Flooding	Rainfall	Rainfall
Description of hazard, and its cause and effect		Flash flood and debris affect bridges requiring more frequent inspections and repairs, and causing shutdown of railway for an extended period; potential for consequential structural failure and damage to freight and equipment, and injury/death to personnel/ passengers.	Increased scour of bridge piers, river bank protection works etc. requiring extensive repairs and causing shutdown of railway for an extended period; potential for consequential structural failure and damage to freight and equipment, and injury/death to personnel/ passengers.	Inadequate drainage/minor slips causing failure of the formation and fouling of ballast, resulting in twist/top/cant exceedances requiring frequent repairs and potential for consequential damage to freight and equipment, and injury/death to personnel/ passengers.	Raised water tables and/or soil moisture causing ground instability, leading to localised slips/debris onto the track and/or embankment failure/dropout requiring increased inspections and frequent repairs, and causing shutdown of railway for a short periods; potential for consequential damage to freight and equipment, and injury/death to personnel/ passengers.
Level of certainty		Medium	Medium	Medium	Medium
Likelihood		Very likely	Very likely	Very likely	Very likely
Consequence		Major	Major	Major	Major
Risk*		High	High	High	High
Risk modified by certainty		High	High	High	High
Locations**		–	Significant number of bridges with non-standard founding depth (~100 bridges).	Generally young geology of country and legacy of lower maintenance standards have resulted in widespread mud spots across the network.	System-wide
Potential responses	Reinstate/status quo	Inspection	Inspection	Inspection TSR	Inspection TSR
	Protect	Debris traps	Extend use of flood warning systems; protect/strengthen at–risk piers.	–	Retaining/dewatering of sites showing movement.
	Modify	Protect/strengthen at-risk piers, screen bridge stocks using design criteria accounting for expected storm intensities/return periods.	Protect/strengthen at-risk piers, screen bridge stocks using design criteria accounting for expected storm intensities/return periods.	Upgrade substandard culverts and drainage.	–
	Move/rebuild	–	New construction using design criteria accounting for expected storm intensities/return periods.	–	–
Comments		–	–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.3 (cont.) **Risk register of possible threats to the rail network caused by climate change.**

Aspect		**Risk reference number**			
		RL19	RL12	RL49	RL53
Climate change effect category		High temperature	Flooding	Rainfall	Rainfall
Description of hazard, and its cause and effect		More frequent high temperatures exceeding the trigger point for imposing 'Heat 40' speed restrictions, resulting in increase in delays to services and increased frequency of inspections.	Privately owned structures (e.g. irrigation dams on neighbouring farms) fail, causing flash floods and washout of rail embankments, requiring extensive repairs and causing shutdown of railway for an extended period; potential for consequential damage to freight and equipment, and injury/death to personnel/passengers.	Raised water tables and/or soil moisture causing hydrostatic build-up behind retaining walls and abutments.	Raised water tables and/or soil moisture causing ground instability, leading to increased incidence of blocked lines for short periods by trees blown onto the track or damage to overhead traction wires, resulting in delays to services, with potential for consequential damage to freight and equipment, and injury/death to personnel/ passengers.
Level of certainty		Very high	Medium	Medium	Medium
Likelihood		Almost certain	Likely	Very likely	Very likely
Consequence		Moderate	Major	Moderate	Moderate
Risk*		High	Moderate	Moderate	Moderate
Risk modified by certainty		High	Moderate	Moderate	Moderate
Locations**		System-wide: Rail track is generally designed for neutral temperature (36°C). Legacy of lower maintenance standards have exposed much of the system to risk from higher temperatures (especially areas of CWR which has not yet been de-stressed).	–	–	–
Potential responses	Reinstate/status quo	Rail temp >40°C: impose 'Heat 40 TSR' (unless section of track is proven stable at higher temperatures); inspection.	–	–	Inspect
	Protect	Heat 40 TSR, inspection, increased rate of track stabilising/de-stressing.	–	–	–
	Modify	Raise standards for CWR installation, monitoring and maintenance. Upgrade materials. Trigger point will be financial and/or service driven.	–	–	–
	Move/rebuild	–	–	–	Remove at-risk trees.
Comments		Legacy of lower maintenance standards has exposed much of the system to risk from higher temperatures (especially areas of CWR which has not yet been de-stressed).	–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.3 (cont.) Risk register of possible threats to the rail network caused by climate change.

Aspect		Risk reference number			
		RL39	RL22	RL6	RL64
Climate change effect category		Low temperatures	High temperatures	Drought	Wind
Description of hazard, and its cause and effect		More frequent/lower low temperatures. Greater frequency of joints pulling apart and rail breaks requiring frequent repairs and potential for consequential damage to freight and equipment, and injury/death to personnel/passengers.	Increased restrictions on maintenance activities, e.g. tampers.	Extremes in level of water table resulting in increased shrinkage of cohesive soils and peat, leading to possible settlement of structures, overhead traction poles etc. and twist/top/cant exceedances requiring frequent repairs; potential for consequential damage to freight and equipment, and injury/death to personnel/passengers.	Increased incidence of blocked lines for short periods by trees blown onto the track or damage to overhead traction wires, resulting in delays to services, with potential for consequential damage to freight and equipment, and injury/death to personnel/passengers.
Level of certainty		Very high	Very high	Medium	Medium
Likelihood		Very likely	Very likely	Very likely	Likely
Consequence		Moderate	Moderate	Moderate	Moderate
Risk*		Moderate	Moderate	Moderate	Moderate
Risk modified by certainty		Moderate	Moderate	Moderate	Moderate
Locations**		System-wide: Legacy of lower maintenance standards have exposed much of the system to risk from low temperatures. Sections without signalling present greater potential for derailment from undetected breaks.	System -wide: Rail track is generally designed for neutral temperature (36°C). Legacy of lower maintenance standards have exposed much of the system to risk from higher temperatures (especially areas of CWR which has not yet been de-stressed).	Track crossing peat swamps e.g. Whangamarino, Ruahura and Rukahia.	–
Potential responses	Reinstate/ status quo	Increase joint maintenance.	Stop work at rail temperatures >40°C.	Inspection and increased frequency of ballast tamping and geometry correction.	Inspection >25 m/s.
	Protect	Increased ultrasonic testing for rail defects; increased rate of repair/ maintenance.	–	–	Vegetation control
	Modify	Raise standards for CWR installation, monitoring and maintenance. Upgrade materials. Trigger point will be safety, financial and/or service driven.	Shift mainentance activities to cooler parts of day/year.	–	Programme to clear trees from corridor.
	Move/rebuild	Replace existing at-risk rail and area of jointed track with new heavyweight CWR.	–	–	–
Comments		Legacy of lower maintenance standards have exposed much of the system to risk from low temperatures (converse of the high temperature problems). Internationally, rail systems already operate in wider extremes of temperature than does the New Zealand rail system. Assuming New Zealand adopts similar standards of infrastructure and maintenance, it could accommodate wider ranges than currently experienced.	–	Rail structure designed to accommodate significant deflection, readily corrected with mechanical tamping/ lining.	Sometimes a contentious issue with adjoining landowners who want shelter and noise protection from rail corridor. Many line side trees that are large enough to cause disruption are not on railway land.

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.3 (cont.) **Risk register of possible threats to the rail network caused by climate change.**

Aspect		**Risk reference number**				
		RL61	RL57	RL54	RL55	RL40
Climate change effect category		Wildfire	Storms	Rainfall	Rainfall	Low temperatures
Description of hazard, and its cause and effect		Increased incidence of trackside fires caused by sparks from trains.	Increased incidence of blocked lines for short periods by trees blown onto the track or damage to overhead traction wires, resulting in delays to services, with potential for consequential damage to freight and equipment, and injury/death to personnel/ passengers.	Increased rail service disruption and inspection as a safety precaution against embankment failure.	Raised water tables, saturated track beds and potential of reduced ballast electrical resistance causing track circuit failures, leading to signal failures and disruption to traffic.	Greater frequency of frozen points, requiring frequent repairs and potential for consequential damage to freight and equipment, and injury/death to personnel/ passengers.
Level of certainty		Low	Low	Medium	Medium	Very high
Likelihood		Likely	Likely	Likley	Likely	Likely
Consequence		Moderate	Moderate	Moderate	Moderate	Moderate
Risk*		Moderate	Moderate	Moderate	Moderate	Moderate
Risk modified by certainty		High	High	Moderate	Moderate	Moderate
Locations**		–	–	System-wide	–	Sub-alpine areas, Central Plateau, Arthurs Pass.
Potential responses	Reinstate/status quo	Adapt current vegetation management over time.	Inspection >25 m/s.	Inspect	Inspect input block working.	Inspection and maintenance.
	Protect	–	Vegetation control.	–	–	Install heaters on high-risk equipment.
	Modify	Clear growth from corridor.	Programme to clear trees from corridor.	–	–	–
	Move/rebuild	–	–	–	Upgrade track drainage and install pumps in low-lying areas.	–
Comments		–	–	–	Raise track level in relation to water table.	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.3 (cont.) Risk register of possible threats to the rail network caused by climate change.

Aspect		**Risk reference number**					
		RL29	RL34	RL35	RL14	RL15	RL2
Climate change effect category		Inland erosion and instability	Inland erosion and instability	Inland erosion and instability	Flooding	Flooding	Coastal flooding
Description of hazard, and its cause and effect		Fluctuations in rainfall leading to increased deep cracking of soil and/or build up of pore water pressure reducing shear strength.	Soil erosion from surrounding ground combined with over-track flow paths for heavy rainfall, causing ballast contamination, increase in formation failure and decrease in track condition.	Increase of drought conditions causing increase in soil erosion when one-off rain events occur.	Increased rail service disruption and inspections as a safety precaution against possible flooding.	Localised flooding causing shorting out of electrical equipment, signalling or overhead line power.	Coastal defences overtopped and scoured, leading to washout and potential for consequential damage to freight and equipment, and injury/death to personnel/ passengers.
Level of certainty		Medium	Medium	Medium	Medium	Medium	Very high
Likelihood		Likely	Likely	Likely	Likely	Likely	Possible
Consequence		Moderate	Moderate	Moderate	Moderate	Moderate	Major
Risk*		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Risk modified by certainty		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Locations**		–	–	–	–	–	–
Potential responses	Reinstate/status quo	–	Inspection, monitoring and regular maintenance.	–	Inspection	Pumping water away, drying out equipment.	Inspection; stop trains when embankment is overtopped.
	Protect	–	–	–	Extend use of flood warning systems.	–	Extend use of flood warning systems
	Modify	–	Improve track drainage to prevent over-track flooding.	–	–	–	Strengthen coastal defences at high-risk sites. Triggers will be financial, service and safety driven.
	Move/rebuild	–	–	–	–	Relocating equipment away from flooding source.	Realign
Comments		–	–	–	–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.3 (cont.) Risk register of possible threats to the rail network caused by climate change.

Aspect		**Risk reference number**				
		RL63	RL56	RL16	RL5	RL31
Climate change effect category		Wildfire	Wind	Fog and humidity	Coastal flooding	Inland erosion and instability
Description of hazard, and its cause and effect		Increased controls on 'hot works' during high fire risk periods.	Overhead traction lines out of alignment, causing dewirement, and torn down by pantograph.	Visibility reduced below signal sighting distance, resulting in signals passed at danger and potential for collision and consequential damage to freight and equipment, and injury/death to personnel/passengers; speed restrictions.	Increased rail service disruption and inspections as a safety precaution against possible flooding.	Increased incidence of blocked lines for short periods by small slips caused by increasing frequency of rain events which cause small landslides, resulting in delays to services increased inspections and repairs.
Level of certainty		Low	Medium	Low	Medium	Medium
Likelihood		Likely	Possible	Likely	Likely	Almost certain
Consequence		Moderate	Major	Moderate	Moderate	Minor
Risk*		Moderate	Moderate	Moderate	Moderate	Moderate
Risk modified by certainty		High	Moderate	High	Moderate	Moderate
Locations**		–	–	–	–	Geology of country is generally young, with significant sections of line constructed along known slip faces.
Potential responses	Reinstate/status quo	Inspection	Inspection and TSR >30 m/s.	TSR	Inspection	Inspection, monitoring and regular maintenance.
	Protect	–	–	–	Extend use of flood warning systems.	–
	Modify	–	–	–	–	Design/construct retaining measures for sites with active movement and/or high risk sites. Triggers will be financial, service and safety driven.
	Move/rebuild	–	–	–	–	–
Comments		–	–	–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.3 (cont.) Risk register of possible threats to the rail network caused by climate change.

Aspect		Risk reference number					
		RL38	RL65	RL66	RL70	RL62	RL58
Climate change effect category		Lightning	Wind	Wind	Wind	Wildfire	Storms
Description of hazard, and its cause and effect		Increased danger from lightning to trackside workers (e.g. those working on gantries or near trees).	Impact on vehicle safety.	Increased wind damage to buildings and rail-side infrastructure e.g. overhead traction lines out of alignment, causing dewirement, and torn down by pantograph.	Increased wind damage to buildings and railside infrastructure.	Increased risk of trackside fires, resulting in damage of equipment and vegetation within and outside the rail corridor; train delays and fire fighting costs. Potential for water shortages for fire fighting.	Effect on vehicle stability.
Level of certainty		Unknown	Medium	Medium	Medium	Low	Low
Likelihood		Possible	Possible	Possible	Possible	Possible	Possible
Consequence		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Risk*		Low	Low	Low	Low	Low	Low
Risk modified by certainty		High	Moderate	Moderate	Moderate	High	High
Locations**		–	Isolated 'funnels', high exposed viaducts, etc.	–	–	–	Isolated 'funnels', high exposed viaducts, etc.
Potential responses	Reinstate/status quo	–	Stop trains at at-risk sites >30 m/s.	Inspection; TSR >30 m/s.	–	Adapt current vegetation management over time.	Stop trains at at-risk sites >30 m/s.
	Protect	–	–	–	–	–	–
	Modify	–	Wind fences at at-risk sites.	–	–	Clear growth from corridor.	Wind fences at at-risk sites.
	Move/rebuild	–	–	–	–	–	–
Comments		–	–	–	–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.3 (cont.) **Risk register of possible threats to the rail network caused by climate change.**

Aspect		Risk reference number				
		RL36	RL37	RL32	RL20	RL26
Climate change effect category		Lightning	Lightning	Inland erosion and instability	High temperatures	High temperatures
Description of hazard, and its cause and effect		Increased numbers of lightning strikes causing power outages.	Increased numbers of lightning strikes causing damage to infrastructure.	River bank erosion affecting rail lines, resulting in delays to services, and increased inspections and repairs.	Increased degradation of structures from pest infestation e.g. damaging marine organisms (e.g. toledo worm, which damages timber bridge piles) found further south, requiring increased inspection and remedial works.	Generally higher temperatures and higher extreme temperatures causing thermal expansion of bridge joints.
Level of certainty		Unknown	Unknown	Medium	Very high	Very high
Likelihood		Possible	Possible	Possible	Possible	Possible
Consequence		Moderate	Moderate	Moderate	Moderate	Moderate
Risk*		Low	Low	Low	Low	Low
Risk modified by certainty		High	High	Moderate	Low	Low
Locations**		–	–	–	Timber structures in estuarine locations.	–
Potential responses	Reinstate/status quo	–	–	Inspection, monitoring and regular maintenance.	Inspection/ maintenance	–
	Protect	–	–	–	Increased inspection	–
	Modify	–	–	Design/construct retaining measures, for sites with active movement and/or high risk sites. Triggers will be financial, service and safety driven.	–	–
	Move/rebuild	–	–	Realignment to avoid erosion.	Replace at-risk components.	–
Comments		–	–	–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.3 (cont.) Risk register of possible threats to the rail network caused by climate change.

Aspect		Risk reference number					
		RL10	RL13	RL8	RL3	RL1	RL33
Climate change effect category		Flooding	Flooding	Drought	Coastal flooding	Coastal flooding	Inland erosion and instability
Description of hazard, and its cause and effect		Embankments overtopped in low-lying areas, resulting in more frequent and/or lengthy closures.	Flooding undermining trackside equipment, e.g. overhead gantries.	Increased risk of trackside fires, resulting in damage of equipment and vegetation within and outside the rail corridor, train delays and fire fighting costs; potential for water shortages for fire fighting.	Embankments overtopped by waves in low-lying areas, resulting in more frequent and/or lengthy line closures.	Increased coastal erosion rates threatening rail lines in coastal areas.	Increased rail service disruption and inspections as a safety precaution against embankment failure.
Level of certainty		Medium	Medium	Medium	Very high	Medium	Medium
Likelihood		Possible	Possible	Possible	Possible	Possible	Likely
Consequence		Moderate	Moderate	Moderate	Moderator	Moderate	Minor
Risk*		Low	Low	Low	Low	Low	Low
Risk modified by certainty		Moderate	Moderate	Moderate	Low	Moderate	Moderate
Locations**		Low-lying embankments in flood-prone river systems and catchments.	–	–	–	–	–
Potential responses	Reinstate/ status quo	Inspection; Stop trains when embankment is overtopped.	–	–	Inspection; stop trains when embankment is overtopped.	Inspection	Inspection, monitoring and regular maintenance.
	Protect	Extend use of flood warning systems.	–	–	Extend use of flood warning systems.	–	–
	Modify	Raise embankments when occurrences justify expenditure.	–	–	Raise embankments when occurrences justify expenditure.	–	–
	Move/rebuild	–	–	Clear vegetation	–	–	–
Comments		–	–	–	–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.3 (cont.) Risk register of possible threats to the rail network caused by climate change.

Aspect		**Risk reference number**					
		RL21	RL4	RL67	RL68	RL69	RL59
Climate change effect category		High temperatures	Coastal flooding	Wind	Wind	Wind	Storms
Description of hazard, and its cause and effect		Increased vegetation/longer growing seasons causing visual obstructions, fire risk etc., requiring increased controls and extended maintenance periods.	Increased salt water corrosion from floods and sea spray from more severe storms and/or storm surges.	Wind-borne missiles hitting trains and passengers.	Restrictions on loading/ unloading freight in high winds.	Increased rail service disruption and inspections as a safety precaution against possible wind effects.	Increased snowfall in alpine regions, increased inspections and snow clearing, and disruptions to rail traffic.
Level of certainty		Very high	Low	Medium	Medium	Medium	Unknown
Likelihood		Likely	Likely	Possible	Possible	Possible	Possible
Consequence		Minor	Minor	Minor	Minor	Minor	Minor
Risk*		Low	Low	Low	Low	Low	Low
Risk modified by certainty		Low	High	Moderate	Moderate	Moderate	High
Locations**		System-wide	–	–	–	–	Alpine regions
Potential responses	Reinstate/status quo	Inspection/ maintenance	–	–	–	–	Inspection
	Protect	–	–	–	–	–	–
	Modify	Adapt current vegetation management over time.	–	–	–	–	–
	Move/rebuild	–	–	–	–	–	–
Comments		–	–	–	–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.3 (cont.) **Risk register of possible threats to the rail network caused by climate change.**

Aspect		**Risk reference number**					
		RL50	RL51	RL52	RL23	RL24	RL25
Climate change effect category		Rainfall	Rainfall	Rainfall	High temperatures	High temperatures	High temperatures
Description of hazard, and its cause and effect		Increased wet weather degradation (rotting, corrosion) requiring additional protective/ cosmetic maintenance e.g. bridge painting.	Wet weather disruptions to maintenance activities.	Increased wheel slip rates, requiring more frequent removal of wheel/rail flats.	Temperature dependent degradation of electrical systems, insulation, etc.	General high temperatures and higher extreme temperatures causing overheating of signalling equipment.	General higher temperatures and higher extreme temperatures causing overheating of freight containers, passenger carriages, locomotive cabs etc.
Level of certainty		Medium	Medium	Medium	Very high	Very high	Very high
Likelihood		Possible	Possible	Possible	Possible	Possible	Possible
Consequence		Minor	Minor	Minor	Minor	Minor	Minor
Risk*		Low	Low	Low	Low	Low	Low
Risk modified by certainty		Moderate	Moderate	Moderate	Low	Low	Low
Locations**		–	–	–	–	Buildings containing signalling equipment.	Freight containers
Potential responses	Reinstate/ status quo	–	–	–	–	–	–
	Protect	–	–	–	–	–	Install cooling or air conditioning equipment.
	Modify	–	–	–	–	–	–
	Move/rebuild	–	–	–	–	–	–
Comments		–	–	–	–	–	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.3 (cont.) Risk register of possible threats to the rail network caused by climate change.

Aspect		**Risk reference number**			
		RL27	RL28	RL17	RL7
Climate change effect category		High temperatures	High temperatures	Fog and humidity	Drought
Description of hazard, and its cause and effect		Possible limitations on periods of maintenance activities because of health and safety concerns.	Increased incidence of freight fires for hazardous cargo caused by overheating.	High humidity effects on electrical equipment, e.g. increased arcing of conductors, etc.	Loss of vegetation, causing embankment instability during periods of heavy rainfall.
Level of certainty		Very high	Very high	Low	Medium
Likelihood		Possible	Unlikely	Possible	Unlikely
Consequence		Minor	Moderate	Minor	Moderate
Risk*		Low	Low	Low	Low
Risk modified by certainty		Low	Low	High	Moderate
Locations**		–	–	–	–
Potential responses	Reinstate/ status quo		–	–	–
	Protect		–	–	–
	Modify		–	–	–
	Move/rebuild		–	–	–
Comments		Restrictions typically begin at 30°C; heat exhaustion possible at 40°C.	–	–	In the New Zealand environment, something will grow in its place.

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.4 Risk register of possible opportunities to the rail network caused by climate change.

Aspect		Risk reference number				
		RL41	RL71	RL43	RL44	RL60
Climate change effect category		Low temperature	–	Low temperatures	Low temperatures	Snow
Description of hazard, and its cause and effect		Decreased frequency or less extreme low temperatures will reduce frequency of joints pulling apart and rail breaks requiring frequent repairs and potential for consequential damage to freight and equipment, and injury/death to personnel/ passengers.	Increased freight/traffic levels because of lower emissions etc. from rail traffic.	Decreased frequency or less extreme low temperatures for extended periods will reduce icing of overhead line equipment, or icicles forming on structures. Short circuiting of power supply though earthing, or wires sagging or down under ice load.	Decreased frequency or less extreme low temperatures for extended periods, causing ice forming on rails, loss of track circuits.	Decreased snowfall in alpine regions, reduced inspections, snow clearing and disruptions to rail traffic.
Level of certainty		Very high	Unknown	Very high	Very high	Unknown
Likelihood		Very likely	Likely	Possible	Possible	Possible
Consequence		Moderate	Moderate	Moderate	Moderate	Minor
Risk*		Moderate	Moderate	Low	Low	Low
Risk modified by certainty		Moderate	High	Low	Low	High
Locations**		–	–	Ice forming on overhead lines in exposed locations; icicles forming on tunnel mouths or any overhead structure.	Signalling failure as track circuits become inoperable, causing operational stoppages.	–
Potential responses	Reinstate/ status quo	–	–	–	–	–
	Protect	–	–	Increased inspection, keeping units running to prevent build-up of ice on wires; visual inspection at structures to clear icicles.	Block entry system; signals fail to danger when track circuits fail.	–
	Modify	–	–	Replan work away from severe weather conditions and keep trains operational.	Run de-icer units across area at times of low forecast temperatures.	–
	Move/rebuild	–	–	–	–	–
Comments		–	–	Periods of continuous cold which stop operations.	This is commonly done in Europe throughout the winter months.	–

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

G3 Threats and opportunities affecting the coastal shipping network

Table G.5 Risk register of possible threats to the coastal shipping network caused by climate change.

Aspect		Risk reference number					
		CS27	CS32	CS11	CS23	CS13	CS31
Climate change effect category		Coastal flooding	Coastal flooding	Flooding	Wind	Flooding	Coastal flooding
Description of hazard, and its cause and effect		Sea level rise and surge will result in some wharf levels being too low at high spring tides.	Sea level rise will result in low-level port areas being permanently underwater and will cause drainage problems.	Increased frequency of flooding may interrupt navigations at river port operations.	Wind damage to port buildings and infrastructure.	Low-lying port areas will be subject to surface flooding.	Sea level rise and surge will cause overtopping of breakwaters and wave action in harbour with too much ship movement at berth.
Level of certainty		Very high	Very high	Medium	Medium	Medium	Very high
Likelihood		Very likely	Very likely	Very likely	Very likely	Very likely	Likely
Consequence		Catastrophic	Catastrophic	Severe	Major	Major	Severe
Risk*		High	High	High	High	High	High
Risk modified by certainty		High	High	High	High	High	High
Locations**		Nationwide but will only affect some low-level structures.	Ports with low-lying backup land.	Western ports such as Greymouth, Westport and Wanganui.	Nationwide	Nationwide, particularly river ports.	All ports that rely on breakwater protection.
Potential responses	Reinstate/status quo	Raise wharf deck level.	Raise land level and rebuild.	Raise wharf deck levels.	Repair damage.	After flood, remove surface water.	Raise height of breakwaters.
	Protect	Lock systems (unlikely).	Temporary dykes.	Construct protection groynes.	Improve fixing connections, etc.	Construct flood banks.	Increase seaward armouring defences.
	Modify	Add higher deck to existing structure.	N/A	–	Modify structures to improve wind resistance.	Improve drainage.	Add concrete Acropods[5] or similar.
	Move/rebuild	Rebuild new wharf.	Move buildings and facilities to higher ground.	Close port if effects are serious.	Construct stronger structures.	Raise operations area.	Add to width and length of breakwater.
Comments		Individual ports will need to identify vulnerable structures and plan for action (gap).	Accurate contour plans are needed to plan for effects of inundation by sea level rise and identify areas affected.	Need to identify risk of increased flood frequency for each port and will vary depending on existing facilities.	Port companies will encourage engineers to assess structural integrity.	Ports may need to improve drainage protection or raise operation levels depending on flood frequency.	Ports will plan for upgrading seawall or breakwater defences in advance of design parameters being exceeded.

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

[5] An Acropod is a type of concrete block defence or armour typically used to protect the seaward side of breakwaters by dissipating wave energy.

Table G.5 (cont.) Risk register of possible threats to the coastal shipping network caused by climate change.

Aspect		Risk reference number					
		CS34	CS24	CS19	CS36	CS30	CS39
Climate change effect category		Coastal erosion	Wind	Inland erosion and instability	High temperatures	Coastal flooding	Coastal flooding
Description of hazard, and its cause and effect		Coastal erosion will cause loss of port land bordering the harbour.	High winds will cause delay to loading and unloading craned cargo.	Erosion behind or under wharves may affect structures' stability.	Freight storage buildings may be more at risk of fire with higher temperatures.	Sea level rise may affect operational limits of roll-on roll-off equipment.	Increase in tidal area/ more water volume increases tidal current velocities, which may affect safe navigation at times.
Level of certainty		Medium	Medium	Medium	Very high	Very high	Very high
Likelihood		Very likely	Very likely	Likely	Likely	Likely	Likely
Consequence		Major	Major	Major	Major	Major	Major
Risk*		High	High	Moderate	Moderate	Moderate	Moderate
Risk modified by certainty		High	High	Moderate	Moderate	Moderate	Moderate
Locations**		Ports with erosion-prone foreshore land.	Nationwide	River ports	Ports subject to hotter temperatures and which are ill-equipped for fire resistance.	Nationwide but particularly Picton and Wellington for Cook Strait ferries.	Ports with low-lying backup land Nelson, Picton (Tory Channel).
Potential responses	Reinstate/status quo	Repair	Wait until wind abates.	Repair	Improve insulation.	Raise hinge levels, ramps and operating equipment.	Raise land levels.
	Protect	Foreshore protection	N/A	River bank protection under structure.	Install fire sprinklers.	Lock system (unlikely).	Construct dykes.
	Modify	Improve existing defences.	Create shelter.	Improve revetment design.	Improve ventilation and replace with fire resistant.	As for 'reinstate'.	Widen channels.
	Move/rebuild	Rebuild new seawalls.	N/A	Reconstruct if vulnerable.	Rebuild to modern building codes.	Rebuild ferry berths (unlikely).	Extra channel
Comments		Vulnerable areas to be identified for assessment of effects (gap).	Ports and stevedore companies need to plan for increased wind effects on crane loading of freight.	Ports to identify possible weak banks under facility and plan for improved protection.	Port companies to assess increased risk of fire to all storage buildings.	Operational constraints to be assessed and trigger level established (gap).	Accurate contour plans required to identify extra volume of tidal prism and channel current velocity.

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.5 (cont.) Risk register of possible threats to the coastal shipping network caused by climate change.

Aspect		Risk reference number					
		CS22	CS21	CS10	CS7	CS9	CS18
Climate change effect category		Wind	Wind	Rainfall	Rainfall	Rainfall	Inland erosion and instability
Description of hazard, and its cause and effect		Increased winds will result in rougher seas, causing delays in passage.	Increased winds will result in ship handling difficulties during berthage.	Increased heavy rain will cause interruptions to repairs and maintenance on ships and port facilities.	Increased heavy rainfall means more interruptions to loading/ unloading ships.	Increased heavy rain affects navigation visibility, slowing ships – possible delays.	Riverbank erosion may affect port operations land.
Level of certainty		Medium	Medium	Medium	Medium	Medium	Medium
Likelihood		Very likely	Very likely	Very likely	Very likely	Very likely	Very likely
Consequence		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Risk*		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Risk modified by certainty		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Locations**		Nationwide but particularly Cook Straight ferry service.	Nationwide but particularly in exposed ports such as Wellington.	Nationwide	Ports likely to experience more rainfall, such as West Coast ports and New Plymouth.	Shipping routes subject to increased heavy rain.	River ports
Potential responses	Reinstate/status quo	N/A	More powerful tugs	N/A	N/A	N/A	Repair
	Protect	Port wind/wave protection.	More tugs per vessel.	Provide shelter where possible.	Undercover loading.	Modern radar equipment.	Riverbank protection.
	Modify	Larger ships, better equipment.	Upgrade port bollards and berthage systems.	Reschedule work.	Flexible work time.	N/A	Move area away from bank.
	Move/rebuild	Replace with larger ship better equipped for rough seas.	Replace older ships with modern fore-aft propulsion units.	N/A	N/A	N/A	Move storage area to new location.
Comments		Shipping companies will need to assess existing ships capability to operate in increasingly rougher seas.	Depends on increase of wind velocity and direction and individual ports (gap).	Ports and shipping companies to plan for likely delays on work or for critical work to provide temporary or permanent shelter.	Rainfall records to indicate trends from which stevedores and port companies can plan for introducing more shelter or area lighting for flexible working hours.	Shipping companies to invest in the best available all-weather navigation aids.	Ports to plan for possible event.

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.5 (cont.) Risk register of possible threats to the coastal shipping network caused by climate change.

Aspect		Risk reference number					
		CS2	CS5	CS6	CS12	CS14	CS16
Climate change effect category		High temperatures	High temperatures	High temperatures	Flooding	Drought	Drought
Description of hazard, and its cause and effect		Increased seal bleeding, etc. in roading for portside operations and in paved storage areas.	Port and ship storage may need improvement to counter higher temperatures.	Extreme high temperatures may affect productivity of labour not used to conditions.	Increased debris causing a navigational hazard.	Droughts will decrease farm product exports.	Shortage of fresh water may affect availability of washdown facilities.
Level of certainty		Very high	Very high	Very high	Medium	Medium	Medium
Likelihood		Very likely	Very likely	Very likely	Very likely	Very likely	Very likely
Consequence		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Risk*		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Risk modified by certainty		Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Locations**		Areas where seal is not designed for higher temperatures.	Nationwide, especially those handling vulnerable cargos.	Nationwide	Nationwide, particularly river ports. Risk at each port will vary depending on existing facilities.	Ports that are mainly reliant on primary produce exports.	Ports with equipment subject to salt water immersion or spray.
Potential responses	Reinstate/status quo	Maintenance repairs.	N/A	Employ people from tropical climates (e.g. India or Philippines) used to working in hot conditions.	Clear debris	Ship other products.	Clean after drought.
	Protect	Sand coating (temporary).	Mechanically lower temperature.	Provide some air conditioning for interior work.	Deflection barriers.	Irrigate farms.	Protect water resources.
	Modify	Amend design standards.	Improve insulation in buildings and containers.	Alter working times.	N/A	N/A	Improve water storage.
	Move/rebuild	N/A	–	N/A	N/A	–	Construct water storage tanks
Comments		Hot weather seal design to be implemented.	Ship owners, stevedores and ports need to access effect of higher temperatures on storage and containers.	Interior of buildings, ships' holds etc. may become unbearably hot; and ports and shipping companies may have to plan to improve working conditions.	Ports may need to employ suitable craft/labour to clear debris after floods.	Ports and shipping companies to have contingency plans for drop in port activity.	Ports may look into installing standby desalination plants (used extensively in the Middle East).

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.5 (cont.) Risk register of possible threats to the coastal shipping network caused by climate change.

Aspect		Risk reference number				
		CS33	CS17	CS3	CS26	CS1
Climate change effect category		Coastal erosion	Inland erosion and instability	High temperatures	Fog and humidity	High temperatures
Description of hazard, and its cause and effect		Coastal erosion will cause increased sedimentation in ports and harbour entrances.	Erosion and slips will increase sediment flow at ports, resulting in sea floor rise.	Dustier conditions at unsealed log storage areas.	Increased fog will increase danger of collision.	Higher temperatures and humidity and higher rates of corrosion, leading to more maintenance costs.
Level of certainty		Medium	Medium	Very high	Low	Very high
Likelihood		Very likely	Likely	Likely	Unlikely	Possible
Consequence		Moderate	Moderate	Moderate	Catastrophic	Moderate
Risk*		Moderate	Moderate	Moderate	Moderate	Low
Risk modified by certainty		Moderate	Moderate	Moderate	High	Low
Locations**		Ports with constrained entrance channels or shallow draft.	River ports, in particular, may experience deposits, requiring more dredging to maintain draft .	Timber export ports.	Nationwide but particularly in busy coastal shipping ports such as Cook Strait ferries, particularly entrance to Tory Channel and Wellington.	More typical of northern ports.
Potential responses	Reinstate/status quo	Increase dredging maintenance.	More maintenance dredging.	Suspend operations.	Fog warning communications.	More maintenance and preventative measures.
	Protect	Coastal protection measures.	Sediment traps	Water sprinklers or oil spray.	Introduce large wind generators at critical locations.	Protection coatings
	Modify	N/A	Modify discharge location.	Seal vulnerable areas.	Temporarily re-route shipping.	Alternative materials or coating system.
	Move/rebuild	N/A	N/A	N/A	N/A	N/A
Comments		Vulnerable areas to be identified for assessment of effects (gap).	Identify catchment areas and erosion/slip-prone areas likely to affect port sedimentation.	Timber ports need to review effect of dust nuisance.	Increased fog unlikely with warmer temperatures.	Ports and shipping companies will need to review and implement higher standards or maintenance (protective coating) programmes.

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.5 (cont.) Risk register of possible threats to the coastal shipping network caused by climate change.

Aspect		Risk reference number		
		CS35	CS25	CS25
Climate change effect category		High temperatures	High temperatures	Fog and humidity
Description of hazard, and its cause and effect		Fire risk may increase, with higher temperatures affecting some cargos.	container cranes, train delivery, etc. on rails may experience buckling of rails.	Increased fog will result in slower speeds and delays in passage.
Level of certainty		Very high	Very high	Low
Likelihood		Unlikely	Unlikely	Unlikely
Consequence		Major	Major	Minor
Risk*		Low	Low	Low
Risk modified by certainty		Low	Low	High
Locations**		More tropical temperatures in north.	Nationwide where ports are equipped with rail lines.	Nationwide but particularly Cook Strait ferries, Marlborough Sounds and Wellington.
Potential responses	Reinstate/status quo	N/A	Shut down and replace rails.	Fog warning communications.
	Protect	Safety measures	N/A	Introduce large wind generators at critical locations
	Modify	Ships to be modified for safe storage of volatile or hazardous cargos.	Undertake strengthening works if delays occur more than once every two years.	Temporarily re-route shipping.
	Move/rebuild	N/A	Rebuild and improve design standards if delays occur more than three times per year at a specific location.	N/A
Comments		Shipping companies to review risk of higher temperature and volatile cargos (gap).	Railway lines are known to buckle at air temperatures of 35°C.	Increased fog unlikely with warmer temperatures.

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Table G.6 Risk register of possible opportunities for the coastal shipping network caused by climate change.

Aspect		Risk reference number					
		CS40	CS20	CS8	CS15	CS28	CS29
Climate change effect category		Coastal flooding	Snow	Rainfall	Drought	Coastal flooding	Coastal flooding
Description of hazard, and its cause and effect		May improve inland navigation prospects for canal construction on low-lying land for tug and barge operations.	Decrease in snow/ ice/ hail will lessen delays of ship loading.	Decreased heavy rainfall will lessen loading interruptions.	Drought-prone areas will have less rainfall at ports, resulting in fewer delays.	Sea level rise will provide greater draft for ships in shallow harbours.	Sea level rise will initially result in less maintenance dredging.
Level of certainty		Very high	Unknown	Medium	Medium	Very high	Very high
Likelihood		Very likely	Very likely	Very likely	Very likely	Very likely	Very likely
Consequence		Moderate	Minor	Minor	Minor	Minor	Minor
Risk*		Moderate	Low	Low	Low	Low	Low
Risk modified by certainty		Moderate	High	Moderate	Moderate	Low	Low
Locations**		Harbours with low-lying surrounding land.	Southern South Island ports.	Ports likely to experience less rainfall, such as those on eastern coasts, e.g. Timaru and Napier.	Extreme low temperatures for extended periods, causing ice forming on rails, loss of track circuits.	Nationwide but beneficial for shallow harbours.	Nationwide but particularly ports with draft restrictions, e.g. Nelson, Timaru and Dunedin.
Potential responses	Reinstate/ status quo	N/A	N/A	N/A	N/A	N/A	Cancel dredge contracts
	Protect	N/A	N/A	N/A	N/A	N/A	N/A
	Modify	Dredge canals along existing waterways	N/A	N/A	N/A	N/A	N/A
	Move/rebuild	N/A	N/A	N/A	N/A	N/A	N/A
Comments		Accurate contour plans required to identify barging routes to port (e.g. timber etc.).	Records of past/present delays from these elements from which to expect improvements.	Rainfall records to indicate trends.	Climate forecasting of trends.	Improved navigable space would allow larger ships to use port.	Lower maintenance dredging costs.

* likelihood x consequence
** critical locations, factors which determine critical locations, geographical variation and comments

Appendix H Glossary and abbreviations

Definitions

Acropod: An Acropod is a type of concrete block defence or armour typically used to protect the seaward side of breakwaters by dissipating wave energy.

LiDAR: A method of detecting objects and determining their position, velocity or other characteristics by analysis of pulsed laser light reflected from their surfaces.

Resilience: The ability of a system or component to withstand stressors.

Risk: The chance of something happening that will have an impact of objectives (AS/NZS 4360: 2004).

Tidal prism: The difference in the volume of water in a water body between high and low tides.

Vulnerability: The susceptibility to failure or meet expected performance. A system or component is said to be vulnerable if it has a low tolerance to failure (in some regards it is the opposite of resilience).

H2 Abbreviations

ABARE: Australian Bureau of Agricultural and Resource Economics
AOGCM: Atmosphere–Ocean Global Climate Model
ARC: Auckland Regional Council
ARI: Average Recurrence Interval
ARRB: Australian Road Research Board
ARTA: Auckland Regional Transport Authority
CDEMA: Civil Defence and Emergency Act
CLINZI: Climage Long-term Impact on the New Zealand Infrastructure
CO_2: Carbon Dioxide
CRI: Crown Research Institute
CRPS: Canterbury Regional Policy Statement
CSIRO: Commonwealth Scientific and Industrial Research Organisation
CWR: Continuous Welded Rail
DOTARS: (Federal) Department of Transport and Regional Services (Australia)
ENSO: El Niño Southern Oscillation
FAR: Fourth Assessment Report
FRST: Foundation for Research, Science and Technology
GIS: Geographical Information System
ICCA: Interdepartmental Group for Climate Change Adaptation
IPCC: Intergovernmental Panel on Climate Change
IPENZ: Institute of Professional Engineers, New Zealand
IPO: Inter-decadal Pacific Oscillation
LGA: Local Government Act
LIDAR: Light Deflection and Ranging
LINZ: Land Information New Zealand
LTA: Land Transport Act
LTCCP: Long-Term Council Community Plan
LTMA: Land Transport Management Act
MAF: Ministry of Agriculture and Forestry
MED: Ministry of Economic Development
MfE: Ministry for the Environment
MHWS: Mean High Water Springs
MoT: Ministry of Transport
MRST: Ministry of Research, Science and Technology

NIMT: North Island Main Trunk (railway line)
NIWA: National Institute of Water and Atmospheric Research
NZTA: NZ Transport Agency
NZTS: New Zealand Transport Strategy
RLTS: Regional Land Transport Strategy
RMA: Resource Management Act 1991
SOI: Southern Oscillation Index
SRES: Special Report on Emission Scenarios
TAR: Third Assessment Report
TLA: Territorial Local Authority
TSR: Temporary Speed Restriction