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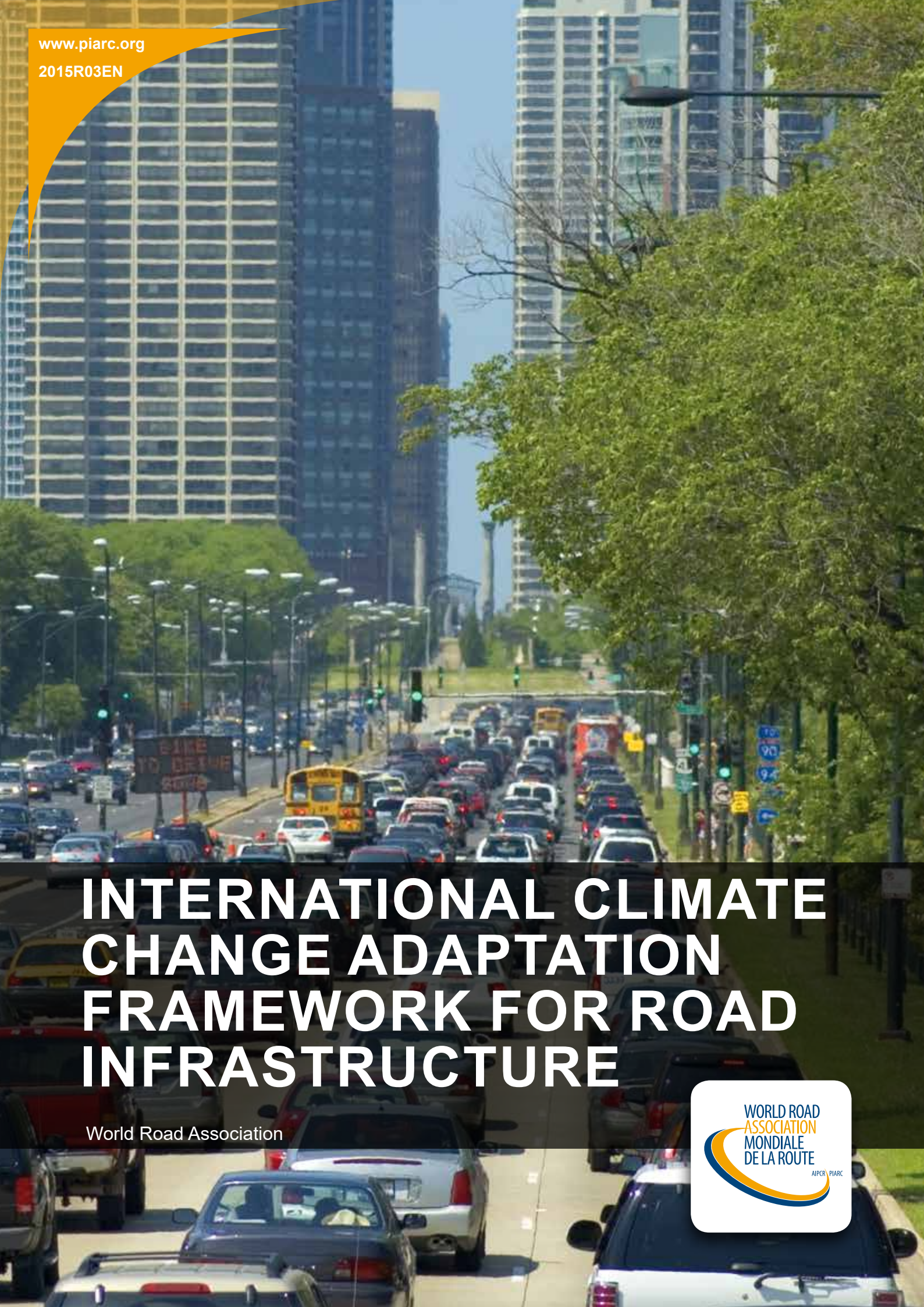

INTERNATIONAL CLIMATE CHANGE ADAPTATION FRAMEWORK FOR ROAD INFRASTRUCTURE

World Road Association

WORLD ROAD ASSOCIATION
MONDIALE DE LA ROUTE
AIPCR PIARC

STATEMENTS

The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

This report was developed as a special project by the World Road Association after this issue was identified as a priority by the Association's Executive Committee.

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- Roads Fund Board - Tanzania; and,
- The Asian Development Bank.

EXECUTIVE SUMMARY

2015R03EN

INTERNATIONAL CLIMATE CHANGE ADAPTATION FRAMEWORK FOR ROAD INFRASTRUCTURE

The climate change debate has moved away from whether or not there is evidence of climatic change to what must be done to reduce the magnitude of further changes and minimise the impacts. There is now an overwhelming body of **scientific evidence** highlighting the **serious and urgent nature** of climate change, largely due to emissions of greenhouse gases as a result of human activities.

With a predicted 30-40 year lag time between the emission of greenhouse gases into the atmosphere and the effect being seen in our climate, as well as the uncertainties in natural cycles, estimating what climatic changes might occur is a complex science. However, this inertia that exists in our climate means that past greenhouse gas emissions will result in the Earth undergoing a **certain inevitable level** of climate change.

Key IPCC (Intergovernmental Panel on Climate Change) projections are that:

- The Earth will become warmer;
- Some regions will become wetter overall and some will become drier;
- Sea levels will rise and storm surge height will increase;
- Snow cover and the extent of sea-ice will reduce; and,
- The frequency and severity of extreme weather events (such as storms, heat waves, drought and periods of prolonged and heavy precipitation) will increase.

These changes are set to have **significant impacts** on the design, construction, maintenance and operation of global road infrastructure. For example, drier and hotter weather will lead to more incidences of infrastructure subsidence and heat damage to pavements and structures; more frequent heavy precipitation events will result in increased incidences of flooding in low-lying areas and floodplains; and sea level rise may make some networks and assets temporarily or permanently inaccessible. These impacts will lead to disruption to services and increased operational, maintenance and emergency repair costs. Communities, businesses and localities that rely on the networks will be impacted if part of a network becomes inaccessible as a result of the impacts of climate change or an extreme weather event.

Therefore, in order to networks and assets and services to be resilient to in the face of a changing climate, effective and targeted **action must be taken** to minimise this disruption, damage and cost. Existing road infrastructure design, construction, maintenance and management policies and standards are typically based on historical climate data but attention now needs to shift to these future predictions. Road infrastructure owners and operators **must therefore adapt** their programmes, strategies, activities, policies and standards for these changes.

With these climate change risks and opportunities in mind, this framework has been developed by the World Road Association (PIARC) to guide road authorities through identifying relevant assets and climatic variables for assessment, identifying and prioritising risks, developing a robust adaptation response and integrating assessment findings into decision-making processes. The framework provides a life-cycle and iterative approach to climate change adaptation.

The framework been developed through **extensive research and consultation** with road authorities globally. It **synthesises evidence** of best practice and knowledge available internationally, and direct

input from a range of road authorities, into an **effective and useable tool** for use by any road authority, irrespective of geographical, climatic, economic, environmental or climatic condition. It is acknowledged that there may be **barriers to taking action** to understand and adapt to climate change, and this framework is designed to ensure any road authority (even those with very limited resources and knowledge) can start taking effective steps to increase the resilience of their roads to climate change.

The framework facilitates the identification and replication of lessons learned from other countries and takes account of the varying levels of preparedness and adaptive capacity and knowledge from country-to-country and region-to-region. It is also designed to be **applicable at any scale** (such as national, regional, local or asset specific.)

It guides road authorities through the process of increasing the resilience of their networks and assets through the following stages:

- **Stage 1** - Identifying Scope, Variables, Risks and Data;
- **Stage 2** - Assessing and Prioritising Risks;
- **Stage 3** - Developing and Selecting Adaptation Responses and Strategies; and,
- **Stage 4** - Integrating Findings into Decision Making Processes.

Climate change risks and impacts should not be assessed and addressed in isolation. They can be strongly linked to other risk types (both natural and man-made) and other forms of environmental, social and economic impact. Climate change impacts may lead to new risks emerging and/ or existing risk and impacts becoming more apparent.

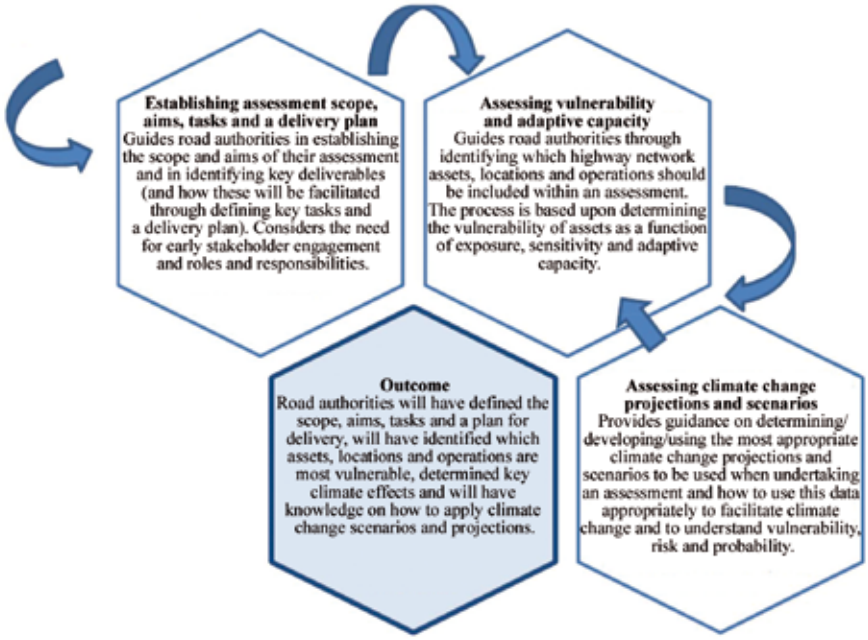
Furthermore, the process used to identify, understand and assess climate change risks is not necessarily any different to the assessment of any other types of risk. Therefore, risk assessment processes and approaches already used by a road authority to understand and manage risks can often be adapted applied for climate change risks.

Assessing, understanding and responding to climate change risks is most effectively achieved through an integrated and collaborative approach involving a range of individuals, groups and stakeholders. This can include includes designers, hydrologists, environmental experts, risk modellers, business and investment managers, operational staff, policy makers and the supply chain. Assessing and addressing climate change risks in an integrated and collaborative way ensures the interests of these different groups is taken into account, information is shared, and the resources and knowledge available to address risks are maximised.

Any assessment undertaken should be considered as ‘live’ and updated or refined as more information become available, priorities and evidence change, and if resource levels increase. As a result of the interdependencies and interconnectivities between road infrastructure and other sectors, and also between climate risks and other risk types (such as other natural hazards and security risks), investing in climate change adaptation responses can be seen as investing in the wider economy and increasing the resilience wider infrastructure and society. For the same reason, climate change risks should not be considered in isolation and should always from part of a holistic approach to risk management.

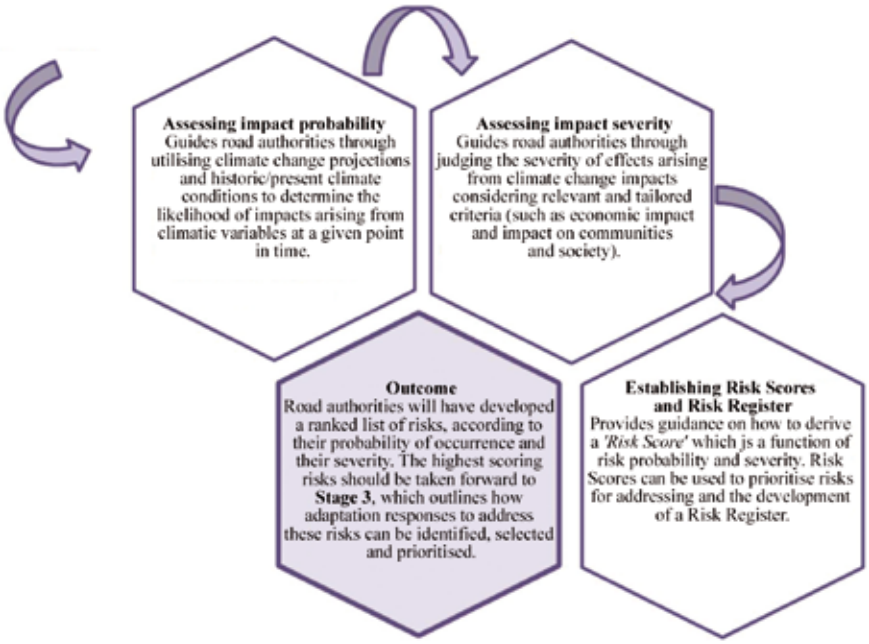
STAGE 1 - IDENTIFYING SCOPE, VARIABLES, RISKS AND DATA

Stage 1 of the framework guides road authorities through a series of steps to allow for the identification of assessment scope and activities and to define which assets, locations, risks and climate change



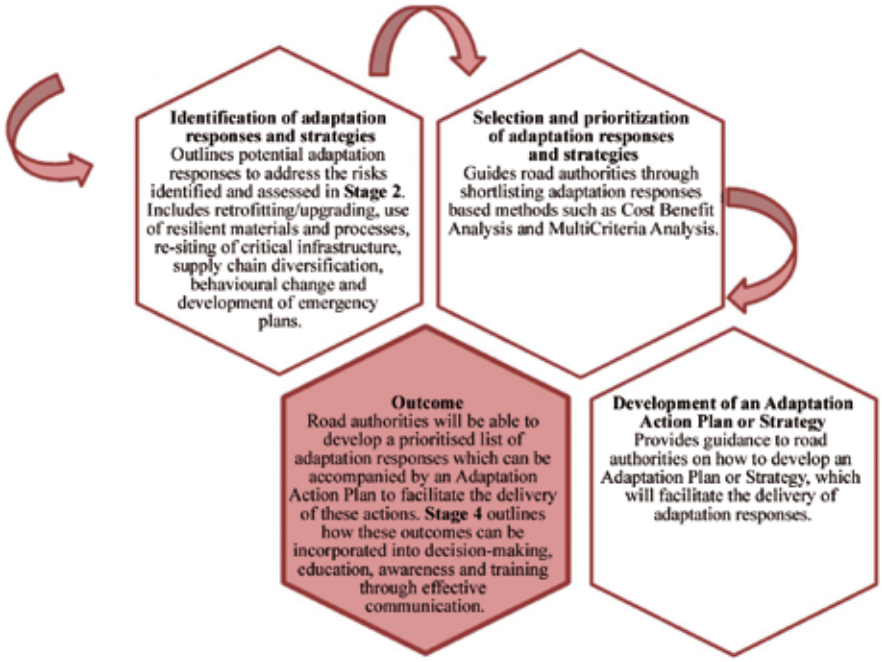
STAGE 2 - ASSESSING AND PRIORITISING RISK

Stage 2 of the framework takes findings from **Stage 1** and provides guidance on assessing the probability and severity of climate change risks on road infrastructure and enables road authorities to understand and quantify the risks posed to their network and assets in an effective, accessible, iterative and yet robust and holistic way.



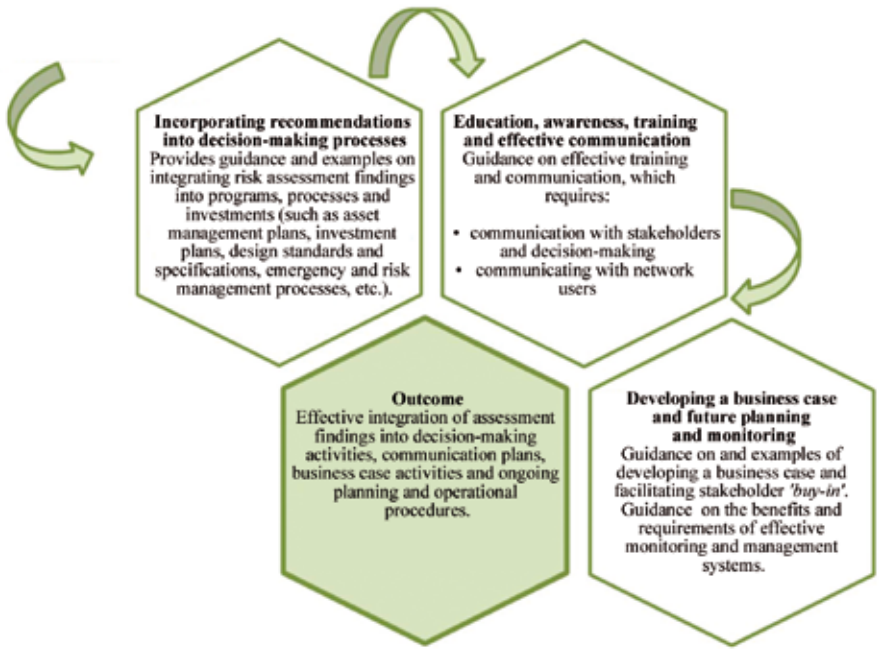
STAGE 3 - DEVELOPING AND SELECTING ADAPTATION RESPONSES AND STRATEGIES

Stage 3 of the framework outlines the process for the identification, assessment, selection and prioritisation of adaptation responses to the climate risks and opportunities identified within **Stages 1 and 2** of the assessment process.



STAGE 4 - INTEGRATING FINDINGS INTO DECISION-MAKING PROCESSES

Stage 4 of the framework provides guidance on effectively incorporating findings from an assessment into road infrastructure programmes, processes, investments, strategies and systems such as Transport Asset Management (TAM). This is essential in ensuring road infrastructure is resilient to future climate change and extreme weather events.



Outcome

Effective integration of assessment findings into decision-making activities, communication plans, business case activities and ongoing planning and operational procedures.

Developing a business case and future planning and monitoring

Guidance on and examples of developing a business case and facilitating stakeholder *'buy-in'*.

Guidance on the benefits and requirements of effective monitoring and management systems.

Box 1 - Key Terms

- **Adaptation:** Adaptation is adjustment within natural or human systems in response to actual or projected climatic stimuli or their effects, which aims to moderate harm or exploit beneficial opportunities. Typically when climate change adaptation is discussed it is in reference to changes to human systems and involves 'changing the way we do things' to prepare for the potential effects of climate change. Examples of adaptation can include using scarce water resources more efficiently; adapting design codes to future climate conditions and extreme weather events; building flood defences; and developing emergency response procedures to be used during extreme weather events. Adaptation aims to moderate harm (such as flooding) and/or exploit beneficial opportunities derived as a result of climate change (such as lengthened crop growing seasons). Adaptation differs from climate change mitigation that refers to measures taken to reduce and prevent greenhouse gas emissions, which contribute to climate change. Simply, mitigation attempts to address climate change causes, whereas adaptation seeks to adapt to climate change effects.
- **Adaptive Capacity:** The ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behaviour and in resources and technologies
- **Climate:** Average weather conditions temporally and spatially.
- **Climate Change:** Climate change refers to any significant change in the measures of climate lasting for an extended period of time. In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among others, that occur over several decades or longer.
- **Climate Projections:** Scientific climate model-derived estimates of future climate.
- **Climate Variables:** Factors that determine and govern the climate. Main factors include rain, atmospheric pressure, wind, humidity, and temperature.
- **Emergency:** A situation that poses immediate risks to the environment, human health and life or property.
- **Extreme Weather:** Weather phenomena that are at the extremes of the historical distribution, especially severe or unseasonal weather.
- **Hazard:** Something that has the potential to cause risk events and therefore adverse consequences.
- **Resilience:** A capability to anticipate, prepare for, respond to, and recover from threats with minimum damage to social well-being, the economy, and the environment.
- **Risk:** An event that is a possible yet not certain outcome of a particular circumstance and is undesirable or has undesirable consequences.
- **Road authority:** National, regional or local government organisation responsible for the design, construction, management and/or operation of road infrastructure
- **Sustainability:** Something is considered to be sustainable when it promotes social justice, environmental responsibility and economic viability.
- **Vulnerability:** The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes.
- **Weather:** Short-term atmospheric conditions (temperature, humidity, precipitation, cloudiness, wind).

CONTENTS

FOREWORD

During the past decade, climate change has become a major source of concern for road administrations worldwide. Although the road system´s exposure to various types of natural events has not necessarily increased in all countries, the road network's exposure to stronger rainstorms and longer dry periods has become more evident. At the same time, carbon emissions from the transport sector have not stopped growing and the risks that individual roads face due to landslides, floodings and water flows have increased.

Actions undertaken to mitigate the negative effects of climate change on road networks have varied from one country to another. They include legal, regulatory and institutional measures; promoting other transport modes; introducing new, green technologies; undertaking permanent supervision of embankments and slopes to reduce risks of collapse, accidents and interruptions of service, as well as developing new methodologies and analytical tools to identify, assess and mitigate risks and thus reduce the vulnerability of the road infrastructure.

Despite all these efforts, dealing with the effects of climate change is still a new topic and there are no easily accessible references to help transport and road decision-makers to cope with the problem and manage it systematically and efficiently. While some countries have made progress on this subject, others are yet to start their own efforts. In recognizing this situation, the World Road Association has completed a special project on climate change to help member countries adopt a consistent approach to analyze the effects of climate change on their road networks and thus help them identify, propose and prioritize the most appropriate measures to mitigate risks associated with extreme weather events.

The United Nations Convention on Climate Change meetings that will take place in Paris in December 2015 will hopefully give a new impulse to worldwide efforts on this subject. Given the growing pressures felt by roads and road transport to make significant progress in carbon emission controls and in reducing the exposure of the road system to climate change, this report from the World Road Association offers a timely, useful, updated and practical tool to help reach those objectives.

Oscar de Buen Richkarday,
President of the World Road Association, 2013-2016

INTRODUCTION

This framework has been developed by the World Road Association (PIARC) to guide road authorities through a series of steps to identify potential impacts of climate change on their networks, evaluate the level of potential risk and vulnerability, understand how to respond to these risks effectively, and direct them towards appropriate and useful resources, evidence and supporting information.

There are a range of existing frameworks, decision tools, information sources and literature available globally to assist road authorities in understanding the potential effects of climate change and extreme weather on road infrastructure and the responding adaptation strategies implemented to address these challenges. However, there is much inconsistency in the approaches and level of information provided. Some countries are advanced in their understanding of, and level of preparedness to, future climate change impacts on their road networks, whereas other countries and entire regions appear to have very limited guidance and information available to assist them in decision making. The purpose of this framework is to collate and synthesise the best practice and knowledge available internationally into an effective and useable tool that can be applied within any road authority.

The framework has been designed to be iterative and road authorities are therefore encouraged to continuously review and update their research, strategies, plans and policies as more information becomes available, as new risks become apparent and as new drivers and priorities emerge.

The framework is also designed to be applicable to road authorities operating under any geographical, climatic, economic and environmental condition. It is applicable to all road and network types and for road authorities at any stage of understanding and responding to climate change and extreme weather risks.

It is acknowledged that not all road authorities will be able to apply all principles set out in this framework, and that certain aspects of the guidance set out may be more relevant than others to an individual authority. However, this framework acts as an example of good practice and provides guidance for the development and utilisation of similar resources that have been developed specifically to meet the requirements of different authorities. Therefore, the guidance and case study examples set out in this framework should be adapted to suit individual road authority needs and priorities.

It is also acknowledged that climate change adaptation is a difficult and complex subject and that understanding and quantifying risks and opportunities can be made difficult by the uncertainties that surround climate change. Through a detailed review of existing effective approaches and examples of good practice and innovation, and through extensive consultation with a wide range of road authorities internationally, this framework provides a structured and effective process to guide road authorities through the complex subject of climate change adaptation.

Climate change risks and impacts should not be assessed and addressed in isolation. They should be assessed using an integrated and collaborative approach involving a range of individuals, groups and stakeholders. Assessing and addressing climate change risks in an integrated and collaborative way ensures the interests of different groups are taken into account, information is shared, and the resources and knowledge available to address risks are maximised.

Box 2a - Impacts on highway networks – Flooding of roads in Malawi, Mozambique and Zimbabwe (January 2015)[1]

In January 2015, tens of thousands of people were forced out of their homes in Malawi, Mozambique and Zimbabwe by flooding, caused by a deep low-pressure system that led to several weeks' worth of rain in many places in just a few hours. Mozambique's major north-south arterial road was damaged after two bridges collapsed in heavy flooding that killed 25 people and displaced nearly 20,000. An estimated 2,500 people were stranded on patches of high ground due to local roads being impassable due to flooding.

Maarten van Aalst, who is a Lead Author for the Intergovernmental Panel on Climate Change, said that: *"a preliminary analysis of climate models and current observations suggests there probably was a climate change component in this extreme-weather episode. As always, there are challenges with the quality of the data and models, and there's also variability from one decade to the next that makes attributing extreme rainfall to climate change more difficult"*.

Box 2b - Impacts on highway networks – Landslides closing roads in Scotland[2]

Specific sections of the A83 in Scotland are prone to recurring landslides due to periods of intense and prolonged rainfall. In January 2015, the Scottish Government announced that an additional £3m was to be spent on the A83 over the coming year. Such money added to the £9m which has already been spent in the area to improve resilience and help keep local communities in Argyll economically and socially connected in the event of landslides which sever critical transport corridors. Funding for adaptation resilience, in this instance, is focusing on stopping debris flow rubble reaching the road and thus keeping disruption to a minimum and maintaining journey time reliability.

CLIMATE CHANGE IMPACTS ON ROAD INFRASTRUCTURE

Projected change to the global climate will almost certainly have a significant impact on the appraisal, planning, design, construction, operation and maintenance of road infrastructure[3]. Put simply, climate change should be regarded as a strategic risk to road authorities, which requires consideration and the adoption of adaptation principles to address the climate-induced impacts. Given the long-term nature of road infrastructure, it is reasonable to assume that the asset will be exposed to an increased frequency in one-time localised weather-related disasters as well as multiple longer-term hazards that will increase in severity over time (i.e. sea level rise).

[1] International Federation of Red Cross and Red Crescent Societies (2015). IFRC mobilizes in southern Africa to help nations hit by disastrous seasonal floods. Available at: *http://www.ifrc.org/en/news-and-media/news-stories/international/ifrc-mobilizes-in-southern-africa-to-help-nations-hit-by-disastrous-seasonal-floods--67906/.*

[2] STV News (2015). Scottish Government announces a further £3m for landslide-hit A83. Available at: *http://news.stv.tv/scotland/306524-government-announces-3m-for-landslide-road-a83-in-argyll/.*

[3] Defra (2010). Adapting energy, transport and water infrastructure to the long-term impacts of climate change. Available at: *https://www.gov.uk/government/publications/adapting-energy-transport-and-water-infrastructure-to-the-long-term-impacts-of-climate-change*

Road infrastructure is typically designed to withstand local weather and climate. As such, designers and engineers typically rely on historical records of climate when designing road infrastructure. However, due to climate change, using historical climate data alone is no longer a reliable predictor of future impacts. Most road infrastructure is now built to last for 50 years or longer and understanding how future changes in climate might affect this infrastructure is important to protecting long-term investments.

There is already evidence of climate change having an impact on road infrastructure *(Boxes 2a and 2b, left page)*, such as through increased frequency and severity of flooding events, increased landslide frequency, damage to roads from excessive heat, and reduced snow and ice coverage in some regions. Climate change can lead to new risks and hazards, or can exacerbate and contribute to other existing risks and hazards.

Adapting to climate change is a process, which should be built into a road authority's normal planning and risk management procedures. Successful forward planning – not just responding to emergency situations – will enable an authority to make investment decisions at the right time, making sure that it continues to provide the levels of service that its stakeholders and network users expect, both now and in the future[4]. The Stern Report argues that the sooner an organisation begins to plan adaptation to the effects of a changing climate, the less it will cost and the better equipped it will be to cope with these and other potential changes in the future.

Climate change risks should not be considered in isolation and should be assessed and responded to in conjunction with other risk types, for example from other natural hazards (such as earthquakes or pollution) or hazards resulting from human activity (such as migration or terrorism). Addressing infrastructure resilience as a holistic approach, but without ignoring the importance of climate change, is important.

Over time, international and national critical infrastructure (i.e. water and power utilities, telecommunications, emergency and government services etc.) has become increasingly interconnected and interdependent, and increasing reliant upon transportation systems. It therefore is important to recognise these interdependencies within and between infrastructure sectors and it is essential that these interdependencies are both understood and managed to improve the resilience of infrastructure to future climate change. Therefore, developing resilience and building adaptive capacity of highway networks, especially in regards to climate change, is integral to accessing and delivering critical infrastructure, whilst sustaining the global economy.

For example, the Infrastructure Consortium for Africa[5] recognises the interdependencies between roads and other types of infrastructure, and how these interdependencies impact upon resilience levels. The purpose of the Consortium is to help remove some of the technical and political challenges and barriers to forging a better connected and coordinated infrastructure; in order to ensure long term resilience and national prosperity.

Damage to road infrastructure from climate change and extreme weather can also have an impact on local communities and businesses. Restrictions on the movement of people, goods and supplies

[4] Centre for Climate Change Economics and Policy. (2010). Adaptation in the UK: A Decision-Making Process. Available at: *http://www.cccep.ac.uk/Publications/Policy/docs/PB-adaptationUK-ranger.pdf*
[5] The Infrastructure Consortium for Africa website: *http://www.icafrica.org/en/*

around a region will almost certainly lead to impacts upon the local economy, environment and the health and wellbeing of residents. Social implications range from a lack of access to medical care to community isolation with residents who are unable to access employment and pursue normal activities. Ultimately, climate change impacts may be responsible for short or long-term population migration, which may indirectly affect highway networks and traffic control.

CLIMATE CHANGE IMPACT TYPES

Global climate change projections show that there will be:

- gradual changes to average climatic conditions; and,
- changes to the frequency, severity and location of extreme weather events.

Gradual changes related to climatic variables are those experienced over a period of time such as months, years, decades and/or centuries. Such impacts include sea-level rise, changing seasonal precipitation levels, and gradual climatic warming. Extreme events are typically those, which occur suddenly, sometimes with limited warning, typically over a period of hours, days or weeks. These events include heavy and/or prolonged precipitation events leading to surface water flooding, storm surges and landslides, heat waves, single very hot or cold days, and prolonged periods of drought.

It is likely that a road authority will have a reasonable idea of the climate change effects and impacts their assessment will consider as a result of direct knowledge about historic events, present conditions and future projected trends. An indicative list of potential impacts is provided below[6]. The potential impacts are split into five broad effect categories:

- Impacts associated with **changing temperatures**;
- Impacts associated with **prolonged and/or heavy precipitation and storms**;
- Impacts associated with **sea level rise and heightened storm surge**;
- Impacts associated with **changes to snowfall, permafrost and ice coverage**; and,
- Impacts associated with **other climatic effects**.

A more comprehensive list of potential impacts is to be found in *Appendix C, page 77*.

Whilst the impacts of climate change and extreme weather may predominantly be negative in nature, there are also a range of opportunities and benefits, which should also be taken into account in any assessment or strategy. These can include[7]:

- Operation:
  - increase in mean temperature would lead to less salt needing to be spread on the network during winter months.
  - changes in weather conditions that reduce the incidence and/or severity of incidents would place less demands on traffic management, including the traffic officer service.

[6] List of potential climate change impacts has been developed using information from the Asian Development Banks's Guidelines for Climate Proofing Investment in the Transport Sector and the Department for Transport's Adaptation Plan.
[7] Highways Authority (2011). Climate Change Risk Assessment. Available at: *http://assets.highways.gov.uk/about-us/climate-change/HA_Climate_Change_Risk_Assessment_August_2011_v2.pdf?bcsi_scan_AB11CAA0E2721250=0&bcsi_scan_filename=HA_Climate_Change_Risk_Assessment_August_2011_v2.pdf*

– for short distance journeys, warmer summers could attract some road users away from private cars. This has potential benefits of reducing the levels of localised congestion and air pollution.

- Maintenance:
  – a reduction in the frequency of freeze-thaw events would benefit the integrity of the pavement surface. We can expect less degradation with a reduction in surface cracking/pot holes.
  – customer satisfaction:
  – reduction in summer rainfall should create safer, more reliable driving conditions
  – a reduction in the number of fog days during the winter months is likely to have a beneficial impact in reducing the number of serious incidents
  – a reduction in the number of icy days during the winter months is likely to have a beneficial impact in reducing the number of serious incidents
  – fewer days with salt on the road would mean less corroded vehicles and highways assets
  – a longer growing season would mean that the soft estate (verges) could look greener for longer, enhancing the aesthetic of the network.
  – secondary benefits include potential health gains of a shift from private motorised transport to walking, cycling and rapid transit/public transport.

FRAMEWORK DEVELOPMENT AND OUTLINE

The development of this framework has comprised a thorough literature review of existing relevant frameworks, strategies, guidance, good practice case studies and *'lessons learnt'*, along with a series of consultation interviews with a range of road authorities in late 2014/early 2015. A selection of the various resources that have been reviewed throughout the development of this framework are outlined in *Boxes 6a to 6g* *(Appendix B, page 72)*.

Consultation has taken place throughout the framework's development with:

- The Quebec Ministry of Transport;
- Ministry of Land, Infrastructure, Transport and Tourism – Japan (Road Bureau and National Institute for Land and Infrastructure Management);
- New Zealand Transport Authority;
- Norwegian Public Roads Administration;
- Public Works Department, Malaysia;
- Transport Scotland;
- US Federal Highways Administration;
- Research Institute of Highway of the Ministry of Transport - China;
- Mexican Institute of Transportation;
- National Professional Association of Roads and Bridges - Romania;
- Roads Fund Board - Tanzania; and,
- The Asian Development Bank.

The purpose of consulting with the above authorities was to collect information on their existing approaches to capturing, understanding and recording the impacts of climate change on their road networks, and to understand what they would like to see from the Framework in terms of its structure, content and functionality. The authorities were selected as they represent one of two categories:

1. Countries which have already implemented policies and plans to assess and prepare their road networks for the impacts of climate change and have their own reference documents;

2. Countries at a less advanced stage of taking action to assess and prepare their road networks for the impacts of climate change.

This has allowed for a wide range of views and information to be included in the framework. Each road authority was also invited to provide case study examples of the ways in which they are taking action to adapt their network to the impacts of climate change. *Appendix A, page 69* outlines the questions asked during the initial consultation process and documents the responses received.

Each road authority was also invited to review the draft framework in early 2015. Their comments and feedback were used to determine the content and structure of the final document.

The framework aims to be an invaluable tool for road authorities, road asset owners, operators and managers operating at different scales, with different priorities, facing different drivers and barriers and within different economic, political, social, environmental, geographical and climatic conditions to better understand and address the impacts of climate change on their networks and assets. The framework builds on recognised experience in climate change adaptation policy, advice, risk assessment, adaptation framework development and implementation and is applicable to all countries and regions at a national, regional and local level irrespective of preparedness level.

The framework consists of four main stages:

Stage 1: Identifying scope, variables, risks and data
- Establishing assessment scope and aims
- Defining key tasks and delivery plan
- Early stakeholder consultation and establishing roles and responsibilities
- Assessing vulnerability
- Assessing adaptive capacity
- Assessing climate change projections and scenarios

Stage 2: Assessing and prioritising risks
- Assessing impact probability
- Assessing impact severity
- Establishing Risk Scores

Stage 3: Developing and Selecting Adaptation Responses and Strategies
- Identification of adaptation responses and opportunities
- Selection and prioritisation of adaptation responses and opportunities
- Development of an Adaptation Action Plan or Strategy

Stage 4: Integrating findings into decision-making processes
- Incorporating recommendations and requirements into programs, processes and investments
- Education, awareness and training
- Effective communication
- Developing a business case
- Future planning and monitoring

The framework can be used by road authorities at their various stages of adaptation programmes and provides a lifecycle and iterative approach from the identification of scope to quality management and review.

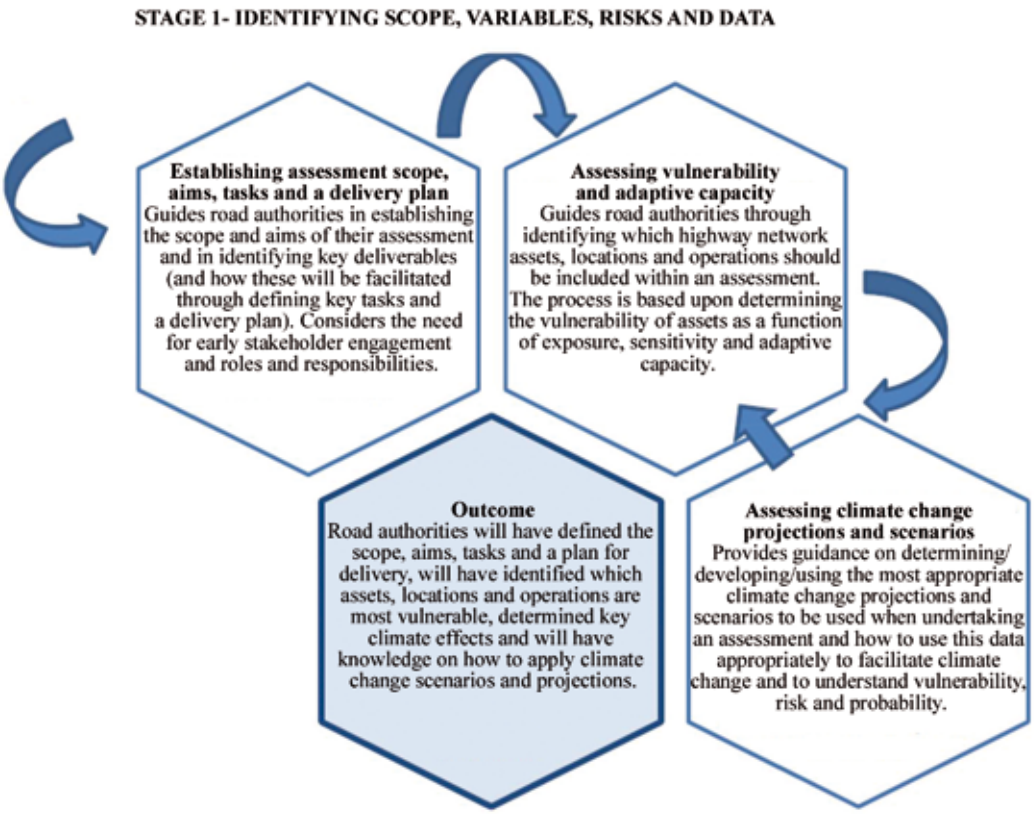
STAGE 1- IDENTIFYING SCOPE, VARIABLES, RISKS AND DATA

Stage 1 guides road authorities through the identification of which climatic variables and which assets, locations and operations should be included within an assessment. In order to define these variables, guidance is given on setting assessment scope, aims and objectives.

Before reading this section of the framework, authorities may wish to consider the following questions:

- What climatic effects have already led to impacts upon the highway network?
- Which assets, locations and operations are deemed the most important/valuable and have already been impacted by climatic effects?
- What do you want to achieve as a result of an assessment?

The structure, steps, purpose and outcomes of **Stage 1** are shown below.



Stage 1 findings/outcomes are used in **Stage 2** of the framework (assessing and prioritising risk).

ESTABLISHING ASSESSMENT SCOPE AND AIMS

Typically, the key aim and driver behind the delivery of any type of climate change adaptation assessment is to ensure and enhance the resilience of a network, asset, operation or service to the effects of climate change and extreme weather. Other key aims may include:

- to meet national climate change legislation;
- to have a formal climate change adaptation policy;
- to understand how asset design standards need to be adapted;
- to have a good level of understanding of climate change risks across the organisation and bring climate change adaptation to the attention of senior managers and decision makers;
- to understand the road authority's overall network vulnerability to climate change;
- to prioritise assets and operations for adaptation; and,
- to support the development of a business case to obtain financial support adaptation actions within national Government and organisational spending reviews.

The aim(s) of any assessment will be specific to the road authority and should be defined and agreed at the beginning of the assessment process.

The complexity, scope and content of an assessment are determined by these aims. High level assessments typically have a broader, more qualitative scope and associated objectives. Conversely, more focussed asset or service specific projects and assessments tend to have a narrower, quantitative scope and objectives.

There are a number of factors that also contribute to the development of an assessment scope, particularly relating to climate change adaptation of highway networks and these include:

- availability of climate change scenarios data, highway network data and whether such data is quantitative and/or qualitative (qualitative assessments may lend themselves to high level more strategic assessments);
- financial **resources** and expertise available (An increasing amount of resources often lends itself to a more comprehensive assessment, it must be noted however that varying levels of resources may be made available dependent of assessment outcomes. Irrespective of this, a general idea behind resource availability will contribute to determining assessment scope);
- the **target audience** of an assessment may influence scope and objectives. The target audience of the assessment may influence the scope and objectives alike. The UK Department for Transport's *Climate Change Adaptation Plan for Transport 2010-2012: Enhancing Resilience to Climate Change*[8] had a very broad stakeholder audience including internal employees, local communities, academic institutions, investors, designers, local/national government, and external stakeholders. As an alternative, *A Framework for Dialogue Between Local Climate Adaptation Professions and Policy Makers*[9] produced by the Stockholm Environment Institute was produced for a very specific target audience.

[8] Department for Transport (2010). Climate Change Adaptation Plan for Transport 2010-2012: Enhancing Resilience to Climate Change. Available at: *http://archive.defra.gov.uk/environment/climate/documents/dft-climate-change-plan.pdf*
[9] Stockholm Environment Institute. (2011). A Framework for Dialogue Between Local Climate Adaptation Professionals and Policy Makers. Available at: *http://www.sei-international.org/mediamanager/documents/Publications/SEI-ResearchReport-Larsen-AFrameworkForDialogueBetweenLocalClimateAdaptationProfessionalsAndPolicyMakers-2011.pdf*

The detail required in an assessment is also shaped by the desired end result and output, such as:

- **Climate change resilience policies related to roads**: For example, an objective within the Scottish Climate Change Adaptation Programme[10] is to *Implement Secure and Resilient - A CNI Strategy for Scotland*, which provides the overarching vision and strategic direction for all Critical Infrastructure (CI) Resilience stakeholders in Scotland, with the ultimate aim of enhancing the resilience of CI in Scotland;
- **Tool(s)**: For example, an objective within the Australian Government's 'National Climate Change Adaptation Strategy'[11] is to "Develop capacity and tools for the planning sector including working with the insurance and finance industries to share nationally consistent data on climate change risks and impacts and resilience";
- **Action Plan**: For example, Scotland's Climate Change Adaptation Programme[12] includes a series of sectoral Action Plans such as the Transport Scotland Biodiversity Action Plan. Transport Scotland's Climate Change Adaptation Programme supersedes Scotland's Climate Change Adaptation Framework which also utilised Action Plans;
- **Guidance**: For example, the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT)'s 'Practical Guidelines on Strategic Climate Change Adaptation Planning – Flood Disasters'[13] provides guidance on a number of issues such as evacuation of communities during extreme weather events; and,
- **Strategies**: For example, a targeted strategy to enhance the resilience of road infrastructure against flood risk and impacts of climate change and improve capacity to respond promptly and effectively in a crisis or emergency.

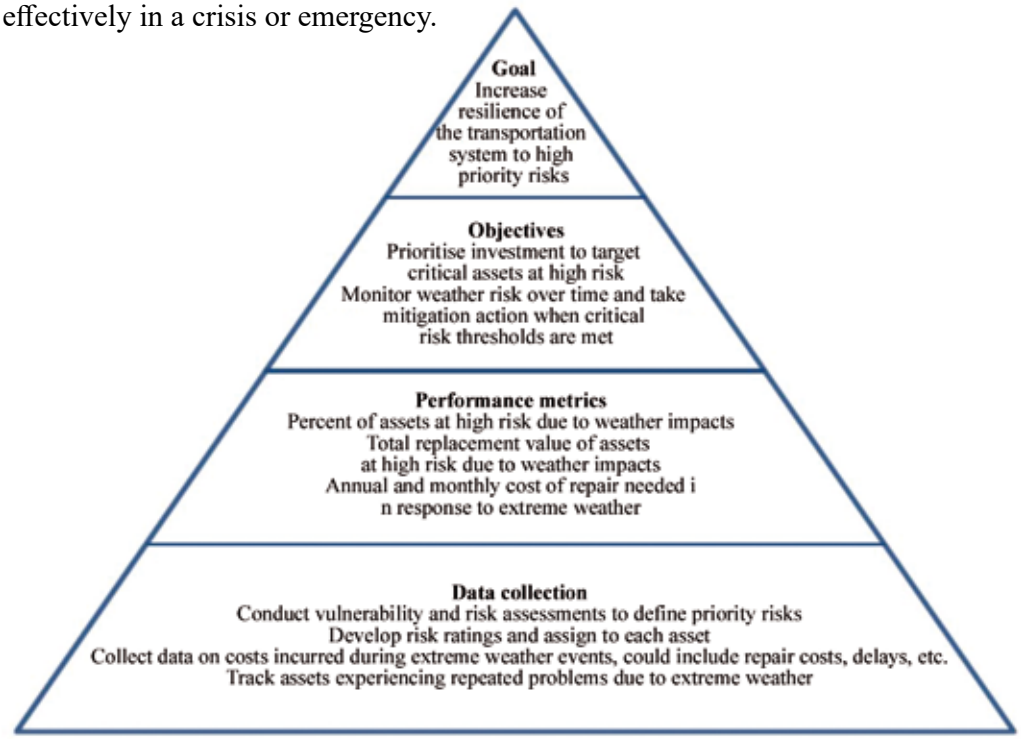


Illustration 1 - AASHTO Risk Management Process

[10] The Scottish Government (2013). Climate Ready Scotland: Scottish Climate Change Adaptation Programme Available at: *http://www.gov.scot/Resource/0042/00426516.pdf*
[11] Australian Government (Department of the Environment) (2007). National Climate Change Adaptation Framework. Available at: *http://www.environment.gov.au/climate-change/adaptation/publications/national-climate-change-adaptation-framework*
[12] The Scottish Government (2013). Climate Ready Scotland: Scottish Climate Change Adaptation Programme Available at: *http://www.gov.scot/Resource/0042/00426516.pdf*
[13] Ministry of Land, Infrastructure, Transport and Tourism (2010). Practical Guidelines on Strategic Climate Change Adaptation Planning: Flood Disasters. Available at: *http://www.mlit.go.jp/river/basic_info/english/climate.html*

DEFINING KEY TASKS AND DELIVERY PLAN

By developing and defining tasks and a plan for the delivery of an assessment at the earliest opportunity, the road authority will be able to clarify, or at least have an awareness of:

- the level of scientific detail, information and evidence required in the assessment;
- the stakeholders who should be consulted;
- the need to consider local versus national interest and concerns;
- the locations and/or assets to be assessed (for example, critical or high value assets, assets in particular locations, or particular categories of assets);
- the timescale for achieving outcomes; and,
- the level of resources required to define and implement actions.

The development and definition of tasks and a delivery plan is dependent on the aim and scope of the assessment. The American Association of State Highway and Transportation Officials' (AASHTO)[14] provides useful guidance for establishing the objectives and stages of any assessment, based on the overarching aim/ goal *(illustration 1, previous page)*.

This approach may be useful for other authorities in determining how to link overarching aims and intended goals/outputs with objectives and a delivery plan.

When establishing tasks, it can be useful to review the tasks within similar assessments conducted by, or on behalf of, other road authorities. For example, the UK's Department for Transport's 'Delivering a Sustainable Transport System'[15] set out a series of strategic aims, one of which was to support economic growth. Tasks and activities were then created to improve the performance of existing networks and enhance the reliability of transport networks to reduce lost productive time and improve average journey times. Such an approach recognised that ensuring the network was resilient to the effects of climate change and extreme weather events were central to achieving the strategic aim(s).

Examples of potential assessment tasks could include:

- developing an understanding the vulnerability of a road authority's overall transportation system to climate change on a very general level;
- identifying which assets are most vulnerable, through a review of recent impacts of extreme weather events and evaluation of future climate projections and threats;
- evaluating the scale and cost of climate impacts;
- raising awareness among the public about activities to manage climate risks or efforts to bolster sustainability[16];
- identifying possible sector wide and/or strategic changes that will be required[17];
- promoting coordinated programmes of work on impacts and adaptation nationally, working in collaboration with stakeholders and other researchers in national, regional and sectorial contexts;

[14] American Association of State Highway and Transportation Officials. (2012). Integrating Extreme Weather Risk into Transportation Asset Management. Available at: *http://climatechange.transportation.org/pdf/extrweathertamwhitepaper_final.pdf*
[15] Department for Transport (2008). Delivering a Sustainable Transport System. Available at: *http://webarchive.nationalarchives.gov.uk/+/http:/www.dft.gov.uk/about/strategy/transportstrategy/dasts/*
[16] The Federal Highway Administration (2012). Climate Change and Extreme Weather Vulnerability Assessment Framework. Available at: *http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability_assessment_framework/*
[17] URS (2010). Adapting Energy, Transport and Water Infrastructure to the Long-term Impacts of Climate Change. Available at: *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/183472/infrastructure-full-report.pdf*

- delivering information to support climate change adaptation decision-making at the national, regional, and local levels through coordination, integration, synthesis and communication of research.

Establishing a delivery plan at the beginning of an assessment helps to confirm and direct tasks and ensure all tasks and actions are working towards fulfilling the overall assessment aims and leading to the desired deliverable(s).

Box 3 - Stakeholder workshop on highway network climate change risks

The 3 Counties Alliance Partnership (3CAP), representing three local authority highway departments in the East Midlands (England) held a workshop to obtain the views of each authority on the effects of climate change on their networks and to identify possible adaptation responses. The workshop was attended by representatives from drainage, structures and environment teams. It included a series of group activities to define key risks and opportunities, identify adaptation options, and develop and agree an Adaptation Action Plan for implementation.

EARLY STAKEHOLDER ENGAGEMENT AND ESTABLISHING ROLES AND RESPONSIBILITIES

Stakeholder engagement can strengthen the development of assessment aim, scope and delivery at the beginning of any assessment, and also increases the likelihood of successful delivery. Stakeholder consultation can ensure the needs of different groups are acknowledged, and if practicable, met. In addition, assessment deliverables and the effectiveness of any outcomes and recommendations may be dependent upon the actions of certain stakeholders. Therefore their early engagement can be a vital component in the achievement of the assessment goals. Establishing genuine *'buy-in'* from stakeholders will ensure they understand and are committed to the adaptation process.

There will be key individuals in any road authority that will be critical in the delivery of an assessment's findings and outputs, such as network managers, asset managers, engineers, finance managers etc. Therefore, understanding and identifying who these individuals are is a crucial first step in any assessment.

It is also important that early within an assessment, road authorities should consider whether their authority's resources and structure can accommodate a plan, programme or strategy, and that there will be a team or individual in place to lead the implementation of the assessment's outputs and recommendations.

Effective methods of early engagement include the delivery of stakeholder workshops and briefing sessions with key decision-makers, and groups or individuals who are likely to be able to provide input to the assessment and take ownership of the outcomes *(Box 3, previous page)*. The most effective forms of communication vary between groups. For example, government departments may have formal, pro-active mechanisms for consultation, whereas engaging with local communities may take a more informal approach.

More information on effective communication with stakeholders can be found in Section *Communicating with stakeholders and decision-makers, page 53*. A *Climate Change Adaptation Communications Plan Guidance* document is available alongside this framework.

When determining the scope and objectives of an assessment or strategy, the assignment of roles (and responsibilities) to each objective and associated action is recommended. The assignment of roles can promote a sense of ownership and helps to strengthen the governance arrangement necessary to achieve the outputs of an assessment.

ASSESSING VULNERABILITY

After assessment scope, aims and objectives have been defined, road authorities can begin to consider the assets, climatic variables and impacts which will be scoped into their assessment. Regions around the world are impacted differently by climate change, which will require a customised approach to evaluating risks based on location-specific data and information[18].

In order to do this, information is provided upon the following aspects which will guide authorities through determining which variables to include within an assessment:

- assessing **vulnerability** levels of different assets and locations, based on exposure and sensitivity levels;
- assessing existing levels of **adaptive capacity** and how these affect vulnerability; and
- assessing and using climate change **projections** and scenarios to understand future climatic conditions and the impact of vulnerability.

Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variables and extremes. Vulnerability, in the context of this framework, is a function of the character, magnitude and rate of climate change and variation to which a system is exposed **(its exposure)**; and the degree to which something is affected, either adversely or beneficially, by climate-related stimuli **(its sensitivity)**.

Vulnerability is also determined by the type of asset, location or operation's **adaptive capacity**; essentially the system's ability to cope and adapt to existing climatic variability and future changes.

There are a number of approaches which can be taken when assessing vulnerability and each road authority should consider the data which is available to them prior to assessment and which method suits the type of data which is made available to them. Vulnerability assessments are

[18] USAID (2013). Global Climate Change, Adaptation, and Infrastructure Knowledge Management Support. Methodology for Incorporating Climate Adaptation in the Design and Engineering of Infrastructure.

likely to have a high degree of site-specificity and must therefore be assessed appropriately as determined by the authority.

The steps below provide a suggested approach to assessing vulnerability, which parts of the network, assets and operations are likely to be most at risk from climate change.

Selecting assets and locations for inclusion

To define any vulnerability assessment, road authorities should decide which assets and/ or locations should be included in an assessment.

A road authority might choose to assess a broad range of assets across the country (for example, if the purpose of the assessment is to evaluate the national scale and cost of climate impacts). Alternatively, the road authority might want to prioritise its assessment by focusing on critical assets that are of the greatest value to the transportation network and the public, or on low-performing assets that are already of concern. The assessment could even focus on a particular geographic location if that area is of high importance to the economy of the country. Identifying the relevant transportation assets to assess can also help narrow the scope of the assessment, bringing it in line with the resources available to conduct the study. To assure that the purpose of the study is achieved and resources are most efficiently employed, road authorities should include in their delivery plan an initial determination of which assets, or categories of assets, will be assessed. Stakeholder input *(Early stakeholder engagement and establishing roles and responsibilities, page 15)* should be used to inform or validate the list of assets. The list might be adjusted in later stages as the assessment begins to clarify vulnerabilities and risks (for example, assets found to have low risk and low vulnerability might drop out of the study).

Assessing exposure

Once a road authority has taken the first step to define the assets and/or locations for inclusion in an assessment (for example, critical assets only, all assets located in a specific region etc.), exposure to the impacts of climate change can be evaluated. Road authorities can categorise exposure through assessing:

- existing exposure levels – based on historical and recent events and observations, local and technical knowledge, and existing research; and/or,
- expected future exposure levels to different climate change effects, which can be informed by an analysis of climate change projections *(Assessing climate change projections and scenarios, page 22)*. This may indicate that assets or locations that are not currently *'exposed'* to the effects of climate change may be in the future.

The following matrix can be used to identify the exposure of specific assets and/ or locations[19]. *Table 1, next page* demonstrates how asset/ location exposure can be recorded by road authorities. Road authorities should select climate variables appropriate to their location and again based on existing/ historical experience and events, and future projections information and expectations.

[19] USAID (2013). Global Climate Change, Adaptation, and Infrastructure Knowledge Management Support. Methodology for Incorporating Climate Adaptation in the Design and Engineering of Infrastructure.

TABLE 1 - EXPOSURE MATRIX						
	Extreme Heat	**Mean Heat**	**Drought**	**Mean Rainfall**	**Storms/ Extreme Rainfall**	**Sea Level Rise and/ or Storm Surge**
Asset/ Location/ Operation A						
Asset/ Location/ Operation B						
Asset/ Location/ Operation C						
Asset/ Location/ Operation D						

Exposure can be scored as follows:

- X = No or negligible exposure now and/or in the future
- 1 = Low exposure now and/or in the future
- 2 = Medium exposure now and/or in the future
- 3 = High exposure now and/or in the future

Assessing sensitivity

Sensitivity *is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli*. Sensitivity can be assessed using:

- **Experience of recent and historical events** – for example, road flooding in a certain location may have led to greater widespread environmental and economic damage that similar flooding levels in another similar area;
- **Geographical location** – for example, road assets located in on slopes are likely to be more sensitive to landslide and scour than those located in flat regions, and areas of a network that act as major links between large urban areas will suffer a higher level of disruption during extreme weather events than areas of the network in lesser populated and urbanised areas; and/ or,
- **Asset condition and design life** – for example, poorly maintained and poor condition parts of the network are likely to be more sensitive to the impacts of extreme weather than recently constructed or well-maintained areas or assets. Furthermore, if an asset is nearing the end of its design life it may be more sensitive to climatic impacts. The Highways Authority's (England) 'Climate Change Risk Assessment'[20] includes a schematic of the design life of their assets, as shown in *illustration 2, page de droite*.

Illustration 2, page de droite shows that pavements and electrical equipment have shorter design lives than assets such as structures and may therefore be more vulnerable, especially if subject to deterioration prior to climatic changes. The design life of property and central reserve assets may be broader and therefore harder to define.

[20] Highways Authority (2009) Climate Change Adaptation Strategy and Framework Available at: *http://assets.highways.gov.uk/about-us/climate-change/CCAF_Strategy_and_Vol_1_Rev_B_Nov.pdf*

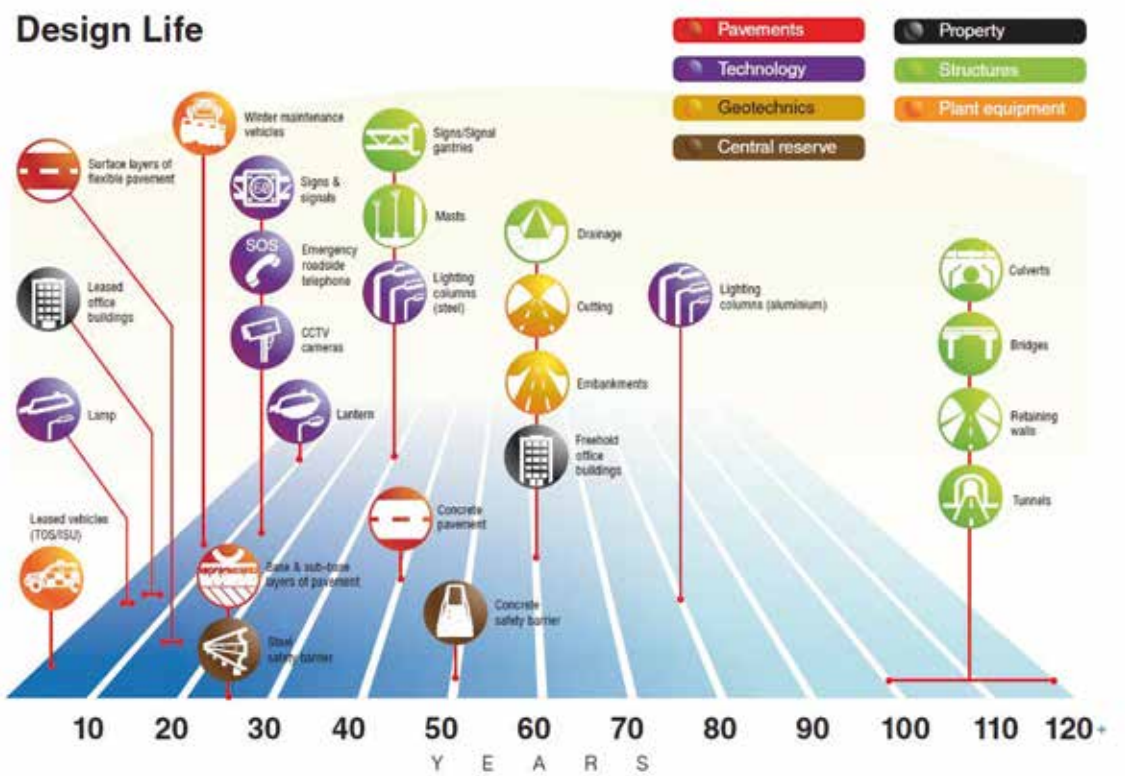


Illustration 2 - Design Life of Highways Assets[21]

Table 2 provides an example scale to help assign high, medium and low sensitivity. The level of sensitivity assigned should be informed by current levels of sensitivity and should not take climate change projections into account as future probability and severity this is covered in **Stage 2**.

TABLE 2 - SENSITIVITY SCALE[21]		
Level of Sensitivity		**Description of Sensitivity Level to Infrastructure (example)**
3	High	Permanent or extensive damage requiring extensive repair
2	Medium	Widespread infrastructure damage and service disruption requiring moderate repairs. Partial damage to local infrastructure.
1	Low	Localised infrastructure service disruption. No permanent damage. Some minor restoration work required.
0	Negligible	No infrastructure service disruption or damage.

Calculating vulnerability levels

Through combining the exposure and sensitivity ratings, it is possible to identify whether the asset is vulnerable, to what degree, and to which climate variables. Assets having high exposure and sensitivity will have a higher vulnerability to the climate variable than those with a low exposure and low sensitivity. Those with low vulnerability to the climate variable are less likely to require adaptation strategies to be put in place to protect them. The Vulnerability Matrix shown in *Table 3, next page* provides an example of how exposure and sensitivity can be used to determine overall vulnerability level.

[21] USAID (2013). Global Climate Change, Adaptation, and Infrastructure Knowledge Management Support. Methodology for Incorporating Climate Adaptation in the Design and Engineering of Infrastructure.

TABLE 3 - VULNERABILITY MATRIX			
Exposure	**Sensitivity**		
	Low	Medium	High
High	4 (Medium)	5 (High)	6 (Extreme)
Medium	3 (Low)	4 (Medium)	5 (High)
Low	2 (Very Low)	3 (Low)	4 (Medium)

Should a road authority wish to quantify the level of vulnerability the following categories can be used:

- **Extreme Vulnerability**: The network or asset is extremely vulnerable, immediate adaptation and/or mitigation will be required to prevent loss.
- **High Vulnerability**: The network or asset is highly vulnerable; adaptation and/or mitigation will be required to prevent loss.
- **Medium Vulnerability**: The network or asset is moderately vulnerable, adaptation and/or mitigation will be required to prevent damage.
- **Low Vulnerability**: The network or asset is less vulnerable, adaptation and/or mitigation would be beneficial.
- **Very Low Vulnerability**: The network or asset is not vulnerable, adaptation and/or mitigation is very unlikely to be necessary.

These categories are simply provided for guidance purposes. It is likely that each asset, location and operation will not wholly comply with these categories and therefore professional judgement will be required. It is recommended that road authorities produce their own categories dependent on their own requirements and data availability.

An assessment of this kind is likely to be one heavily based on professional judgement which will be underpinned by scientific understanding, knowledge of previous and current conditions and trends and supported by climate change projections.

An example scenario demonstrating this approach being applied to assessing vulnerability is included at the end of **Stage 1**.

ASSESSING ADAPTIVE CAPACITY

Once vulnerability has been assessed and a list of vulnerable locations, assets and operations has been established, the existing **adaptive capacity** of the system should be evaluated.

Adaptive capacity can be defined as the ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behaviour and in resources and technologies. Adaptive capacity can be a difficult concept to quantify and evaluate due to a range of internal and external factors. For instance, whilst an asset, location or operation may be highly exposed and sensitive to hazards (giving a high vulnerability level), it may have an enhanced capacity for adjusting to impacts and therefore its overall vulnerability is considered to be lower when adaptive capacity is taken into account.

It is likely that networks, assets and operations already have a certain level of adaptive capacity and will be able to accommodate projected climatic changes to varying degrees. Common attributes of an asset, location and/or operation that indicate strong adaptive capacity include[22]:

- **Repair**: The ability to quickly repair damages;
- **Redundancy**: Relates to the existence of alternative transport routes which enable access to destinations which would otherwise be inaccessible as a result of temporary/permanent highway closure;
- **Resilience**: An ability to readily adjust to short term climatic events (such as precipitation-related flooding) in order to minimise disruption on the network stakeholders.

When assessing adaptive capacity the following questions should be asked[23]:

- **Is the asset, location or operation able to accommodate changes in climate?** For example, have there been any reported climate-related impacts on the aspect in question? Has the asset been designed with climate changes in mind? Is the network/ asset in a good condition?
- **Are there any barriers to an asset's, location's or operation's ability to accommodate for, and adapt to, a changing climate?** For example, constrained resources; political will; ownership uncertainties/disputes; a lack of defined roles and responsibilities; a lack of community integration and education; and, a focus on other deliverables considered to be shorter term goals rather than longer-term capacity building exercises?
- **Is the network already facing (non-climatic) challenges that will limit the ability of highway networks to accommodate changes in climate?** For example, there may be a strong requirement to upgrade existing roads to meet growing traffic levels and resources are focused on this. (In this instance an opportunity for retrofitting an adaptation solution into design and upgrades may be possible).
- **Is the rate of projected climate change likely to be faster than the adaptability of the system?** For example, will asset design life be reduced as a result of the increasing pressures posed by climate risks? Will assets, locations and operations, which have an inbuilt ability to adapt to a changing climate, be able to do so prior to the asset, location or operation reaching threshold limits?
- **Are there already efforts and processes underway which aim to address climate change impacts related to the network?** For example, are there plans, programmes or strategies in place to enhance adaptive capacity? Is there a mechanism in place to ensure the communication of risks and hazards to network users? Are there contingency plans in place for the temporary/ permanent failure and/or loss of an asset/location or operation? Are there emergency and communication procedures and plans in place?

Once the answers to these questions have been determined, road authorities should be able to begin to define an approximate adaptive capacity value for their assets, locations and operations.

[22] *http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability_assessment_framework/page01.cfm*

[23] Centre for Science in the Earth System (The Climate Impacts Group), Joint Institute for the Study of the Atmosphere and Ocean, University of Washington and King County, Washington. (2007). Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments. Available at: *http://cses.washington.edu/db/pdf/snoveretalgb574.pdf?bcsi_scan_AB11CAA0E2721250=1*

It is useful to quantify or categorise the varying levels of adaptive capacity. An example of potential groupings is shown below[24]:

- **very high adaptive capacity**: Adaptive capacity of assets, locations and operations is very high. Almost all assets, locations and operations would be able to adapt to climate impacts in the medium-long term (as defined by a road authority's assessment scope).
- **high adaptive capacity**: Adaptive capacity of assets, locations and operations is high. Most assets, locations and operations would be able to adapt to climate impacts in the medium-term (as defined by a road authority's assessment scope).
- **moderate adaptive capacity**: Adaptive capacity of assets, locations and operations is moderate. Some assets, locations and operations would be able to adapt to climate impacts in the medium-term (as defined by a road authority's assessment scope), yet others would struggle to achieve this.
- **low adaptive capacity**: Adaptive capacity of assets, locations and operations is low. It is unlikely that assets, locations or operations could adapt to projected climatic changes even in the short-medium term.
- **very low adaptive capacity**: Adaptive capacity of assets, locations and operations is very low. It is very unlikely that assets, locations or operations could adapt to projected climatic changes even in the short term.

Those locations, assets and operations classed as having moderate, low and very low adaptive capacity are most in need of attention and should be taken forward into a more formal risk assessment to understand risk probability and severity (**Stage 2**), and how the level of risk can be minimised through adaptation responses (**Stage 3**).

However, whilst the adaptive capacity of an asset, location or operation may be low, this does not necessarily mean it will be a considered as a priority for adaptation. Other factors, such as asset criticality, stakeholder expectations and social, political and environmental acceptability and economic viability should be considered and can heighten a level of risk.

ASSESSING CLIMATE CHANGE PROJECTIONS AND SCENARIOS

To understand how road infrastructure may be affected by future climatic change, a road authority needs to develop an understanding of the climate change projections relevant to their country or region. The following sections provide guidance on:

- using geographical location to determine key climate change types;
- using existing climate change projections data and evidence to determine future conditions;
- developing climate change scenarios and projections where this information does not already exist.

Geographical location

The geographical location of an area for assessment will play a large part in determining the climatic variables that should be considered as risks. Consequently, road authorities must

[24] The Federal Highway Administration (2012). Climate Change and Extreme Weather Vulnerability Assessment Framework. Available at: *http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability_assessment_framework/*

consider their geographical location at both the global and local scale and identify associated climatic variables in line with this.

Geographical factors to consider when identifying future climate change risk types include but are not limited to:

- **the presence of water bodies**: For instance coastal areas are more likely to consider sea-level rise than inland areas;
- **altitude**: Areas at higher altitudes may be more concerned with extreme weather events such as high wind speeds and increased precipitation levels associated with an increased frequency and magnitude of storms associated with climate change;
- **land-use**: Areas which are heavily urbanised may be focused on damage to highway drainage systems and road and pavement fabrics whereas more rural areas may be concerned with access and over-reliance on road structures as a result of a lack of redundancy;
- **topography**: Topography is likely to be a major consideration for national road authorities especially in regards to excess surface water runoff associated with flood events exacerbated by climate change;
- **soil and geology**: This will be a consideration for authorities who have previously experienced landslides and will be a factor in flood risk; and,
- **accessibility**: Some geographical locations may have poor access and/or transportation links that may be further affected and limited by climatic variables such as extreme weather events including flooding.

Considering these variables, as well as existing evidence and scientific understanding of climate change within a particular region helps to determine which climate change types are most likely to be felt and have an impact within that region.

Using existing climate change projections data and evidence to determine future conditions

Climate change data, scenarios and the timescales associated with them are important considerations when determining which climatic variable and impacts to include within an assessment. In order to deliver an effective climate change adaptation assessment or strategy for road infrastructure it is essential that the data used is from a reliable and robust source, as it will form the basis of any risk assessment process going forward.

The Intergovernmental Panel on Climate Change's (IPCC) climate projections[25] are seen to be the most reliable and transparent source of information and provide a global overview of climate change projections. The IPCC provides projections for future climate for a range of different emission scenarios. However, IPCC projections are based on international, continental and national levels, which may be of limited value to regional and/or local projects. To address this issue a number of tools and information sources have been developed (or are currently in development), which downscale global projections to a more localised level. This includes: the UK Climate Impacts Programme projections *(Box 4a, next page)*; the Climate Projection Database for Roads (CliPDaR)[26] *(Box 4b, next page)*; and XGEO, a risk management tool developed in Norway *(Box 4c, page 25)*. While these tools cannot all readily be used in other countries, they do provide useful models and approaches for downscaling climate data that another country could replicate, if the resources are available to do so.

[25] *http://ipcc.ch/*
[26] Matulla et al. (2013). CliPDar. Available at: *http://meetingorganizer.copernicus.org/EGU2013/EGU2013-9810.pdf*

Box 4a - UK Climate Impacts Programme Downscaled Climate Projections

In 1997 the Department for Environment, Food and Rural Affairs (Defra)[27] established the UK Climate Impacts Programme (UKCIP) as a coordinating organisation to integrate recent and ongoing sectorial and regional studies on climate change impacts in the UK. UKCIP's work is largely based upon progress in the development of climate change scenarios and the downscaling of global climate change projections, carried out by the Climate Research Unit at the University of East Anglia and the Hadley Centre of the Met Office. Models predicting future trends in climate change and weather patterns have been developed by the Hadley Centre and their models are accepted as the most authoritative guidance on the possible future changes in weather over the next 100 years in the UK.

The latest set of UKCIP's Climate Change Scenarios for the UK was published in 2009; these are known as the UKCP09 projections. The climate change projections in UKCP09 were developed from findings from the regional climate model HadRM3, which adopts the IPCC methodology. UKCP09 go beyond the previous projections, made in 2002, by accounting for uncertainties in future changes and uncertainties associated with physical, chemical and biological processes. UKCP09 allows users to downscale global climate projections to within a 25 km resolution.

Although the projections are based on a number of uncertainties and assumptions, they allow users to be able to judge and understand the risks and opportunities, and to be well placed to make decisions about mitigating and adapting to the effects of climate change.

Box 4b - Climate Projection Database for Roads (CliPDaR)[28]

The European road sector is vulnerable to extreme weather, which can cause large socio-economic losses. Almost every year there are several weather-triggered events (like heavy precipitation, floods, landslides, high winds, snow and ice, heat or cold waves, etc.). In order to avoid negative impacts it is essential to know present and future threats to roads from extreme weather.

CliPDaR focuses on parts of the European road network and contributes, based on the current body of knowledge, to the establishment of guidelines helping to decide which methods and scenarios to apply for the estimation of future climate change based challenges in the field of road maintenance. Based on regional scale climate change projections specific road-impact models are applied in order to support protection measures.

In recent years, it has been recognised that it is essential to assess the uncertainty and reliability of given climate projections by using ensemble approaches and downscaling methods. CliPDaR is going to collect the existing approaches and methodologies in European countries, discuss their differences and - in close cooperation with the road owners - develop a common line on future applications of climate projection data to road impact models. As such, the project will focus on reviewing and assessing existing regional climate change projections regarding transnational highway transport needs.

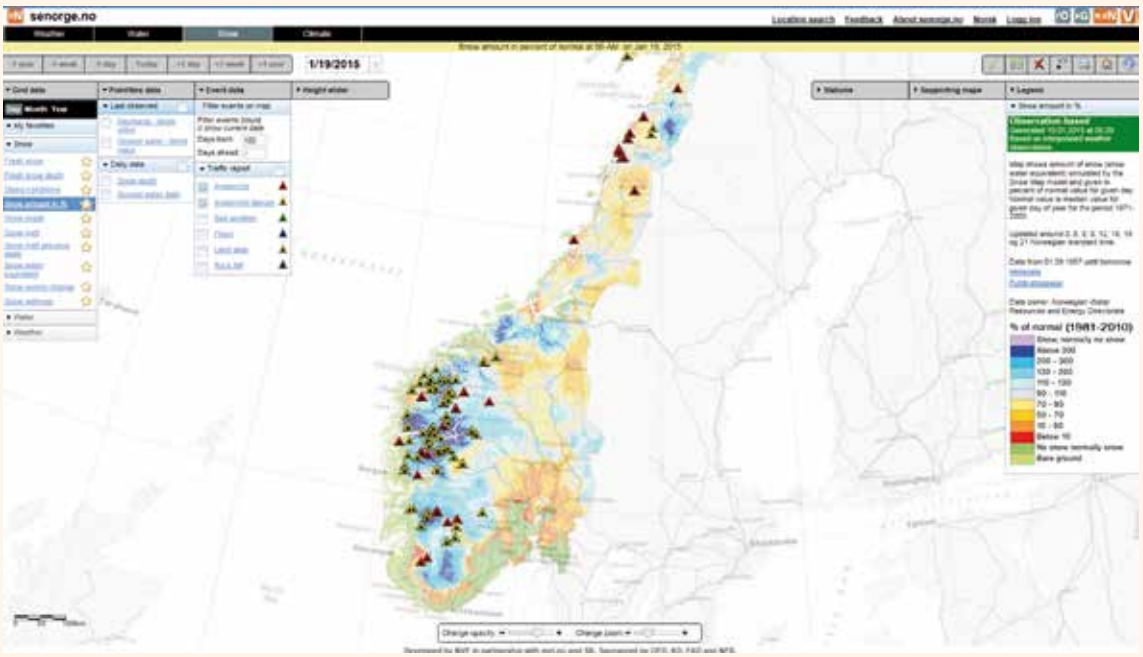
[27] Department for Environment, Food and Rural Affairs Website. Available at: *https://www.gov.uk/government/organisations/department-for-environment-food-rural-affairs*
[28] *http://adsabs.harvard.edu/abs/2013EGUGA..15.9810M*

Box 4c: XGEO – Risk Management Tool (Norway)[31]

XGEO is a map centric tool for visualising temporal and spatial climate and climate change data. The tool has been developed and maintained by the Norwegian Water Resources and Energy Directorate, in collaboration with the Norwegian Meteorological Institute, the National Public Road Administration and the National Rail Administration. The data derived from the system allows preparing, monitoring and forecasting floods, avalanches, landslides and other natural hazards. The Norwegian Public Road Association utilises the system to issue an appropriate level of preparedness during extreme weather events.

XGEO allows for geographical areas to be categorised according to their level of preparedness. XGEO utilises temporal and spatial data from various sources (historical maps of snow conditions, weather observations, predictions based on European atmospheric models, gridded water balance, climate means and anomalies, real-time weather observations). XGEO also incorporates a layer of administrative information and other static maps including existing roads and rail infrastructure, forecast regions, tree lines, etc.

The tool is operated under open data policy and is available to everyone. The picture below shows an example output from XGEO and maps avalanche activity over a period of 100 days in Norway.



[31] XGEO Risk Management Tool (Norway) Available At: *http://www.xgeo.no/aboutXgeo.html*

Box 5 - Promoting and accessing climate change research and evidence

ClimateXchange[29] is Scotland's centre of expertise on climate change. It provides a research, advice and analysis service to Scottish Government policy teams and associated public authorities. Researchers in 16 of Scotland's leading research and higher education institutions are members of ClimateXChange. It connects climate change research and policy and gives government bodies, including Transport Scotland, access to these research groups to carry out small and specific pieces of research.

However, in many developing countries, detailed climate observations and downscaled climate change projections may not available. While this will create some uncertainty, road authorities can respond by making conservative estimates based on available data. This can be informed by consulting available data in other similar parts of the region, using traditional knowledge, drawing from studies conducted under similar conditions, or by conducting new studies[30] *(Developing climate change scenarios and projections, below)*.

Developing climate change scenarios and projections

Where funds are available and climate change projections and data have not already been developed, engaging with research establishments and academia to undertake climate science and climate projections studies is recommended. Being able to base any climate change adaptation assessment on sound and verified climate projections data allows for confidence in the findings and recommendations to be maximised. Developing mechanisms at the national or regional level to develop and continuously improve climate change knowledge and understanding facilitates and strengthens effective risk assessments and adaptation responses. This type of mechanism can be seen in Scotland's ClimateXChange programme *(Box 5)*.

Using climate change projections information

Once climate change projections information has been gathered, road authorities are able to use this information to:

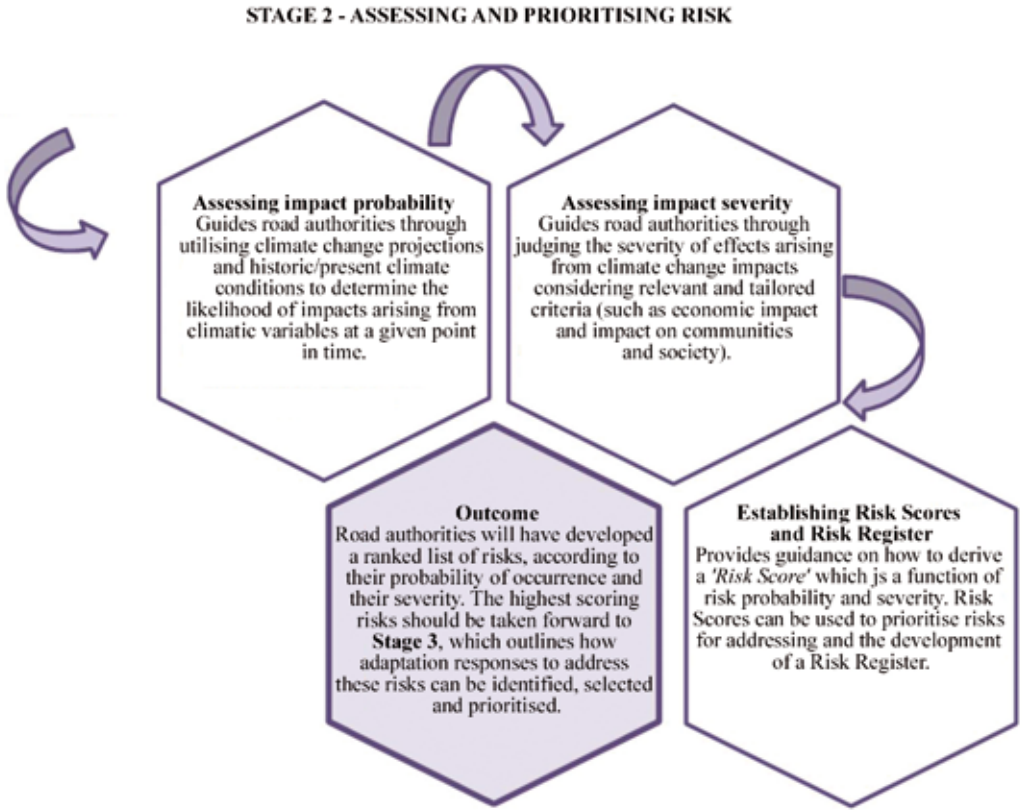
- understand and evaluate road infrastructure exposure and, ultimately, future levels of vulnerability *(Assessing vulnerability, page 16)*; and,
- Assess future risk probability levels for the selected assets and/ or locations *(Stage 2)*.

[29] ClimateXChange. Website Available at: *http://www.climatexchange.org.uk/*
[30] USAID (2013). Global Climate Change, Adaptation, and Infrastructure Knowledge Management Support. Methodology for Incorporating Climate Adaptation in the Design and Engineering of Infrastructure.

STAGE 2 - ASSESSING AND PRIORITISING RISKS

Stage 1 facilitated the identification of road infrastructure vulnerability to climate change and an understanding of future climate change effects.

Stage 2 provides guidance on understanding risk levels.



The approach outlined here should enable authorities to understand, and where possible to quantify, the risks posed to their networks and assets in a simplistic, accessible, iterative and yet robust and holistic way following risk assessment principles.

By following the steps of **Stage 2**, road authorities will be able to rank their assets, locations and operations according to the level of risk probability and/or severity. This approach will identify where the most significant risks are expected to occur and shall prepare authorities for **Stage 3** of the framework wherein adaptation responses are developed and prioritised.

Prior to assessing risks it is essential that the following variables are defined as outlined within **Stage 1**:

- the climate effects and impacts which have been scoped into the assessment; and,
- the assets, locations and operations that have been scoped into the assessment.

There is scope to modify the above variables throughout the assessment process.
For the purpose of this framework, risk is considered to be a function of **probability** and **severity**.

TABLE 4 - IMPACT PROBABILITY SCORING		
Probability of effect	**Definition**	**Score**
Almost Certain	More likely to happen than not (probability close to 100%)	5
Likely	Fairly likely to occur (probability greater than 50%)	4
Unlikely	Possible it may occur (probability less than 50%)	3
Rare	Low, but not impossible (low, but noticeably greater than zero)	2
Highly Unlikely	Very low, close to zero	1

TABLE 5 - EXAMPLE IMPACT SEVERITY SCALE (OTHER CRITERIA CAN BE USED/ ADDED AS NECESSARY)					
Score / **Criteria**	**1 (Very Low)**	**2 (Low)**	**3 (Medium)**	**4 (High)**	**5 (Very High)**
Population and communities	Less than 1% of the population affected	Between 1-2% of the population affected	Between 2-5% of the population affected	Between 5-10% of the population affected	More than 10% of the population affected
Economic impact	Less than US $1m	Between US $1m and $2m	Between US $2m and $5m	Between US $5m and $10m	More than US $10m
People and employees	Employees within a local works/depot affected	Employees within an major office affected	Employees within a function affected (e.g. within maintenance)	Employees within a Business Unit affected	All employees affected
Society	Local disruption of essential services, social practices and events	Regional disruption of essential services, social practices and events	Regional disruption of essential services, social practices and events	National disruption of essential services, social practices and events	International disruption of essential services, social practices and events
Stakeholders and Supply Chain	One stakeholder or element of supply chain affected	More than one stakeholder or element of supply chain affected	One group of stakeholders or elements of supply chain affected	More than one group of stakeholders or element of supply chain affected	All stakeholder or supply chain elements affected

ASSESSING IMPACT PROBABILITY

Impact probability relates to the likelihood of an impact occurring within a given timeframe. Due to the uncertain nature of climate change, assessing probability of impacts occurring can be difficult. However, approximations can be made using climate change projections *(Assessing climate change projections and scenarios, page 22)*, evidence of past events, vulnerability levels, and other conclusions drawn from **Stage 1** of the assessment.

The assessment should also take account any in-built mitigation measures and existing adaptive capacity *(Assessing adaptive capacity, page 20)* but should not include any measures that are not currently in place. Probability should be scored for a specified point in time or timeframe (e.g. 2040 or 2030-2050).

A process for assessing and scoring the likely probability of climate change risks facing highway networks, assets, locations and operations is set out in *table 4*.

An example of how probability can be scored for a particular impact type is provided at the end of **Stage 2** *(Establishing Risk Scores and a Risk Register, page 30)*.

ASSESSING IMPACT SEVERITY

Severity relates to a judgement about the severity of an impact (such as flooding of a road, heat damage to a bridge, a landslide in a particular location etc.) if it were to be realised, regardless of the probability of occurrence. Severity is assessed by the user on the basis of knowledge, estimation and evidence of past similar events (at a similar scale, at the same of similar asset, or at the same or similar location) and can be scored using a Severity Scale *(table 5, page 28)*. Criteria and the associated metrics within the Severity Scale should be tailored according to local needs and priorities and the example below is provided as an example only. Defining scoring criteria and metrics is ideally done in a workshop setting with key stakeholders to identify important criteria to be used to assess consequence.

The assigned overall Severity Score should be that corresponding to the highest rated criterion. So, for example, if the Service criterion is scored as 5 (Very High) and all other criterion are scored as 4 (High), then the overall Severity Score should be 5 (Very High).

It is recommended that the reason(s) for selecting the key criterion (e.g. Value Very High) should be recorded. This may be based, for example, on information regarding the costs of similar extreme weather events in the past or knowledge about the potential size of the population affected should the risk be realised, etc.

An example of how severity can be scored for a particular impact type is provided at the end of **Stage 2** *(Stage 3 - Identifying and Selecting Adaptation Responses and Strategies, page 31)*.

TABLE 6 - RISK SCORE MATRIX

Likelihood	Severity				
	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

TABLE 7 - RISK CATEGORIES AND RESPONSES

Extreme ≥ 20	• Extreme risks demand urgent attention at the most senior level and cannot be simply accepted as a part of routine operations without executive sanction. • These risks are not acceptable without treatment.
High ≥ 12	• High risks are the most severe that can be accepted as a part of routine operations without executive sanction but they are to be the responsibility of the most senior operational management and reported upon at the executive level. • These risks are not acceptable without treatment.
Medium ≥ 5	• Medium risks can be expected to form part of routine operations but they will be explicitly assigned to relevant managers for action, maintained under review and reported upon at the senior management level. • These risks are possibly acceptable without treatment.
Low < 5	• Low risks will be maintained under review but it is expected that existing controls will be sufficient and no further action will be required to treat them unless they become more severe. • These risks are can be acceptable without treatment.

ESTABLISHING RISK SCORES AND A RISK REGISTER

As detailed above, *'Risk'* can be seen as a combination of probability and severity. By multiplying together the score for these two criteria, a *'Risk'* score of between 1 and 25 is calculated.

Based on this numerical score, each risk can be graded and colour coded as shown in *table 6*. From this scoring, levels of action and attention can be determined, as shown in *table 7* [32], *previous page.*

This method of assessing *'Risk'* shows the absolute risk at the time it might occur but does not show the trend in risk over time. This approach can be used as a starting point when seeking to understand and prioritise climate change impacts according to their probability and severity. Assessing how risk level varies over time can simply be achieved through undertaking the same analysis for different timeframes (for example, 2040-2050, 2080-2090). Severity score will remain unchanged but probability is likely to vary over time. This can be established through the review of climate change projections data.

It is important that each road authority develops a method of quantifying probability and severity that is applicable to their circumstances and assessment. Consultation on this part of the assessment is therefore suggested amongst relevant and responsible groups and associate stakeholders.

Impacts can be rated and prioritised for action according to their overall *'Risk'* score and used to develop a Risk Register. Prioritising risks in this way will subsequently aid the development and prioritisation of adaptation responses and strategies that is covered within **Stage 3** of this framework. Road authorities should decide, using the evidence gathered through the risk assessment, which impacts to address and take forward to the next stage.

A template for use by road authorities when scoring probability and severity, and when developing a Risk Register, accompanies this framework.

An alternative approach to establishing impact probability as used by the US Department of Transport is reproduced in *Box 6, right page*.

[32] USAID (2013). Global Climate Change, Adaptation, and Infrastructure Knowledge Management Support. Methodology for Incorporating Climate Adaptation in the Design and Engineering of Infrastructure.

Box 6 - Alternative Approach to Establishing Impact Probability – US Department of Transport Asset Hazard Likelihood Scoring

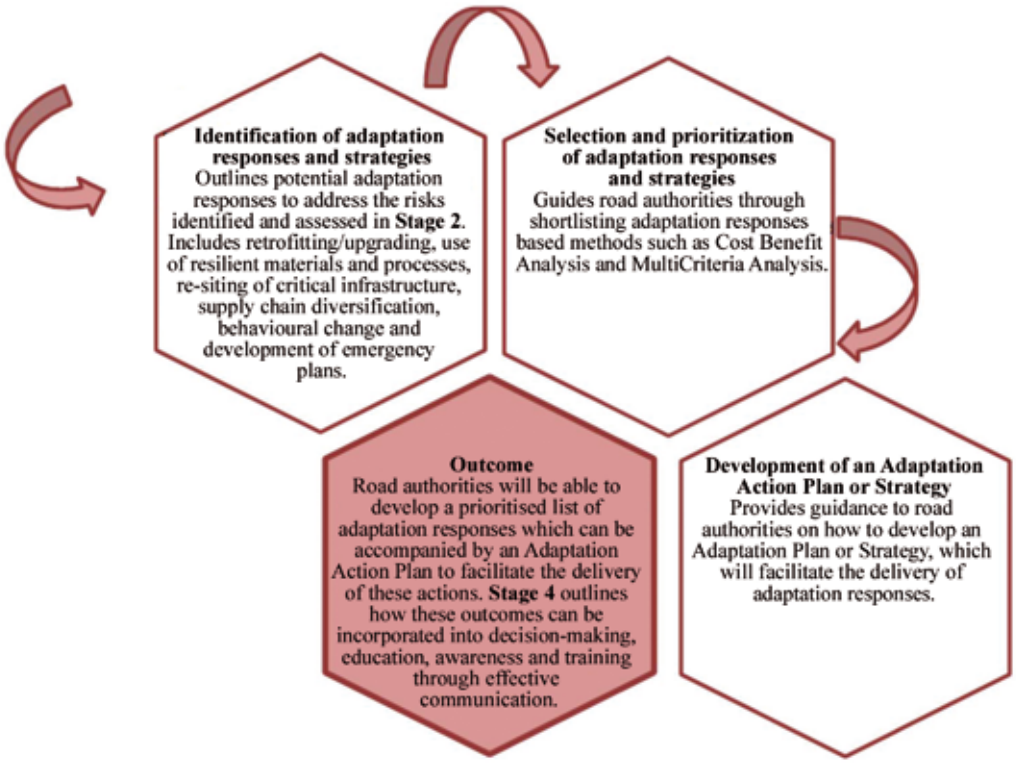
The U.S. Department of Transportation's Federal Highway Administration's report *Climate Change and Extreme Weather Vulnerability Assessment* highlights the challenges posed in determining the probability of future climate impacts. However, although climate models rarely agree with one another, generally there is certainty regarding the direction of change. It is recommended that authorities categorise assets into the following categories:

- **Category 1**: Assets have a low likelihood of being impacted by a future climate condition and a low consequence of being impacted by that condition;
- **Category 2**: Assets have a low likelihood of being impacted by a future climate condition and a high consequence of being impacted by that condition;
- **Category 3**: Assets have a high likelihood of being impacted by a future climate condition and a low consequence of being impacted by that condition; and,
- **Category 4**: Assets have a high likelihood of being impacted by a future climate condition and a high consequence of being impact by that condition.

STAGE 3 - IDENTIFYING AND SELECTING ADAPTATION RESPONSES AND STRATEGIES

To deliver an effective response to the impacts of climate change on a road networks, appropriate adaptation responses must be developed in response to the risks identified *(Stage 2)*. These key identified risks should be used to guide the determination, short-listing and prioritisation of adaptation responses as shown below:

STAGE 3 - DEVELOPING AND SELECTING ADAPTATION RESPONSES AND STRATEGIES



This section also provides guidance on the actions that could potentially be undertaken by road authorities when adapting their networks to become increasing resilient to the projected impacts of climate change. Indicative examples of the types of adaptation responses that could be implemented will also be demonstrated.

IDENTIFICATION OF ADAPTATION RESPONSES AND OPPORTUNITIES

The risks identified as being the most severe in terms of probability and/or severity (leading to the overall *'Risk'* score – *Stage 2*) can be addressed through the identification and prioritisations of adaptation responses.

A number of frameworks, strategies, plans, guidance, programmes and successful case studies exist which exhibit a wide range of potential adaptation responses, a summary of which is provided in the following sections and in *Boxes 7a-f, page 35*. These act as a guide for road authorities to begin thinking about the adaptation measures they may take in order to enhance the resilience of their networks. The list is by no means extensive and each authority should consider their own needs and requirements when considering potential adaptation measures.

Input from individuals and groups who hold local knowledge and past experience should always be sought when looking to identify and select adaptation responses as they are most likely to know which options are the most feasible, realistic and have the biggest potential to be effective and successful.

The responses set out below simply act as a guideline for potential adaptation measures, and vary widely according to how simple they are to implement (in terms of cost, resources and technical feasibility) and some can be delivered through existing maintenance programmes, whereas others would require standalone capital investment. Through professional judgement, expertise and knowledge of the road network, authorities should be able to produce a bespoke list of potential adaptation responses suited to their particular assessment and road network.

Guidance on shortlisting and prioritising adaptation responses will be given within *Selection and prioritisation of adaptation responses and opportunities, page 40* of the framework.

Sea level rise and storm surges – adaptation responses:

- Using appropriate structural materials and providing lateral protections
- Raising road and pavement levels
- Constructing levy banks with drainage/seawalls
- Road realignment
- Including additional longitudinal and transverse drainage systems
- Construction of seawalls, jetties, offshore breakwaters, groins, ripraps to protect shorelines from coastal erosion and submersion
- Protecting levy bank with suitable mangroves
- Planting artificial reefs
- Replacing metal culverts with reinforced concrete
- Development or strengthening of flood risk management plans
- Re-siting of critical infrastructure from areas that are forecast to be most at risk from rising sea-levels
- Development of a Coastal Strategy which identifies the most appropriate shoreline management plan and whether coastal defences are required/ need managing/need implementing etc.

Reduction in rainfall and increased drought – adaptation responses:

- Using flexible pavement structures
- Increasing water retention capacity and slowing infiltration through environmental measures and bio retention systems to recharge aquifers and reduce surface flow runoff
- Re-vegetating with drought tolerant species
- Using matting/erosion control blankets
- Applying granular protection
- Ensuring the selection of materials with high resistance to dry conditions
- Implement a reactive landscape and maintenance regime which accommodates for reduced rainfall
- Maintenance of soil moisture and nutrient levels

Increase in precipitation – adaptation responses:

- Applying a safety factor to design assumptions
- Reducing the gradient of slopes
- Increasing size and number of engineering structures (hydraulic structures, high river crossings)
- Increasing water retention capacity and slow infiltration through natural or bioengineered systems
- Raising pavements and adding additional drainage capacity
- Using water capture and storage systems
- Realigning natural water courses
- Enclosing materials to protect from flood water (impermeable linings)
- Using materials that are less affected by water
- Allowing for alternative routes in the event of a road closure
- Highway drainage plan
- Gully and pumping station renovation
- Mapping of flood hotspots
- Updated design standards for drainage systems
- Production of a Surface Water Management Plans, Local Flood Risk Management Plans etc.
- Pollution prevention control methods due to increased volumes of diffuse pollution resulting from increased runoff
- Implementation/ broadening of emergency warning systems in the instance of flooding
- Improved communication methods for network users in the event of an emergency
- Improved coverage of street lighting due to reduced visibility
- Slope stability studies in an attempt to minimise landslides as a result of increased precipitation
- Measures to enhance slope stability and prevent landslides and rock fall
- Soil moisture removal techniques to prevent the deterioration of the structural integrity of roads, bridges and tunnels

Increased wind strength – adaptation responses:

- Modifying the design of supports and anchorages
- Installing protection systems such as windbreaks
- Planting coastal forest and mangroves
- Increased frequency of gully maintenance activities
- Improved communication systems and warnings for network users
- Structural assessment of suspension bridges, signs and tall structures

Increased temperatures – adaptation responses:

- Using more resilient materials and processes which have heat-resistant properties
- Relocation of street traffic control equipment
- Development and implementation of emergency and resilience plans and changes to working practices and policies
- Improved conditions for vegetative growth may require an increased level of management
- Increased use of heat and fire resistant materials
- Improved coverage of fire-fighting equipment
- Enhanced cooling and ventilation of electrical equipment
- Use of anti-corrosion paint due to increase in surface salt levels in some locations
- Maintenance of soil moisture and nutrient levels

Changes to snowfall, permafrost and ice coverage – adaptation responses:

- Soil stability studies
- Production of a Surface Water Management Plans, Local Flood Risk Management Plans etc.
- Development and implementation of emergency and resilience plans and changes to working practices and policies
- Heat extraction using air convection in embankments on permafrost (this involves cooling embankments in an effort to maintain or cool frozen ground conditions)
- Use of heat drain to facilitate heat extraction from the embankment during winter
- Insulating the permafrost to mitigate thawing
- Soil stabilisation techniques used to reduce frost action in subgrade soils
- Use of a pavement surface having a high albedo (surface solar reflectivity) in order to minimise heat transfer to the underlying subgrade
- Structural assessment of road and structure integrity as a result of subsidence and weakening as a result of permafrost thaw

Beyond the adaptation responses outlined above, it is important that emergency, reactive measures and procedures are also in place. For instance, staff should be trained on how to respond to extreme weather situations and it may be useful to ensure long-term contracts with relevant contractors and suppliers are set-up in advance to intervene and address damaged network assets promptly and to avoid delays resulting from procurement and contracting procedures. Having robust emergency procedures in place also helps to safeguard employees during extreme weather events. Ensuring resilience within the supply chain is also important. For example, avoiding reliance on only once maintenance contractor may lead to difficulties if the location in which they are based in is left inaccessible during an extreme weather event.

Case study examples of where action has been taken by road authorities to adapt their networks and assets to the impacts of climate change are included in *boxes 7a-f, pages 35 to 39* and *box 8, page 39 and 40*.

Furthermore, the Asian Development Bank has developed *'Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects*[33]. Within this guidance, examples of engineering and non-engineering interventions are provided, as shown in *box 8, page 39 and 40*.

Box 7a - Adaptation Case Study - Addressing Climate Change Impacts in Vanuatu[34]

Epi Island is one of 83 islands that make up Vanuatu. It is the site of the Pacific Adaptation to Climate Change (PACC) Project that spans 14 different Pacific island countries. The PACC project supports on the ground projects to help communities adapt to climate change in one of three key areas; food production and food security, water resource management, and coastal zone management.

Approximately 40% of the current roads on Epi are located next to the high water mark. This makes the roads vulnerable to coastal erosion, and leads to them becoming dangerous and inaccessible. Studies by the Vanuatu Meteorological Service and the science component of the Australian International Climate Change Initiative (ICCAI) show that sea levels in Vanuatu have risen by at least 11cm since 1993, which is over twice the global average rate of sea level rise.

Parts of their road network are currently being relocated to avoid the impacts of climate change. Detailed surveys of segments of the road on the island that need to be relocated have been conducted and designs have incorporated the impacts of climate change. The project will include changes to drainage design specifications to allow for run-off during heavy rainfall and the installation of sedimentation ponds, which will limit sedimentation from heavy rain reaching the island's coral reef.

Box 7b - Adaptation Case Study - Improving Climate Resilience in Sri Lanka[35]

Climate related hazards pose a significant threat to Sri Lanka's socioeconomic development. For instance upland areas are particularly vulnerable to landslides triggered by extreme rainfall events. In recent years, Sri Lanka's road network has been rapidly expanding without due attention to landslide risks. Consequently, unstable slopes have led to road damages and subsequently detours that have associated costs.

The Sri Lankan Ministry of Irrigation and Water Resources Management has established a clear investment program for the modernisation of road and water resources. Investment will be focused on reinforcing road infrastructure across a wide highway network with approximately 3km of unstable, high-risk roadside slopes being augmented to improve resilience to landslides triggered by heavy rains. To mitigate against flood risks to low-lying bridges, nine key vulnerable river crossings will be strengthened, raised and/or lengthened.

[33] Asian Development Bank (2011). Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects. Available online at: *http://www.adb.org/documents/guidelines-climate-proofing-investment-transport-sector-road-infrastructure-projects*

[34] Secretariat of the Pacific Regional Environment Programme. (2012). Vanuatu Addressing Climate Change Impacts with Vital Roads. Available at: *http://www.sprep.org/Climate-Change/vanuatu-addressing-climate-change-impacts-with-vital-roads*

[35] *http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2014/01/27/000442464_20140127121120/Rendered/PDF/842180PID0P1460Box382130B00PUBLIC0.pdf*

Box 7c - Adaptation Case Study - Making Transport Climate Resilient in Mozambique[36]

The Mozambican road network will be vulnerable to changes in rain patterns and, to a smaller extent, increased temperatures, sea level rise and cyclones. The World Bank has developed a series of recommended measures report to make Mozambique's road networks climate resilient.

Design measures:

- revise parameters used for the design storm in order to create a robust standard design flood estimation method for all drainage systems and structures;
- design culverts that cause limited damage to roads during floods;
- investigate the use of spot improvements in high risk areas;
- design gravel roads and community roads with a variety of materials suitable for the climate and topography; and,
- new alignments need to consider likely future change to the environment considering increases in rainfall, groundwater, sea level rise, storm surge, and the impacts on flooding and transboundary rivers.

Maintenance measures:

- prioritise maintenance and drainage updates in areas that are most at risk of flooding;
- increase the frequency of drainage maintenance in relationship to the increased frequency of large storms; and,
- repair and clean channels and drainage structures in high-risk areas before the rainy season.

Research measures:

- create a database for bridges and culverts;
- further research on suitability of marginal materials on road construction;
- establishment of a database with an extensive inventory of road building materials; and,
- continue to improve models for the prediction of flood magnitudes and probability of these floods, updating them with the latest climate change scenario data where possible.

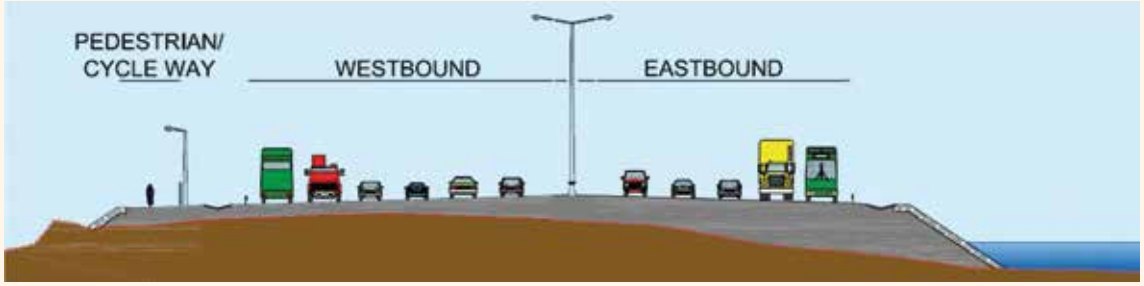
[36] World Bank (2010). Making Transport Climate Resilient. Available at: *http://www.ppiaf.org/sites/ppiaf.org/files/publication/Mozambique_Making-Transport-Climate-Resilient.pdf?bcsi_scan_AB11CAA0E2721250=0&bcsi_scan_filename=Mozambique_Making-Transport-Climate-Resilient.pdf&bcsi_scan_E956BCBE8ADBC89F=0&bcsi_scan_filename=Mozambique_Making-Transport-Climate-Resilient.pdf*

Box 7d - Adaptation Case Study - Causeway Upgrade Project Construction (New Zealand)[37]

The New Zealand Ministry for the Environment recommends specific sea level rise values that all government authorities should consider as part of the planning process. The New Zealand Transport Authority (NZTA) incorporated this sea level rise planning recommendation as part of the design for the SH16 Causeway Upgrade Project. The Causeway is a key part of the Western Ring Route – one of the country's seven roads of national significance. As part of the project the Causeway is being raised to reduce flooding during extreme tidal conditions (see below).

Existing Causeway Configuration in 2013

Final Causeway Configuration by 2017



This represents an upgrade project of national importance, and when completed Auckland's Western Ring Route will form a vital alternative north-south route to the existing State Highway 1 for regional and national traffic movements in the Auckland area. This development is also expected to promote economic growth in the Western Ring Route.

The overall estimated cost of the project is $220m with a plan to be completed by 2017. Project delivery has shown an outstanding level of stakeholder satisfaction and acceptance. The Causeway Alliance has indicated the importance of early collaboration and engagement with stakeholders and communities.

[37] New Zealand's Transport Authority (2014). SH16 Causeway Upgrade Project.
Available at: *http://www.nzta.govt.nz/projects/sh16causeway/index.html*

Box 7e - Adaptation Case Study - Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions (Quebec, Canada)[38]

Permafrost underlies approximately half of the Canadian landmass and is essential for highway networks in the north that are reliant upon the strength of permafrost soils. Permafrost is highly sensitive to changing thermal conditions and is therefore affected by any changes to the climate. Ensuring a reliable northern transport system is essential to maintaining and improving the quality of life of vulnerable and isolated communities.

The Transportation Association of Canada has worked with multiple Canadian provinces and territories to produce *Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions*. The guide provides a compendium of best practices for development, planning, design, construction management, maintenance and rehabilitation of transportation facilities in regions of northern Canada with permafrost terrain. It includes guidance relating to the following key areas:

- Route Investigation in Permafrost Regions;
- Embankment and Pavement Materials;
- Engineering Considerations;
- Drainage and Erosion Control;
- Construction;
- Maintenance; and,
- Emerging Technologies.

This guidance also provides information on existing and emerging methods to adapt road infrastructure to the impacts of changing permafrost conditions, including:

- Heat extraction using air convection in embankments of permafrost to maintain or cool frozen ground conditions
- Permafrost insulation;
- Soil Stabilisation; and
- Development of durable, light coloured pavements for use in permafrost environments (high albedo minimises heat transfer to underlying subgrade).

[38] *http://tac-atc.ca/sites/tac-atc.ca/files/site/doc/resources/primer-permafrost2010.pdf*

Box 7f - Adaptation Case Study - The TRACC-EXPERT Project - Techniques Road Adapted to Climate Change[39]

An informatics tool, TRACC-EXPERT, has been developed by the French Ministry of Transport and regional authorities, in cooperation with Spanish and Portuguese local authorities. Its goal is to help road authorities, design engineers and private contractors to choose the best suited technique regarding climate change adaptation when it comes to either building a new road or maintaining an existing road.

The tool is available free of charge and takes into account environmental, economic and social conditions when selecting techniques and solutions. To date, TRACC-EXPERT has been used on 35 projects, and the outputs of the tool have been taken forward for further consideration and implementation in 60% of cases.

Box 8 - Road Infrastructure Projects Interventions[40]

Engineering/ Design Standard Interventions:

- **Subsurface conditions**: The type, strength, and protection of subsurface conditions and materials may have to be increased to control and prevent soil saturation from damaging infrastructure. The composition of the subsurface materials can be adjusted to account for changing climatic conditions. Availability of water for compaction during construction may be an issue in some areas where rainfall is projected to diminish. Melting permafrost may also be a critical factor in some countries.
- **Material specifications**: The strength of materials may have to be increased to withstand increased or decreased moisture contents. The protection of these materials may have to be enhanced to preserve the expected lifetime of the structure, or other materials may need to be used. For example, because of increased salinity, steel reinforcements and culverts may be replaced with less corrosive materials.
- **Cross section and standard dimensions**: For example, standards may need to be revised to increase the slope of pavement in areas where one can expect a need to remove more water from the road. Similarly, standards (or guidelines) pertaining to road elevations or the vertical clearance of bridges over waterways may have to be revised upward to withstand more extreme flood conditions.
- **Drainage and erosion**: Attention must be paid to standard designs pertaining to drainage systems, open channels, pipes, and culverts to reflect changes in future expected runoff or water flow. Further, it may be appropriate to include a provision for use of superfluous drainage water for domestic or irrigation purposes.
- **Protection engineering structures**: Protective engineering structures can be used to fend off rising sea levels and storm surges. These may include dikes, seawalls, rocky aprons, breakwater systems, and other structures. Retaining walls can also be planned for areas where land and mudslides are increasing, with the same caveat that reducing the causes of such events in the first place may be more effective.

[39] Institut Des Routes, des Rues et des Infrastructures pour la Mobillité. The TRACC EXPERT Project. Available at: *http://www.idrrim.com/comites-operationnels_groupes_travail-idrrim/methodologie/groupe-national-tracc-expert/*

[40] Asian Development Bank (2011). Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects. Available online at: *http://www.adb.org/documents/guidelines-climate-proofing-investment-transport-sector-road-infrastructure-projects*

Non-Engineering Options:

- **Maintenance contracting and early warning**: For infrastructure that is already in place, increasing maintenance contingency budgets in areas where climate change impacts are acute will allow more intensive supervision and monitoring of the most vulnerable areas. Maintenance planning systems can include early warning systems to anticipate extreme events so that crews and contractors can be prepared for an upcoming high rainfall event and possible landslides.
- **Alignment, master planning and land use planning**: Consider whether roads are opening up development in areas that are hazard prone. For example, the location of coastal infrastructure in many cases, including for transportation, needs to be revisited to avoid damages related to sea level rise and increased storm surges. Where realignment is a plausible adaptation solution to protect transport infrastructure, care must be given to understanding the implications of resettlement of populations and economic activities.
- **Environmental management**: Harnessing the services provided by environmental buffers can moderate the damages from floods, droughts, and landslides. Examples include ensuring increased vegetative land cover and preserving and conserving mangroves, peatlands, and forests, which help to regulate the hydrologic cycle and minimise the severity of floods. Adjustments can also be made to environmental management plans that are usually prepared for road development projects. Furthermore, it is important to assess and reduce the impact that a road development may have on the region's vulnerability.

SELECTION AND PRIORITISATION OF ADAPTATION RESPONSES AND OPPORTUNITIES

At this stage of the assessment road authorities will have a list of potential adaption responses to key risk facing their network assets, operations and locations. Due to resource constraints, adaptation responses that best meet the assessment scope and aims should be selected for further consideration.

As part of the selection process the following factors should be considered:

- Does this response fall within the remit of the scope and expected outcomes of the assessment?
- Would adequate resources be available to fulfil this response?
- Would the response be technically feasible?
- Would the response be socially acceptable to local communities?
- Would the implementation of this response offer synergies with national policies?

Whilst an adaptation measure may not wholly comply with each of the above factors, there should be a degree of compliance with each. Where a response is predicted to have adverse impacts upon each factor, road authorities may wish to discount it from their assessment. However, where options fall outside of the assessment scope yet would derive greatest benefit they should be taken up as part of an upstream planning process and flagged for higher-level discussions.

If a response is shown to have a high to moderate level of compliance with the above factors it should be selected as a potential adaptation response and should be scoped into further assessments wherein it will be ranked against other responses in terms of priority.

After scoping out and shortlisting the adaptation responses that do not suit the requirements of an assessment, road authorities are likely to be left with a more manageable, condensed list of potential adaptation responses.

However, as a result of resource constraints and government planning periods it is likely that not all adaptation measures will be implemented in the first instance. Consequently a method of prioritisation must be developed to determine which response(s) should be enacted first in order to derive the greatest benefit. Determining which adaptation responses to prioritise can require professional judgement and input from a range of stakeholder groups. Therefore, consultation with relevant groups can be essential.

Two common methods of prioritising adaptation responses associated with road networks include cost-benefit analyses (CBA) and multi-criteria analysis (MCA). Typically CBA focuses specifically on associated costs of adaptation responses and the derived financial benefits in doing so. MCA goes beyond financial considerations, yet is often inclusive of them, and considers wider factors such as social and environmental impacts. When conducting either a CBA or MCA, consideration should be given not only to direct, but also indirect costs. For example reduced access may limit tourism whilst enhanced road access in tandem with hotter climates may enhance tourism and consequently economic benefit. CBA and MCA are discussed in more detail in *Cost-Benefit Analysis, below and Multi-Criteria Analysis, page 43*.

There are a number of high-level assessments that consider priorities for climate change adaptation of road infrastructure. Whilst each road authority assessment is highly specific, it is useful to gain a broader understanding of which assets are prioritised by other authorities internationally. *Box 9, next page* outlines the approach taken in England to prioritise assets for adaptation.

Cost-Benefit Analysis

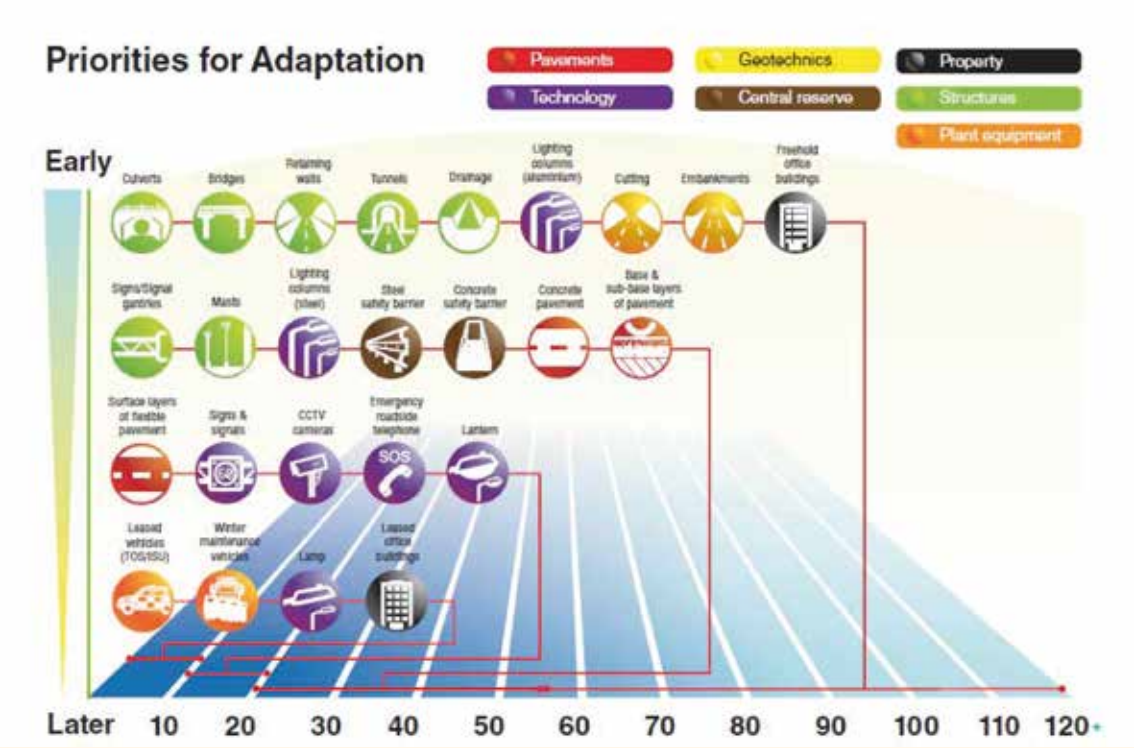
A cost-benefit analysis (CBA) is the most commonly accepted approach to compare and prioritise the effectiveness of adaptation options[41]. The benefit of an adaptation response can measured by the reduction in the climate change induced cost of damages between now (where no adaptation has been undertaken) and a time in the future (when the adaptation response has been implemented), which is discounted to current values to provide an estimate of the present value of benefits from implementing options. A CBA can be used to appraise and compare different adaptation option or groups of options.

The Asian Development Bank's 'Climate Proofing Road Investments'[42] provides a comprehensive overview of applying economic analysis techniques to climate change adaptation responses. A CBA approach to adaptation prioritisation may be the most robust route to determine the responses that should be undertaken first when improving the adaptive capacity of road infrastructure.

[41] USAID (2013). Global Climate Change, Adaptation, and Infrastructure Knowledge Management Support. Methodology for Incorporating Climate Adaptation in the Design and Engineering of Infrastructure.
[42] Asian Development Bank (2011). Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects. Available at: *http://www.pacificdisaster.net/pdnadmin/data/original/SRDP_ADB_2011_Guidelines_climate_proofing.pdf?bcsi_scan_E956BCBE8ADBC89F=0&bcsi_scan_filename=SRDP_ADB_2011_Guidelines_climate_proofing.pdf.*

Box 9 - Prioritising Assets for Adaptation[43]

Priority assets identified in England (by Highways England, previously the Highways Agency - as shown below) in the next ten years included culverts, signage, and surface pavement materials. In the next 50 to 100 years, priorities change and the assets of importance include drainage, lighting, base and sub-base layers of pavements and embankments. Often priorities change over time as a result of climatic variables and projected changes in climate trends, a consideration when prioritising adaptation responses.



By undertaking a CBA, decision makers are provided with indicative information relating to the expected costs and benefits of each adaptation response. Subsequently, responses can be ranked according to net total benefit. In order for the costs and benefits of a scheme to be determined, the impact of climatic variability upon assets, operations and locations must be considered in relation to two scenarios:

1. the expected impacts of the future climate variable upon the asset, location and/ or operation if no adaptation measures are to be put in place; and,
2. the expected impacts of the future climate variable upon the asset, location and/ or operation if adaptation measures are to be put in place.

In order to determine the expected impacts of the future climate variable upon an asset, location and or operation without adaptation measures, the following should be considered:

- the damage which may arise to the asset, location and operation in question as a result of climatic variables;

[43] Highways Authority (2009) Climate Change Adaptation Strategy and Framework
Available at: *http://assets.highways.gov.uk/about-us/climate-change/CCAF_Strategy_and_Vol_1_Rev_B_Nov.pdf*

- how much this damage would cost to repair; and,
- how often such repairs would be required (as a function of climatic variability).

In order to determine the expected impacts of the future climate variable upon the asset, location and/or operation if adaptation measures were to be implemented, the following should be considered:

- the total cost of adaptation measures (as a proportion of existing network upgrade costs if adaptation measures include retrofitting/maintenance of the existing network);
- the damage which may arise to the asset, location and operation in question as a result of climatic variables (in spite of adaptation measures);
- how much this damage would cost to repair; and,
- how often such repairs would be required (as a function of climatic variability).

Further considerations made throughout any CBA should include whether the adaptation options delivers additional benefits beyond building adaptive capacity, and whether the adaptation response climate proofs road infrastructure at the expense of other sectors of the economy/ transport sector.

It is also important to recognise that climate change impact probability and severity (and also levels of vulnerability) can change over the lifetime of an adaptation programme.

Attempting to quantify costs and benefits of adaptation responses can be challenging as a result of the uncertainties associated with climate change projections and climate change risks. Consequently, risk and uncertainty must also be accounted for; this can be achieved through methods such as probabilistic analysis *(Box 10, next page)*.

Multi-Criteria Analysis

Economic efficiency cannot always be used exclusively as the evaluation criteria when assessing climate change adaptation responses. Techniques such as CBA work well as a decision-making tool when costs and benefits can be valued in monetary terms. However, many environmental and social impacts cannot be valued in this way. Many climate change impacts cannot be valued in monetary terms so other criteria should be considered, such as; flexibility, political sensitivity, public acceptance, sustainability and environmental impact.

Multi-Criteria Analysis (MCA) is a comparative assessment of options that accounts for several criteria simultaneously. It is mainly used to assess aspects that either cannot be readily quantified in monetary terms or at stages in options development where detailed cost implications have not yet been developed[44]. The advantage of MCA is that it accounts for significant environmental and social impacts that are not easily assigned monetary values since measurement of indicators does not have to be undertaken in monetary terms. The disadvantage of MCA is that it does not provide easy comparison of projects when multiple benefits arise, is subjective, and can lead to inappropriate trade-offs.

[44] USAID (2013). Global Climate Change, Adaptation, and Infrastructure Knowledge Management Support. Methodology for Incorporating Climate Adaptation in the Design and Engineering of Infrastructure.

Box 10 - Probabilistic Analysis of Adaptation Responses

Probabilistic analysis involves attaching a probability distribution for the possible value of any given specific cost or benefit component of an adaptation response or project instead of attaching a single deterministic value. The outcome of this process is a probability distribution of new present values which allows the computation of an *'expected'* net present value of the option.

An example of a CBA which followed this approach is the World Bank's Road Upgrade Project in Timor-Leste[45] as shown below:

In a road upgrade project where the sole identified benefit of an adaptation measure was a reduction in future road expenditures for both operations and maintenance and rehabilitation (O&M/REHAB), the economic analysis proceeded along the following steps:

Step 1: Looking into the future, specify the expected annual O&M/REHAB regime and expenditures that will be needed to maintain the road to a given desired standard for each year of its useful life (for example, *the drainage works and surface materials are specified to withstand a maximum extreme precipitation event of 5 inches [12.5 cm] per hour*) without climate change. In the absence of climate change, past O&M/ REHAB regime and expenditures may provide a reasonable basis for assessing future O&M/REHAB regime and expenditures.

Step 2: Looking into the future, estimate the expected annual O&M/REHAB expenditures for each year of the useful life of the road with climate change, but assuming no adaptation. In circumstances where climate change is expected to increase the need for road maintenance, O&M/REHAB expenditures would generally be expected to increase.

Step 3: Compute the cost of climate change as the difference between the present value of the O&M/ REHAB expenditures without climate change and the present value with climate change.

Cost of climate change = present value of O&M/REHAB expenditures with climate change
- present value of O&M/REHAB expenditures without climate change

Step 4: Identify all sets of adaptation measures that may prevent or avoid some or all of the projected cost of climate change, as identified, quantified, and monetized above. While these adaptation measures may be structural (e.g., wider drainage work, elevated roads and bridges, sea dykes, etc.), also consider the possibility of bioengineering options (e.g., reforestation of a denuded hill or watershed).

Step 5: Quantify and monetize the impact of the identified adaptation measures on the "cost of climate change." This monetized impact (avoided cost of climate change) will represent the present value of the expected benefits of the adaptation measures.

Step 6: Assess the present value of the cost of the adaptation measure itself.

Step 7: Calculate the net present value of the adaptation measure. Recommend adoption if the NPV of the adaptation measure is positive; reject the measure otherwise. If more than one adaptation measure delivers a positive NVP, recommend the adaptation measure with the highest NPV.

[45] World Bank (2014). *Timor Leste – Building Climate/Disaster Resilience Along the Dili-Aianoro and Linked Road Corridors Project*. Available at: timor-leste-building-climatedisaster-resilience-along-dili-aianoro-linked-road-corridors-timor-leste

MCA can be undertaken in various forms and can be as simplistic or complex as required by road authorities and can be conducted without specialist software or techniques. Additionally, the information required to conduct a MCA is likely to be readily available internally within the authority. Consequently, MCA can be used by all road authorities irrespective of resource availability. For example, the Ethiopian National Adaptation Programmes of Action evaluated adaptation options across five criteria including cost effectiveness (measured in US$); climate change risk (measured in economic losses avoided by poor people per year) and complementarities with national and sectorial plans. Each of these criteria was measured on a scale of 1-5 based on expert judgement[46].

In order to assess the range of adaptation responses developed using MCA, a single list of evaluation criteria should be established. The choice of evaluation criteria, their definition and their relative weighting are central to the process of MCA. The criteria needs to be as exhaustive as possible and should represent the views and concerns of the decision-makers and the users of the road network. The criteria should contribute to the achievement of the objectives set out in original project and organisational aims.

Example MCA evaluation criteria analysis is shown in *Box 11* [47], *next page*. Similarly to the majority of the guidance given within this framework, the approach outlined to MCA is provided as an example only and can be tailored by road authorities to best suit their network and road infrastructure.

Box 12, page 47 shows how a scoring system can be devised using the MCA evaluation criteria to score adaptation responses in a fair, efficient and methodical way.

DEVELOPMENT OF AN ADAPTATION ACTION PLAN OR STRATEGY

After prioritising adaptation responses, road authorities will be left with a ranked list of adaptation measures which they will be looking to implement. In order to implement these measures successfully it is likely that a number of sub-actions, priorities, timescales and responsibilities will need to be determined and assigned.

A number of highway network adaptation plans, programmes and strategies have developed by various road authorities, as shown in *Boxes 13a and 13b, page 48*.

An Adaptation Action Plans should provide details relating to adaptation measure and the timescale in which these measures will be delivered. Other factors that could be included within an Adaptation Action Plan include:

- **Measure / Scheme:** Details on the action, what it is trying to achieve, and the risks it aiming to address.
- **Delivery:** Organisation/team/individual who will lead and/or support the measure or scheme.
- **Programme:** Start, review and end dates of the action or scheme.

[46] USAID (2013). Analyzing Climate Change Adaptation Options Using Multi-Criteria Analysis. Available at: *http://community.eldis.org/.5b9bfce3/Multi-Criteria%20Analysis_CLEARED.pdf*
[47] The Three Counties Alliance Partnership (3CAP) (2009). The Effect of Climate Change on 3CAP's Highway Network Policies and Standards. Available at: *http://www.leics.gov.uk/climate_change_adaptations.pdf*

- Funding: Estimated costs and funding source(s).
- Priority: how the action ranks in relation to other actions. This information is likely to be of use when determining which action highway authorities and authorities should undertake next.

An Adaptation Action Plan should be seen as a live document and review of the plan on a regular basis is recommended.

An Adaptation Action Plan template is provided for use by road authorities alongside this framework document.

Box 11 - MCA Evaluation Criteria

1. **Cost – capital:** what will be the initial cost for implementing the response? Will new staff, machinery or other resources be needed?
2. **Cost – whole-life:** what will the whole-life cost of the adaptation be? Will the cost be continuous or is it likely to increase/ decrease over time?
3. **Technical feasibility:** is the adaptation response technically feasible with the available technology? Will it require the investigation of alternative techniques or technologies?
4. **Practicality:** is the adaptation response practical? Can it be carried out in accordance with existing county council practices and principles?
5. **Political acceptance:** is the adaptation response politically acceptable? Does it comply with existing legislation and government strategy? Will it attract political criticism or scrutiny?
6. **Public acceptance:** is the adaptation response publically acceptable? Does it address public concerns and priorities? Will it attract public criticism or scrutiny?
7. **Future-proof:** will the adaptation response meet future needs? Will there be an end-of-life cost scenario? Is the response adaptable to changes in demand, impact and resource availability?
8. **Environmental impact:** what is the environmental impact of the adaptation response? Will the response lead to adverse environmental effects (to air, water, land etc.)? Will the response contradict county council objectives for reducing carbon emissions and reducing waste?
9. **Level of road authority control / responsibility:** how much influence and control does the authority have over the impact area? Will the authority be able to effectively implement and manage the adaptation response without outside influence and interference? Does the authority need the approval and assistance of outside organisations or regulatory bodies to be able to implement the adaptation?
10. **Sustainability of the response:** is the adaptation response sustainable? Can the response be embedded into existing council policies and standards and be implemented in a sustainable and long-term manner?
11. **Risk of no action:** what is the risk associated with doing nothing? Will the end cost of doing nothing be greater than the cost of implementing the adaptation response?
12. **Scale / impact of the response:** what will be the overall impact of the adaptation response? Will the magnitude of the effect make the additional cost and resource implications worthwhile? Will it be possible to audit the adaptation's level of success?
13. **Resources / skills / knowledge available to implement the adaptation response:** does the authority have the resources available to implement the adaptation response immediately with the existing skills and knowledge in their authority?

Box 12 - MCA of Adaptation Responses[48]

Each of the thirteen criteria is assigned scores from 1 to 3 (e.g. for whole-life cost a score of 1 = high whole-life cost, whereas a score of 3 = a low whole-life cost). This method will mean that those adaptation responses with the highest scores at the end of the evaluation will be the response that are likely to be the most realistic, effective and successful at helping the highway network to adapt to climate change.

Evaluation Criteria	Scorina System	Notes
Cost - capital	1-3	1 = high capital cost, 3 = low capital cost
Cost - whole-life	1-3	1 = high whole-life cost, 3 = low whole-life cost
Technical feasibility	1-3	1 = not technically feasible, 3 = high technical feasibility
Risk of no action	1-3	1 = low risk associated with doing nothing, 3 = high risk associated with doing nothing
Environmental impact	1-3	1 = significant adverse environmental impact, 3 = no significant adverse environmental impacts or significant beneficial environmental impacts
Sustainability of the response	1-3	1 = low level of sustainability, 3 = highly sustainable
Practicality	1-3	1 = not practical, 3 = highly practical
Level of county council control/ responsibility	1-3	1 = no or little county council control, 3 = full county council control
Scale/ impact of the response	1-3	1 = the adaptation response will have minimum impact, 3 = the adaptation response will have significant impact
Politically acceptable	1-3	1 = not politically acceptable, 3 = politically favourable
Publically acceptable	1-3	1 = not publically acceptable, 3 = publically favourable
Resources/ skills/ knowledge available to implement the adaptation	1-3	1 = lack of resources/ skills / knowledge, 3 = readily available resources/ skills/ knowledge
Future-proof	1-3	1 = unlikely to be future-proof, 3 = high likelihood of being future-proof

[48] The Three Counties Alliance Partnership (3CAP) (2009). The Effect of Climate Change on 3CAP's Highway Network Policies and Standards. Available at: *http://www.leics.gov.uk/climate_change_adaptations.pdf*

Box 13a - Example of an Adaptation Action Plan[49]

Below is an excerpt from the Adaptation Action Plan as part of their review of climate change impacts on their highway network policies and standards.

Policy/ Standard Area	Adaptation Response Number	Adaptation response information	Timescale
Bridges and Other Structures	AR1	Carry out a risk assessment to identify which structures are most at risk from climate change. Identify the nature and frequency of changes that are needed to the inspection and maintenance regimes of bridges and other structures.	Immediate
	AR2	Increase the number and frequency of maintenance works carried out to increase the BCI values for bridges assessed as liable to risks from climate change. Ensure all strengthening and repair work that is outstanding for failed or below standard bridges is carried out.	Immediate
	AR3	Carry out flood studies with the help of other authorities and organisations	Immediate
	AR4	Ensure all data (new and historical) is transferred into a single system to make assessments of maintenance and repair priorities and needs, more effective.	Immediate
Drainage	AR5	Invest in asset management and location reviews, carry out drainage surveys, improve the knowledge of drainage assets, hydraulic capacity and ownership, and carry out flood studies with the help of other authorities and organisations.	Immediate
	AR6	Undertake a risk assessment to determine vulnerable areas and establish a prioritised scheme for maintenance	Immediate

Box 13b - Example of an Adaptation Action Plan[50]

Below is an excerpt from Scotland's Climate Change Adaptation Framework's Transport Sector Action Plan

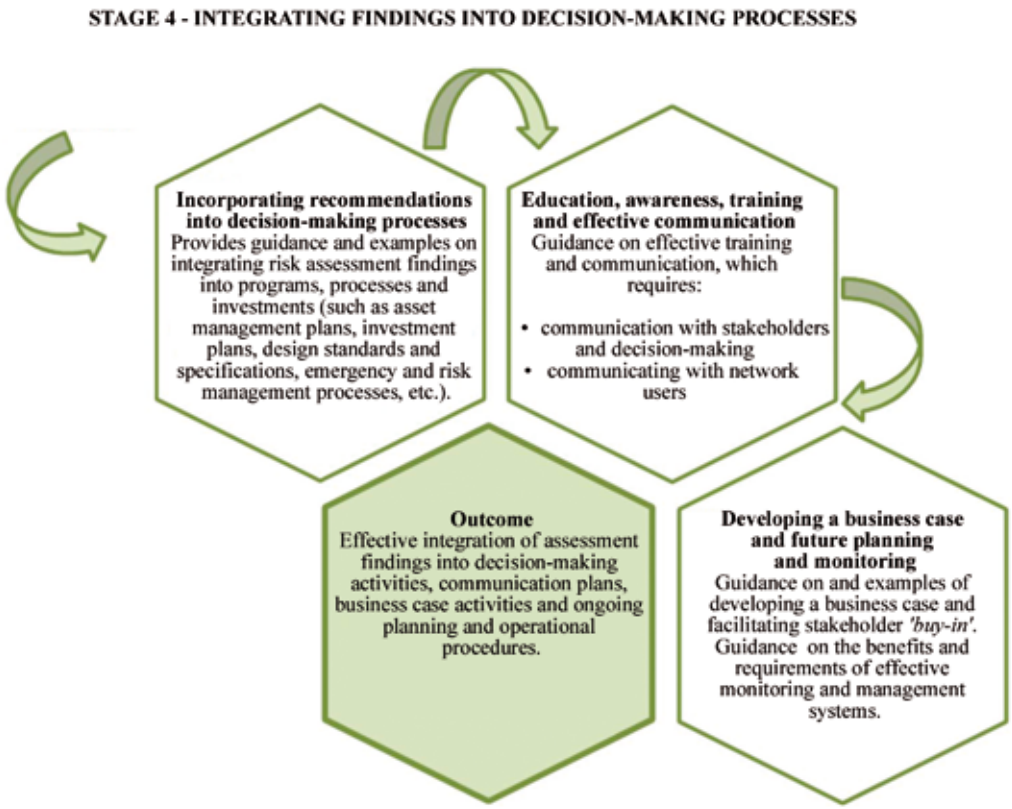
Task/ Action	**Delivery**	**Timescales**	**Deliverables**
Review and adapt procedures and maintenance regimes so that transport networks and emergency responders can react effectively to unexpected events.	Owner of the transport asset along with emergency responders and the Scottish Government Emergency Planning.	Short-term	Enhance existing processes and review existing standards – end 2012.
Review the various transport network maintenance regimes so that works to prevent subsidence are dealt with as a priority, and comprehensively, where financial resources allow.	Transport asset owners	Ongoing	Transport Scotland to produce progress report – end 2012
Learn from organisations further south what changes may be required to materials for road surfaces in order to cope with warmer temperatures.	Transport Scotland and local authorities	Medium-term	Discussion at the UK Roads Board - 2020
Support the development of freight and non-freight driver education programmes and learner training to cover how to drive in extreme conditions.	Transport Scotland leading development to Scottish Guidance	Short-term	Guide on driving in bad weather to be updated – end 2012

[49] The Three Counties Alliance Partnership (3CAP) (2009). The Effect of Climate Change on 3CAP's Highway Network Policies and Standards. Available at: *http://www.leics.gov.uk/climate_change_adaptations.pdf*

[50] Scotland's Climate Change Adaptation Framework Transport Sector Action Plan. Available at: *http://www.gov.scot/Topics/Environment/climatechange/scotlands-action/adaptation/AdaptationFramework/SAP/Transport/PDF*

STAGE 4- INTEGRATING FINDINGS INTO DECISION-MAKING PROCESSES

The purpose of **Stage 4** is to provide guidance on how to incorporate the findings from an assessment **(Stages 1-3)** into road infrastructure programmes, processes and investments and wider plans programmes, strategies and policies. This stage of the framework also provides guidance on developing strategies for effective and successful communication of climate change vulnerability and resilience, developing a business case for action, producing effective and understandable outputs and communication tools, and engaging stakeholders.



Before beginning **Stage 4** it may be useful to consider the following questions:

- What is the current level of interest from senior decision-makers in my authority to adapt to the impacts of climate change?
- Who do I need to engage with to ensure the Adaptation Action Plan developed during Stage 3 is implemented and monitored?
- Which plans, programmes, strategies and policies could the findings of this assessment support?
- Is the current level of education, awareness and training amongst key stakeholders adequate in implementing climate change adaptation responses and works?
- How effective have communications relating to climate change adaptation been in the past and how could they be improved (if relevant)?

INCORPORATING RECOMMENDATIONS AND REQUIREMENTS INTO PROGRAMMES, PROCESSES AND INVESTMENTS

Integrating the results of a risk or vulnerability assessment into decision making that informs existing and new practices and policies is vital to ensuring road infrastructure networks and assets are resilient to future climate change and extreme weather events.

Climate change must be considered as one of the many risks requiring attention in transportation decision-making, rather than as a separate standalone issue. Road authorities may be able to incorporate climate change vulnerability assessment results into (for example):

- asset management plans, inventories and policies;
- landscape strategies;
- traffic management strategies;
- investment plans;
- design standards and specifications
- emergency and risk management processes;
- hazard mitigation plans;
- transportation planning project selection criteria; or
- environmental reviews and strategies.

An example of the successful incorporation of climate change risk assessment into planning and investment can be seen in New Zealand's National Infrastructure Plan *(Box 14)*.

Box 14 - Incorporating climate change risk into planning and investment

New Zealand's 2010 National Infrastructure Plan[51] outlined New Zealand's priorities for infrastructure and highlighted future investments for all major sectors, including transportation. The plan acknowledged the need to consider climate change adaptation as part of the planning and development process for new infrastructure projects. In the subsequent 2011 National Infrastructure Plan, infrastructure resilience emerged as a guiding principle, driven in part by two major earthquakes in the country's Canterbury region. In the 2011 plan, the New Zealand Government set a new vision for infrastructure, committing to create resilient infrastructure that is coordinated and contributes to economic growth and increased quality of life.

According to the National Infrastructure Plan, *"the concept of resilience is wider than natural disasters, and covers the capacity of public, private and civic sectors to withstand disruption, absorb disturbance, act effectively in a crisis, adapt to changing conditions, including climate change, and grow over time"*.

In addition, New Zealand's National Land Transport Programme[52] includes the aim to have a national infrastructure network investment and management approach to resilience in place by 2017. To achieve this, the New Zealand Transport Authority (NZTA) will undertake an annual risk assessment to determine where funding is required and feasible for adaptation works. This will be reflected in the 2018-2021 National Land Transport Plan.

[51] New-Zealand National Infrastructure Unit (2013). National Infrastructure Plan. Available at: *http://www.infrastructure.govt.nz/plan*
[52] New Zealand Transport Authority (2014). About the 2012-2015 National Land Transport Programme. Available at: *http://www.nzta.govt.nz/planning/nltp-2012-2015/about.html*

Box 15 - Integrating Extreme Weather Risk into TAM[53]

The American Association of State Highway and Transportation Officials (AASHTO) has developed guidance on 'Integrating Extreme Weather Risk into Transportation Asset Management'. This document examines how Transportation Asset Management (TAM) provides a mechanism for integrating consideration of extreme weather risk into decision-making. It describes a risk assessment framework and explores how consideration of extreme weather risk can be integrated from the beginning of the TAM process.

The guidance states that a road authority should use the TAM approach to address five core questions:

- What is the current state of my assets?
- What are my required levels of service and performance delivery?
- Which assets are critical to sustained performance delivery?
- What are my best investment strategies for operations, maintenance, replacements, and improvement?
- What is my best long-term funding strategy?

The focus on monitoring asset condition, evaluating performance, and data-driven decision-making reinforces the relevance of TAM as a platform for mitigating the impacts of extreme weather events on transportation infrastructure.

Transportation Asset Management (TAM) is a strategy or system that road authorities can use as a platform for evaluating and addressing climate change and extreme weather impacts. Consideration of resilience, replacement, and restoration of assets can be integrated into TAM processes effectively[54].

TAM systems typically include the collection of data on asset location, criticality/priority and condition and can therefore be valuable in understanding which assets are most vulnerable and at risk from climate change and extreme weather events. Using a TAM system also helps road authorities to understand how to best target vulnerable assets for protection, reinforcement, or rebuilding.

A road authority in the early stages of developing a TAM system could begin by using TAM data to document, analyse, and better understand the impacts of climate change and extreme weather on specific assets and on the network as a whole. As an authority increasingly adopts TAM strategies, opportunities exist to integrate consideration of weather risk into TAM objectives, data collection, performance measurement, monitoring, and resource allocation decisions[55].

[53] American Association of State Highway and Transportation Officials. (2012). Integrating Extreme Weather Risk into Transportation Asset Management. Available at: *http://climatechange.transportation.org/pdf/extrweathertamwhitepaper_final.pdf*
[54] The Federal Highway Administration (2012). Climate Change and Extreme Weather Vulnerability Assessment Framework. Available at: *http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability_assessment_framework/*.
[55] American Association of State Highway and Transportation Officials. (2012). Integrating Extreme Weather Risk into Transportation Asset Management. Available at: *http://climatechange.transportation.org/pdf/extrweathertamwhitepaper_final.pdf*

The integration of weather and climate information into a TAM system or strategy will help road authorities make targeted investments or allocation decisions to increase the resilience of the network and the resilience of individual assets to extreme weather events. Guidance on integrating extreme weather risk into TAM is given in *Box 15, previous page* with examples of US authorities, which have done so in *Box 16*.

Box 16 - Incorporating Climate Risks with Asset Management Processes - US State Examples[56]

The Maryland State Highway Administration (MDSHA)[57] uses its asset management system as a climate adaptation tool. The authority collects data related to climate change and extreme weather vulnerability in its Transportation Asset Management Program (TAMP) to better analyse priority assets. These data include age, elevation, materials used, design lifetime and stage of life, flood maps, current and historical performance and conditions, vegetation, soil type, average daily traffic, bridge scour criticality, and length and width of bridges. Using this approach, the MDSHA has mapped and identified roads, bridges, and culverts vulnerable to sea level rise and high levels of precipitation.

The Los Angeles County Metropolitan Transportation Authority (LACMTA)[58] recently added climate adaptation considerations into its construction contracts. Under the environmental provisions section of the contract, LACMTA specifies that the contractor must consider projected climate impacts in the design and construction of the project. LACMTA is currently undertaking a further project to integrate climate change information and adaptation into the authority's environmental management system (EMS).

EDUCATION, AWARENESS AND TRAINING

Road authority employees need accessible and robust information, tools and guides to allow them to make informed decisions. Incorporating climate change into education and training programs is an effective way of communicating the message. Furthermore, the provision of employee training to increase capabilities and knowledge within a road authority relating to climate change risk, adaptation and resilience can play a significant role in the success of any policy, strategy or investment.

Training at all levels should be encouraged, for example; design, construction, operation and maintenance. Training should be refreshed as new information and knowledge becomes available and as new risks and opportunities present themselves.

Successful training and engagement of internal employees requires listening and incorporating their feedback and perspective. If these staff members are engaged in a training or educational programme they will feel that they can take ownership over the issue.

[56] The Federal Highway Administration (2012). Climate Change and Extreme Weather Vulnerability Assessment Framework. Available at: *http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability_assessment_framework/*.
[57] Maryland State highway Administration. Website available at: *http://www.marylandroads.com/home.aspx*
[58] Los Angeles County Metropolitan Transportation Authority (LACMTA). Website available at: *http://www.metro.net/*

Potential actions[59]:

- develop and implement a comprehensive internal communications strategy to raise awareness of climate change impacts and the advantages of early attention to adaptation,
- seek to develop partnerships with academia and key national professional, research and interest groups to develop best practice networks and training programmes.
- integrate climate change into education and training for either priority or (depending upon the resources available) all employee groups.
- encourage the supply chain to also consider and train employees on climate change adaptation issues.

EFFECTIVE COMMUNICATION

Communicating with stakeholders and decision-makers

Effective and active stakeholder communication and engagement with decision-makers through the development and implementation of climate change adaptation activities is essential to their success. Engaging with and involving the target audience ultimately increases understanding, *'buy-in'* and the level of support given to adaptation actions and strategies. The guidance provided within this section is universal yet may require adjustment in line with community values and perspectives on a regional basis. Effective stakeholder communication and engagement also helps to facilitate and support cross-disciplinary coordination and collaboration among the public sector, private sector and local stakeholders, which ultimately leads to more successful action.

The appropriate method of engaging stakeholders and decision-makers will vary according to the authority, context, and objectives[60]. It is very important to plan for a specific target audience, and authorities often engage different groups of stakeholders in stages. Different target groups and different communication vehicles (e.g., workshops, reports, animations, summary sheets, and fact sheets) must be considered.

Effective communication with decision makers will help to ensure climate change adaptation and resilience is embedded within the planning, design, construction, operation and maintenance stages of all road projects. It can support the development of appropriate objectives and understanding of the local context, help ensure climate risks are correctly identified, and help to build a consensus among stakeholders on the findings of a risk assessment and the risk treatment selected for implementation.

Adaptation Scotland has developed *A practical guide to values-based communication*[61]. The guide is primarily aimed at staff within public bodies that want to communicate effectively on climate change adaptation within their workplace, to external stakeholders and to members of the public. This guide provides clear, concise summaries of the principles of engagement,

[59] Australian Government (Department of the Environment) (2007). National Climate Change Adaptation Framework. Available at: *http://www.environment.gov.au/climate-change/adaptation/publications/national-climate-change-adaptation-framework*
[60] The Federal Highway Administration (2012). Climate Change and Extreme Weather Vulnerability Assessment Framework. Available at: *http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability_assessment_framework/*.
[61] Adaptation Scotland (2014) Communicating Climate Change Adaptation: A Practical Guide to Values-Based Communication. Available at: *http://adaptationscotland.org.uk/Upload/Documents/COINSniffer_communicatingadaptation_FINAL.pdf*

combined with practical examples of how public bodies in Scotland can use and tailor these principles in their work.

A series of principles of for climate change communication are put forward in the guide and can be applied by any road authority as shown below. Similarly, the US FHWA has also provided guidance on strategies for successful implementation *(Box 17, right page)*:

- **pay close attention to your audience's values:** Values are the bedrock on which attitudes to climate change are built. Use a values map to help identify the values of your audience that you want to engage with.
- **frame your messages in the right way:** Look for the overlap between the values that are important to your target audience and values such as *'protecting the environment'* and *'helping others'* that are crucial for building longer-term support for tackling climate change. Frame your messages so that they build a bridge between the values of the audience and the values of a more sustainable society.
- **overcome the *'psychological distance'* of climate change:** Whom are you trying to engage with? What are the things they are passionate about? How can you make climate change adaptation relevant to their lives? Identify the interests of your audience and think about how climate change affects them.
- **don't focus on *'doom and gloom'*:** Emphasising the benefits of climate adaptation policies is much more effective that pointing to the risks of not adapting.
- **extreme weather can be a powerful opportunity to engage on climate change:** People will not necessarily 'join the dots' between extreme weather and climate change on their own. Use severe weather as an opportunity to discuss preparing for future events, and emphasise the benefits of adaptation using the powerful narratives of resilience, community pride and mutual caring that often emerge during the experience of severe weather events. Experience for the Tanzanian NRA supports that suggestion that severe weather offers an opportunity to communication yet highlights that convincing stakeholders to take preventive measures so as to avoid climate risks towards highways networks requires a coordinated, well-researched approach to communication. Stakeholders in areas that have experienced such disasters/ damages in the past may be more receptive to preventive measures.
- **promote the health benefits of adapting to climate risks:** Connecting climate change with health problems which are already familiar and seen as important - such as heat-stroke, hypothermia or asthma - can make the issue seem more personally relevant.
- **try to engage across the political spectrum:** Scepticism about climate change is more common among political conservatives. But it doesn't have to be this way. Use language and 'narratives' that have been designed to appeal to the *'right'*, as well as the *'left'* of politics – for example by focusing on conserving the beauty of the Scottish countryside, or improving the health and wellbeing of communities.
- **harness the power of social norms and social networks:** Representatives of diverse social communities can communicate with their own groups better than any politician or public figure. People respond well when they can see that *'people like them'* are also taking climate adaptation seriously. Promote social norms on climate change wherever possible.

A Communication Plan can be a useful for structuring and planning communication activities. A ***'Communications Plan'*** template is included as an *Appendix D, page 80* to this framework. The main aim of the Communications Plan is to facilitate the effective delivery of climate change adaptation measures across highway networks by identifying effective methods of stakeholder communication.

A ***'Senior Management Briefing Note'*** template is also included as an Appendix to this framework. This can be used to communicate risk assessment findings and key messages and recommendations to senior managers and decision-makers in an effective and succinct way.

Box 17 - Strategies for successful communication

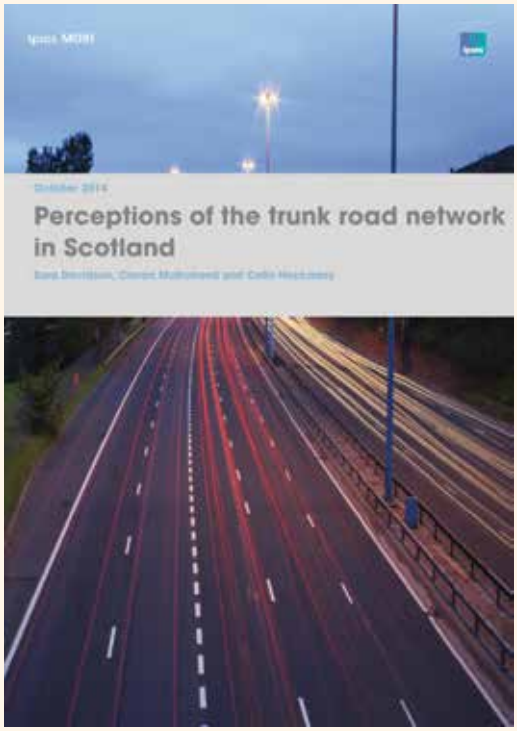
A 2010 pilot study into the communication of climate change vulnerability by the US Federal Highway Administration (FHWA) identified several successful and effective strategies:

- in order to avoid confusing the issue of climate change adaptation with the politics of climate change mitigation, some authorities use the terms *"extreme events", "event management", "all-hazard management"* and *"resilience"* as effective terms for communicating impacts and adaptation issues;
- another strategy for communicating the need for adaptation is to expand conceptions of sustainability and asset preservation to include resilience. Authorities can emphasise that climate change adaptation is simple, good business practice that should be integrated throughout the authority;
- frame adaptation as better planning and responsible risk management;
- frame adaptation as saving money. Stress that preventing impacts is almost always cheaper than cleaning up and rebuilding after an extreme weather event;
- use past events, such as a memorable flood or heat wave, to help communicate the meaning of climate projections;
- highlight possible solutions to climate impacts. Frame the issue as one of rising to the challenge;
- use graphics;
- tailor the message to your audience;
- talk in the here and now. Explain how the climate is already changing in the geographic area the audience is concerned with and the impact on assets and services that the audience values (many individuals are not aware that climate change impacts are already occurring).

Box 18 - Road User Perceptions

Transport Scotland undertakes an annual survey that looks at road user perceptions of their road network[62]. This includes views and perceptions of severe weather disruption and the provision of information to road users during extreme weather events.

The results provide a useful insight into how people want to receive and access information relating to extreme weather events. In 2014, radio and television were the most commonly used methods (used by 43% and 35% of survey respondents respectively) to obtain information about the status and condition of Transport Scotland's roads during and after extreme weather events. There are variances amongst demographic subsets of the population with younger individuals being more likely to use social media. Consequently, the target audience should be considered prior to developing communication mechanisms and tools.



Communicating with users of the network

Establishing an effective way of communicating with users of a road network prior to, during and after an extreme weather event, ensures disruption is minimised and reactive or emergency work can be carried out without delay or constraints. Informing users about hazards and risks also helps to reduce the number of incidents and the risk of people being stranded. Road users are typically most concerned about the availability of the network, and when the network is likely to return to normal following an extreme weather event.

Effective ways to communicate these messages to road users include:

- use of Variable Messaging Signs (VMS) along the network to inform road users about hazards and incidents;
- use of mobile phone technology and social media) to alert road users of hazards in real time;
- weather warnings broadcast on television and radio channels;
- use of a dedicated website to inform the public about climate and weather related hazards, risks and incidents;
- ongoing educational and awareness-raising campaigns to discourage unnecessary travel during extreme weather events and encourage safe driving.

[62] Ipsos Mori (2014). Perceptions of the Trunk Road Network in Scotland.Available at: *http://www.transportscotland.gov.uk/system/files/documents/tsc-basic-pages/2014%20Trunk%20roads%20report.pdf*

Recently Transport Scotland undertook an annual survey which assessed road user perceptions of the road network and their views on communication which is likely to provide useful guidance for other authorities undertaking a climate change adaptation plan, programme or strategy *(Box 18, left page)*.

DEVELOPING A BUSINESS CASE

A lack of 'buy-in' from key stakeholders, such as senior managers and decision-makers, is often cited as a key barrier to the successful implementation of any climate change risk assessment findings and adaptation responses. The development of a business case is likely to raise awareness of these stakeholders to climate change effects and impacts upon highway networks and facilitate their involvement/backing in climate change adaptation measures. A business case is typically seen as a report that documents the rationale behind the initiation of a particular action or measure. Road authorities can use the findings of their climate change risk assessment to develop a business case for taking action to adapt and build resilience on their networks.

There is a range of internal guidance documents available relating to the development of a business case for climate change adaptation. For instance the Institute of Environmental Management and Assessment (IEMA) in their *Climate Change Adaptation: Building the Business Case* guidance provides information relevant to environment and sustainability practitioners and identifies a number of key principles in building a business case *(Box 19, next page)*.

Box 19 - IEMA's Climate Change Adaptation Building the Business Case Guidance[63]

IEMA's guidance provides some key principles relating to building a business case relating to Climate Change Adaptation as follows:

- understand your business;
- engage widely across your business and build awareness, seek interest, share the challenge and use business relevant language;
- use existing decision making opportunities;
- look for opportunities on the back of other projects and developments;
- use recent and future weather impacts as an early opportunity for business response;
- in addition to risk, consider opportunities and dependencies, including competitive advantage from an increased resilience to extreme weather and climate;
- look for *'early mover'* opportunities.

The guidance document also provides a brief overview of the potential stages an authority may undertake in developing a business case and leaning from past experiences, an excerpt of which is shown below:

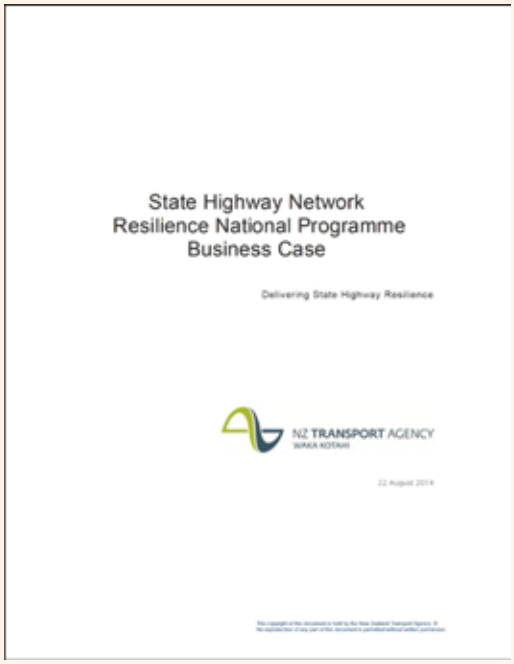
PRINCIPLES	LEARNING POINTS (FROM PRACTICE)
First understand your business and your context	Understand its purpose, culture and approach to decision making. Know what you are up against. Map key stakeholders and decision making routes. Evaluate and develop your role to the business context (e.g. lead? Inspire? Support? - probably all three at different times)
Engage key internal stakeholders	Communicate with (and seek advice from) a range of critical functions such as finance, marketing, procurement, logistics and operations. Further develop your understanding of the organization and internal decision making, business drivers etc. Build awareness and support. Introduce the business relevance of climate change risks, opportunities and dependencies
Use business relevant language	In discussions either avoid terms like 'adaptation' or be careful to consistently translate. Use business language - profitability, disruption, staff welfare, client and customer service, liabilities, added value, winning business, loss of reputation, insurance costs, changing asset value, and constraints on future business
Use direct business experience	Draw on recent experience within the business of extreme weather impacts - use to win interest in early action (this can also help the visualization of future increased risk). Make sure that you present both the worst case scenario and the most likely outcome. Avoid the tendency to present just doom and gloom, and ensure that the work is solutions focused.
Consider wider skill needs	Training may be valuable at early stage and can support internal scoping workshops. External expertise may be needed (e.g. flood risk).

[63] IEMA (2013). Climate Change Adaptation: Building the Business Case. *http://www.iema.net/readingroom/articles/cca-business-case-guidance*

Box 20 - NZTA Business Case

The New Zealand Transport Authority (NZTA) published a *State Highway Network Resilience National Programme Business Case*[64] in August 2014. This follows on from their joint resilience operating policy and was developed to seek funding for 2015-18 to fill information gaps, improve practice and to establish a national consistent prioritisation framework that will be used to build a more detailed capital improvement programme in 2018-2021.

Increased funding is sought for existing preventative maintenance programmes that have already been shown to increase resilience by reducing the risk of closures and improving safety at high-risk locations. The Business Case sets out the strategic context, the outline need for investment (including the benefits, KPIs and an evidence base) an option and alternative assessment, a recommended programme, a financial case and a monitoring and review schedule.


State Highway Network
Resilience National Programme
Business Case

Delivering State Highway Resilience

NZ TRANSPORT AGENCY
WAKA KOTAHI

22 August 2014

Similarly, The New Zealand Transport Authority (NZTA) has published a 'State Highway Network Resilience National Programme Business Case', which provides a good example of effective adaptation business planning *(Box 20)*.

Prior to developing a business case, the Welsh Government in their guidance *The Business Case for Action on Climate Change*[65] suggests that there are five considerations that road authorities should bear in mind:

1. **be selective:** Choose the benefits to build the business case around carefully (relating to the organisations/organisational partners business case), build credibility for the case and include known 'win-wins' with quick returns alongside longer-term measures and priorities.
2. **challenge the status quo:** Question whether 'business as usual' will be effective in the long-term delivery of climate change adaptation measures and responses.
3. **take control of risk:** Ensure that the current risks posed by climate change across the sector and associated sectors are accounted for within the business case.
4. **go beyond the case itself:** Is there a need to actively influence decision makers involved? Often a business case may not be enough.

[64] New Zealand Transport Authority (2014). Resilience. Available at: *http://hip.nzta.govt.nz/technical-information/resilience*
[65] Welsh Government (2012). Public Sector: The Business Case for Action on Climate Change. *http://gov.wales/docs/desh/publications/121008ccbcasepublicsecten.pdf?bcsi_scan_AB11CAA0E2721250=0&bcsi_scan_filename=121008ccbcasepublicsecten.pdf*

5. **link policy and delivery:** Ensure that the business case acknowledges and complements other policy demands across varying sectors.

Typically a business case can include information relating to the following[66]:

- **the drivers behind climate change adaptation responses:** Drivers include legislative and policy drivers, public/business/client expectations, historic incidents of climate change impacts that have resulted in substantial costs, and community pressures from local groups and communities shown to be at risk etc.
- **the risks posed by climate change effect and the impacts of a failure to adapt:** Overlaps with climate change adaptation *'drivers'*, as typically the risks posed act as a driver for action. The risks posed to transport networks can include network disruption, reduced accessibility, and financial costs.
- **the potential benefits of climate change adaptation:** This may include efficiency savings, service improvement, reputational benefits, improved disaster response and recovery, and protection and enhancement of the local environment.
- **associated costs:** A business case should communicate that typically the cost of inaction is far higher than the cost of action and that adaptation does not necessarily mean spending large sums of money now. Adaptation requires planning for future change and may relate to small changes to measures already underway such as maintenance procedures. Where a cost-benefit analysis has been conducted as part of the adaptation response prioritisation process, the information derived from this process can be used to justify investment in a particular activity or intervention.

To strengthen a business case, Innovate UK[67] recommends that a case for action becomes stronger when:

- costs and benefits over time can be taken into account in establishing initial expenditure;
- adaptation derives a competitive advantage;
- adaptation allows new opportunities to be exploited;
- all stakeholders are shown to favour the proposed measures;
- business processes and decision making is integrated;
- there is an increasingly apparent 'common good';
- networks become increasingly vulnerable and are likely to be affected by climate risks;
- the frequency and magnitude of extreme events is heightened;
- the certainty of future risks is increased;
- underlying uncertainty can be reduced and understood;
- proposed measures/technology is *'tried and tested'* and shown to be successful;
- there is evidence that the proposed measures have longevity;
- stakeholders are open to innovation; and,
- the stakeholder views climate change adaptation as *'business as usual'*.

Consequently when developing a business case, authorities may wish to review their approach and recommendations against this list in order to ensure their proposed business case is as strong as possible.

[66] Welsh Government (2012). *Public Sector: The Business Case for Action on Climate Change.* http://gov.wales/docs/desh/publications/121008ccbcasepublicsecten.pdf?bcsi_scan_AB11CAA0E2721250=0&bcsi_scan_filename=121008ccbcasepublicsecten.pdf
[67] Innovate UK (2014). *The Business Case for Adapting Buildings to Climate Change: Niche or Mainstream?* https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/378061/Adapting_buildings_to_climate_change_execsummary_T14_142_webfinal191114.pdf

FUTURE PLANNING AND MONITORING

Ongoing monitoring and review of climate change risks, vulnerabilities and the effectiveness of adaptation responses is essential. Road authorities are encouraged to continuously review their findings, strategies and plans as more information becomes available and as new risks become apparent.

According to the United Nations Framework Convention on Climate Change (UNFCCC)[68]:

"Monitoring and evaluation of projects, policies and programmes forms an important part of the adaptation process. Ultimately, successful adaptation will be measured by how well different measures contribute to effectively reducing vulnerability and building resilience. Lessons learned, good practices, gaps and needs identified during the monitoring and evaluation of ongoing and completed projects, policies and programmes will inform future measures, creating an iterative and evolutionary adaptation process."

Furthermore, the Institute of Development Studies[69] states that there are a number of clear benefits to monitoring and evaluating adaptation interventions, such as:

- increases in funding,
- gathering political momentum,
- evolving approaches to evaluation of development assistance,
- increasing understanding of adaptation and its relationship with development.

The effectiveness of an intervention (for example, a policy, investment or strategy) should be assessed to ensure future adaptation planning draws on lessons learnt. To determine success, it is necessary to set out what needs to be measured, how it can be measured, over what time frames the measurement will take place, and what successful outcomes will look like when they are achieved[70].

Example indicators that could be included within a monitoring and evaluation assessment include:

- policies and plans revised on the basis of climate change risks and opportunities;
- investment decisions made on the basis of risk assessment findings and climate change scenarios/ projections;
- resilience of networks and assets to the impacts of climate change and extreme weather enhanced;
- capacity to plan and respond effectively to extreme weather events enhanced; and,
- employees, users of the network and other stakeholders more aware of climate and weather related risks and impacts.

[68] UNFCCC (2010) Synthesis Report on Efforts Undertaken to Monitor and Evaluate the Implementation of Adaptation Projects, Policies and Programmes and the Cost and Effectiveness of Completed Projects, Policies, and Programmes and Vews on Lessons Learned, Good Practices, Gaps and Needs. Available at *http://unfccc.int/resource/docs/2010/sbsta/eng/05.pdf*

[69] Institute of Development Studies. (2008). Desk Review: Evaluation of Adaptation to Climate Change from a Development Perspective. Available at: *http://www.climate-eval.org/sites/default/files/events/alexandria/IDS_Report_on_Evaluating_Adaptation_for_GE_publication_version.pdf?bcsi_scan_E956BCBE8ADBC89F=0&bcsi_scan_filename=IDS_Report_on_Evaluating_Adaptation_for_GE_publication_version.pdf*

[70] Centre for Urban Research (2014). A Review of the Monitoring and Evaluation Literature for Climate Change Adaptation. Available at: *https://gallery.mailchimp.com/b38874b25e686137780eb836e/files/M_E_Lit_Review.pdf*

The United Nations Development Programme (UNDP) has developed a set of indictors that can be used to measure the success of a policy, action, investment or strategy[71]:

- **Coverage:** the extent to which projects engage with stakeholders (individuals, businesses, communities, community-based organisations, government authorities, policymakers, etc.);
- **Impact:** the extent to which projects deliver the intended results, or bring about changes in behaviour that support the objectives;
- **Sustainability:** the ability of stakeholders to continue to implement adaptive interventions on timescales that extend beyond project lifetimes; and,
- **Replicability:** the extent to which projects generate results and lessons that are potentially useful in other, comparable contexts, and the extent to which these lessons are disseminated and acted upon.

Similarly, the UK Climate Impacts Programme has developed a Toolkit that helps authorities to evaluate adaptation progress and performance *(Box 21, right page)*.

There are challenges around developing indicators and measures for monitoring climate change adaptation performance. However, monitoring and evaluation should be embedded into the adaptation process allowing for iterative, ongoing learning and opportunities to modify, change and improve responses to climate change[72].

SYNTHESIS

This framework provides guidance and a global case for action to seek to understand and address the impacts of climate change and extreme weather events on road infrastructure. The framework is applicable to all countries and regions regardless of economic, environmental, social, climatic and geographical situation, and is also applicable at a national, regional and local level.

Through input from road authorities internationally, scientific evidence and examples of good practice and successful approaches implemented globally, the framework also facilitates the identification and replication of lessons learned from other countries and takes account of the varying levels of preparedness and adaptive capacity and knowledge from country-to-country and region-to-region.

In **Stage 1**, guidance is given on identifying scope, variables and data. After completing this Stage, road authorities will have the information required to develop a list of network assets, locations and operations for further assessment (based on vulnerability and adaptive capacity) and will have knowledge of how to use existing climate change projections data and evidence to determine future conditions, or to develop climate change scenarios and projections where this information does not already exist.

[71] UNDP (2007). Monitoring and Evaluation Framework for Adaptation to Climate Change
Available at: *http://www.seachangecop.org/files/documents/2007_UNDP_ME_Framework_for_CCA_draft.pdf*

[72] Centre for Science in the Earth System (The Climate Impacts Group), Joint Institute for the Study of the Atmosphere and Ocean, University of Washington and King County, Washington. (2007). Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments. Available at: *http://cses.washington.edu/db/pdf/snoveretalgb574.pdf?bcsi_scan_AB11CAA0E2721250=1*

Box 21 - UKCIP AdaptME Toolkit[73]

The UK Climate Impacts Programme (UKCIP) has developed the *AdaptME Toolkit* in response to a growing demand for practical support in evaluating adaptation progress and performance.

The toolkit identifies common reasons for embarking on an evaluation (such as to evaluate effectiveness, provide accountability, and assess outcomes) and helps a user to:

- refine evaluation purpose and objectives;
- understand how specific traits of climate adaptation can make evaluation challenging and how these challenges can be overcome;
- draw out, understand and re-evaluate assumptions;
- consider how progress and performance might be best measured and evaluated;
- identify examples, good practice and techniques which may help ensure an evaluation is robust in the context of climate change; and
- prioritise evaluation activities, recognising that evaluations need to be proportionate to the investment and are resource limited.

In **Stage 2**, the risks posed to the assets, locations and operations identified in **Stage 1** of an assessment are assessed and prioritised through defining impact probability and severity. From this assessment, Risk Scores can be devised and a prioritised Risk Register developed. The highest and most significant risks are then taken forward to **Stage 3**.

Stage 3 outlines how adaptation responses to address these risks posed in **Stages 1 and 2** can be identified, selected and prioritised.

Stage 4 outlines how prioritised adaptation responses and other assessment findings can be incorporated into decision-making processes, how to enhance education, awareness and training, and how assessment findings can be effectively communicated, used to form a business case. The importance of ongoing evaluation and monitoring is also highlighted.

[73] UKCIP (2011) AdaptME Toolkit: Adaptation Monitoring and Evaluation. Available at: *http://www.ukcip.org.uk/wordpress/wp-content/AdaptME/AdaptME.pdf?bcsi_scan_AB11CAA0E2721250=0&bcsi_scan_filename=AdaptME.pdf*

Beyond the guidance provided within the framework, the success of any assessment will require collaborative working, agreed roles and responsibility, robust communication channels and networks, and active stakeholder engagement and support. Any assessment undertaken should be considered as 'live' and updated or refined as more information becomes available, priorities and evidence change, and if resource levels increase.

As a result of the interdependencies and interconnectivities between road infrastructure and other sectors, and also between climate risks and other risk types (such as other natural hazards and security risks), investing in climate change adaptation responses can be seen as investing in the wider economy and increasing the resilience wider infrastructure and society. For the same reason, climate change should not be considered in isolation and should always from part of a holistic approach to risk management.

STAGE 1

After working through the guidance outlined in **Stage 1**, road authorities should now have an understanding of how to:

- establish assessment scope, aims, tasks and a plan for delivery;
- identify which assets, locations and operations are most vulnerable to climate change – through an assessment of their exposure, sensitivity and adaptive capacity; and,
- how to use existing climate change projections data and evidence to determine future conditions, or develop climate change scenarios and projections where this information does not already exist.

The most critical and vulnerable network elements should be taken forward to **Stage 2**, which outlines how risks can be assessed, quantified and prioritised for action.

Stage 1 - Scenario Example

Over the past 10 years there has been an increasing frequency of river and surface water flooding on a 5km stretch of a road network. This area of road is located close to a major river and has a major urban settlement located next to it. It is also located 1.5km from the coast. There are no other problems with flooding of this nature on any other park of the regional road infrastructure network.

Selecting assets for inclusion
In this case, only one location is to be assessed.

Assessing exposure
Recent events have shown that the frequency and severity of flooding events is increasing. A review of the best available climate projections data for the country (developed by an academic institution) suggest that there could be an increase in mean winter precipitation levels of 35% by the 2050s and that sea eves in the region could rise by 5cm over the next 20 years. Anecdotal evidence also suggests that the frequency of storms is already showing signs of increasing. Using this evidence, exposure can be scored as follows:

	Extreme Heat	Mean Heat	Drought	Mean Rainfall	Storms/ Extreme Rainfall	Sea Level Rise and/ or Storm Surge
5 km stretch of road	X	X	X	2	2	2

Key:
X = No or negligible exposure now and/or in the future
1 = Low exposure now and/or in the future
2 = Medium exposure now and/or in the future
3 = High exposure now and/or in the future

A score of 2 is therefore assigned to represent exposure.

Assessing sensitivity
Recent flooding events have had a major and immediate impact on the 5km stretch of road. Due to the proximity to a major urban settlement, the damage and disruption is fairly widespread. The condition of the road is somewhat poor and is not regularly maintained. It is also at the end of its expected design life. Using this evidence and the *'Sensitivity Scale'* below, a *'Medium'* level of sensitivity can be assigned (score of 2).

Level of Sensitivity		Description of Sensitivity Level to Infrastructure (example)
3	High	Permanent or extensive damage requiring extensive repair
2	Medium	Widespread infrastructure damage and service disruption requiring moderate repairs. Partial damage to local infrastructure.
1	Low	Localised infrastructure service disruption. No permanent damage. Some minor restoration work required.
0	Negligible	No infrastructure service disruption or damage.

Calculating vulnerability levels
Through combining the exposure and sensitivity ratings, a vulnerability score of 4 ('Medium' vulnerability) is assigned.

		Sensitivity		
		Low	Medium	High
Exposure	High	4 (Medium)	5 (High)	6 (Extreme)
	Medium	3 (Low)	4 (Medium)	5 (High)
	Low	2 (Very Low)	3 (Low)	4 (Medium)

Therefore, adaptation will be required to prevent damage.

Assessing adaptive capacity
Due to the poor condition of the road and recent events, low adaptive capacity is assumed – it is unlikely that assets, locations or operations could adapt to projected climatic changes even in the short-medium term.

This medium level of vulnerability and low adaptation capacity indicates that the risk should be taken forward to Stage 2 to understand probability and severity.

STAGE 2

After working through the guidance outlined in **Stage 2**, road authorities now should have a ranked list of risks, according to their probability of occurrence and their severity if they do occur. The highest and most significant risks should be taken forward to **Stage 3** which outlines how adaptation responses to address these risks can be identified, selected and prioritised.

Stage 2 - Scenario Example

This uses the same scenario example as in **Stage 1.**

Assessing impact probability
The road authority wants to understand what the probability of there being at least one major flooding event on the 5km stretch of road is each year, by both the 2020s and the 2050s.

Based on climate change projections developed by a regional academic institution, and recent trends and occurrences of flooding events following periods of heavy rainfall and storms, the probability of a flooding event occurring at least once per year can be defined (using the scoring scale below) as *'Likely'* (Score of 4) by the 2020s and *'Almost Certain'* by the 2050s (Score of 5).

Probability of effect	Definition	Score
Almost Certain	More likely to happen than not (probability close to 100%)	5
Likely	Fairly likely to occur (probability greater than 50%)	4
Unlikely	Possible it may occur (probability less than 50%)	3
Rare	Low, but not impossible (low, but noticeably greater than zero)	2
Highly Unlikely	Very low, close to zero	1

Assessing impact severity
It is assumed that the severity of a flooding event will be the same at any point in time. Using the severity scale and criteria provided in *Assessing Impact Severity, page 29*, experience of recent flooding events, and road authority knowledge and expertise, severity can be scored as follows:

- Population and communities: 3 (2-5% of the population affected)
- Economic Impact: 3 (loss of earnings and productivity between US$ 2 million and US$ 5 million)
- People and economy: 1 (employees within a local works/depot affected)
- Society: 2 (regional disruption of essential services, social practices and events)
- Stakeholders and supply chains: 2 (more than one stakeholder or element of supply chain affected)

Therefore, the overall severity score for this impact scenario would be 3.

Establishing a Risk Score

'Risk' can be seen as a combination of probability and severity. By multiplying together the score for these two criteria, a *'Risk'* score is calculated. Using the scores assigned for probability and severity, and the Risk Score Matrix below, it can be concluded that:

- by the 2020s, the Risk Score for the impact will be **12 – *'High Risk'***
- by the 2050s, the Risk Score for the impact will be **15 – also *'High Risk'***

	Severity				
Likelihood	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

This indicates that the risk needs attention as soon as possible. High risks are the most severe that can be accepted as a part of routine operations without executive sanction and it is suggested that they are to be the responsibility of the most senior operational management and reported upon at the executive level.

Therefore, it can be recommended that this risk is taken forward to **Stage 3** (identifying and selecting adaptation responses).

STAGE 3

After working through the guidance outlined in **Stage 3**, road authorities will have a prioritised list of adaptation responses. This can be accompanied by an Adaptation Action Plan that will support the delivery of these actions in the future.

Stage 4 outlines how these outcomes (i.e. the prioritised adaptation responses and action plan) can be incorporated into decision making processes, enhancing education, awareness and training, and how these findings can be communicated and used to form a business case.

STAGE 4

After working through the guidance outlined in **Stage 4**, road authorities will have the knowledge required to:

- incorporate assessment findings into wider plans, programmes, policies and strategies;
- provide education, awareness and training to stakeholders relating to climate change adaptation;
- communicate effectively with stakeholders, decision makers and network users;
- develop a business case; and,
- deliver an effective monitoring regime.

Box A1 - IPCC Observed Climate Change Impacts and Vulnerabilities[74]

The IPCC Fifth Assessment Report (AR5) states that warming in the climate system is unequivocal, with many of the observed changes unprecedented over decades to millennia: *"the atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen and the concentrations of greenhouse gases have increased"*[75].

IPCC AR5 summarises the key observed climate change impacts and vulnerabilities, which includes the following:

- In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Evidence of climate-change impacts is strongest and most comprehensive for natural systems.
- In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality. Glaciers continue to shrink globally due to climate change, affecting runoff and water resources downstream. Climate change is causing permafrost warming and thawing in high latitude regions and in high-elevation regions
- Differences in vulnerability and exposure arise from non-climatic factors and from multidimensional inequalities often produced by uneven development processes. These differences shape differential risks from climate change. People who are socially, economically, culturally, politically, institutionally, or otherwise marginalized are especially vulnerable to climate change and also to some adaptation and mitigation responses.
- Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability. Impacts of such climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, morbidity and mortality, and consequences for mental health and human well-being. For countries at all levels of development, these impacts are consistent with a significant lack of preparedness for current climate variability in some sectors.
- Climate-related hazards exacerbate other stressors, often with negative outcomes for livelihoods, especially for people living in poverty.
- Violent conflict increases vulnerability to climate change. Large-scale violent conflict harms assets that facilitate adaptation, including infrastructure, institutions, natural resources, social capital, and livelihood opportunities.

[74] IPCC (2013). Climate Change 2013: The Physical Science Basis (Working Group I Contribution to Fifth Assessment Report of the Intergovernmental Panel on Climate Change). Available at: *http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_ALL_FINAL.pdf*

[75] IPCC (2013). Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate.

APPENDIX A - SCIENTIFIC BACKGROUND

The climate change debate has moved away from whether or not there is evidence of climatic change to what must be done to reduce the magnitude of further changes and minimise the impacts. There is now an overwhelming body of scientific evidence highlighting the serious and urgent nature of climate change, largely due to emissions of greenhouse gases as a result of human activities. The most recent Assessment Report (AR5) of the Intergovernmental Panel on Climate Change[76] (IPCC) reinforces the conclusions of the previous four assessment reports which state that *"the balance of evidence suggests that there is a discernible human influence on global climate"*[77] with the result being that we have now driven the climate beyond natural variability. The key observed climate change impacts and vulnerabilities highlighted by the AR5 are reproduced in *Box A1, left page*.

Rising global temperatures are already altering weather patterns, causing sea levels to rise and increasing the frequency and intensity of extreme weather[78]. It is very likely (90-100% probability) that the number of cold day and nights has decreased and the number of warm days and nights has increased at the global scale. Whilst precipitation changes are harder to analyse it is likely (66-100% probability) that there are more land regions where the number of heavy precipitation events has increased than where it has decreased.

Even if anthropogenic (human) emissions stop today, evidence indicates that changes to the climate will continue for at least the next three decades[79]. There is a consensus that a temperature rise of over 2°C will have major consequences globally.

[76] IPCC (2013). Climate Change 2013: The Physical Science Basis (Working Group I Contribution to Fifth Assessment Report of the Intergovernmental Panel on Climate Change). Available at: *http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_ALL_FINAL.pdf*

[77] IPCC (1990). Climate Change: The IPCC Scientific Assessment. Available at: *http://www.ipcc.ch/publications_and_data/publications_ipcc_first_assessment_1990_wg1.shtml*

[78] IPCC (2013). Summary for Policymakers: Climate Change 2013: The Physical Science Basis (Working Group I Contribution to Fifth Assessment Report of the Intergovernmental Panel on Climate Change). Available at: *https://ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf*

[79] Department for Environment, Food and Rural Affairs (DEFRA) (2009). Adapting to Climate Change: UK Climate Projections. Available at: *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69257/pb13274-uk-climate-projections-090617.pdf*

Box A2 - Climate Change – Key Questions

The reference document[80] makes clear what is well established, where consensus is growing, and where there is still uncertainty. It echoes and builds upon the long history of climate-related work from both national science academies, as well as the newest climate change assessment from the IPCC. It answers the following 20 key questions using the latest scientific evidence and understanding:

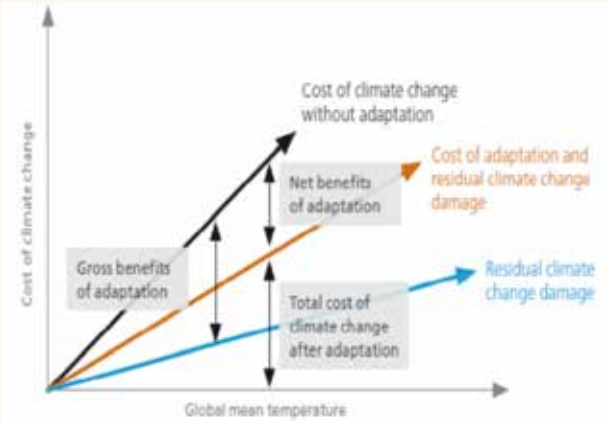
1. Is the climate warming?
2. How do scientists know that recent climate change is largely caused by human activities?
3. CO_2 is already in the atmosphere naturally, so why are emissions from human activity significant?
4. What role has the sun played in climate change in recent decades?
5. What do changes in the vertical structure of atmospheric temperature – from the surface up to the stratosphere – tell us about the causes of recent climate change?
6. Climate is always changing. Why is climate change of concern now?
7. Is the current level of atmospheric CO_2 concentration unprecedented in Earth's history?
8. Is there a point at which adding more CO_2 will not cause further warming?
9. Does the rate of warming vary from one decade to another?
10. Does the recent slowdown of warming mean that climate change is no longer happening?
11. If the world is warming, why are some winters and summers still very cold?
12. Why is Arctic sea ice reducing while Antarctic sea ice is not?
13. How does climate change affect the strength and frequency of floods, droughts, hurricanes and tornadoes?
14. How fast is sea level rising?
15. What is ocean acidification and why does it matter?
16. How confident are scientists that Earth will warm further over the coming century?
17. Are climate changes of a few degrees a cause for concern?
18. What are scientists doing to address key uncertainties in our understanding of the climate system?
19. Are disaster scenarios about tipping points like *'turning off the Gulf Stream'* and release of methane from the Arctic a cause for concern?
20. If emissions of greenhouse gases were stopped, would the climate return to the conditions of 200 years ago?

[80] The Royal Society and the US National Academy of Sciences (2014). Climate Change: Evidence & Causes. Available at: *https://royalsociety.org/policy/projects/climate-evidence-causes/*

Box A3 - The case for early action

The Stern Review of the Economics of Climate Change showed that climate change is not solely an environmental issue: there is a convincing economic case for action to tackle climate change.

The graph to the right illustrates how the total costs of climate change without adaptation (top black line) contrast with reduced costs through adaptation (orange line). Adaptation incurs costs but results in net benefits by reducing the residual damages from climate change.



Key IPCC projections are that[81]:

- there will be further warming and changes in all components of the climate system;
- global surface temperature change for the end of the 21st century is likely to exceed 2.0°C in most emission scenarios. Warming is very likely to continue beyond 2100 and this warming will exhibit interannual-to-decadal variability and will not be regionally uniform;
- changes to the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions;
- it is very likely that the Arctic sea ice cover will continue to shrink and thin and that Northern Hemisphere spring snow cover will decrease during the 21st century as global mean surface temperature rises. Global glacier volume will further decrease; and,
- global mean sea level will continue to rise during the 21st century. The rate of sea level rise will very likely exceed that observed during 1971 to 2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets.

Climate change is also expected to exacerbate the frequency and magnitude of extreme weather events, such as drought, heat waves, storms, prolonged and heavy precipitation events, and periods of very hot or very cold days.

The Royal Society and the US National Academy of Sciences have developed a reference document *(Box A2)* for decision-makers, policy-makers, educators, and other individuals seeking

[81] IPCC (2013). Summary for Policymakers: Climate Change 2013: The Physical Science Basis (Working Group I Contribution to Fifth Assessment Report of the Intergovernmental Panel on Climate Change). Available at: *https://ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf*

authoritative answers about the current state of climate change science, and to address some of the uncertainly that still exists about the nature and direction of climate change. This type of information helps road authorities to understand what is meant by climate change and the potential impacts on their networks. Information of this nature can also be used by road authorities when developing business cases and briefing notes for senior managers and decision-makers, and for when communicating climate change risks to stakeholders.

Clear economic drivers exist to support the call for adaptation of road infrastructure now, even though the exact future climate is still somewhat uncertain. The 2006 Stern Review of the Economics of Climate Change[82] argued that there is a convincing economic (and environmental) case for tackling climate change *(Box A3)*. Stern concluded that uncertainty regarding the future climate should be acknowledged but not be seen as a barrier to action.

APPENDIX B - EXAMPLES OF CLIMATE CHANGE ADAPTATION FRAMEWORKS, TOOLS AND GUIDANCE

Box B1 - US Federal Highway Administration's (FHWA)
'Extreme Weather Vulnerability Assessment Framework'[83]

The framework outlines a process for conducting an assessment of the vulnerability of road infrastructure to extreme weather events and climate change, and provides guidance on how to incorporate the results of an assessment into decision-making. The assessment results can also feed into the development of adaptation strategies, asset management programmes and transportation system planning. The guidance stresses the importance of identifying and setting goals and objectives at the beginning of the vulnerability assessment process as this will assist in determining the level of detail and data required for conducting a successful assessment. The assessment framework approach is shown below.

Step 1: Define scope
- Identify key climate variables
- Articulate objectives
- Select & characterise relevant assets

Step 2: Assess vulnerability
- Collect & integrate data on assets
- Develop climate inputs
- Develop information on asset sensitivity to climate
- Incorporate likelihood & risk (optional)
- Identify & rate vulnerabilities
- Assess Asset Criticality (Optional)

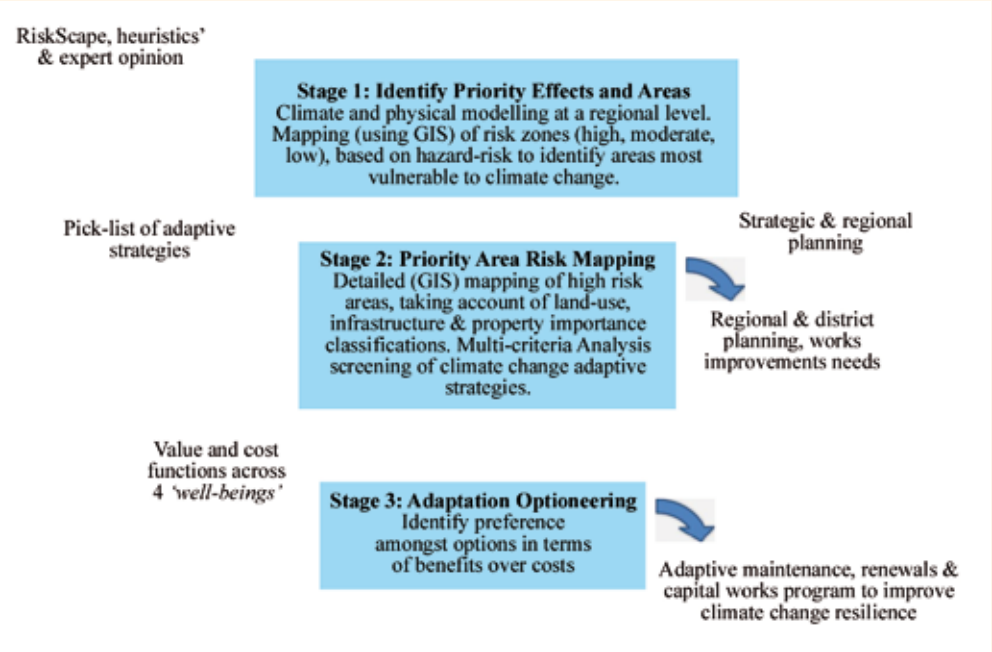
Step 3: Integrate into decision making
- Incorporate into asset management
- Integrate into emergency & risk management
- Identify opportunities for improving data collection, operations or designs
- Educate & engage staff & decision makers

The framework also offers examples of climate change vulnerability and risk assessment pilot projects across individual States.

[82] Stern, N. (2006). The Economics of Climate Change: The Stern Review. Available at: *http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/stern_review_report.htm*
[83] The Federal Highway Administration (2012). Climate Change and Extreme Weather Vulnerability Assessment Framework. Available at: *http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability_assessment_framework/.*

Box B2 - New Zealand's National Institute of Water and Atmosphere Research's 'Toolbox-Based Decision Framework for Climate Change Adaptation[84]

The Decision Framework sets out a process for understanding, analysing and adapting to the impacts of climate change (process shown below).



Box B3 - Adaptation Scotland '5 Steps to Managing Climate Risk'[85]

Adaptation Scotland, in collaboration with public bodies from across Scotland, has developed *"Five Steps"* of operational guidance to managing climate risks. The guidance takes into account legislative changes and builds on recent adaptation planning successes in Scotland. This was developed, in part, to help public bodies respond to and meet the requirements of the Climate Change (Scotland) Act 2009.

The guidance can be used as a basis to identify cost-saving actions, for example, by working with communities and community planning partners to build resilience.

Adaptation Scotland provide a range of free-to-download tools on their website *(http://www.adaptationscotland.org.uk/5/170/0/Five-steps-to-managing-your-climate-risks.aspx)*:

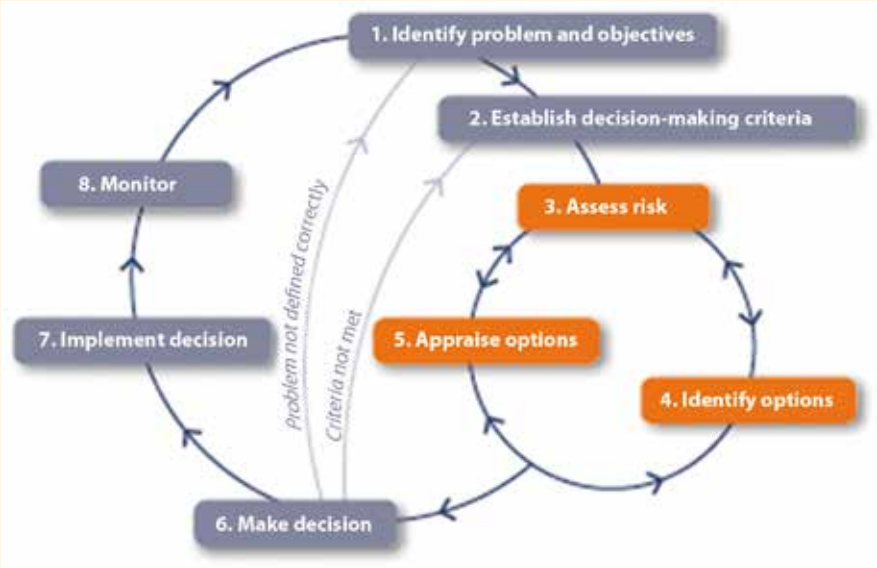
- screening questionnaire,
- weather impacts table,
- climate impact assessment,
- climate risk matrix,
- action plan.

[84] New Zealand's National Institute of Water and Atmosphere Research (2011). Toolbox-Based Decision Framework for Climate Change Adaptation. Available at: *http://www.niwa.co.nz/sites/niwa.co.nz/files/toolbox_decision_framework_for_climate_change_adaptation.pdf.*

[85] Adaptation Scotland (2013). Five Steps to Managing Your Climate Risks – A Guide for Public Bodies in Scotland. Available at: *http://www.adaptationscotland.org.uk/Upload/Documents/v6SNIFPublicSectorGuidelines.pdf*

Box B4 - UK Climate Impacts Programme (UKCIP)[86]

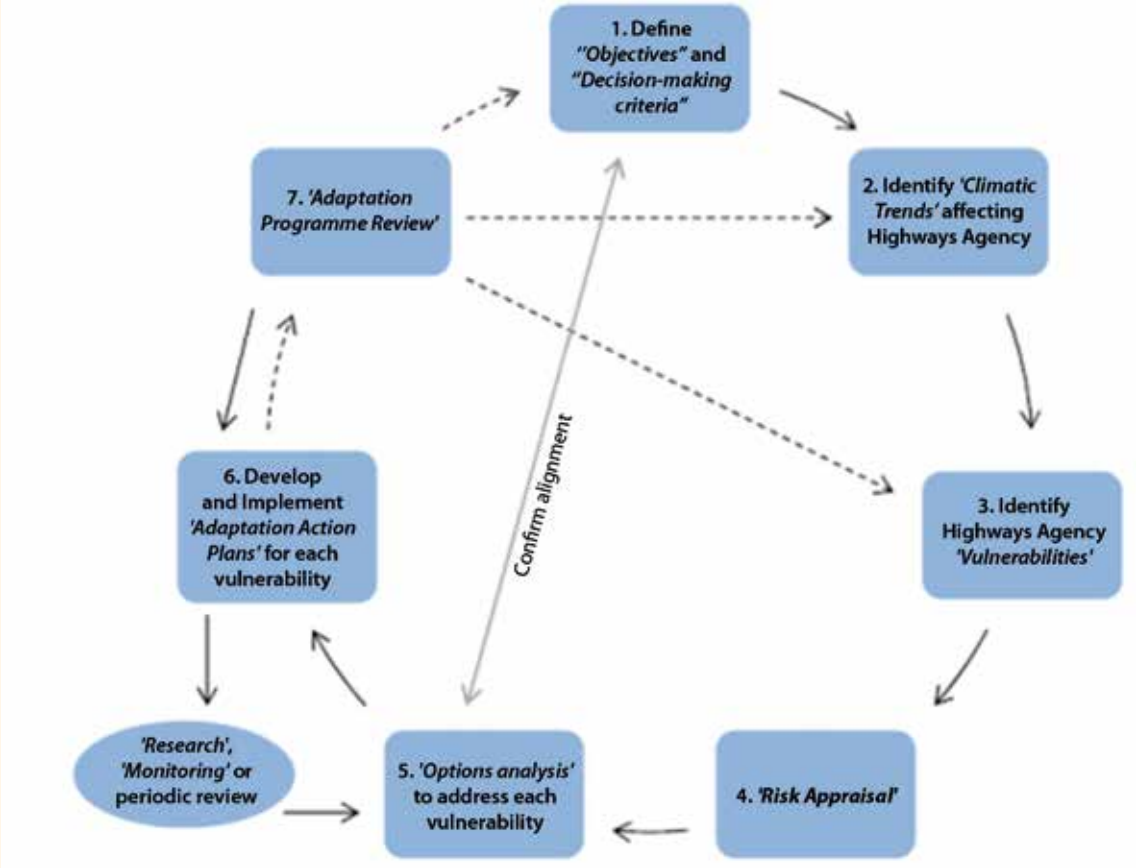
Within the UK, the UK Climate Impacts Programme (UKCIP) has developed a series of tools and guidance documents to help governmental, public and private sector organisations and businesses understand how to most effectively adapt their operations, assets and services to the impacts of climate and extreme weather. This includes guidance on how to undertake *'Local Climate Impacts Profile'* (LCLIP), a *'Business Areas Climate Impacts Assessment Tool'* (BACLIAT), a *'Climate Adaptation Resource for Advisors'* (CLARA), and an *'Adaptation Wizard'*. UKCIP's risk uncertainty and decision-making framework[87] is a step-by-step process to help assess what adaptation measures are most appropriate for an organisation.



[86] UK Climate Impacts Programme website Available at: *http://www.ukcip.org.uk/*
[87] UK Climate Impacts Programme (2013). UKCIP Risk Framework. Available at: *http://www.ukcip.org.uk/wizard/about-the-wizard/ukcip-risk-framework/*

Box B5 - GRaBS Project[88]

The GRaBS (Green and Blue Space Adaptation for Urban Areas and Eco Towns) project is a network of leading pan-European organisations involved in integrating climate change adaptation into regional planning and development. The GRaBS project has 14 partners, drawn from eight European Union member states, representing a broad spectrum of authorities and climate change challenges, all with varying degrees of strategic policy and experience. The GRaBs project aims to advance the knowledge and climate change adaptation expertise of decision makers, politicians and communities as well as regional and local municipalities across Europe. GRaBS Policy Guidelines provides a database of case studies of adaptation strategies applied on transport infrastructure.



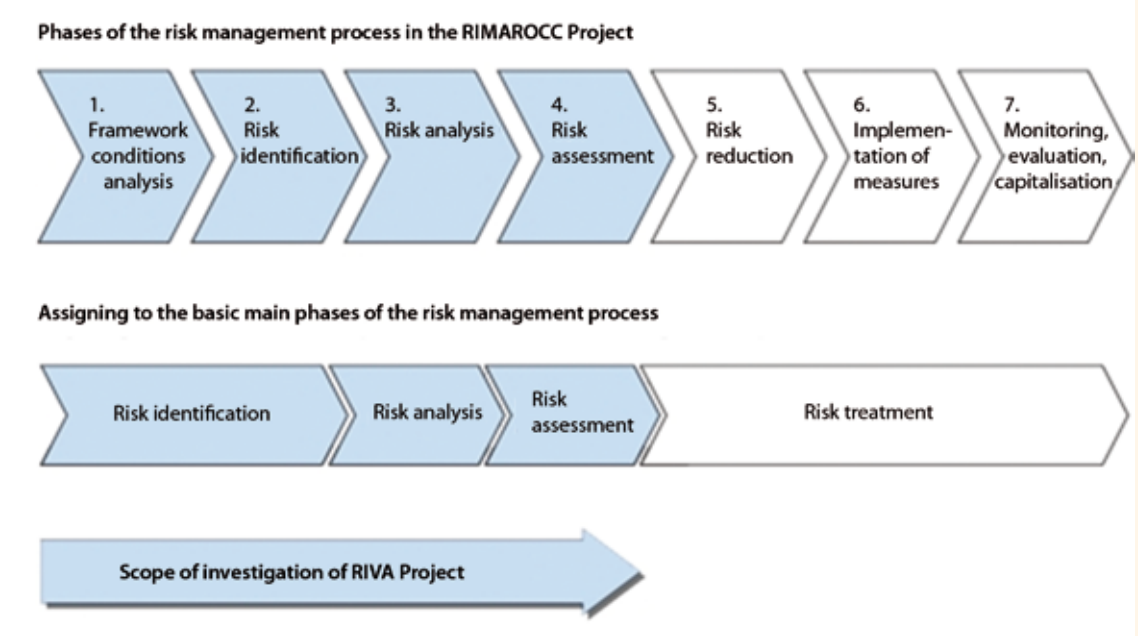
[88] GRaBS (2012). Policy Guidelines Summary - Adapting Transport Systems to Climate Change. Available at: *http://www.grabs-eu.org/downloads/PGS_Transport%20FINAL.pdf*

Box B6 - Climate change adaptation frameworks, tools and guidance - RIMAROCC RIsk MAnagement for ROad owners in a Changing Climate[89]

RIMAROCC is currently under development and aims to provide a method for risk management of road infrastructure in relation to climate change. End users are expected to be road owners and operators in Europe. The result of the project will be a structured process that supports decisions to be made by road owners. The project will give guidance on how to identify, analyse, evaluate and treat climate change risks.

Box B7 - Climate change adaptation frameworks, tools and guidance RIVA, AdSVIS projects[90]

'Risk analysis of key goods and transit axes including seaports' (RIVA) is a key project within the AdSVIS *(Adaptation de l'infrastructure routière au changement climatique)* programme. The aim of the project is the development of tools for the identification, analysis and assessment of risks due to climate change. The RIVA project interlinks with the road project RIMAROCC. Results using the RIVA method allow prioritisation of climate-related risks and aids decision-making.



[89] Deltares (2012). RIMAROCC (Risk Management for Road owners in a Changing Climate). Available at: *http://www.deltares.nl/en/project/192879/rimarocc-risk-management-for-road-owners-in-a-changing-climate*

[90] Bast (2015). Climate Change and Road Traffic Infrastructure. Available at: *http://www.bast.de/EN/FB-S/Subjects/e-klimawandel/e-klimawandel.html*

APPENDIX C - POTENTIAL IMPACTS OF CLIMATE CHANGE

The impacts listed below are not intended to comprise a comprehensive list, but should act as an initial resource for road authorities to determine their own climate change risks.

- Impacts associated with changing temperatures:
  - heat damage and deterioration of structures and pavements such as softening, deformation and cracking,
  - traffic related rutting and migration materials,
  - thermal expansion of bridge expansion joints and paved surfaces,
  - fire risk,
  - overheating of electrical equipment,
  - corrosion of steel and concrete structures due to increase in surface salt levels in some locations,
  - health and safety risk to road users (e.g. from brake failure) and employees,
  - increased frequency of fog episodes, which reduce visibility and road access,
  - road damage from slush flow,
  - acceleration of the thermal erosion and permafrost melting,
  - changes in travel patterns of network users, e.g. tourism causing a stress on a network with a pre-defined design capacity,
  - longer vegetation growing seasons leading to a reduction in soil moisture and/or increased tree leaf coverage combined with an increased magnitude and frequency of storm events may result in tree fall;

- Impacts associated with prolonged and/or heavy precipitation and storms:
  - damage to roads, subterranean tunnels, and drainage systems due to flooding,
  - increased runoff from adjacent land contributing to surface water flooding,
  - reduced safety as a result of standing water,
  - reduced visibility,
  - increase in scouring of roads, bridges and support structures,
  - increased slope instability and landslides,
  - increased debris and mud flow onto roads,
  - damage to pavements, earthworks and structures,
  - overloading of drainage systems,
  - inaccessible networks and assets,
  - deterioration of structural integrity of roads, bridges and tunnels due to increase in soil moisture levels,
  - health and safety risks to workers and the local population,
  - pollution from surface runoff,
  - slope collapse,
  - suspension bridges, signs and tall structures at risk from increasing wind speeds,
  - reduction in summer rainfall levels leading to drainage dilution levels and subsequently effects on water quality,
  - increased wind gust,
  - slope instability leading to landslides, rock fall etc.,
  - changing groundwater levels and height of the water table;

- Impacts associated with sea level rise and heightened storm surge:
  - damage to roads, underground tunnels and bridges due to flooding, inundation in coastal areas and coastal erosion,
  - increasing risk of coastal erosion and submersion,
  - damage to road infrastructure and increased probability of infrastructure failures,
  - increased threat to stability of bridge decks,
  - increased damage to signs, lighting fixtures and supports,
  - rising groundwater levels,
  - temporarily or permanently inaccessible networks and assets,
  - more frequent flooding of underground tunnels and low-lying infrastructure,
  - erosion of road base and bridge supports,
  - reduced clearance under bridges,
  - decreased expected lifetime of highways exposed to storm surges,
  - permanent asset loss at coastal sites,
  - health and safety risk to road users and employees,
  - increased salinity of groundwater;

- Impacts associated with changes to snowfall, permafrost and ice coverage:
  - reduced need for snow clearing,
  - safety risks due to snow and ice,
  - changes to soil stability and more unpredictable *'marginal'* days where snow and ice may or may not be risk,
  - increasing ice/snow melt leading to flooding,
  - changing nature and location(s) of avalanche risk,
  - increased risk of drifting snow (when accompanied by increased wind gusts),
  - changes in road subsidence and weakening of bridge supports due to thawing of permafrost (in very cold areas),
  - reduced ice loading on structures such as bridges (in very cold areas, a positive impact),
  - reduced pavement deterioration from less exposure to freezing, snow and ice (positive impacts),
  - landslides due to rapid snow melting,
  - deterioration of pavements and increased safety risks due to an increase in freeze-thaw conditions in some locations (where the temperature hovers around 0°C),
  - reduced pavement friction coefficient,
  - increased disruption to road users as a result of increased frequency and magnitude of snow fall,
  - increased coastal erosion from reduced ice coverage,
  - acceleration of thermal erosion and permafrost melting,
  - increased area of the active permafrost layer and decreased depth of permafrost;

- Other potential impacts:
  – damage to infrastructure from land subsidence and landslides,
  – wind and sand storms,
  – damage to infrastructure due to increased susceptibility to wildfires as a result of drought,
  – damage to infrastructure form mudslides in areas deforested by wildfires as a result of drought,
  – *'summer ice'* – occurs after a prolonged period of no rain when dirt and oil residue builds up on the road. When the first rain event occurs this material becomes incredibly slippery and dangerous (similar to ice on the road),
  – high winds blowing trees/other debris onto network routes,
  – operational constraints at exposed locations e.g. high-sided vehicles,
  – damage to power supply for electrical storms,
  – fog and reduced visibility,
  – increased and/or more variable UV radiation,
  – increasing number of overturned vehicles due to increased wind speeds and storms.

APPENDIX D - CLIMATE CHANGE ADAPTATION FRAMEWORK WORK BOOK

This practical implementation document is provided in a separate Excel file, to be download from the World Road Association's website. *Click here.*

APPENDIX E - CONSULTATION QUESTIONS AND RESPONSES

This appendix summarises the key findings from the road authority survey which was distributed during the first round of stakeholder engagement. Responses were received from:

- The Quebec Ministry of Transport;
- Ministry of Land, Infrastructure, Transport and Tourism – Japan (Road Bureau and National Institute for Land and Infrastructure Management);
- New Zealand Transport Authority;
- Norwegian Public Roads Administration;
- Transport Scotland;
- US Federal Highways Administration;
- Research Institute of Highway of the Ministry of Transport - China;
- Mexican Institute of Transportation;
- National Professional Association of Roads and Bridges - Romania; and
- The Asian Development Bank.

Q1: Is there political initiative taken at a national level for adaptation to climate change; for example, through national legislation or the publication of a national adaptation strategy or plan?
All respondents identified climate change adaptation measures within legislative frameworks of plans, programmes and strategies. However, often road authorities highlighted the fact that such plans, programmes and strategies failed to address climate change directly i.e. Mexico and China. New Zealand in particular appeared to have a number of relevant plans, programmes and strategies, as did Scotland and Norway.

Q2: Does your road agency have an official strategy or plan for adaptation to climate change?
The majority of respondents did not have an official strategy or plan for climate change adaptation. Road authorities with strategies and plans included New Zealand, Norway, Canada and Scotland.

Q3: Do you have access to historic climate data and climate change projections data for your country/ region? If so, what is this data and do you use it to understand potential future climate trends and risks?
All authorities have access to data (both historic and future projections) bar Mexico which unfortunately does not have access to such data. Typically, 'historic data' is collated from local meteorological records.

Q4: What sources and types of information and guidance do you use to help understand and manage the impacts of climate change an extreme weather? For example national guidance, local knowledge, academic research.

Authorities were shown to utilise a broad range of data as follows:

- traffic safety information;
- meteorological stations and data;
- early warning systems and emergency response plans/data;
- academic Research;
- local knowledge and experience;
- climate change projections;
- national guidance;
- national databases; and,
- collaborative working and sharing information.

It should be noted that local knowledge and expertise was frequently quoted as a source of data by road authorities and therefore its place in delivering an effective climate change adaptation programme should not be underestimated.

Q5: What do you understand to be the main issues and risks in relation to climate change, which have the potential to have an impact on your roads? Are there specific locations, asset types or operations that you feel are most at risk?

The answer to this question was highly location-specific. However, typically road authorities were aware of the main issues and risks that face their highway networks. For information and potential use within adaptation plans, programmes and strategies the issues faced by each authority have been reproduced below:

- **China:** Limited visibility, extreme precipitation rates, heavy snow and ice cover caused by climate change may have certain impacts on traffic safety, operation, maintenance and road infrastructure. Fog in the northeast of China and ice, snow and frozen soil in Qinghai and Tibet put these regions at risk.
- **Japan:** Crisis and risk management in response to incidents (such as flooding, slope failure and embankment damages) caused by rapidly and locally occurring cloudbursts which are occurring more frequently, management of road networks after heavy snowfall and landslides caused by rapid thaw.
- **Mexico:** There are issues with the maintenance and condition of roads across Mexico and climate change risks haven't been assessed and are therefore not understood. There is some evidence of coastal roads floods and damages in recent years along with an increased frequency of heavy rainfall events.
- **New Zealand:** Inundation of low-lying coastal highway infrastructure as a result of sea-level rise and storm surge, future flood risk under climate change for sections of state highway that are currently prone to flooding or may become so. The Transport Agency is also aware of the potential for reduced slope stability due to increased weather effects and accelerated material weathering. This could result in coastal erosion causing damage to road or structures. Other issues include drainage systems prone to flooding, increased or new flooding of state highways and accelerated structure and bridge scour.

- **Norway:** Landslides, rock falls, mudslides, debris flows, avalanches (wet landslides are a particular risk; mud flows are a problem as they are very difficult to predict and can happen anywhere whereas landslides are more predictable and isolated to specific places). Other impacts include intense rainfall and /or heavy short spells of rain along with bridges and culverts being at risk due to poor management. There is an increasing body of evidence to suggest that climate change impacts are occurring with increased frequency.
- **Canada:** Canada has five main issues and these include permafrost, changes in ice coverage and consequently water levels, coastal erosion (along the east), river erosion and ground movement. There have also been an increasing number of extreme precipitation events.
- **Romania:** The main problems include:
  – Lack of information on vulnerabilities of the road network
  – Inconsistency of monitoring
  – Lack of communication and information exchange between meteorological and transportation agencies
  – Certain locations experience the effects of extreme weather (rain, inundation, snow flow).
- **Scotland:** Heavy and/or prolonged precipitation events are the biggest risk and leads to landslides, flash flooding, road drainage overflows and coastal erosion. This has impacts on the surrounding area and networks. Other impacts include an increased frequency and magnitude of storms and the changing jet streams in oceans. There is also the general risk of Transport Scotland and their networks being unprepared for *'bad weather'*.

Q6: Do you recognise any possible opportunities and beneficial effects of climate change on your roads, and if so, what are they?

In general, the road authorities did not perceive there to be a great number of beneficial impacts arising from climate change. Authorities that did perceive them to be opportunities are listed below:

- **China:** New sources of electricity;
- **New Zealand:** Dryer periods may reduce the road damage currently experienced;
- **Norway:** Recent modelling has shown that warmer weather would be beneficial and that heavy rainfall would be very problematic to their network.
- **Canada:** Longer warmer summers may result in pavements and structures being less at risk from frost and ice, there may also be better access to remote areas and ports if sea levels rise and sea ice melts.
- **Scotland:** Warmer weather could increase tourism and result in less snow and ice which could reduce costs and disruption.

Q7: Have you experienced barriers when seeking to understand and take action to reduce the risk of climate change impacts on your agency's roads? For example, lack of resources, lack of political will, lack of funding, lack of knowledge, or other priorities being deemed more important? If so, how have you worked to overcome these barriers?

The majority of authorities highlighted a number of barriers to effective climate change adaptation, bar Japan. However, Japan acknowledges that barriers may become apparent in the future. Barriers that were mentioned multiple times include a lack of resources and a lack of understanding/education or will to change behaviours. These barriers span a number of stakeholder groups from politicians to local communities.

Q8: What are the main barriers you expect to face going forward when seeking to understand and take action to reduce the risk of climate change impacts on your agency's roads? Do you have any plans in place to overcome these barriers (for example, staff training provision)?

A number of authorities suggested that the barriers currently experienced were likely to continue. Beyond this, a wide range of potential future barriers were highlighted, many of which related to resource provision. Barriers included:

- lack of knowledge, understanding, guidance and expertise relating to climate change adaptation (including barriers relating to modelling climate change effects and impacts);
- difficulties in identifying priorities for action (especially when other sector demands may seem to take precedence;
- financial resources;
- understanding and communicating barriers effectively;
- incorporating climate change adaptation into other sectors, plans, programmes, strategies etc.;
- collaboration with other sectors, stakeholders etc.; and,
- user behaviour.

Q9: What do you feel are the information, research and development gaps and needs in the field of climate change adaptation for roads?

Answers to this question were broad and wide ranging; this is likely to be a result of the varying environmental, geographic, political, technological, social and economic condition of the survey respondents. Data availability, quality, dissemination and access were seen to be a *'gap'* in climate change adaptation for roads amongst a number of authorities. Authorities suggested that there was insufficient data relating to:

- extreme weather events;
- more gradual climate change relating to river dynamics, storm surge and increase tide levels;
- main stressors causing changes to weather and climate (and the degree of this change);
- Best practice climate change and adaptation (especially relating to Latin America – requested by Mexico);
- innovative technologies and designs;
- climate and weather monitoring databases and guidance on their use;
- increasing drainage capacity in a cost effective manner;
- interdependencies with other sectors; and,
- incorporating climate change adaptation into other sectors, plans, programmes, strategies etc.

Other areas of perceived deficiencies included:

- insufficient technologies and materials;
- lack of guidance for decision making processes;
- employee training;
- standard text and modes for incorporating climate change adaptation into contracts;
- guidance/methodology/tools for understanding and prioritising risks;
- guidance on developing a business case to be delivered to decision makers;
- guidance, case studies and data relating to natural hazards such as submersion and river erosion and ways to compare and understand solutions;

- applied research such as pilot projects;
- cost-benefit analysis guidance;
- guidance on downscaling and how to interpret climate models to the local scale;
- guidance on forming and mandating emergency response procedures; and,
- guidance relating to communication and cooperation with other sectors.

Q10: Have you undertaken (or do you plan to undertake) a structured risk assessment or survey to understand the likelihood and severity of climate change impacts and to understand which assets, locations and operations are most at risk? If so, please explain how this was (or will be) done. Have you faced any difficulties or barriers?

Generally, the road authorities have undertaken some risk assessment work yet may not have conducted a fully structured risk assessment. Half of the authorities that answered this question in the survey have conducted risk assessment activities as follows:

- **China** (research on the effects of adverse weather conditions on traffic safety and operation);
- **New Zealand** (Risk assessment in national land transport programme and coastal effects guideline); and,
- **Scotland** (Risk assessment undertaken for landslides).

Whilst Japan has not undertaken a risk assessment, research has begun to identify all possible risks that climate change poses on transportation infrastructure in order to develop adaptation measures. Norway has undertaken some systematic work yet no risk assessment of the current network has been undertaken. In the future, Norway will be undertaking a risk assessment of particularly vulnerable areas and assets which will feature in existing asset inventory records and data. Similarly, Canada has not undertaken a structured risk assessment yet has carried out assessments to see which infrastructure is most at risk; this is supported by a network of monitoring equipment alongside decision making tools. Romania is yet to undertake a risk assessment.

Q11: Do you use specific tools or methodologies when conducting climate change risk and adaptation assessments and studies? If yes, what are they and are they developed /owned by your organisation?

Generally, most authorities did not state that they used any specific tools or methodologies when conducting climate change risk and adaptation assessments and studies. Japan stated that they refer to the UK Highways Agency (Climate Change Risk Assessment) and FHWA literature. In New Zealand tools and methodologies are still being developed whilst Romania uses general information relating to climatic conditions as prepared by the National Administration of Meteorology. Norway has been shown to expand on existing methodologies and is part of a consortium with Sweden and the Netherlands on the risk assessment of roads in relation to climate change that provides useful information. Canada uses the following information:

- LiDAR;
- Mapping areas of landslide risk;
- Use of ISO standards for risk assessments; and,
- Ministerial requirements for conducting a risk assessment for new developments in regards to permafrost.

Q12: Have you already needed to take action to adapt your roads to the effects of climate

change and extreme weather (e.g. installed flood defences, changed design specifications)? If so, what action has been taken and how successful have the actions been?

The majority of the road authorities have found it necessary to adapt to the effect of climate change and extreme weather upon their network.

- **China:** Developed mobile traffic/weather monitoring systems system and low visibility intelligent guidance system used at low visibility and snow/ice prone sections of the road – Operates successfully in a number of areas. Additionally, China researches new materials and tries to develop innovative structures in order to alleviate the impacts of ice on pavements. In addition to this, flood defence, drainage, monitoring and warning systems are enhanced and operated by professional staff.
- **Japan:** Action is centred around extreme weather and the following actions have been undertaken:
  1. Highways Flooding
     – detection, alert and drain systems are installed in the locations where risk of flooding is high; and,
     – patrols to assess the incidence of highways flooding.
  2. Countermeasures and actions in response to quickly emerging local cloudbursts
     – regular/Periodic slopes inspections and management;
     – implementation of slope protection measures; and,
     – emergency roads closures.
  3. Actions in response to heavy snow (are being developed at the moment)
     – timeline and procedures for road closures;
     – effective communication with drivers; and,
     – rescue operations organised in response to other reasons (Rescue operation for stuck cars and drivers is already been effectively implemented.)
- **New Zealand:** The New Zealand Transport Agency's Bridge Manual (3rd Edition) requires consideration of climate change impacts in the design of bridges and culverts. The New Zealand Ministry for the Environment recommends specific sea level rise values that agencies should consider as part of the planning process. The New Zealand Transport Agency incorporated this sea level rise planning recommendation as part of the design for the SH16 Causeway Upgrade Project.
- **Norway:** Alterations to design specifications to ensure assets are more robust and built to withstand increasingly heavy precipitation (e.g. increasing drainage capacity to 200 year flood level for road).
- **Canada:** Changing design specifications for culverts (increase in capacity by 10%), utilisation of a canal for full scale trials – storm surge, wave height etc. and have changed maintenance activities in the North.
- **Scotland:** The agency has changed design codes for new infrastructure to accommodate for an increased frequency and severity of flooding.

Q13: Has your road agency taken (or do you plan to take) any action to calculate the potential cost of climate change damage, and also the cost of taking action to adapt and build resilience? If so, how?

Generally, the authorities have not currently attempted to calculate the potential cost of climate change damages yet it is something they intend to do in the future. Norway has tried to calculate the cost of introducing proposed measures (e.g. increasing drainage capacity). Whilst Canada

has not calculated the potential costs of climate change damage explicitly, they are monitoring identified solutions and attempting to understand the cost of conventional vs. new designs/approaches. Scotland has begun work at looking at the economic impacts of climate change such as the cost of needing to close a road during an extreme weather event. Scotland has also done some work at looking at the economic impact of landslides which will be further developed over the next few years.

Q14: Are climate change adaptation measures a part of day-to-day operation and maintenance across your road network and are they being implemented within planning, design, construction, maintenance and operation?

Generally, adaptation measures appear to be becoming increasingly integrated into everyday operations of highway networks (i.e. Canada and Scotland). However, this appears to be a slow process for instance China are gradually bringing traffic meteorological monitoring facilities into road monitoring and control system and putting them into practical use together with road construction and maintenance operations. New Zealand stated that measures are taken into consideration in the design of any work where a definitive response to climate change can be built into the work. Norway stated that design and repair is carried out according to new requirements and standards and that there is a need to incorporate climate change adaptation within longer-term planning and to have better monitoring procedures in place. Where adaptation measures are not integral to everyday operations, there is scope to do so in the future (Romania).

Q15: How do you communicate climate change issues with your staff, stakeholders and the general population? Do you undertake any public awareness raising activities or initiatives?

A number of authorities do not actively communicate climate change issues with staff, stakeholders and the general population. In China, transportation and meteorological departments often discuss and share information about climate change issues. These departments communicate traffic/weather information to general public by the media (Variable Message Signs and radio). Some of the road users (logistics companies in particular) require more details pertaining to weather related information for their business routes (e.g. trip duration). Other methods of communication include:

- **New Zealand** have publically available documents such as the State Highway Environmental Plan;
- **Norway** communicates major events;
- **Canada** delivers presentations and seminars for staff, works with academics to integrate climate change adaptation in courses and has also developed a workshop/course for employees. In addition to this there is ongoing communications with a steering committee and consultation with all stakeholders who may be potentially affected by the implementation of a project. Information is also available on the agencies website and through Ouranos which is used as a key communication tool and channel;
- **Scotland** has campaigns for bad weather and additional campaigns are planned, potentially using Smart Phone technology.

Q16: What type and level of staff training has been necessary at all levels (for example, design, construction, operation, maintenance) to help ensure your roads are resilient to future climate change?

The importance of staff training is clearly identified amongst the majority of road authorities; however the progress on delivering training varies widely across agencies. New Zealand states

that it is challenging to implement training when it is unclear what concrete measures need to be highlighted, similarly Romania have staff training planned yet will only implement such after analysis of the process is complete. In China, a top-down approach to training has proven to be effective and they acknowledge that training at all levels is essential with the importance of training for leaders being emphasised. In Norway, training for contractors is provided on climate change adaptation and resilience, which provides them with, better mapped information on the area and the assets that need special attention, to date there has been a focus has been on landslides and contingency planning. In Scotland, an annual severe weather exercise has been developed and all staff are kept up to date on policy changes. Scotland has also been working with the Institution of Civil Engineers to incorporate climate change adaptation into engineering degrees and within the school curriculum.

Q17: What type and level of staff training do you feel is lacking and necessary to help ensure your roads are resilient to future climate change?

Training was considered to be lacking in the following areas:

- general training for administrative and design staff;
- training and information on typical issues related to climate change and highways is lacking along with who is responsible for taking relevant action in these circumstances;
- engineering expertise and knowledge (particularly in relation to coastal erosion and hydraulics);
- training on climatology and risk assessment;
- training on design code changes;
- innovative design and techniques; and,
- cross-boundary cooperation and working collaboratively.

Q18: Do you feel that there are any difficulties or barriers when communicating climate change risk and adaptation issues with your staff, stakeholders and the general public?

The majority of the road authorities considered barriers to be apparent when communicating climate change risk and adaptation measures to the public. Barriers included:

- senior management buy-in;
- conflicting and confusing information – risk of confusing the public;
- the fact that mitigation may still be seen as more important than adaptation;
- concerns regarding climate change risks and adaptation may be less than other threats;
- the mentality that climate change is distant and not applicable now;
- scepticism; and,
- lack of resources.

Q19: What sources of information/ guidance/ tools etc. would you find useful for undertaking climate change adaptation and resilience studies?

The road authorities identified a number of resources that would aid in their climate change adaptation and resilience studies:

- examples of best practice (reports, resources, responses etc.);
- meteorological data;
- guidance on how to effectively communicate information to the public;
- guidance on identify risks along with flow chart and data to support risk evaluation;
- identification of clear steps/works that could be undertaken to increase resilience with clear links to specific identified climate effects;
- guidance and examples for carrying out cost benefit analyses that also include timeframes – e.g. how cost severity and probability changes over time;

- guidance on how to present climate change adaptation measures effectively;
- tools and equipment used for adaptation and mitigation;
- guidance on understanding the indirect impacts of climate change risks and adaptation on communities;
- platform/ forum for sharing innovation;
- newsletter on latest knowledge on climate change adaptation in relation to highway networks.

Q20: Do you think that case studies of successful good practice from other countries would help when assessing how to adapt roads climate change?

As identified in Question 19, road authorities suggested that it would be beneficial to have access to case studies of international best practice. The only caveat is that these case studies are relevant, replicable and translated into tools which can be applied by other agencies irrespectively of locality, resources etc.

Q21: Are there any specific additional things that would you find particularly useful within the framework? For example, would you like it to include an outline risk assessment methodology, a communication plan template, signposts to useful climate projections data etc.?

The road authorities (in addition to the examples given above) listed a number of potential resources which would be of use to climate change adaptation programmes as follows:

- risk assessment methodology and procedure;
- best practice case studies;
- cost-benefit analysis guidance;
- communication tools and examples; and,
- guidance from other sectors beyond highways.

Q22: Do you have any interesting examples of innovative ways in which your road agency has taken action to understand and assess climate change risks, and/or to build resilience?

A number of road authorities had examples of innovative best practice:

- **China:** The introduction of mobile traffic/weather monitoring system that predict pavements conditions and issues warnings;
- **New Zealand:** The Agency is working on a risk assessment framework to allow all aspects of risk to be compared and the greatest risks nationally to be addressed. The action is to ensure a less ad hoc approach to delivering resilience and ensuring better targeting of funding.
- **Norway:** The agency has a risk management tool – XGEO – which is a joint effort between roads, rail and the meteorological institute. This is a mapping tool incorporating recent events, future projections etc. – threshold values are currently being determined.
- **Canada:** Canada has a number of innovative case studies relating to permafrost and coastal erosion.
- **Scotland:** Scotland has evidence of effective communication with the public and has developed a smart phone 'App' to be used during extreme weather events. In addition to this the agency has developed a winter maintenance information system.

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