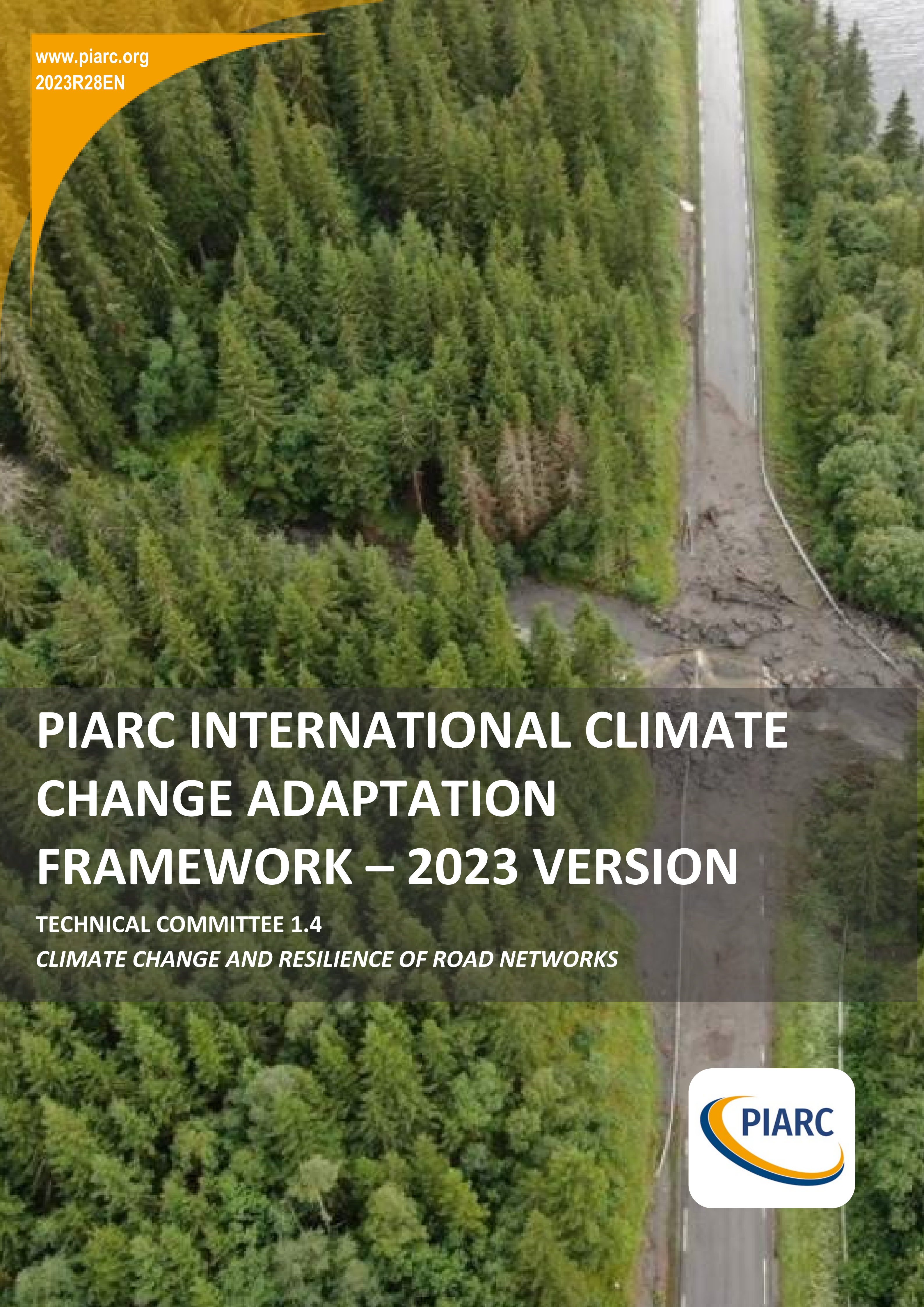

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PIARC INTERNATIONAL CLIMATE CHANGE ADAPTATION FRAMEWORK – 2023 VERSION

TECHNICAL COMMITTEE 1.4

CLIMATE CHANGE AND RESILIENCE OF ROAD NETWORKS

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.

The study that is the subject of this report was defined in the PIARC Strategic Plan 2020–2023 and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated by the member national governments for their special competences.

Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organisations or agencies.

This report is available from the internet site of the World Road Association (PIARC): http://www.piarc.org

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ISBN: 978-2-84060-803-5

Front cover © Norwegian Public Roads Administration

PIARC INTERNATIONAL CLIMATE CHANGE ADAPTATION FRAMEWORK 2023 VERSION

TECHNICAL COMMITTEE 1.4
CLIMATE CHANGE AND RESILIENCE OF ROAD NETWORKS

AUTHORS/ ACKNOWLEDGEMENTS

The Report is written within the mandate of the Technical Committee (TC) 1.4 “Climate Change and Resilience of Road Networks”, of the World Road Association (PIARC). This Report has been prepared by Working Group 2 of the Technical Committee, and is a result of teamwork by the members of the Working Group.

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The Technical Committee was Chaired by Caroline Evans (Australia).

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This Technical Report is highly based on the structure provided by the original version of the Framework (FW2015). It has used sections of text from the original version, and updates have been included according to international advancements in the area of climate change adaptation and resilience. Working Group 2 of TC 1.4 wishes to acknowledge the exceptional work done by the authors of FW2015, which provided the foundation for further development of the work into this updated version.

The Working Group leaders, Gordana Petkovic (Norway), Stuart Woods (New Zealand) and Laura Parra (Spain), were responsible within the Technical Committee for the quality control for the production of this report.

The translation into French was carried out by Fabien Palhol (France). The translation into Spanish was carried out by Juan Fernando Mendoza (Mexico). The English edit was conducted by Caroline Evans (Australia), Louis Bettini (Australia) and Stuart Woods (New Zealand).

Length of the report: The main part of the report (Sections 1 – 4) is on 212 pages, while additional 200 pages include case studies and appendices.

The target audience for the report are institutions, such as road organisations, who have the responsibility of providing resilient road networks. This includes assessing needs and possibilities, assessing vulnerability and risk, possible adaptation measures and their implementation in a sustainable working process.

EXECUTIVE SUMMARY

2023TRXXEN

PIARC INTERNATIONAL CLIMATE CHANGE ADAPTATION FRAMEWORK - 2023 VERSION

PIARC background

The World Road Association (PIARC) aspires to be "*the world leader in the exchange of knowledge on roads and road transport policy and practices within an integrated sustainable transport context.*"

TC 1.4 consists of two Working Groups (WG) and an internal Case Study Task Force. The 2020-2023 TC 1.4 effort builds on related work that started in 2014 and continued during the 2016-2019 work cycle, culminating in the publication of two reports in 2019. The work carried out during this current cycle has been:

- WG 1 has identified approaches to increase transportation system resilience for climate change and other hazards
- WG 2 has updated PIARC International Climate Change Adaptation Framework for Road Infrastructure - *this report*
- The Case Study Task Force has collected international case studies to support both WGs.

Climate change is a strategic risk to road organisations. 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. These climate changes are anticipated to have significant impacts on the design, construction, operation, maintenance and use of global road and transport infrastructure. This is why adaptation principles to address these climate hazard-induced impacts are needed.

Purpose of the Framework

The Adaptation Framework (FW) can help organisations identify adaptation principles and increase the climate resilience of transportation assets, operations, and services. Unlike the Framework of 2015, the 2023 version does not include one specific assessment method. Instead, it provides a structure upon which various methods can be applied. It is flexible, based on different levels of expertise, data availability, and resources to suit a variety of situations and specific needs. Case studies are included to provide real-life examples of the different approaches described in the report.

Features of the Framework

The structure and ways to use the Framework are illustrated in Figure A. The Framework consists of four main stages according to a suggested sequence:

Stage 1 Preparation – identify scope, variables, risks, and data
Stage 2 Assessment pathways – assess and prioritise vulnerability and risk
Stage 3 Adaptation measures – develop and select adaptation responses and strategies
Stage 4 Incorporating findings – integrate outcomes into decision-making processes

In addition to the stages above, optional sub-steps are described and shown as a “honeycomb” that demonstrates interconnections between stages and sub-steps. Stage 2 allows for adjustments to the needs and resources of the user.

The updated Framework emphasises the need to plan for the iteration of adaptation work, reviewing and improving the baseline, and ensure compatibility of adaptation work with other systems and processes to support implementation.

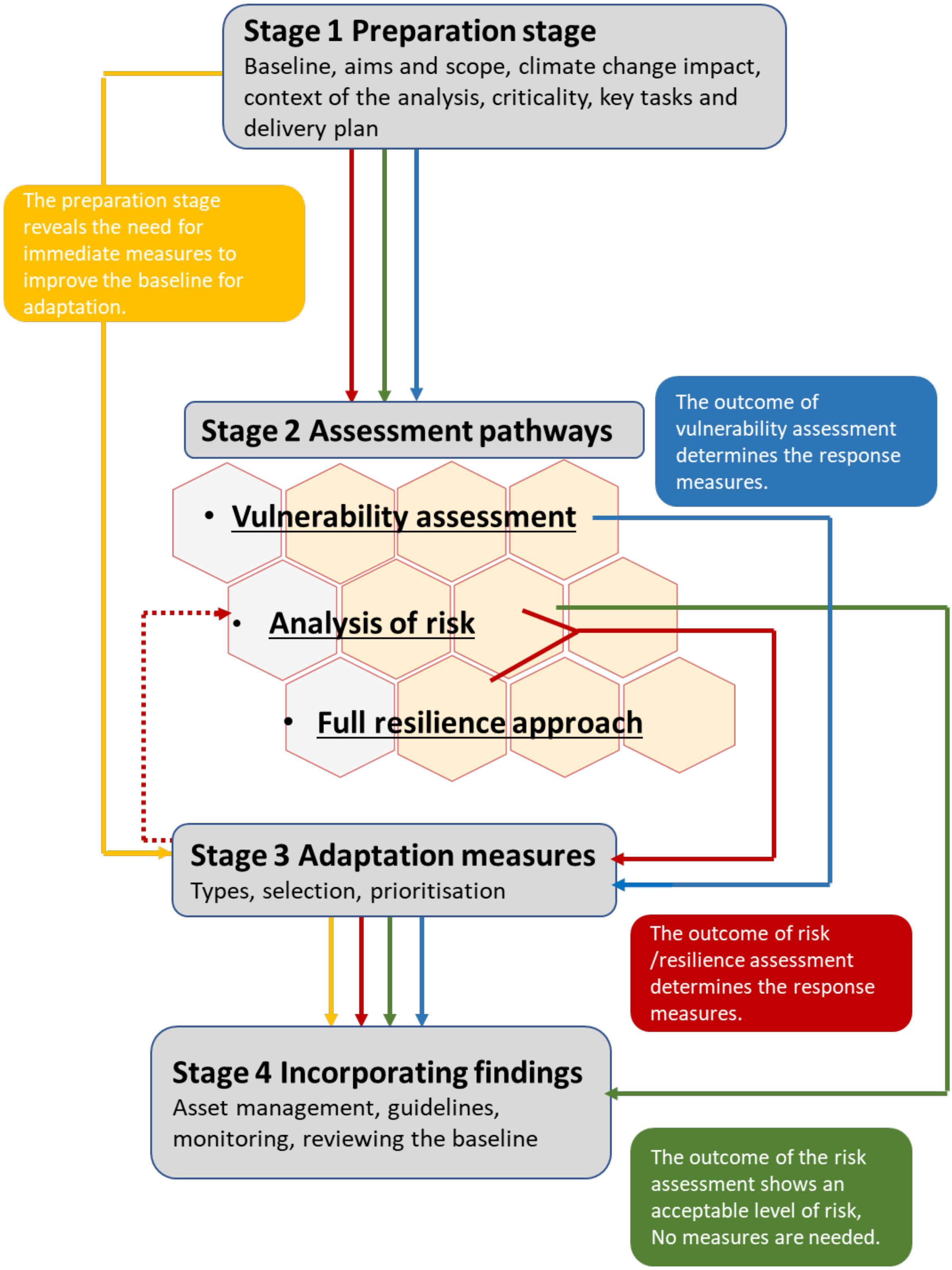


Figure A. The structure of the Framework, with the most usual assessment pathways drawn in as yellow, blue, green and red lines.

Stage 1 - Preparation Stage

A road organisation should start by laying out the reasons for doing an adaptation assessment.

1.1 Assessing the baseline for adaptation to climate change

This step investigates the realistic options for assessing needs and possibilities for adaptation to provide a basis for the choice of next steps. The FW provides guidance on these steps:

- Identify the main drivers for the work on adaptation to climate change. E.g., legislation, economic issues, or capacity building.
- Identify the values you wish to protect or improve; e.g. material assets, operations, or services.
- Inventory the types of data available, including maps, GIS, geological data, demographic data, overview of costs, earlier events on the road network, etc. (checklists suggested)
- Assess the main policies and strategies that can help implement the outcomes of the analysis if they are adjusted to incorporate climate change.
- Determine possible barriers to adaptation and potential ways to overcome them.

The baseline exercise may reveal the need to implement immediate measures to improve datasets, resources, expertise, capacity, etc., and improve conditions for future adaptation work. This corresponds to the yellow line in the diagram in Figure A.

1.2 Establishing aims and scope

Aims define what needs to be achieved, and scope establishes what should be done to achieve the aims. The assessment can be a development effort, a proactive intervention, or a response after an event. It is in this phase where practical indicators of success can be identified, including thresholds or acceptable limits to indicators.

1.3 Gathering relevant information on the climate

The next step is to investigate climate change and its impacts. This step provides guidance on how to identify relevant sources of meteorological information and connect to knowledge and data providers. Check available sources of regional, national or global climate projections. Select the appropriate level of data and apply existing projections.

1.4 Determining the context of the analysis

To determine the context of the analysis will help road organisations understand how its adaptation work fits into internal and external surroundings, such as the existing systems and expertise and relevant stakeholders, and provide ground for good communication.

1.5 Assessing criticality

It is vital to identify risks and prioritise analysis for assets that are most important to the organisation, community, or individuals. The FW provides advice on how to assess criticality, including physical, functional, and social criticality. Criticality can be one initial criteria for defining the scope of the risk or vulnerability assessment and/or can be a parameter used to calculate risk.

1.6 Defining key tasks and a delivery plan

This final step requires defining the investigation that is required for the next stages of the assessment with all the elements of an executive project or task, including detailed plans, responsibilities, deliverables, resources, time plans, etc. These decisions depend on the road organisation's ambitions and realistic possibilities, available data, expertise, and resources. The FW provides advice on the types of assessment in Stage 2.

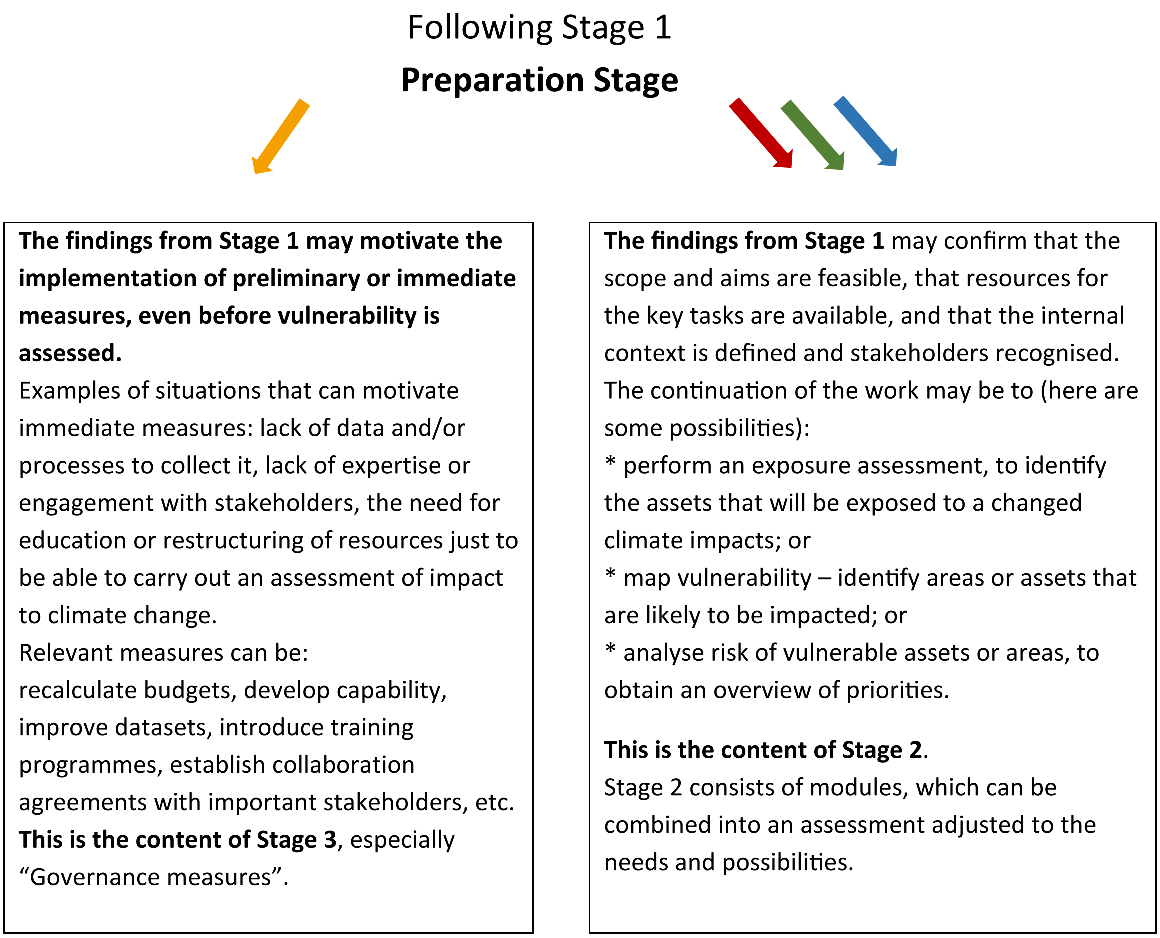


Figure B. Illustration of how the outcome of Stage 1 influences the decision on how to continue the work. Stage 1 may motivate some immediate actions and measures, or inform the process of assessment in Stage 2.

Stage 2 – Assessment pathways

Stage 2 describes approaches to identifying the assets most vulnerable to climate impacts based on their exposure, characteristics, and capacity to absorb and adapt to those impacts.

Stage 2 also introduces methods to assess risks to road users and communities affected by climate impacts. It describes approaches to identifying assets where the risk of impacts is highest, based on the likelihood of impacts occurring and the severity of impacts when they do. The goal is to help road organisations strategically prioritise investments based on the potential for climate impacts and their own approach to risk management.

Stage 2 is composed of modules, see Figure C, each corresponding to a task in the assessment. The concept is that the users of the FW should be able to combine the modules in a way they find practical and select the assessment pathway that is most suitable to their needs and possibilities.

While it is useful to go through all the steps of Stage 1 – Preparation stage, it is usually neither practical nor necessary to carry out all the steps of Stage 2. The preparation work (Stage 1) should provide a basis for deciding upon the best way to proceed and for selecting the tasks to include in the assessment of interest. This will depend on available resources, data, capacity, etc.

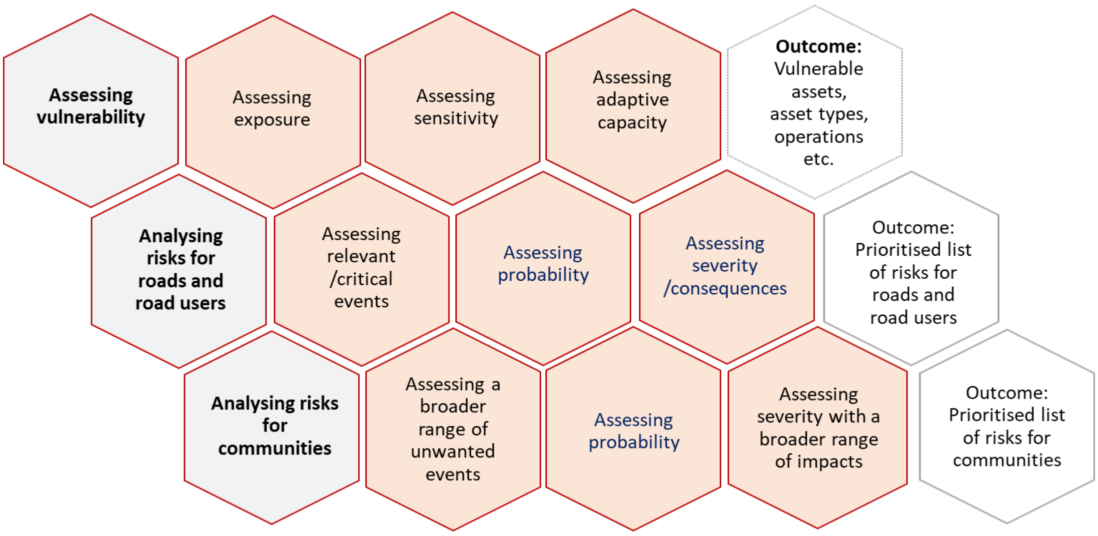


Figure C. Structure of Stage 2 "Assessment pathways". This Stage can be composed in different ways, depending on the road organisation's needs, formulated aims, data availability and resources. Section 5 provides examples of the variations in this Stage.

This Framework has not yet been directly implemented anywhere. However, the working group has gathered examples of assessments of impact, vulnerability or risk and compared them with the Framework. This is the content of Section 5 in the report.

2.1 Assessing vulnerability

This stage has the purpose of identifying assets or operations that are especially exposed or sensitive to climate impacts, because of their location or because of their characteristics, or both. Usually, this is done by combining three factors: exposure, sensitivity and adaptive capacity. It can also be estimated using vulnerability functions.

2.1.1. Assessing exposure

This step involves identifying the assets or operations that may be impacted by climate change due to location. In order to do so, data is needed that helps us to identify the hazards that may occur in the area of the network, now or in the future. Obtaining data can be difficult, so if this is the case, other sources can be available, such as technical expertise from professional staff or local knowledge. The outcome of this stage is a map or hazard map that identifies the exposure of an asset (or asset category) or operation.

2.1.2. Assessing sensitivity

Next is to identify assets and operations that might be impacted by climate change due to their current characteristics, such as design capacity, age or maintenance level. Here, information is needed regarding the characteristics and condition of the assets and operations under investigation. This data might come mainly from road inventories and/or inspections.

The outcome of this part of the assessment is an overview of the assets (or asset category) or operations that could be more affected by climatic impacts due to their age, condition or other structural characteristic.

2.1.3. Assessing adaptive capacity

The assessment of vulnerability should also take into account the possibility to adapt to unfavourable conditions. Again, data is needed, mainly about the ability of the system to respond to and recover successfully from climate impacts. The outcome of this stage is an understanding of the factors and characteristics that have the ability to reduce the effects of a disruptive event.

2.1.4. Assessing vulnerability by combining exposure, sensitivity and adaptive capacity

This can be the usual way of assessing vulnerability. It can be done by using matrices that combine exposure and sensitivity, together or not with different levels of adaptive capacity. Alternatively, a vulnerability assessment can be undertaken by using some simple functions. Several examples and case studies about this can be found in the report.

2.1.5. Assessing vulnerability with the help of vulnerability functions

Vulnerability can also be expressed as a monetary value, corresponding to the expected damage caused by natural hazards. This can be calculated by using vulnerability functions, which are based on the statistical analysis of recorded damage values.

2.1.6. Outcome

The outcome of the work done during this stage should be a map or listed overview of vulnerable areas, assets (or assets categories) or operations that can be affected by climate impacts. If the aim is to provide a basis to prioritise adaptation measures, a risk analysis must be considered.

On the other hand, the result of the assessment might determine the need to establish response measures straight away, which is the subject of Stage 3. This corresponds to the blue line in the diagram in Figure A.

2.2 Analysing risk

The purpose of this sub-stage is to guide the analysis of the probability and consequences of climate hazards of interest to determine the risk to assets, networks or operations, and the residual risks related to potential intervention proposals. It also allows the determination of relative risk to assets, networks or operations for prioritisation of responses and risk management decisions.

2.2.1. Recognising events of concern

The first task in the risk assessment is to identify the most relevant or most critical events or hazards (of concern), and confirm the type and extent of related challenges. This can allow for early limiting of the scope to increase the efficiency of the analysis. Prior to assessing risks, it is essential to define and agree upon the following variables for use in the assessment (during Stage 1): climate hazards (and times) of concern; locations and operations or services at risk; and types of impacts.

2.2.2. Assessing probability

Estimating the (changing) probability of the events of concern relates to the likelihood of an impact occurring within a given timeframe for the current situation, or for the future. Due to the uncertain nature of climate change, assessing the probability of impacts occurring can be difficult. However, approximations can be made using climate change projections, local experience and expertise. The outcome of the probability assessment should be information (numerical or descriptive) of the likelihood of occurrence of the events of concern, which is a key input to the risk assessment.

2.2.3. Assessing severity

Severity or consequence relates to the outcome of an (adverse) event on objectives or systems. It can relate to either the magnitude or intensity of a natural hazard event, or the size of an impact caused by the event. The key initial focus for the assessment of the severity should be on the direct implications, or size of the event, based on information and data available, with cascading or compounding effects being considered where possible. Attention should be given to all modes present and affected. The outcome of the severity/consequence assessment should be information (numerical or descriptive) on the potential range of severities and related consequences for various potential hazards.

2.2.4. Assessing risk

A risk assessment involves the identification, analysis, and evaluation (grading and prioritisation) of risks relevant to an asset, operation, and/or service. The risk analysis approach used in this framework is based on the basic construct of Risk = Probability * Consequence (or Severity). The nature of the available data affects the types of assessment possible: quantitative, semi-quantitative or qualitative. Sensitivity testing is advocated, to develop ranges and distributions of results, rather than relying upon a single fixed number or narrow rating. This gives a better understanding of the key issues which influence the risks. Risk assessments of potential strategies should consider risk tolerance and residual risks.

2.2.5. Outcome

The outcomes of this risk analysis phase are to have identified the (climate change) risks confronting the location, assets or operations as identified in Stage 1 and to provide key content for the activities in Stage 3. The risk analysis framework will enable the impacts and risks of the base case (as identified in Stage 1) to be rated and prioritised for action. Prioritising these base case risks in this way will subsequently aid the development and prioritisation of adaptation responses and strategies for targeting the priority risks within Stage 3 of this FW (and allow consideration of residual risks for each strategy). These rated and prioritised impacts and risks can be used to develop a Risk Register.

2.3 The resilience approach

The purpose of this sub-stage is to flag and discuss taking the risk analysis task to another step to consider the wider concept of resilience. This involves outlining the key considerations and rationale for a resilience assessment without providing the same level of guidance and methodologies, given that the full resilience approach is considered outside the scope of this FW report. This sub-stage is not required to be undertaken before moving to Stage 3.

2.3.1. Overview

Resilience is a system characteristic and desired outcome which is broader than a risk assessment process. Through resilience assessments, road organisations are seeking to focus on effects on services provided, and potential socio-economic impacts to the customers or communities. They are increasingly concerned to minimise adverse impacts on customers and business from disruptions of the services being provided by the transport system for which they are responsible, rather than just focussing on the conditions and functioning of their assets.

Undertaking a resilience assessment or programme would broaden the scope beyond the risk analysis focus on assets and networks to a wider ranging set of issues and impacts that cover more complex target levels of service analysis, distributions of effects (and equity) and multi-system and service-provision thinking. In this approach, both tangible and in-tangible effects are assessed.

2.3.2. Data and information needs

A full resilience assessment needs additional information above and beyond that of a standard risk analysis approach. This would be required to support a range of different indicators and would cover areas such as: macro and local economic conditions; socio-demographic conditions; system interdependencies; or sites of cultural significance. It is likely that some surrogate information sources will be required as direct information for indicators of some outcomes and community concerns may not be available or directly measurable.

2.3.3. Resilience assessed through monetised damages and losses

The Framework suggests an option for resilience assessment. It considers expected damages from climate hazard events and expected losses for the users of the disrupted infrastructure. Vulnerability functions and criticality assessment are used for assessing expected annual damage and losses. This platform enables cost-benefit assessments to be performed including for an uncertain future. Non-tangible consequences, such as fear of hazards, inconvenience, or other aspect of quality of life are currently not included but could be through integration with alternative methods.

2.3.4. Community Resilience

Should a road organisation wish to undertake a full and comprehensive resilience assessment, establishing a common ground and understanding on what is meant by 'community resilience' is needed. There is no evidence of a common, agreed definition of community resilience and initial stages of a resilience assessment should agree on this. A 4-step approach for refining and harmonizing the approach to 'community resilience' is proposed for establishing a stakeholder understanding and agreement on basic principles and definitions.

2.3.5. Outcome - Taking the resilience approach forward

Full consideration of the Community Impacts/Full Resilience Approach goes beyond the scope of this FW update. Discussion on the differences between risk assessment and resilience assessment (in the context of this FW) concludes that a resilience assessment starts with the risk assessment, but needs to go on to account for a wider range of hazard impacts and associated response actions. Guidelines for a Full Resilience Approach could form a part of the next key update in future PIARC work cycles.

Stage 3 – Developing and selecting adaptation measures

3.1 Identification of adaptation responses and strategies

This section explains how to identify, select and prioritise adaptation responses or strategies and how to compile an adaptation plan.

A full climate change Adaptation Plan that covers the full breadth and scope of a road organisation's role or function may be developed as a result of this work. However, various constraints need to be considered, including technical capacity, funding and resources.

3.2 Types of adaptation responses and strategies

To assist with understanding what a road organisation may implement within its adaptation plan and to assist with developing comprehensive approaches, an explanation of the various types of adaptation responses and strategies has been provided and categorised against a resilience cycle and the typical functions within a road organisation.

3.3 Selection and prioritisation of adaptation responses and strategies

The Framework provides guidance on how to prioritise response measures and strategies using various methods including cost-benefit analysis, multi-criteria analysis, life cycle costing analysis and probabilistic analysis. This stage also provides an outline of the approaches to selecting adaptation measures and strategies related to a level of resilience that is sought.

3.4 Approaches to assess deep uncertainties – Adaptation pathways and real option analysis

Deep uncertainty, in relation to climate change, stems from its long-time scales and complexity. It occurs when decision makers and stakeholders do not know, or cannot come to a consensus on, how likely different future climate change scenarios are, or what are the consequences from decisions made today. This Framework details approaches to assessing deep uncertainties through economic assessments that can improve decision-making under deep uncertainty such as Real Option Analysis and Adaptation Pathways.

3.5 Development of an adaptation plan or strategy

After identifying and prioritising adaptation responses, a full climate change adaptation plan can be developed to carry out the selected measures. This section describes what to include within the plan itself. An Adaptation Plan provides details relating to the selected adaptation measures such as actions, sub-actions, performance indicators, expected benefits, costs, resources, organisational capacity, legislative considerations and implementation risks, and assigning timescales, priorities, and responsibilities.

3.6 Outcome

The outcome at the end of Stage 3 is that the road organisations should have developed a list of possible adaptation responses or measures, which may include the quantification of the benefits from their implementation. These adaptation responses can be prioritised, and ideally, worked into an Adaptation Plan to provide management oversight for the delivery of these actions.

Type of adaptation measure	**Infrastructure related**	**Traffic and hazard management related**	**Maintenance**	**Network and operational planning**
Governance: Organisational policy, strategic planning, community readiness, capacity building, critical link analysis, stakeholder engagement, research				
Stage in the resilience cycle	**Design & construction**	**Operation (and incident management)**	**Maintenance**	**Planning**
Prevent & protect	Design standards & design strategies Protection Measures Upgrading infrastructure or structural adaptation	Guidelines and frameworks	Asset management	Road planning
Prepare	Strategic network management and increasing redundancy	Operational management or master planning Monitoring	Preventative maintenance Contract amendments Vulnerability assessments	Critical link analysis Strategic network management and increasing redundancy
Respond	Emergency repairs and maintenance	Road user awareness and behaviour Traffic management & detours	Emergency repairs and maintenance	Road user awareness and behaviour
Recover	Build back better	Monitoring, evaluation and feedback	Road maintenance	

Stage 4 – Integrating findings into decision-making

This stage provides guidance on how to incorporate the information, results and lessons learned in Stages 1 – 3 into the decision-making processes of the road organisation.

4.1 Incorporating recommendations into routines and processes

It is generally accepted that incorporating adaptation measures in the usual tasks and practice of the road organisations (mainstreaming) is the most efficient way to adapt. A possible asset management system is the natural place to introduce new information relevant for climate resilience. Amending design rules is an efficient way of ensuring that resilience will be considered in all new projects. Finally, all these changes should be established in an Adaptation Plan. It defines what to do and why, when, by whom and with which resources.

4.2 Communicating the findings

How are findings communicated and to whom? The Framework provides advice and examples. Senior management needs to be informed in an efficient way, in order to take the decisions that support implementation. Road users and affected communities are important receivers of information about the measures being taken, but they also provide valuable input to the next round of adaptation work.

4.2 Formalising stakeholder networks

The importance of recognising and collaborating with stakeholders was described in Stage 1.
In Stage 4, examples are given on some established and formalised collaboration networks, which ensure sustainability of adaptation work.

4.3 Education, awareness, training

Incorporating climate change adaptation into road authorities' education and training will support adaptation significantly. Potential actions are training courses, collaboration with other state agencies and expert environments, teaching partners doing planning, design, maintenance or operation about the importance of including climate change aspects in their work. The exchange of knowledge, experience and best practice with other road authorities, is also beneficial.

4.4 Developing a business case for adaptation

A business case for adaptation explains the rationale behind the implementation of an adaptation strategy (or initiation of a particular action or measure) to senior managers and decision-makers. The FW provides some advice and examples.

4.5 Monitoring, reporting, review

Finally, monitoring and evaluation (M&E) are needed to determine the effectiveness of selected adaptation interventions. In this phase, adaptation plans are analysed and evaluated, in order to ensure progress, inform stakeholders, and reveal obstacles. This step helps ensure long-term success. Indicators for estimating the success of adaptation work, recognised early in the process (Stage 1), should now be reviewed and adjusted if necessary. A M&E plan should be developed, to assesses progress against the adaptation and implementation plan.

4.6 Using the findings, reporting and reviewing

The M&E findings should be used to update, revise and readjust the adaptation strategy. They can motivate continued use of good practices or identify gaps and needs. 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.

Recommendations

Use the PIARC framework!

Recommendation for users and decision-makers

- Invest in good preparations work - adjust the ambitions to the level of data and resource availability. Use the findings of the preparation work as an indication of what should be improved for the next round of work.
- Adjust / tailor your assessment - select the steps that are most important for your needs and resources.
- Provide the basis for an iterative process - provide sustainable institutional setup and capacity to carry out planning and implementation of adaptation work. Anchor climate change adaptation capacity development in institutionalised planning systems and processes for sustainable implementation.
- Share and publish your experience - experience from the use of the framework is valuable for others! Ensure good communication and documentation!

Recommendations for PIARC

- Develop a resilience framework for climate change and other hazards - a more general resilience framework, including other hazards (in line with the scope of WG1 in this cycle). The resilience framework should address complexity, such as coinciding events and amplifying effects, interdependencies and cascade effects, etc. General instability because of climate change challenges may add to aspects of vulnerability.
- Support implementation and feedback - it is important to assess the value of a product developed and prepared through the current TC process. Define the process for dissemination and endorsement of the product. Following publication, actively encourage application by member states and establish mechanisms to collect feedback from implementation.

CONTENTS

0. INTRODUCTION

0.1. OUTLINE OF PIARC

The World Road Association (PIARC) aspires to be "the world leader in the exchange of knowledge on roads and road transport policy and practices within an integrated sustainable transport context". PIARC's work programme and offering is focussed around the following four Strategic Themes within its Strategic Plan 2020-2023: "Road Administration", "Mobility", "Safety and Sustainability" and "Resilient Infrastructure" (World Road Association, 2020). This Climate Adaptation framework, in the context of Strategic Theme 1 "Road Administration", represents an output of Technical Committee (TC) 1.4 "Climate Change and Resilience of Road Networks".

TC 1.4 consists of two Working Groups and an internal Case Study Task Force.

- Working Group 1 aims to identify uniform and methodological approaches to increasing resilience of roads. It covers hazards and environmental threats within the context of road infrastructure resilience and identifies methodologies and approaches to increase resilience.
- Working Group 2 is responsible for the present report, which is an updated edition of "*International Climate Change Adaptation Framework for Road Infrastructure*" (PIARC 2015 R03EN), also referred to as "FW2015". [1]
- Internal Case Study Task Force has had the overall goal to collect international case studies, and to review these in order to provide structured information in a consistent form to supplement both Working Groups.

0.2. THE IMPACT OF CLIMATE CHANGE ON THE TRANSPORT SYSTEM

Climate change is increasingly impacting on our roads and transport systems and is affecting planning, design, construction, maintenance and operation. Adapting to climate change is a process, which now needs to be built into a road organisation's normal road management procedures. Successful forward planning – not just responding to disruptive or emergency situations – will enable an organisation to make appropriate investment decisions at the right time and right place, making sure that it continues to provide the levels of service that its stakeholders and network users expect, both now and in the future.

The United Nations' (UN) Intergovernmental Panel on Climate Change (IPCC) comments that climate "Adaptation is defined, in human systems, as the process of adjustment to actual or expected climate and its effects in order to moderate harm or take advantage of beneficial opportunities." Additionally, it notes that "Adaptation plays a key role in reducing exposure and vulnerability to climate change. ….. In human systems, adaptation can be anticipatory or reactive, as well as incremental and/ or transformational." [2]

According to the IPCC, global mean temperatures (global warming) will continue to rise throughout the 21st century. Although the general direction and trends of climate change are more certain than in their earlier reports, the IPCC notes that details of future climate change are uncertain. The uncertainty is the result of the range of possible anthropogenic and natural environment futures, as well as the existence of natural internal climate variability. Also, the climate system models are incomplete and imprecise. It is however possible to consider and plan for future climate change using projections, scenarios and models that characterise outcomes and uncertainties under specific assumptions related to potential future contexts.

Climate change should be regarded as a strategic risk to road organisations, which requires consideration and the adoption of adaptation principles to address the climate hazard-induced impacts. Climate change can lead to new risks, or it can exacerbate existing risks and hazards. 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.

To add complexity to the situation, these projections are not expected to develop uniformly or linearly across the planet nor even across regions. Increasingly work is occurring to downscale the IPCC projections to provide insights at much more local levels. In overview, the projections indicate that the earth will become warmer, some regions will become wetter, and some will become drier, sea levels will rise, and storm surge heights will increase, snow cover and the extent of sea ice will reduce, and the frequency and severity of extreme weather events will increase. All these changes to the climate are anticipated to have significant impacts on the design, construction, use, maintenance and operation of global road and transport infrastructure.

0.3. The 2015 Climate Change Adaptation Framework and its Revision

The aim of the PIARC Framework is to assist road organisations in managing the impacts of climate change on road networks and systems. It provides guidance for identifying potential impacts of climate change, selecting responses and embedding climate change into decision-making processes. It is intended to be applicable to any geographical, climatic, economic, and environmental condition.

In May 2014, PIARC launched a call for proposals for PIARC special projects. The initiative to develop an international framework for climate change adaptation occurred at a meeting of PIARC's Technical Committee 1.3 "Climate Change and Sustainability" in Bali, Indonesia (2014). The task to develop the Framework was entrusted to consultants URS (now AECOM). The Framework was launched at the World Road Congress in Seoul in, November 2015.

The short timeline for developing the Framework did not allow implementation or detailed consideration of best practice. Additionally, it was identified that the processes and methodological approaches may not meet the requirements of users. Therefore, it became clear that adjustments to the Framework process were required to ensure more effective world-wide application. The work was continued in the following PIARC cycle (2016-2019). TC E.1 "Adaptation Strategies /Resilience" adopted the task to propose refinements of the Framework, based on experience from the first applications of the Framework and on case studies of good practice, which the TC was to compile. Several countries provided feedback on the application of the Framework: Mexico, Australia and Paraguay. In addition, a large number of case studies were collected, covering all aspects of climate change adaptation across PIARC member countries.

In addition to this report, a separate report entitled *Adaptation Methodologies and Strategies to Increase the Resilience of Roads to Climate Change – Case Study Approach* [5], was developed by TC E.1 to provide a collection of case studies relevant to each stage of the Framework. The outcomes of this report, together with the recommendations from the resulting 2019 report, *Refinements of PIARC's International Climate Change Adaptation Framework for Road Infrastructure* [3] sought to build upon the 2015 Framework and formed the basis of one of the focus topics in the current PIARC Strategic Plan for cycle 2020 – 2023. These 2019-reports are key inputs for Technical Committee 1.4 "Climate Change and Resilience of Road Networks" and were integrated and updated into this 2023 version according to new approaches that have been put into practical use since the original Framework. This updated Framework intends to facilitate the applicability of adaptation to climate change assessments in a variety of situations. Box 1 provides an overview of the supporting documents. Those who are interested in the conclusions of the 2019 report and the main changes outlined in this 2023 version can find more information in App 10.0.1 and App 10.0.2, respectively.

Box 1: Supporting documents

The following are the key reports from previous cycles (2012-2015 and 2016-2019) forming the genealogy of this revision:

- "*International Climate Change Adaptation Framework for Road Infrastructure*", (2015), PIARC, 2015R03EN, ISBN 978-2-84060-362-7 [FW2015] [1]
- "*Refinement of PIARC's International Climate Change Adaptation Framework for Road Infrastructure*", (2019) PIARC, 2019R30EN, ISBN 978-2-84060-577-5 [3]
- "*Refinement of PIARC's International Climate Change Adaptation Framework for Road Infrastructure Appendices*", (2019) PIARC, 2019A30EN, ISBN 978-2-84060-605-5 [4]
- "*Adaptation Methodologies and Strategies to increase the Resilience of Roads to Climate Change – Case Study Approach*" (2019) PIARC, 2019R25EN, ISBN 978-2-84060-558-4 [5]

Other key reports produced by TC1.4 in the 2020-2023 cycle ancillary to the key focus areas of the Technical Committees work programme include:

- "*Terminology on Resilience and Coordination with related PIARC Technical Committees"* – (2021) PIARC, 2021BN1.4EN, Internal Document [6]
- "Climate Change, Other Hazards and Resilience of Road Networks – A PIARC Collection of Case Studies", (2022) PIARC, 2022R32EN, ISBN 978-2-84060-733-5 [7]

0.4. THE 2023 VERSION OF THE FRAMEWORK (THIS REPORT)

The purpose of the *PIARC International Climate Change Adaptation Framework for Road Infrastructure* is to assist road organisations in developing appropriate climate change adaptation responses for their road transport infrastructure and systems. It aims at being applicable to a wide range of circumstances, such as data availability, resources, expertise etc, and it is adaptable for application at the national or local level.

In comparison with the first version of the Framework, this updated version does not provide guidance towards a particular assessment methodology. Instead, it provides a structure where various methods can be applied, based on the level of maturity of a road authority or alternative user in addressing climate adaptive action. It lays out a process and supporting material to identify transportation assets and systems that might be exposed and vulnerable to climate change impacts, evaluates the level of risk, and provides guidance on when it is appropriate to make an adaptive response. It identifies the key issues to be considered at each step of the process, and points to potential resources, examples and case studies that aim to help guide the adaptive analysis.

Here are some important features of the updated framework:

- **Baseline for adaptation and iterative process**
  The road organisation is encouraged to analyse its starting point for adaptation (baseline). The Framework is 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 as priorities emerge. With consideration of these elements, this will improve the baseline for adaptation.

- **Tailoring the assessment**
  Should one perform an exposure assessment only, a vulnerability, risk or resilience assessment? This depends on the available resources. Stage 2 consists of a series of steps which can be combined in different ways, to suit the needs and possibilities of the user.

- **Compatibility with other processes and systems**
  Implementation of climate adaptation action will be easier if the selected measures are compatible with existing processes and systems. This is emphasised throughout the Framework and highlighted at the beginning of each step.

It is acknowledged that not all road organisations 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 road organisation. 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. With this approach it is anticipated that this Framework will be applicable to a range of countries with different requirements.

The Framework has been based on drawing together a collection of relevant case studies and the best-practice experience of countries in addressing the impacts of climate change on road transport infrastructure and network operations. It is a result of extensive virtual and in-person meetings held by Working Group 2 within PIARC TC1.4. During the four-year PIARC cycle, the TC held a series of workshops and seminars to further enhance the provision of case studies and experiences relevant to developing this Framework. These events comprised:

- Workshop on *Climate Change Impacts and Road Resilience* hosted by the Federal Highway Research Institute (BASt) and the BMVI Network of Experts, Germany in July 2021 (virtual)

- Seminar on *Climate Change Adaptation and Resilience of Road Networks (in Low- and Middle-Income Countries)* with TC1.4 and the Uganda National Roads Authority in November 2021 (virtual)

- XVI PIARC World Winter Service and Road Resilience Congress (Calgary), where TC1.4 was involved in five technical sessions, roundtables and foresight sessions, February 2022.

- Seminar on Climate Change, Resilience and Disaster Management for Roads, held in joint collaboration with PIARC TC1.5, Ministry of Public Works and Housing and the Road Engineering Association of Asia and Australasia (REAAA) in Yogyakarta, Indonesia in November 2022 and a hybrid (in-person and virtual).

0.5. Structure of the Present Climate Change Adaptation Framework

The Framework document structure is shown in Figure 1.

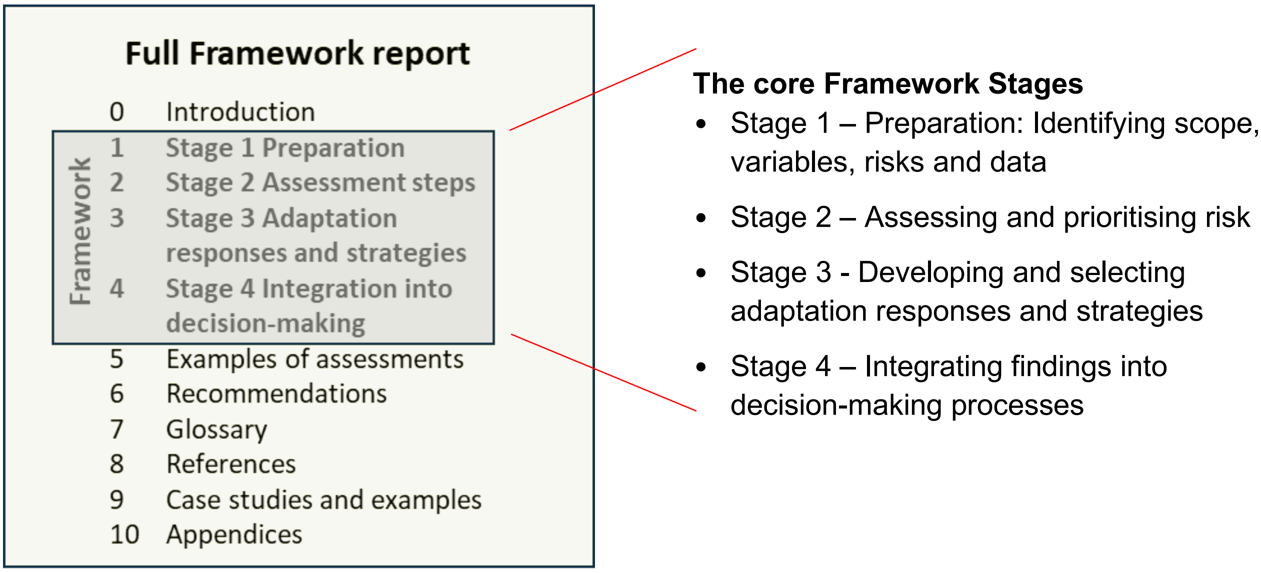


Figure 1. Structure of the Framework

The Introduction (Sections I – VII) describes the purpose of the Framework, its development and structure, how it can be used.

Section 1 (Stage 1 of the Framework) deals with the “Preparation stage”. Stage 1 establishes the assessment scope, aims, key tasks and a delivery plan. It also includes the assessment of climate change projections and scenarios.

Section 2 (Stage 2) provides guidelines for:

- Vulnerability assessments
- Risk assessments with respect to damage to roads and road assets
- Resilience assessments, considering secondary impacts of climate-related events on both the infrastructure and the communities that are dependent on these assets.

Stage 2 covers exposure and vulnerability of the assets and systems, and considers impact probability and impact severity; and analysing risk and establishing a risk register. It is recognised that there are a number of different vulnerability and risk assessments, therefore a range of possible methods are provided, noting how their applicability can be assessed according to different contexts for road organisations. At the end of Stage 2, road organisations will be able to rank their assets, locations, and operations according to the level of risk.

Section 3 (Stage 3) focuses on identification, selection, and design of adaptation responses, which are informed by the outputs from the previous stages. The section gives advice on criteria for choice of response measures and possible methods for prioritising them. The outcome of Stage 3 is that road organisations will be able to develop an adaptation action plan or strategy (often including a prioritised list of adaptation responses).

Section 4 (Stage 4) outlines how to integrate the findings into decision-making processes. The work carried out in the first 3 stages of the Framework gives grounds for implementation of the plan to improve climate resilience. It includes:

- the need and case for incorporating recommendations into decision-making processes,
- developing a business case,
- education, awareness training, and effective communication about climate change and the Adaptation Strategy/Plan, and
- future planning and monitoring.

The desired outcome of this stage is effective integration of assessment findings into decision-making activities, communication plans, business case activities and ongoing planning and operational procedures.

Section 5 contains examples of climate change adaptation assessments (from the collection of case studies) explained in relation to the stages of the Framework. This is called comparative case studies.

Sections 6 summarises the Working Group's recommendations for users of the Framework, and for PIARC.

Sections 7 and 8 contains the Glossary and References.

Section 9 comprises of case studies and examples. Some case studies are linked to from several places in the Report. The "Back" arrow makes it possible to navigate from the main text to the examples and back.

Section 10 (Appendices) provides supplements to the main sections. It is not meant to be read as a continuous text. The appendices vary in detail and purpose. Some contain information or discussion material that was taken out of the main text for better legibility or focus, and should be read in conjunction with the related main text section. Others are additional pieces of information or sources of content for the reader interested in exploring any issues in more detail.

The **Executive Summary** is also available as a separate document. It allows navigation through the stages of the Framework.

0.6. OTHER FRAMEWORKS AND PROJECTS

There are a number of other approaches, strategies and - frameworks - for adaptation to climate change. Many are tailored for certain purposes or national needs. They are nevertheless a valuable source of good ideas and information. This section provides examples of other frameworks and projects.

** **The Research for Community Access Partnership (ReCAP)** (→ Sec. 9.0.1)
The Research for Community Access Partnership (ReCAP) [8], a research programme funded by UKAid, commissioned in 2016 a project to produce regional guidance on the adaptation of rural access roads to climate change.

** FHWA Framework (→ Sec 9.0.2)

The Federal Highway Administration's (FHWA's) Vulnerability Assessment and Adaptation Framework [9] is a manual for transportation organisations responsible for managing the road network to assess the vulnerability of road infrastructure to extreme weather and climate impacts. The Framework provides a structured 6-step process, and includes examples and tools.

** RIMAROCC and ROADAPT risk assessment framework (→ Sec 9.0.3)

"Risk Management for Roads in A Changing Climate" (RIMAROCC) [10] was a European project (ERA-NET Road, 2008-2010) with the objective to develop a common method for risk analysis and risk management for roads with regard to climate change. "Roads of today adapted for tomorrow" (ROADAPT) [11] developed further RIMAROCC's structure into an applicable tool for risk assessment of roads.

** Resilience management concept Germany (→ Sec 9.0.4)

A concept developed with the objective to increase the resilience of the federal transport infrastructure through practical case studies, especially against the background of climate change and extreme weather events. [12]

** Towards a resilient infrastructure in the Netherlands (→ Sec 9.0.5)

This is an example of application of a holistic approach for identifying the effect of future climate conditions, assessing the risk and providing the basis for an adaptation strategy. The stress test of the Dutch highway network was developed and performed in 2020. (Rijkswaterstaat, 2023)

** Plan for Resilience of Infrastructures to Climate Change (PRIAC), Portugal (→ Sec 9.0.6)

Infraestruturas de Portugal, S.A. (IP) is the company responsible for the management of road and rail infrastructures, ensuring the provision of a safe, efficient, and sustainable service. In this context, it has an ongoing Plan for Infrastructure Resilience to Climate Change (PRIAC). PRIAC covers railway, road and telematics networks and aims to achieve understanding the risks associated with the effects of climate change and assess their impacts on the infrastructure, obtaining measures for prevention and adaptation to climate change in a succinct, organised and coherent way for the three networks, making them more resilient. (Infraestruturas de Portugal (IP, SA) 2023).

** European Union Adaptation Strategy (→ Sec 9.0.7)

The European Commission's strategy for adaptation to climate change (2021) [13] sets out how the European Union can adapt to the impacts of climate change. The aim is a climate resilient European Union by 2050. The Strategy has four principal objectives: to make adaptation smarter, swifter and more systemic, and to step up international action on adaptation to climate change.

** HTV Asia Applied Research Programme – State of Knowledge Report (→ Sec. 9.0.8)

The High Volume Transport (HVT) Applied Research Programme, which is funded with UK Aid from the UK Government, is updating vital transport research that reduces poverty and develops economies. The aim of the programme is to make transport safer, greener, more affordable, accessible and inclusive in low-income countries. In 2021, HTV published 'State of Knowledge Report. Adaptation for Transport Resilience to Climate Change (AfTR-CC) for LICs in Africa and South Asia.' [14]

**** ADB 2011 "Guidelines for Climate Proofing Investment in the Transport Sector"** (→ 9.0.9)
The Asian Development Bank published in 2011 a step-by-step methodological approach [15] to assist road organisations to incorporate climate change adaptation measures into transport sector investment projects. The focus is on the project level, but the report provides an improved understanding of climate change impacts also for the design of infrastructure, planning and development policies, and strategies to ensure appropriate resource allocation. Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects | Asian Development Bank (adb.org)

The Framework also refers to several relevant research projects. FORESEE was an ongoing project during the development of this Framework. It is mentioned in several sections.

** **The FORESEE project** is an EU collaborative research project funded by Horizon 2020. The objective was to develop a toolkit to improve road and rail asset management schemes for authorities and infrastructure operators. One project outcome (see Sec. 2.3.4) is CEN workshop agreement 17819, "Guidelines for the assessment of resilience of transport infrastructure to potentially disruptive events."[1] (→ Sec. 9.0.10)

ISO standards related to climate change adaptation, which are referred to many places in the FW, are described in Box 2.

[1] CWA 17819 is available from CWA 018 (cencenelec.eu).

Box 2

ISO 14090 (2019) "Adaptation to Climate Change – Principles, requirements and guidelines" [16]

ISO 14090 sets principles, requirements and guidance on integration of adaptation within or across organisations, understanding impacts and uncertainties and how these can be used to inform decisions.

An assessment of impact shall include both slow onset impacts and sudden impacts due to extreme events. Impacts should be assessed comprehensively, including both direct and indirect impact, and cross-cutting issues.

The standard gives a long list of examples of consequences of weather-related threats, such as damage to assets and business disruption, loss of infrastructure, flooding, contamination, loss of business opportunities. etc. It is important to consider *influencing factors*, which may add to or reduce the impact, for example climate policies or strategies, actions taken by third parties. In addition, non-climatic factors can be important, such as land use, trade patterns, demographics and socio-economic factors.

ISO 14091 (2021) "Adaptation to climate change – Guidelines on vulnerability, impacts and risk assessment" [17]

ISO 14091 gives guidelines for assessing the risks related to the potential impacts of climate change. It describes how to understand vulnerability and how to develop and implement a sound risk assessment in the context of climate change. It can be used for assessing both present and future climate change risks. Risk assessment according to this document provides a basis for climate change adaptation planning, implementation, and monitoring and evaluation for any organisation, regardless of size, type and nature. [ISO.org]

The standard emphasises how risks related to climate change differ from other types of risk, because it is difficult or impossible to quantify probability. Therefore the need for developing other methods of assessment.

Annexes provide useful information, especially Annex E (Examples of indicators for risk and vulnerability assessments), Annex H (Assessing adaptive capacity), Annex G (Components of adaptive capacity).

European Union - Climate change adaptation taxonomy.

In 2020, the EU published Taxonomy regulations with six environmental objectives, one of them being climate adaptation. It provides a framework for understanding adaptation strategies and actions to mitigate the effects of climate change. See Box 3**.**

Box 3 : EU - Climate change adaptation taxonomy

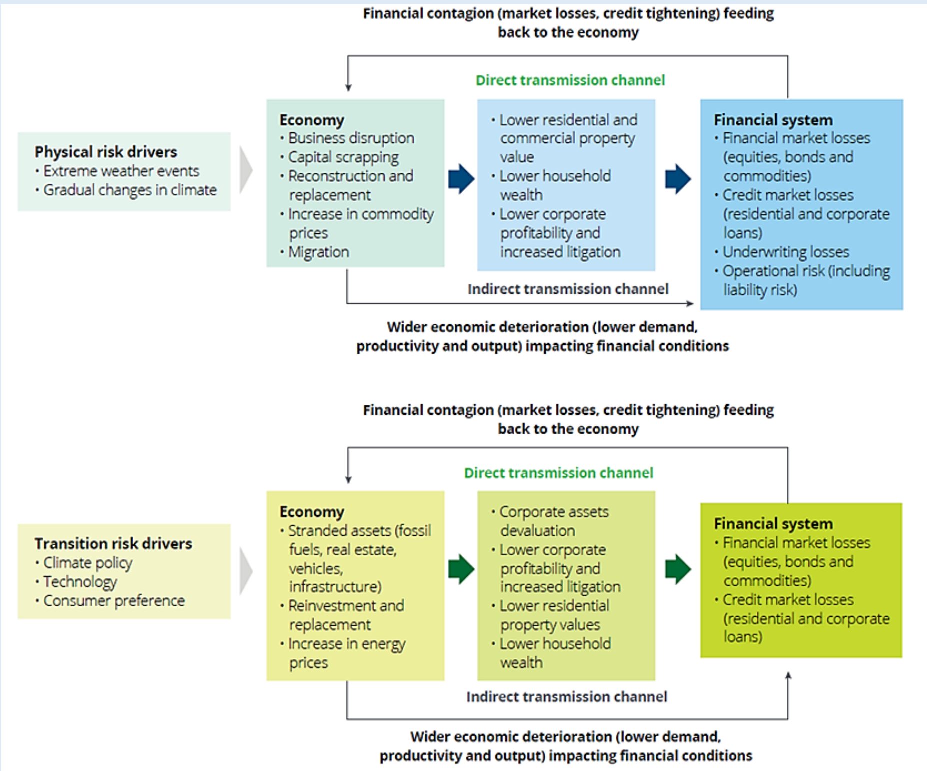
.. is a crucial tool for effective climate change adaptation planning and implementation. It provides a framework for understanding adaptation strategies and actions to mitigate the effects of climate change on two risks dimensions: Physical and Transition.

In 2020, the EU published Taxonomy regulations with six environmental objectives, with climate adaptation being one (*Regulation (EU) 2020/852 Of the European Parliament and Of The Council Of 18 June 2020).*

A 2021 EU regulation established technical screening criteria for conditions by which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation *(Regulation (EU) 2021/2139 of 4 June 2021 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council)*.

The EU also published Commission Notice on Technical guidance for climate-proofing infrastructure for 2021-2027 (2021/C 373/01). Chapter 3.3 addresses adaptation to climate change, with an overview of the climate-proofing process:

- Screening Phase: Sensitivity, Exposure, Vulnerability
- Detailed Analysis Phase: Impacts and climate risks, Likelihood, Impacts, Risks, Adaptation measures
- Climate proofing and project cycle management
- Climate proofing and environmental impact assessment



Ref: BNM's Climate Change and Principle-based Taxonomy, referenced against Network of Central Banks and Supervisors for Greening the Financial System (NGFS) publication

0.7. Using the Framework

Why use the PIARC Framework?

When facing the task of assessing adaptation to climate change of roads, it is difficult to know where to begin. There is a lot of information and documentation available, but a road organisation will need time to understand the needs, identify the resources, find the data and put forward an action plan.

This PIARC Framework has been developed to provide general guidance, and allows for application by all PIARC members countries. Whilst, it is a long document, it is expected to be easy to understand (with several practical examples) and is easily applied, where users can tailor assessments according to the specific needs of the road organisation.

Who should use the Framework?

It is intended that every road organisation can apply this Framework. It is strongly recommended to use this document, within road organisations that are advanced in the implementation of adaptation to climate change, or for organisations which are in the earlier stages of addressing these issues. The Framework will help identify climate change hazards and impacts, recognise possibilities in existing processes or systems, and analysing possible improvements in planning, design and operation of road transport infrastructure.

Even if there are not enough resources to implement the whole Framework, this document can provide valuable input to a road organisation.

How to use the Framework

Sections 1 – 4 cover the process of defining the needs, selecting the tasks, carrying out analysis and using the outcomes of each stage of the Framework.

Section 5 provides a virtual application of the Framework. Existing assessments, from the collected case studies, are compared and retrofitted to the Framework, step by step. The Working Group's intention was to illustrate the applicability of the Framework for various needs and possibilities.

Recommendations for future work are summarised in Section 6.

Section 9 and 10 provides more detailed information about case studies, or additional information. The content of these two sections is available through links in the main text of the Framework (Sections 1 – 4).

Risk and resilience

The Framework highlights the differences between risk and resilience. See Box 4 for further details.

Box 4: Risk and Resilience

For this Framework, it is worth highlighting the differences between risk and resilience. Are risk and resilience assessments different?

Risk is a factor which can be connected to possible threats and opportunities. It is closely linked to uncertainty affecting all the processes and interventions. Section 7, Glossary defines risk as the "Effect of uncertainty on objectives or system operation. Risk is often characterised by reference to the likelihood of potential events, consequences, or a combination of these and how they can affect the achievement of objectives or system operation. Risk is often expressed in terms of a combination of the consequences of an event or a change in circumstances, and the associated likelihood of occurrence."

Risk assessments are a sub-process of the resilience assessment which consists of three parts: Risk Identification; Risk Analysis; and Risk Evaluation. A risk assessment tends to focus on the direct and tangible asset and system condition and provides the identification and assessment of those related risks. Wider risk assessments can expand their scope to the indirect costs and benefits.

Risk analysis of direct impacts seeks to provide understanding of how the road users are impacted when the road is disrupted. Here the duration of repairs comes into consideration, together with redundancy, road usage, and the like. Indirect impacts can also be considered like safety and environment. Again, this can be done for different likelihoods and depending upon the methodology, can ultimately be expressed as Expected Annual Losses which also is a form of risk figure.

Resilience is a concept for which its understanding is evolving. It is being used in a particular way for this Framework. Resilience uses risk assessments, particularly risk analysis; however, it is much more focusing on minimising impacts on services provided to users and communities through the restoration of initial conditions or the adaptation to a new operating scenario. Resilience analysis seeks to gain even deeper understanding in how society is impacted when the road network is disrupted.

It is a concept which incorporates a wide potential range of indicators and considered impacts. The Glossary of this Framework defines resilience as "The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation."

A resilience assessment looks at the impacts on the services provided for users and community and interdependencies with other utilities. It considers the range of users and members of the community, and identifies and assesses the options (physical, operational, collaborations, digital, etc). It looks at the range of impacts and distribution of those impacted and resulting strategies provide recommendations of a programme of actions and interventions to address the service risks.

Resilience is expressed through different indicators (or combined metrics) that include pertaining to specific principles such as learning/transformation/adaptation, preparedness/readiness, responsiveness, recovery, performance and expectations, etc.

In summary, what differentiates risk from resilience is the expansion of the scoping (but not only) in the case of resilience to the customers and communities they are serving – accessibility service.

Stage 1

Preparation Stage

1. STAGE 1 - PREPARATION OF ADAPTATION WORK

Stage 1 is the preparation stage – where the premises for the investigation are laid out and defined, and where the adaptation project starts. The assumption is that the road organisation is about to carry out an investigation that will provide knowledge needed to enhance the resilience of the road network.

This section guides road authorities through the process of defining the starting point (the baseline) for adaptation, on identifying the aims and scope of the investigation, recognising the impacts of climate change and selecting the most relevant climatic variables. Finally, it deals with the context of the analysis to be carried out, identifying the key actors and interest groups, and defining the deliverable products. See Figure 2.

The *International Climate Change Adaptation Framework for Road Infrastructure* seeks to provide the right level of guidance for all road organisations. Identifying the baseline is the first step in the planning process.

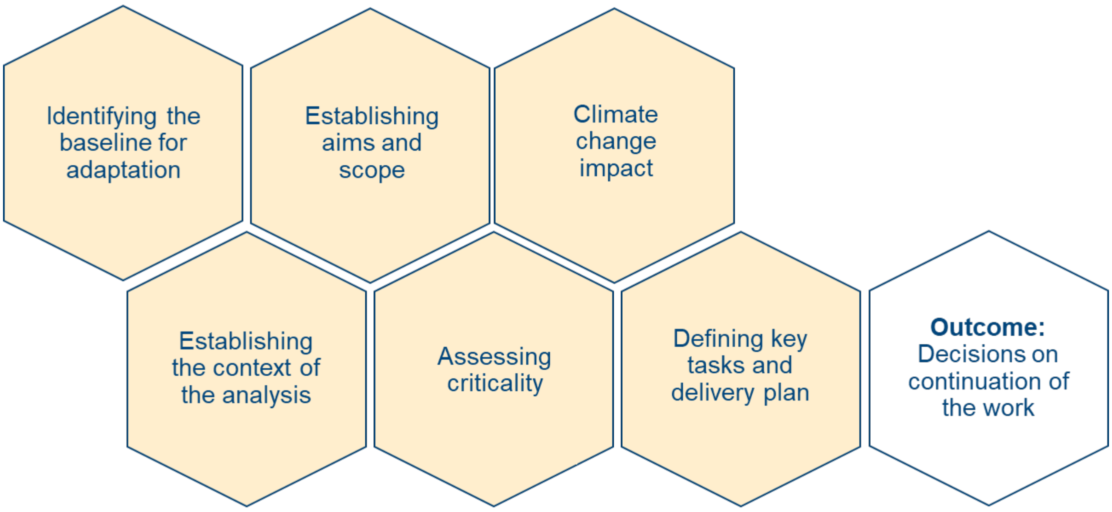


Figure 2. Structure of Stage 1 – Preparation stage

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 is your general ambition with working on climate change adaptation?
- What do you want to achieve as a result of a climate change adaptation assessment?

1.1. IDENTIFYING THE BASELINE FOR ADAPTATION TO CLIMATE CHANGE

Purpose of the work in this step Investigate the realistic options for assessing resilience - based on available data and other resources. Provide a good basis for choosing the path further.
Requirements Knowledge about possible sources of data and information, governance policies, legal obligations, internal systems.
Compatibility with other processes or systems Assessing the baseline can give input to the monitoring process (which will be established in Stage 4). Therefore, if the road organisation already has a monitoring process, it may give input to criteria for assessing the baseline for adaptation.
Outcome Decision-base regarding the aims and scope of the investigation (assessment) to be carried out.

This section explains the introductory work that needs to be done before initiating an assessment of impact, vulnerability, risk or resilience. The introductory tasks will help road organisations decide upon the most reasonable strategies and efforts towards adaptation to climate change.

The initial thinking towards an assessment needs to be dedicated to recognising the starting point for adaptation. The most important issue is seeking a balance between what is desired to achieve, and what is possible to achieve. Here are some questions to start with:

- What are the ambitions and the perceived benefits of adaptation to climate change?
- How do these ambitions suit existing knowledge, resources, established relations with knowledge providers and stakeholders, but also the mere physical state of the road network?
- Are there any special barriers for adaptation to climate change? Are there any special needs to be defined or removed? Any trade-offs to adaptation?

In simple terms, a baseline is a “snapshot” of the current state of the road system being managed. It should include information about the current condition of infrastructure assets, for example traffic conditions, maintenance works, risk prone areas, and history of interventions undertaken as a result of already experienced climate change effects. Creating a baseline is a data collection and management process. The purpose is to provide enough insight to be able to compose a feasible assessment, with achievable goals and useful scope.

Adaptation to climate change is an iterative process. Each iteration of the process will provide new and better knowledge and more complete data, which will provide a baseline for the next iteration.

By following the steps of this Framework, some important questions will require their awareness. These might not all be solved during the process, but it is useful to have them in mind. See Figure 3.

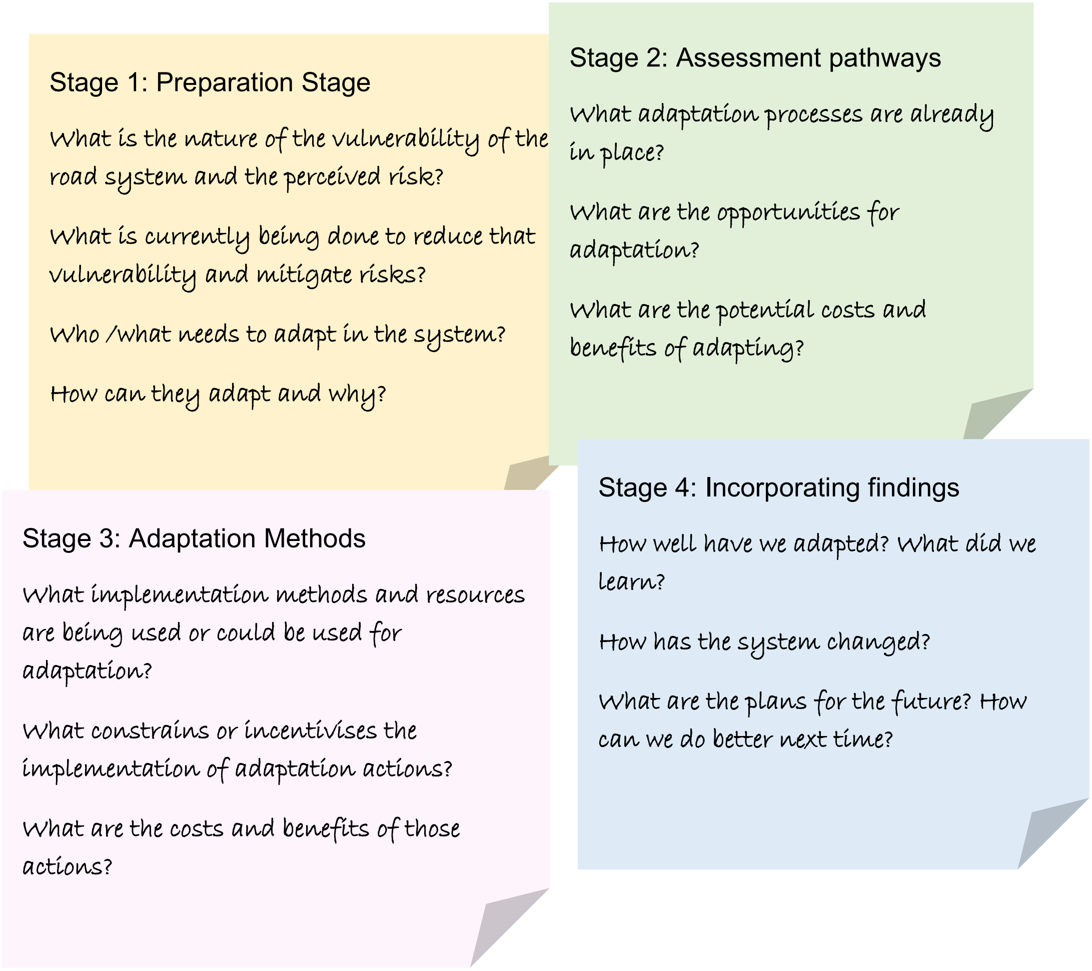


Figure 3. Important questions to keep in mind during the different stages of the adaptation process [18]

1.1.1. Identifying the drivers of adaptation to climate change

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 [FW2015]. The driver may be a concern about vulnerability, experience from historical impacts or legal obligations and political issues.
The road organisation may be motivated by:

- Legislation: for example implementing, or developing and updating national policy for climate change adaptation.
- Economic issues: the wish to protect assets, functionality or operations that are repeatedly damaged or placed out of function because of climate related events. Also, knowledge about possible economic consequences and the wish to mitigate them.
- Knowledge and capacity: to build the expertise for managing risks associated to climate change; the wish to bring climate change adaptation principles to the attention of senior managers and decision makers.

Each of these drivers for adaptation can be *development* efforts – motivated by a vision of better and sustainable transport infrastructure and services), or *reactive* efforts – responding to the need to solve and manage challenges with, for example, frequent disruptions associated with adverse weather-related events or increasing damage repair costs. Sometimes adaptation work can be motivated by a single serious adverse event.

All action for adaptation to climate change must maintain the important principles of road safety and environmental protection, including strategies for cutting greenhouse gas emissions. It also has to be in compliance with concessions, or any other relevant constraints.

In most low- and middle-income countries (LMICs), road damage backlogs from adverse climatic effects are increasing at an alarming rate, hence increasing the need for appropriate guidance to address the negative impacts. These backlogs severely impact the attainment of core values such as safety of communities and access to social services and economic nodes. With the ever-increasing frequency, intensity and longer duration of these events, road organisations are unable to keep up with the needed repairs and/or maintenance, hence there is the need for increased resilience of the priority infrastructure through effective climate adaptation strategies and actions.

In this context, maintenance budgets are often not adequate to deal effectively with climate effects. They require better return on investment and help with a Do Nothing/Minimal/Managed Retreat approaches to climate adaptation in view of the scarcity of resources. In most circumstances, anticipatory adaptations (occurring before impacts of climate change are observed) will result in lower long-term costs, and are considered to be more effective than reactive adaptations.

Recognising the need for collaboration

In this early phase, it is necessary to acknowledge that the transportation sector is not acting in an isolated manner. Section 1.4.2 will discuss contacts with stakeholders, and the importance of their involvement.

1.1.2. Values at stake

Although there are generally numerous and differing values that various societies may wish to maintain and protect, priority ones include:

- safety of communities and their livelihoods;
- structural and functional integrity of physical assets/infrastructure;
- access to goods and services including schools, health centres, economic nodes and other critical services.

The condition of the road network has an impact on all sectors of the economy. *Values* should, therefore, ideally be defined in a multidisciplinary and multisectoral manner through a Climate Change Adaptation steering committee at a national level. This has worked well in a number of countries. Inputs from other sectors will enhance the overall effectiveness (and level of acceptance) of the measures. When selecting the values to prioritise, it is important to consider a wide range of factors, such as avoided damage or avoided delays, co-benefits or implementation barriers. The potential socio-economic implications, especially impact on marginalised people, should also be considered. Based on the prioritised values, countries may wish to develop some indicators to assess the adequacy of their strategy to safeguard these values (see Section 4.6, Monitoring, reporting, review).

Furthermore, the climate risk and vulnerability assessment process must link with road asset management and the Road Asset Management System (RAMS). The RAMS should be the source of road network information that is required for the risk and vulnerability assessment process. The outputs from this process must feed back into the RAMS to be used as additional indices in conjunction with the regular indices (e.g., the Visual Condition Index) when calculations are made to prioritise roads in terms of maintenance or adaptation needs. More in Sec. 4.1.2.

The priorities of road organisations may differ depending on the climatic area, general level of services etc. They may also vary from year to year. When performing an adaptation assessment, priorities can be specifically chosen.

1.1.3. Assessing availability of data and information

An important element that will make it possible to frame the planning of the adaptation process, is the availability of information that exists in the country, the region or specific place of study. In this phase, the task is to assess data availability at a general level – what the road organisation has or can easily obtain from other institutions. See Section 4.1.2 on asset management systems and adaptation.

It is recommended to assess availability and quality of data belonging to five main categories: governance, infrastructure data, hazards, demography, and environment. It is not crucial to have all data to start doing adaptation work. It is however crucial to know what is available, to be able to compose an adequate assessment /analysis.

A. Governance data

This set of data includes information about all the legal constraints, policies, strategies, governance structures, processes, systems, technologies, capacity building processes, funding and sets of rules that govern the operations and management of the road organisation.

International, national and local policies or action plans
Actions for climate change adaptation need to be compatible with the policy framework of the country. It is important to be aware of this policy framework as it may have already established the responsibilities and roles that are needed in national or local climate adaptation efforts. Additionally, funding and capacity building sources may also be already identified in these policies. Examples: international agreements signed by the country (e.g., the Paris Agreement from 2015) and any relevant national policies, Climate Change Adaptation Plans or National Disaster Risk Management Plans.

Internal (institutional) strategies, systems, and processes
Adaptation to climate change should be an integral part of road planning, construction, operation, and management. It should, therefore, be embedded in all the relevant systems, regulations, and processes. It is necessary to:

- recognise institutional systems, processes, regulations, planned or ongoing R&D programmes that can, if adjusted to incorporate climate change, support adaptation.
- identify gaps in strategy documents, or needs for better governance rooting.

B. Infrastructure and operation data

This includes data related to the state of all infrastructure assets that a road agency manages – the collection of network data, systems or inventories that organise all the different elements or aspects of the infrastructure for the Program Management Office. This can include data from operations, performance, and maintenance.

If the road organisation has an asset management system, it is considered to be an appropriate source of information about the physical infrastructure. It may include information on design capacity, inspections or maintenance, repair or renewal etc. An asset management system would also be a natural address for the findings of the adaptation assessment.

It should be noted that quality of the infrastructure data is more important than quantity of the data. In order for the data to be useful and producing valuable results, one should have a smaller amount of accurate and precise data, rather than a big dataset of inaccurate and imprecise data.

C. Hazard data

Data on hazards includes all data that can be provided as documentation of hazards that have previously impacted the road network or transport services. Data on observed events and the history of events are needed to understand the risks faced by road infrastructure assets and their users, and also to have an idea of critical thresholds.

Hazards can be geophysical, hydrometeorological, environmental and technological. It is important to include, where available, the potential effects of climate change on the frequency and intensity of the identified hazards. Data on hazards can be collected as geographical information such as geological maps or hazard maps (e.g., flood maps, seismic hazard maps) or as statistical data such as past weather data, future weather projections, or statistics on climate and disaster-related events. Hazard maps for various return periods are of great value for the assessment. Such maps are usually available for flooding.

Sources of information can be: national or sub-national statistics departments, meteorological organisations, environmental, disaster management or planning organisations, relevant national ministries, universities or other research institutions.

Valuable information can come from insurance companies, although there can be challenges concerning data protection and privacy. Information on damage and cost of repair/recovery are valuable for knowledge about climate impact and establishing thresholds. This is interesting for infrastructure companies that are not their own insurers and for private properties in connection to the road.

D. Demographic, socio-economic data

Demographic and socioeconomic data include data regarding the communities and industries served or influenced by the road network. This includes data on traffic and use patterns of the road network, vehicle ownership, economic wellbeing of communities, population data, health data, income data, types on industries, diversity and inclusion data, etc.

Sources of information can be: national or sub-national statistics departments, social or planning organisations, relevant national ministries (e.g., Ministry of Finance, Ministry of Industry), universities or other research institutions.

E. Environment

This includes data regarding the conditions of the environment around the road network, also including potential impacts of climate change. Examples include river flows, water quality, plant and animal life along the road, and changes in temperature or rainfall due to climate change. These datasets can help in related activities such as environmental management and mitigation efforts.

Sources of information can be: national or sub-national statistics, weather, environmental, disaster management or planning organisations, relevant national ministries (e.g., Ministry of Environment), universities or other research institutions.

Assessing availability of resources

In the context of adaptation to climate change, resources are necessary for several purposes and on several levels. For a more elaborate overview of criteria and needs, see App. 10.1.1 In this phase of work, it is important to clarify resources available for the adaptation assessment that is being designed and is about to be carried out. Also, see ISO 14090: "5. Pre-planning" for a list of criteria for assessing the organisation's capability for carrying out an assessment of impact of climate (change), processing its results into decisions and actions, and following it up by monitoring. These criteria include both data and other resources.

Check lists for reviewing information requirements and data availability

To understand what information is available, the use of checklists is suggested. The checklists help to identify the information that road organisations require to be able to face threats from climate change, take actions to generate data and prepare for the adaptation process. By using the checklists, the user will also be able to identify possible gaps in information, and how they can be addressed. Finally, the checklists can help users delimit the feasible scope, establish the level of depth and detail for the coming analysis process based on available data.

An example of a non-exhaustive checklist for the different types of data mentioned highlighted in this section is illustrated in Figure 4, and provided in App. 10.1.2. The last column, "Observations", may be used to comment on the type of data (e.g., qualitative, or quantitative, GIS), quality of data, extent, if it is readily accessible etc.

GOVERNANCE – national policies and systems

No.	Description of the requirement	Yes	No	Observ.
1	National Climate Adaptation Plan			
2	National Disaster Risk Management Plan			
....	.....			

GOVERNANCE – Institutional policies and systems

1	Institutional policies on adaptation to climate change of roads, main strategic documents			
2	Specific budget for road adaptation			
....	.....			

INFRASTRUCTURE DATA – not roads only, but relevant info

	Information on the road network			
1	• Geometry data			
2	• Georeferenced road network			
....	.....			

HAZARDS DATA

1	Historical information on climate change impacts on roads (damage record)			
2	Future climate scenarios (temperature projections, precipitation, etc.)			
....	.....			

DEMOGRAPHIC AND SOCIO-ECONOMIC DATA

1	Population data (i.e., users or beneficiaries)			
2	Traffic data and usage patterns			
3	Economic statistics of influence area (income, inequality, etc.)			
....	.....			

ENVIRONMENTAL DATA

1	Environmental features close to the road network (e.g., rivers, lakes, forests, environmental protected areas, etc.)			
2	Air quality data			
....	.....			

Figure 4. Illustration of the check lists for reviewing information requirements and data availability (full list in App. 10.1.2)

1.1.4. Addressing barriers for adaptation

All processes in adaptation planning, from the creation of strategies to the implementation of adaptation actions, can be hindered by different barriers.

Barriers to adaptation are “challenges, obstacles, constraints or hurdles that impede adaptation options” [19]. Barriers can also be defined as “obstacles that can be overcome with concerted effort, creative management, change of thinking, prioritisation, and related shifts in resources, land uses, institutions, etc” [20].

It is important to identify barriers and the underlying factors that cause them, as this can help road organisations address them, manage them, and make adaptation processes more effective.

It is important to acknowledge that adaptation itself has limits and cannot prevent all losses and damages. It is not possible to adapt to all risks the road system may be facing. The limits to adaptation can be either hard or soft:

Hard limits to adaptation: Adaptive action is not feasible and risks cannot be avoided. These are likely to be the most severe risks with low probability of occurring.

Soft limits to adaptation: Technological tools (and adequate budgets) are not available currently, so immediate action cannot be taken.

Barriers to and opportunities for adaptation planning can be associated with access to quality information, availability of resources, and incentives on which decision-makers have to act [21]. See App. 10.1.3 for a more complete overview.

Box 5: Policy gaps - from the ReCAP-project [8]

Policies and plans should be adaptive and robust, and steer the incorporation of climate change into areas such as spatial planning, long-term improvement plans, facility designs, maintenance practices, operations, and emergency response plans.

Poor coordination between sectors and limited capacity for mainstreaming, and the lack of incorporation of climate adaptation in planning and budgeting, despite the widespread recognition of adaptation as an important issue among public, private and civil society actors has led to ineffective adaptation and mitigation activities.

Policy gaps that fail to adequately address climate change in the transport sector include:

- The lack of in-country collaboration between sectors when dealing with climate change science
- The challenge of working with multiple actors from different decision-making environments
- The scarcity of data when conducting analysis in resource-stricken countries
- The inconsistency between countries in the quality and quantity of available data, and
- Restrictive institutional policies (e.g., data sharing protocols) regarding ownership and custodianship of data sources.

1.1.5. Summary – Baseline for adaptation

Recommended action

- Identify the main drivers behind the work on adaptation to climate change. Is it development and/or a reactive effort? Is it a response to legislation requirements?
- Identify the values to protect or improve. This can be material assets, but also certain operations or services of the road network.
- Obtain an overview of the available types of data: maps, GIS, geological, demographic, overview of costs, overview of earlier events on the road network, …
- Assess the main policies, strategies that – if adjusted to incorporate climate change – can help to implement the outcomes of an analysis.
- Assess possible barriers for adaptation and prioritise overcoming them.

→ **Assess the findings.**
Can this help to *define the aims and scope of the investigation to be performed*?

The baseline exercise may reveal the need to implement some measures (subject of Stage 3) for improving the starting point for future adaptation work.

The baseline exercise also can give input to the monitoring process (which will be established in Stage 4). (Likewise, an organisation that has a monitoring process, may use it to define the baseline for adaptation.)

1.1.6. Case studies

** **The Road Preservation Pyramid – ReCAP project** (→ Sec. 9.1.1)

The ReCAP research project “Economic **G**rowth through **E**ffective Road Asset **M**anagement”, or “GEM”, promoted a change in the approach of rural road organisations towards the management of their road networks. Traditional approaches focus on technical aspects such as network management systems and contracting modalities for road maintenance interventions. It is anticipated that once the GEM methodology is adopted by roads organisations, the planning, prioritisation, implementation of climate adaptation interventions would be done on the basis of the precepts of the Road Preservation Pyramid to enhance resilience of road networks. The GEM project encouraged a holistic approach, where road organisations consider all six building blocks of the Road Preservation Pyramid. Particularly important of these building blocks are the external/political and the institutional building blocks. A functional Road Asset Management System is widely considered to be the first step towards effective climate change adaptation.

** **The Critical Infrastructure Development Pyramid** (→ Sec. 9.1.2)

The needs of road organisations vary largely. Although the aim may be the same – ensuring resilient infrastructure – the starting points may be so different that no single methodology would be applicable and appropriate for all cases. There seem to be different levels at which road operators are operating [22].

**** The Maturity Index – Scotland** (→ Sec 9.1.3)

Transport Scotland, the Scottish Government and partners at Adaptation Scotland and Sniffer, as well as the wider public sector organisations collaboratively created the Adaptation Capability Framework. The Framework is based on the idea that an organisation has adaptation capability that determines its ability to deliver adaptation. This new resource was developed for use in the public sector; however the methodology is also of general value for better understanding adaptation maturity level. Read more: Adaptation Scotland: The Framework

1.2. Establishing aims and scope

Purpose of the work in this step Moving from general ambitions, and using the findings from the baseline analysis, the task is to define the aims and scope of the specific assessment to be carried out.
Requirements: • Historical information about the impact of climate (change) • Road network data • Climate change scenarios • Financial resources and technical know-how • Target audience for the assessment
Compatibility with other processes or systems It is very important that the investigation is in line with all other activities requiring the same expertise, capacity, resources. Mainstreaming climate change adaptation starts with formulating aims and scope that are acceptable for the organisation as a whole.
Outcome Defined aims of the specific investigation to be carried out. A defined scope of the investigation, by establishing the scale, types of assets /values, temporal scope and an idea on main climatic impacts.

This section provides guidance on establishing the aims and scope of the assessment in the stages ahead. This implies converting the general drivers and thoughts on what the road organisation wishes to achieve into more specific aims and priorities.

Aims of the investigation

One of the first steps is establishing *what* is desired to achieve. Aims can be recognised and described through *elements comprising the expected outcome*. They must be within the realistic possibilities (according to the established baseline), and be aligned with the policies of the road organisation, but they need to be concrete and related to the assessment lying ahead.

A major initial clarification is whether the point is to identify the extent of the challenges, or if the assessment is action-focused, and the point is to implement measures, following some priority criteria.

Identifying challenges

The aim may be to gain knowledge about the overall challenges for the road network or in an area, to be able to shape a response strategy in the longer run. Investigate vulnerability for types of assets, or asset categories. Or assess vulnerability of specific assets road structures or sections to gain knowledge about the needs in a specific area or a transport corridor.

Assessing priorities of action

Challenges may already be well known and established. The task then is to gain information on the level of risk for structures /assets /stretches and set up a priority list of action. If possible, it is desirable to compare the risk to a predefined acceptable level of risk.

Recommended questions to discuss and seek agreement upon:

- Is it possible to make priorities among assets, locations, or operations that need to be protected?
- Which of the values deemed as important (1.1.2) have already been (or appear about to be) impacted by climatic effects?
- Is this a responsive adaptation intervention: after a specific climate event?
- Is this a proactive adaptation intervention: in advance of a specific climate event?
- Should this action lead to flexible solutions, which could be adjusted in the future?
- Should the action be robust in a way that it takes into consideration multiple climate hazards or events in advance?

SCOPE of the investigation

Setting the scope of the investigation means establishing *what needs to be done to* achieve the 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. Road organisations have limited resources, so the adaptation of the road infrastructure often does not cover all their road network. Therefore, the scope must establish a balance between all the aspects associated with human and financial resources that the organisation will have to specify.

It is suggested to define the scope with the help of four elements: the scale of analysis to be carried out, indication of the most relevant assets/operations to investigate, indication of main climatic phenomena, and the temporal scale of the analysis (past or future scenarios). These four elements will be discussed in 1.2.1 – 1.2.4.

In addition, it is important to think of the indicators in this preliminary stage, as they will be used to assess results. This will be explained in 1.2.5.

1.2.1. Define the scale of analysis

To identify exposed points that may be vulnerable to climate change, an established classification of scales of analysis from the RIMAROCC Report (2010) [23] can be adopted. In the following it is presented in an adjusted version, Mendoza et al (2019) [24].

Territorial scale

This type of scale of analysis studies the effect of climate or climate change on the roads in a geographically defined territory. Climate scenarios are usually related to a certain territorial scale or region. The aim will be to assess the climate related threats on the roads within a region of interest.

An example of an analysis on the territorial scale would be an analysis of coastal regions exposed to sea level rise and erosion, analyses of road networks in a region that already has a challenging regional climate (such as far north or south), or regions that are of great interest because they are highly trafficked.

Network scale

This scale of analysis seeks to identify the vulnerabilities of a road network. It can also be used as a preliminary analysis, followed by specific analyses in critical sections or critical assets.

Assessing the vulnerability of a network is a strategic approach for a road organisation. It is mainly aimed at obtaining an overview of the most vulnerable sections, assets, or operations. This can be based on the use of current climate maps and overview of earlier impact (current vulnerability) or on maps with future climate scenarios (future vulnerability). In order to assess the observed conditions and identify risk sources it is important to identify the profile of the network of interest, e.g., assess normal operating conditions in a full intact network, develop an inventory of assets, and initially identify critical locations and components.

These identified risks should be analysed at a more detailed level, to identify the level of vulnerability of the asset, and thereby define adaptation strategies.

Road section level scale

This analysis can focus on the road sections identified as vulnerable in the analysis on the network scale. It can also be carried out on road sections chosen for their commercial importance, hierarchy in the network, historical records of road closures, or simply by random selection. More disruption to society will occur if important road segments suffer a reduced functionality.

Asset scale

This scale allows analysing critical points of a road section, which could be a bridge, a tunnel, an intersection, a viaduct, etc. It may also be appropriate to investigate the vulnerability or resilience of a certain *type* of asset (bridge, culverts, etc.).

1.2.2. Selection of relevant transportation assets for the investigation

Within the chosen scale of analysis, road authorities should decide which assets and/or locations should be included in the assessment. 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). 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, in line with 1.1.3.
Road organisations can use the following criteria to identify those assets that, due to their characteristics, can be considered relevant within the entire national or state highway network, depending on the case in question, which are based on the US Federal Highway Agency Adaptation Framework [9].

- **Jurisdictional.** Road organisations may choose to limit the assessment to assets that are within their control (e.g., State-owned facilities for a State Department of Transport analysis). Though less comprehensive, a vulnerability assessment restricted to assets under the organisation's jurisdiction can more directly inform future actions by the organisation.
- **Geographic.** Specific areas may be more vulnerable to some climate variables. For instance, low-lying areas are more vulnerable to sea level rise or river overflows. An organisation might focus on these areas to limit the analysis to the assets most likely to be affected by flooding events.
- **Representative.** An organisation interested in understanding the range of climate variables that might affect its system could select a small number of assets that represent the different types of infrastructure and assets found within its transportation system.
- **Repeatedly impacted.** Assets that are subject to frequent flooding and debris problems or assets that have been repeatedly repaired or replaced due to extreme weather events, may be most vulnerable to additional stressors introduced by climate change.
- **Stage of life.** Organisations may choose to focus on assets that are scheduled for rehabilitation and/or replacement in the near future, or on infrastructure that does not meet current design standards. For assets that have a long design life, transportation organisations do not frequently have opportunities to redesign the asset, so incorporating vulnerability and resilience into the rehabilitation or replacement is especially important. In addition, it may be more feasible and less costly to incorporate adaptation strategies into an asset rehabilitation or replacement project, rather than as a standalone project.
- **Existing and planned assets.** The vulnerability assessment's objectives and audience should help determine whether it is useful for a vulnerability assessment to include planned assets, in addition to existing ones. For example, if the objective of the assessment is to consider climate change impacts in its long-range planning efforts, then it would be useful to include the future, planned assets in the list of assets to be analysed.
- **Most critical.** Organisations focus on the most critical elements of the transportation system, identified using quantitative or qualitative criteria. This method may help conserve resources by limiting the analysis while providing focus early in the study. *This Framework includes a section for the identification of critical assets. See Section 1.6 for more information on assessing criticality.*

1.2.3. Time scope

The temporal scope refers to selecting the period of analysis. It can mean determining the time span in case when historical data are used, or selecting the adequate future perspective for the road assets to be evaluated – a 30-year, 50-year, 100-year, or longer view. Differing periods are useful for different purposes. If the assessment is to be carried out for assets with a long design life, such as bridges, a longer climate development perspective should be considered. In some cases, available data will limit the time scope. For example, if flood statistics are lacking, it is not a good idea to plan a quantitative assessment and study risks hundred years ahead in time. It is important to recognise that long future projections are both liable to many underlying (socio-economic) influences creating unexpected changes and that they can be difficult for both the public and decision-makers to understand.

Road organisations must establish the time scope to identify those assets that are of interest according to their (residual) design life. The choice will also affect the response measures. The measures that are outcome of short-term studies can quickly be incorporated into road maintenance programs.

1.2.4. Key climatic variables

An important limitation of the scope of the analysis is to focus on climate effects that have already led to impacts on the transportation assets or services. This is based on experience – on information from past weather-related events in the area, failure of assets, and how different failure modes of the asset have been activated or accelerated by certain climate phenomena.

Assessing the performance of the transportation system during historical weather events can help understand the sensitivity of the transportation system to weather extremes, supporting the selection of climate variables and their thresholds, providing information that can be used to measure climate-related future impacts and review projections.

A more detailed investigation of the most important climate parameters and the effect of climate change will be the subject of the following steps.

Here are examples of criteria for the selection of climatic phenomena for adaptation [24]:

- Extreme weather conditions that have affected highway assets.
- Frequent weather events that have caused damage to roads, bridges, pavements, or other infrastructure; for example, culverts or signalisation.
- Climatic phenomena that have required high economic investments to repair infrastructure.
- Climatic phenomena that can put critical or economically valuable asset at risk.
- Climatic phenomena that exceed experiences thresholds at which the system begins to experience impacts.
- Climatic phenomena that are especially relevant due to the location of the assets.
- Weather forecasts projecting frequent traffic disruptions.
- Downscaling climate change scenarios.

1.2.5. Formulating indicators

From an operational perspective, when formulating the aims and scope of the assessment, and later the selection of adaptation measures, it is important to begin thinking of the formulation of **indicators** that can be used to assess the performance of the transport system elements under investigation and the effectiveness of our adaptation strategy. Indicators help evaluate the selected adaptation options in terms of criteria such as feasibility, benefits, costs, effectiveness, and efficiency. These indicators will become an essential part of the monitoring systems from the road organisation developing the adaptation efforts (see Section 4.6 – Monitoring, reporting, review).

Indicators should be quantitative, where possible (ISO 14090). Measurable indicators are attractive to policy- and decision-makers, as they provide quantifiable "evidence" of impacts, progress and performance. Examples of relevant indicators include:

- Number of persons/communities impacted by damaged infrastructure/lack of access;
- Losses (economic and financial) arising from the lack of functioning of the infrastructure;
- Resources spent on repairs;
- Number of reported incidents;
- Km of road affected by flooding.

Appropriate indicators need to be defined by each country as per their requirements, available resources and adaptive capacity, among other factors.

These indicators may be developed by the affected community, the road organisation or a combination of both. The challenge, process and information to determine them should not be underestimated – they are difficult to establish. They may be different for different groups (communities, professionals, elected officials, and across different locations) so how to reconcile expectations will need consideration. The potential for the thresholds to change over time, due to changing circumstances or experiences should be allowed for in evaluations and decision-making frameworks.

Box 6 : Latin-American examples

Costa Rica's National Adaptation Plan, in its Axis 4 "Adapted public services and resilient infrastructure", establishes as an indicator the "Reduction in the number of days of public service interrupted by extreme weather events" [25].

Guatemala's National Action Plan for Climate Change Adaptation and Mitigation [26] establishes in one of the plan's objectives to "Improve and build socio-vital infrastructure (basic sanitation systems) and strategic infrastructure (schools, roads, bridges, hospitals, etc.) considering climate variability, risk management and vulnerability and land use plans in the design". The goals are:

- Increase by 5 percent the strategic infrastructure, mainly the road network, which includes construction standards that consider risk factors, climate change and land use planning in the life cycle of the project (pre-investment, investment, post-investment).
- Reduce by 5 percent the road network infrastructure affected by extreme events.

1.2.6. Assessing thresholds and tolerance levels

At this stage, and potentially integrated with stakeholder input, a consideration of thresholds and tolerance levels related to the selected indicators would be valuable.

A threshold is a measure of the level of uncertainty or the level of impact at which a stakeholder may have a specific interest. Below that risk threshold, the organisation will accept the risk. Above that risk threshold, the organisation will not tolerate the risk. Or it can be defined as the condition that triggers some stakeholder action [27].

Thresholds and tolerance limits must be established by national regulations or by the road organisation. Climate reference thresholds are difficult to calculate and are often not available. The exchange of information between the various authorities and road concessions (and possibly the creation of an information platform for this purpose) can be helpful.

Some examples of where the thresholds and tolerance levels can be used:

- In the monitoring process, the threshold values will provide criteria for evaluating the adequacy of the interventions, measures or programmes. See Section 4.6.
- Thresholds can provide references as early warnings or triggers of the need to act when assessing the current (or future) resilience of the network or location.
- Thresholds in the form of desired level of resilience or acceptable level of risk are valuable criteria for assessing if the resilience of our system is within or beyond the limits that require action. See also 3.3.6.

1.2.7. Summary – Establishing aims and scope

Recommended actions

- Use the questions in 1.2 to identify how the drivers for adaptation (1.1) can be narrowed in on the particular assessment to be carried out. Formulate the aims.
- Go through the four recommended factors for defining the scope of the investigation: scale of analysis, the most relevant transportation assets or operations, the adequate time scale and the most relevant climate parameters.

Some examples of possible outcome of the selection process:

- A road organisation 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 organisation 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 focus on a particular geographic location if that area is of high importance to the economy of the country.
- The assessment may also be carried out for an investment project, with the purpose of estimating the risks associated with impact of climate change, identifying how climate change may affect the project's objectives and its benefits.

1.2.8. Case studies

** **Resilience of SANEF Road network** (→ Sec. 9.1.4)

An example of preparation for the adaptation work can be found in the resilience improvement project carried out by Cerema on the SANEF Road network. As a first step, the SANEF group (a highway concession company that finances, operates and maintains 2071km of networks) worked with Cerema to define and prioritise its resilience objectives, the physical, functional, geographical and climatic study scopes and finally, to identify the appropriate governance for carrying out the resilience study [28].

** **Action plan for coastal zones Quebec** (→ Sec. 9.1.5)

The "Action plan for infrastructure management in the context of climate change" (PAGI3C) was adopted by the Ministère des transports et de la Mobilité durable du Québec. This plan establishes the aims and scope of the adaptation work to be carried out: improve governance and management practices, develop expertise, analyse and assess risks, and implement adaptation solutions [29].

The plan focuses on addressing coastal hazards (erosion, flooding, and associated landslides). Other natural hazards will be incorporated, including fluvial erosion and fluvial flooding. It is structured around objectives that aim to: i) improve governance and management practices, ii) develop expertise and improve knowledge transfer, iii) analyse and assess risks, and iv) implement adaptation solutions to improve the resilience of the network.

1.3. CLIMATE CHANGE IMPACT

Purpose of the work in this step The focus in the step is to investigate and analyse the climate change variability and impacts in more detail, by gathering climate-related information. The key climate variables, based on experience, were the subject of 1.2.4.
Requirements: The key climate variables were identified in the scope. The chosen variables were based on the experienced and observed impacts on the road and road assets /services.
Compatibility with other processes or systems This step needs to be in line with decisions already taken by the national met-office, for example scenarios, downscaling methods. Also, hydrology data or statistics already used by the road organisation and collaborating partners and stakeholders.
Outcome Established sources of information on current and/or future climate. Selected data for the climate parameters that appear to be most relevant for the investigation to be carried out.

Records of climate variability and projections are usually developed by other organisations such as meteorological services, and good communication with these organisations or services is necessary to identify optimal adaptation responses.

These organisations can provide the following relevant information:

- records of past and present climate, including extreme weather events,
- records of past and present impact,
- projections of climate changes and expected impacts, following IPCC's scenarios.

Climate data (past and present), weather events, scenarios and projections are important considerations to determine the relevant climate variables and impacts for the specific countries and regions. There are currently a large number of climate change impacts identified (i.a. IPCC reports, Working Group 2), which may vary by region, therefore these impacts must be specified for each adaptation study. To deliver effective climate change adaptation assessments it is essential to use data from reliable and robust sources, as this data forms the basis for the risk assessments.

1.3.1. Assessing past and present climate variability and impact

The first step is to identify the climate parameters that the data should record, i.e., precipitation, temperature, wind data, etc. The climate data should be collected, systemised, and analysed. The average trends, change in variability, seasonal changes, extreme events etc. generally provide information about the climate changes experienced and the potential changes.

It is important to make a distinction between the climatic parameters and the climatic hazards. For example, landslides, floods and wildfires are considered as hazards, whereas temperature, wind data and precipitation are parameters. In general, the mean and extreme values in intensity, frequency or duration of the following parameters and hazards may be useful for a risk assessment:

- temperature: extreme hot/low temperature, heat/cold waves;
- precipitation: rain, snow, drought;
- flooding: sea level rise, fluvial and pluvial flooding;
- geohazards: landslides, rockfall, mudslides, avalanches, clay shrinking and swelling;
- wind speed and direction: extreme winds and storms, cyclones, tornados, hurricanes
- wildfires.

To assess the climate change causing impacts on roads, several case studies have identified some useful questions listed below:

- What is the current characteristic climate of the geographic region(s) where the network or the road assets are located, e.g. mean temperature, mean precipitation, wind patterns?
- Which climate hazards have already occurred in this area, and which have or have not impacted the network: flooding, landslide events, heat waves, storms?
- What type of climate related hazards usually impact the road network/asset (by deteriorating it sooner than expected, destroying it, or causing traffic failure) e.g., freeze-thaw cycle, coastal flooding? Hazards that have not occurred, yet may also be included if relevant. This can be done with the use of climate analogues, e.g., the WATCH tool (CEDR project, in progress).
- How will all these hazards evolve in the future?
- Will the road network face new hazards in the future, in a context of climate change, e.g., drought, heatwaves, fires etc.?

**** DESINVENTAR database** (→ Sec. 9.1.6)
DesInventar is a conceptual and methodological tool for the generation of National Disaster Inventories and the construction of databases of damage, losses and in general the effects of disasters. These methodologies and software have been developed by the DesInventar Project team with support from different institutions as UNDRR, UNDP, etc.

There is no exhaustive overview of climate related threats for roads and corresponding climate parameters. However, there are good examples, e.g., RIMAROCC and ROADAPT, two early projects on climate related risk management for roads.

The RIMAROCC project (Risk Management for Roads in a Changing Climate) developed a matrix that can be used to identify the main climate parameters impacting roads [30]. The parameters are weighed according to severity of impact. Other types of information is also included, such as predictions, resolution and time horizons. See App. 10.1.4.

The ROADAPT project (Roads of Today Adapted for Tomorrow), in Annex 1 of its Guidelines [31], provided a table comprising climate related threats, climate information related to the threat, vulnerability factors that affect the impact from the threat, and a description of possible impacts on roads and road transport.

This comprehensive table provides an excellent basis for a vulnerability and risk assessment, although the contents of the table are indicative only. It is available in App. 10.1.5.

In **"Climate Change Impacts and Adaptation for Transport Networks and Nodes",** a report written by the United Nations Economic Commission for Europe (ECE) [32], a group of experts analysed the impacts of climate change on main transport assets in the ECE region. They considered the main networks and nodes in the ECE region, observed climate changes, as well as future projections. The report presents the analyses of several climate variables relevant to transport networks and nodes within the ECE region and provides a summary of climate change impacts on transport infrastructure and operations.

Figure 5 shows how past climatic impacts and the road infrastructure are interrelated. By considering this relationship, the climate change impacts, the climatic hazards causing the greatest impact on the road network can be defined, e.g. which climate parameter has caused road closure, and which has caused loss of infrastructure. To identify future expected impacts, it is also useful to investigate the frequency, recent changes in events, seasonality of climate change impact on the road assets, etc.

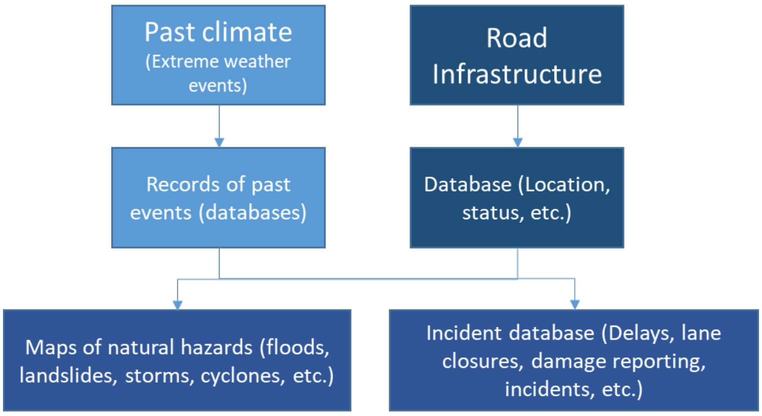


Figure 5. Scheme for determining the impacts of climate change on highway infrastructure [24].

Climate data is often available at meteorological and hydrological institutes. Additionally, some countries have climate centres, universities, research centres etc. that have climate data and records of past climate changes.

On a global level there are many sources of climate data, see examples in Box 7.

However, data availability can be a challenge some places. There are many regions around the world with little or no climatic data. Efforts must be made to gather information of historical climate variability, events and climate related impact on road assets.

Table 1. Potential impacts related to climate parameters [FW2015]. The list is not exhaustive.

Some 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
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
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
Some 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
Some 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
Some 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 sandstorms
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 build up on the road. When the first rain event occurs, this material becomes slippery and dangerous.
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.

1.3.2. Assessing climate change projections and scenarios

Climate change projections and scenarios help to understand how road infrastructure may be affected by future climate changes. Road authorities need to develop an understanding of the climate change projections relevant to their country or region. The following sections provide information about:

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

Box 7: Possible sources of information (see more information in App. 10.1.6)**:**

- The FORESEE project: “The assessment of existing climatic databases”
- The Intergovernmental Panel on Climate Change (IPCC)
- Climate Projection Database for Roads (CliPDaR)
- Interactive Atlas: Regional information
- Coordinated Regional Climate Downscaling Experiment (CORDEX)
- GFCS | Global Framework for Climate Services (wmo.int)
- Climate Change Knowledge Portal (CCKP)

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

Climate change projections provide information about expected future climate changes and their impact on the road networks. The outcome can be information about how rapidly climate changes occur, the trends over time, changes in frequency of events, intensity, etc. There are also models that project impact on road networks and assets.

Climate projections reflect the current understanding of the climate system. The projections are based on the outputs of mathematical models (general circulation models) describing interactions between the earth, the atmosphere, the ocean, etc. Climate change projections are generally better at predicting long term climate changes than extreme climate events. With regards to adaptation responses, the long climate trends should be considered when dimensioning the roads and assets. The extreme events should be considered in risk analyses. Perhaps the roads should not withstand all extreme events, but road organisations should consider if the losses caused by expected extreme events are at an acceptable level.

The time resolution of the projections is of relevance when planning, designing, constructing, managing and maintaining the road network and related services. It has to be taken into account that the various assets in a road network are designed for different lifespans, e.g. a road surface versus a bridge foundation.

Climate projections are dependent on the chosen scenarios, normally there are climatic and non-climatic scenarios that provide various views of future conditions. The climate scenarios represent different greenhouse gas emissions pathways or scenarios that represent the forcing factors of climate change, whilst the non-climatic scenarios represent alternative socio-economic conditions which provide the context in which the climate forcing operates. There are generally available case studies that have compared different scenarios. The choice of the model influences the selection of the climate scenario, as the type of scenario may vary between the models. The road organisations define the scope or purpose of the projections, whilst the climate experts should support and advice on which model(s) and scenario(s) that best fit the purpose. There should also be some guidance on how to interpret the results.

Using geographical location to determine key climate change types

One of the most important steps to find good adaptation measures is to determine key climate change types relevant for the region of interest. The IPCC models are global, but there are also regional models that improve the spatial resolution and consider landscape shapes such as mountains and coastlines. The site-specific conditions in an area or regions plays a pivotal role in determining which climate variables should be considered as risks.

Below is a list of some geographical factors that may help to determine which climate change type to consider (the list is incomplete):

- The presence of water bodies: coastal vs. continental climate variability, coastal areas are prone to sea-level rise, areas near rivers may consider increased erosion and flooding
- Jet winds (shift in precipitation patterns)
- Altitude: High-altitude areas may experience more extreme weather events, changes in precipitation patterns and snow conditions, more wind etc.
- Topography: Excess surface water runoff
- Soil and geology: slope stability and landslides (also in relation to topography)
- Regional considerations also include type of land-use, e.g. urbanised areas may consider pavement and drainage issues whilst rural areas may consider connectivity and over-reliance of certain connecting routes

It is noted that many of these factors can be mapped using existing GIS data sets. For example, CEDR identifies a method for data collection in their ROADAPT Guidelines – Part C: 'GIS-aided vulnerability assessment for roads – Existing methods and new suggestions' [33]. This method uses GIS data sets created from local knowledge, field inventories and map studies.

1.3.3. Developing climate change scenarios and projections

In many developing countries, detailed climate observations and downscaled climate change projections may not be 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.

Where funds are available and climate change projections and data have not already been developed, it is recommended to engage with research establishments and academia to undertake climate science and climate projections studies. Climate change adaptation assessments that are based on sound and verified climate projections allow for confidence in the findings and for optimised recommendations. 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.

1.3.4. Summary – Climate change impact

Recommended action

Climate change and climate change impact vary between regions. At this stage, the main climate change parameters and impact for the region of interest should be identified and the collection of related data should be systemised.

- Current climate: check your available sources of meteorological information, ally with relevant organisations. Identify weather forecasts for roads.
- Climate projections: Check your available sources of climate projections – regional, national or global.
- Select the period for which the climate data will be extracted from the models – short-term or long-term.
- Apply existing projections, data and evidence to determine future conditions in the most relevant way for your assessment.

1.3.5. Examples

** **Towards a more resilient Spanish road network** (→ Sec. 9.1.7)

This is an example of identifying main data sources to assess impacts. Preliminary studies performed within the Spanish methodology for climate change risk assessment [34] propose the use of national climate data sources in order to obtain climate variables as a basis to perform climate change impact assessments. The main data sources relate to: the Spanish Meteorological Agency's web portal for obtaining climate projections, and the National Flood Zone Mapping System (SNCZI).

** **Bruce Highway Link Flood Study** (→ Sec. 9.1.8)

The Bruce Highway Link Flood Study[2] is a project initiated and managed by the Department of Transport and Main Roads (TMR), Queensland. It utilises a hydrologic technique known as continuous simulation to analyse the frequency and duration of multiple, simultaneous road closures along the entire length of the Bruce Highway link from Brisbane to Cairns.

** **The Portuguese Climate Portal** (→ Sec. 9.1.9)

The Climate Portal in Portugal is a collaboration of state organisations disseminates a wide range of climate data in an easily accessible platform, freely available for the general public, namely: historical series, climate change scenarios at regional level and climate indicators for specific sectors in Portugal. (Source: IMT Portugal, 2023)

[2] Bruce Highway Link Flood Study (aecom.com)

1.4. Establish the context of the analysis

Purpose of the work in this step Ensuring that the planned work is compatible with the organisation it is serving, regarding personnel, resources, organisational structure.
Requirements: Organisational structure of the road organisation. Mechanisms of communication of the road authorities.
Compatibility with other processes or systems The work guided by the framework should seek to be compatible and integrate with existing organisational processes and systems.
Outcome An understanding and summary of the context and key factors in which the development of the analysis and outputs of applying the Framework will occur.

The analysis is dependent on allocation of resources, human and financial, and it must be compatible with other relevant plans and systems in the road administration. The following factors are suggested for describing the setting for the analysis: internal context (the organisation, responsibilities, technical capacities and resources, effective communication), and external context, such as stakeholders, target population and communication.

1.4.1. Internal context

The road organisation must establish its internal context for the analysis to be performed. This section deals with internal policies and other documents, and with the composition of the expert team.

Summary of internal "references"

An identification of relevant systems, regulations and processes was already done in the process of determining the baseline for adaptation (Sec 1.1). Based on the results of the baseline, it is necessary to summarise the internal documents that are relevant for the specific assessment at hand. The summary should include references to the following:

- Policies, goals, and objectives on adaptation to climate change and risk management to face natural hazards and extreme events.
- The internal structure (specific areas for adaptation to climate change).
- The processes that will make it possible to implement adaptation and its follow-up.
- Available personnel and degree of training (roles and responsibilities within the organisational structure).
- Ability to deal with emergencies and restore service.
- Levels of risk acceptance in the sector (e.g. risk management, insurance, reconstruction funds).
- Manuals, standards, or technical specifications that include variables associated with climate change.
- Resources available for adaptation to climate change.

See App. 10.1.7 for suggestions of internal documents or systems where the impact of climate change should be included.

Composing an expert team

Assessing risk is multi-disciplinary work. Combining expertise is a good way to ensure that all aspects of risk are addressed, including complicated combinations of risks and inter-dependencies. The team should seek agreement regarding the most critical climate hazards, the most important values to protect, level of analyses and other elements of the analysis.

In Section 1.1.3, an overview of the data and information requirements for analysing resilience has been given. The team performing the analysis should be equipped with the knowledge needed to obtain and use this data.

The expert team should ideally cover the following fields of expertise (2019 report):

- planning and design of road (structures)
- water management (flood, run-off, drainage)
- natural hazards: flood and landslide hazards, experts able to provide and process geological and geotechnical information
- climate specialists, or experts able to provide information on past weather events and the expected climate change, or people able to understand and climate information
- those who have good knowledge about the;
    - geographical area and network of study, past climate hazards, relevant local issues including issues relevant for communities (even if they are not directly related to the network)
    - where relevant: bridge, tunnel or installation specialists.
- people in charge of operation, maintenance, development and technical strengthening of the network of study, who are able to provide information either on the assets, on the functionalities of the networks (e.g. traffic), or on economic and financial issues
- traffic safety
- experience from emergency planning and measures
- traffic management
- other specialists, involved in the development of the needs and the objectives of the risk assessment, e.g. specialists in economics, energy, communication networks, land and urban planning, geology, hydrology etc, as identified for the inter-American Development Bank (IDB) [35]. Maintaining the cross-sectoral picture is essential for adaptation.

The expert team should also aim to develop a competency framework for the organisation. The expert team should establish and agree through stakeholder engagement what are the minimum competencies required by all staff (expert and non-expert) regarding climate change adaptation and resilience, so these topics can be effectively embedded in the business-as-usual activities of the organisation. This also involves determining training schemes for all staff, similar to health and safety training.

1.4.2. External context

Stakeholder engagement

The transportation sector cannot act in an isolated manner. In considering land use and wider infrastructure planning, for example, the transport (and transport infrastructure) sector may closely collaborate and coordinate actions with the agricultural, environmental or the energy sector, among others. These interdependencies need to be recognised because they may significantly affect the work that is planned. Different sectors can be partners in the delivery of various adaptation measures as well as being beneficiaries thereof.

Stakeholder engagement can strengthen the development of the aims, 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. Therefore, their early engagement can be a vital component in the achievement of the assessment goals.

Key objective of stakeholder involvement at this stage is to set policy, objectives, strategy and scope at network level; facilitate knowledge and data sharing at national level (minimise duplication in a resource-scarce environment).

ISO 14090 (in 5. Pre-planning) states that "consultation with interested parties can also facilitate knowledge sharing about climate change adaptation as well as participation in the climate change adaptation process." The interested parties for a road organisation adapting to climate change can be: other units within the road organisation, technical institutions, customers /road users, regulatory authorities or local, regional or national governmental organisations, local communities, etc.

<u>Who are the stakeholders?</u>

Adaptation projects are cross-sectorial, cross-disciplinary projects. Stakeholders are all parties involved in and/or impacted by any stage of the development of the adaptation project, from initiation, planning, execution, and evaluation. Stakeholders include:

- National and Local Government: Policy makers, implementers, and other government sectors impacted by or influencing the project. Stakeholders include but are not limited to: Roads and Transport Authority, Land-use and Urban Planning Authority, Climate Change and Environment Authority, Electricity and Water Authority – Utilities.
- Private Sector: As a public sector partner to bridge the infrastructure funding gap. Projects' executors and potential investors. Stakeholders include, but are not limited to: Roads' contractors, consultants, service providers, material suppliers, and manufacturers.
- Academia: Scientific support, research, and innovation scaling up. Stakeholders include but are not limited to: Climate change adaptation studies, data generation, and analysis.
- Local Communities: Road users and local communities impacted by the project. Providing local knowledge and observed vulnerabilities.
- Finance Sector: Green funding and investment.

Stakeholders' participation

Adaptation projects are complex projects due to climate change's temporal, spatial, and magnitude uncertain characteristics. Therefore, all stakeholders' collective participation would drive effective projects by assessing how different climate risks could produce variable vulnerabilities and how other political, economic, and social externalities would worsen these impacts.

The early participation of all stakeholders from the planning stage of the adaptation project is crucial to avoid unsatisfactory climate action progress and future maladaptation. Stakeholders' participation builds ownership and ensures knowledge co-production, considering that each party's knowledge is partial, and each piece of knowledge is needed to inform the adaptation project development.

How to engage them

Participation can be done in various forms, ensuring that all stakeholders are part of each development stage. The following are to be considered:

- Adequate planning of the participation sessions and building the right team from all relevant stakeholders.
- Assessing the potential challenges that can impact the participation sessions and developing a mitigation plan.
- Awareness sessions on climate change topics and its risks to be delivered prior to the commencement of the participation sessions to ensure all stakeholders possess a good level of knowledge on climate change and adaptation.
- Developing an action plan with a clear scope of work, roles, and responsibilities for each stakeholder.

Expected outcomes

- Improving the communication channels between the different stakeholders and providing more relevant solutions, with the possibility of using the output of one stakeholder as input for the other.
- Preparing all the stakeholders to be active parties in the process. Empowering them by building their capacity would support the successful future implementation of the produced adaptation policies and projects.
- The multi-sectorial and cross-disciplinary participation would mitigate the loss of funds and time due to maladaptation.
- Bridging the knowledge gap between the policymakers, academic sector, private sector, and local community as the end-users.

Stakeholder communication and involvement should occur from the outset. It should be ongoing throughout the assessment process and be facilitated through collaborative work sessions and workshops. These knowledge-sharing sessions should be held throughout to enable and support both cross-disciplinary and inter-departmental coordination and collaboration among the public sector, private sector, and local stakeholders to assess impacts, vulnerabilities, and adaptation options.

Figure 6 shows the result of the analysis carried out by the Inter-American Development Bank [35], on the identification and interactions between stakeholders in the adaptation process.

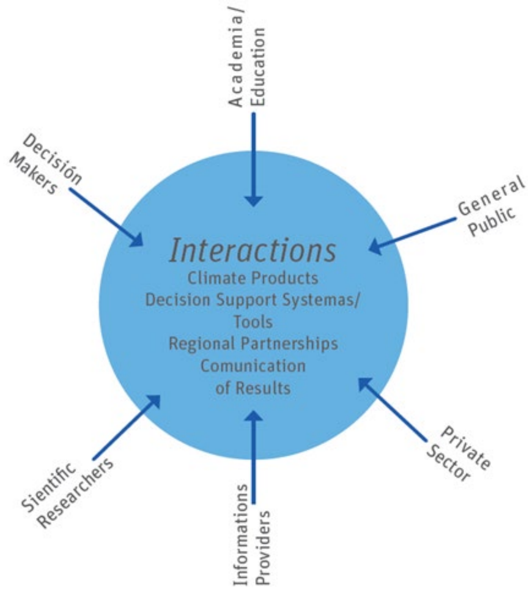


Figure 6. Role of Interactions as a facilitator of communications across actors in the climate dialog and linking scientific research to societal applications. Source: IDB, 2014 [35]

The Federal Highway Agency (FHWA, 2018) suggests a possible list of key actors that can participate in a climate change assessment, see App. 10.1.8.

It is also important to select the *level of participation* of stakeholders in the process. In the case of road users and local communities**,** the IAP2's Spectrum of Public Participation[3] can help to define their role in this public participation process. If the purpose is increasing the impact on the decision one can move from only informing to consulting, involving, collaborating and empowering.

Target population

The needs and expectations of the population in the area of impact of the project can influence the objective and scope of adaptation to climate change. Social acceptance of adaptation measures can ensure the success of the entire process. The target population can be considered those that will be impacted or benefited from the implementation of adaptation actions, such as the population and users of the network, these may vary depending on the type of road, whether it is local, regional or national. The Asian Development Bank [15] suggests carrying out consultations with the target population, through which useful information can be obtained for the process of identification, selection and evaluation of adaptation responses.

[3] Available from: https://iap2.org.au/wp-content/uploads/2020/01/2018_IAP2_Spectrum.pdf

Effective communication with stakeholders and target audience

Effective and active communication and engagement with stakeholders throughout the development and implementation of climate change adaptation activities is essential to their success. 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.

Engaging with and involving the target audience ultimately increases understanding, 'buy-in' and the level of support given to adaptation actions and strategies, which will be better in line with community values and perspectives. It can also facilitate and support cross-disciplinary collaboration.

Sufficient time and resource are needed to be provided for engagement otherwise there grows a risk of lack of buy-in and support for the adaptation plan outputs along with a risk of reduced or missed insights and inputs to its development.

During its development, the nature of the communication and engagement will vary by group, but they all have key and unique inputs to make at each stage. 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.

A Communication Plan can be useful for structuring and planning communication activities, and identifying effective methods for stakeholder communication. A Communication Plan will also facilitate the effective delivery of the findings of the assessment and the selected climate change adaptation measures (Stage 4).

"Communication" can include targeted campaigns, meetings and workshops, websites. Local knowledge will ensure that climate risks are correctly identified and help build consensus among stakeholders.

**** Climate Change Adaptation Communications Plan Guidance**
FW2015 includes an annex with an example of a communication plan. The main points are presented in App. 10.1.9.

**** Climate Change Communication Guide (California Dept. of Transportation)** (→ 9.1.10)

A 2020 pilot study from California had the primary objective to evaluate the District-level vulnerabilities of the State highway system to climate change and develop a tool that Caltrans and other transportation organisations can use to communicate these climate risks. The « Communication Guide » presents strategies for communicating with internal staff and external partner organisations as well as with the broader public on the topic of climate change to educate, inform, and strengthen collaboration.

1.4.3. Summary – Establishing the context

Recommended action

The success of climate change adaptation is very much dependent of internal resources in the organisation and also in the external context.

It is therefore recommended to:

- identify the resources available for adaptation to climate change and how they link to policies and objectives of the organisation
- establish an expert team
- identify relevant stakeholders and set up a plan of communication.

1.5. ASSESSING CRITICALITY

Purpose of the work in this step
The criticality assessment is a vital step in the identification of risk as it provides the starting point. In many circumstances, it is difficult and costly to conduct a thorough risk assessment for all assets, locations and people. The criticality assessment allows the analysis to focus on those assets that are of most importance to the organisation, community or individual and hence prioritise potential climate adaptation measures. The choice of assets to be assessed will be guided to a large extent by the context developed for the risk management activity. It is important to keep clear where in the whole risk /resilience assessment criticality will be included, to avoid duplication.
Requirements
Criticality is a relative characteristic. The road organisation has to select the variables and the criteria for criticality. Generally, three types of data or information will be useful (provided in this section): ○ for physical criticality: road data (geometry, surface, structure, assets, etc) and topography ○ for functional criticality: function of the road, type of services, etc. ○ for social criticality: information on special vulnerabilities of communities relying on the road.
Compatibility with other processes or systems
It is best to align with existing criteria for criticality or classification of roads by criticality, if the road organisation has them.
Outcome
Overview/score of criticality of the studied road assets, operations or services, with the aim of: - narrowing the scope of the investigation (if criticality was among the criteria for the scope, Sec. 1.2), - being used in calculation of risk score in various ways.

PIARC FW2015 does not distinguish between road sections/structures that are crucial for the transport services in a community or region, and roads that are not. In many adaptation frameworks, such issues are covered by the term “criticality”. Others call it “importance” or “relevance” of the road, or “road value”. “Critical assets” in a road network are those that are especially significant for the economic and social well-being of the public services provided by the road, and that therefore require priority attention [36]. See App. 10.1.10 for alternative definitions.

1.5.1. Criteria defining a critical asset and obtaining data

Criticality is a relative characteristic. Even within a road organisation, there may be large regional differences in what is considered important and in which way.

This section of the Framework will propose some general criteria for defining critical assets, operations or services. However, the classification and criteria should be adjusted in each road organisation. The road organisation needs to select the variables that make an asset more relevant or important within the road network, that is, a critical asset.

The road organisation can also choose to *weight* the criteria in different ways. Stakeholder participation is very important both for identifying the necessary criteria and for establishing the weights to be assigned to each criterion. The variables and the criteria for that can be qualitative or quantitative, depending on the aim of the classification and the availability of information.

Criticality assessments generally requires information related to the characteristics of the road asset, data from the road operation, and services.

The criteria to identify and prioritise critical assets, asset categories, operations or services can be based on their physical, functional and social attributes [37].

- **Physical criticality**

Physical criticality is associated with the economic consequences of loss or damage to the road infrastructure and their elements.

The criteria for evaluating physical criticality should allow evaluating the physical magnitude of the road and its elements, without incurring in detailed estimates of the costs that its replacement or repair represents.

Criteria may include: length of the road section or road project; number of lanes; type of surface (pavement road or gravel road - asphalt or concrete); topography; % bridges in the road; % tunnels in the road; numbers of culverts per km; etc.

The data for physical criticality is usually sourced from road databases, asset management systems, etc.

- **Functional criticality**

Functional criticality is associated with the operational consequences that loss or damage to the road infrastructure would represent, and that affect the function of the road with impacts on mobility, accessibility, connectivity and logistics mainly.

The criteria for evaluating functional criticality should be those that affect the operation of the road section, and that according to the magnitude of the project could represent a certain level of impacts.

Criteria may include: road classification; annual average daily traffic (AADT); % heavy vehicles; alternative routes (redundancy); gives access to supply centres, public services, health care centres and hospitals; connect with a local road, collector road, federal highway or with a transport corridor, transport hubs, airports, ports, urban centres (includes periphery), farm roads (agricultural products), recreational and cultural centres, educational centres (schools), food distribution centres (supply centres); etc. Examples and suggestions for assessing functional criticality are provided in Section 1.5.3, see Table 2.

For assessing the functional criticality, one needs to identify the functionalities of the network. A possibility is to recognise and distinguish between essential transport functions, service or accessibility functions and regular travel functions [38]. See App. 10.1.11.

- **Social criticality**

Social criticality is related to social characteristics in the area of influence, and how their capacities can be affected by the failure of the services that a road provides.

Criteria may include: insulation degree (distance to road); marginalisation index (income, education, household); municipalities located in highly marginalised regions; indigenous communities), etc.

In some countries, some of the transport infrastructures that under current legislation are, a priori, considered critical, such as, for instance, under EU legislation:

- 'critical infrastructure' means an asset, a facility, equipment, a network or a system, or a part of an asset, a facility, equipment, a network or a system, which is necessary for the provision of an essential service;
- 'essential service' means a service which is crucial for the maintenance of vital societal functions, economic activities, public health and safety, or the environment;

1.5.2. How to perform a criticality assessment?

There is limited consensus concerning the method/process of calculating the degree/level of criticality. Criticality assessments require a methodology that is adequate to the chosen concept of criticality for the road organisation.

Traditional criticality assessments include the follow steps:

- Select the criteria that can help to perform a criticality assessment
- Define the boundaries and values for each criterion
- Determine the weight for each criterion to establish hierarchy in the process
- Ensure that the information sources to evaluate each criterion are accessible and available
- Develop a "worksheet" tool, with the criteria and their attributes, the boundaries, and assign the weights and schedule the calculations

** **Indicator based criticality analysis – BASt** (→ Sec 9.1.11)

To assess the significance of road sections of the German trunk road network, an indicator-based criticality analysis approach was developed, which includes four steps:

1. Selection of criticality indicators
2. Classification of criticality indicators to indicator groups
3. Weighting of indicator groups
4. Calculation of the overall criticality and cartographic visualisation

The four indicator groups include: traffic indicators (e.g. annual average daily traffic for workdays), economic indicators (e.g. annual average daily heavy traffic for workdays), spatial planning-related indicators (e.g. links between metropolitan regions) and geographical indicators (e.g. topological aspects).

1.5.3. Choice of assessment methodologies for criticality with examples

The choice of methodology is dependent on may factors, for example the purpose of the criticality assessment (the final use of the results), the extent of the study area /network, and data availability.

Table 2 presents some criteria and choice of methodologies most suitable for functional criticality:

- Type of function to be considered (essential transport functions, service or accessibility functions and regular travel functions)
- Extent of the network and/or the territory in the area of study
- Data availability at this scale.

Cerema (2015) [38], including risk assessment methodology, provides guidance on how to choose the most suitable method for criticality assessment, depending on the type of function considered. The functions and type of methodologies are described in Table 2 and the methods are illustrated in examples **1**, **2** and **3** below the table.

Table 2. Assessment methodologies for criticality

	Functionality to be assessed		
	Essential transport function	Service or accessibility function	Regular travel function
Main performance criteria	Supply chain, Economy and growth	Connectivity	Quality of service, capacity, costs
Type of methodology to use	- Assessment of inaccessibility based on indicators of connectivity to economy hubs - Identification of the networks that must be protected	- Assessment of inaccessibility based on indicators of connectivity - Identification of the networks that must be protected	- Assessment of performance losses by a multi-criteria method - Assessment of performance losses with a traffic model
Case study examples	**Example 1**	**Example 2**	**Example 3**

Source: Adapted from [5]

***1* Establishment of criteria that allow determining the criticality of public investment projects for network infrastructure in Mexico** (→ Sec 9.1.12)

An example of criteria to determine the criticality of public investment projects, under a hierarchical structure with three strategic criteria called: Physical, Functional and Social Criticality, and several sub-criteria. Criticality thresholds are used to classify projects according to their degree/level of criticality. If a project exceeds the threshold, it is clear that it requires greater attention.

***2* A methodology to identify the networks that must be protected: RESAU²** (→Sec 9.1.13)

RESAU² (Résilience des Acteurs de l'Urgence et Réseaux)[4] is an approach to identify the networks that must be kept open for rescue services, providing access to inhabitants to essential services such as hospital or supply centres, etc. Three steps: identifying the critical centres, identifying the corresponding networks, identifying measures for maintaining operation.

***3* Assessing regular travel criticality: an example of multi-criteria methodology** (→ 9.1.14)

An example of a criticality assessment focusing on the performance of the network for regular travels of persons and goods. It is based on a multi-criteria method. The network is divided into road sections, and for each section, indicators of criticality are assessed: the traffic, its structure, the alternative roads and their capacity to absorb the rerouted traffic if the studied section was removed from the network.

Box 8: Waka Kotahi NZ Transport Agency commissioned a study "Review of methods to determine criticality of roading networks" (2016) with a goal to better understand areas of high criticality to assist with prioritisation of risk reduction efforts (including investment in improving network resilience) and improved response and recovery planning. It was based on a desktop review of methods to assess the criticality of road networks from around the world.

It found that critical assets can be defined as those that are especially significant to societal wellbeing and that they therefore merit priority attention by utilities in emergency response and recovery. They are also defined as those which have a high consequence of failure. For example, a transport route may be critical because it carries high volumes of traffic, or if it is the only access route to a hospital.

As a result of the literature review and analysis undertaken, a criticality framework was proposed which incorporates three elements:

1. The base road classification.
2. Adjustment factors related to access to lifeline utilities or a lifeline evacuation route.
3. Adjustment factors related to access to essential community services.

Source: Waka Kotahi, New Zealand, 2023

**** Criticality including the aspect of vulnerability** (→ Sec 9.1.15)

There are many examples of different uses of the term "criticality". One of them is the three-step framework, developed by Resallience in France, to identify critical road segments that need to be prioritised for climate-resilience investments. The three steps are: assessing vulnerability, assessing road criticality + assessing territorial criticality. This '*composite criticality*' includes 'vulnerability', implying that assets can be considered 'critical' also because they are vulnerable.

[4] RESEAU Resilience (cerema.fr)

See also the example of SERON project in Box 9.

Box 9: The SERON project, EU[5]

The project has the following approach for assessing the criticality (network importance):

Step 1: Road corridor selection and identification of potentially critical infrastructure objects

The aim of Step 1 is to identify the potentially critical infrastructure objects and rank them according to their degree of criticality.

The road operators or owners select a road corridor they want to investigate. This could be any road corridor for which they are responsible, e.g. a TEN-T corridor which has a vital function in the overall road network of a country or within the EU.

Following this step, the relevant technical data of the infrastructure objects along the selected corridor and the traffic data of the corridor have to be collected. This includes general technical data of bridges and tunnels such as the length, type of construction or material used. The road network data used is Average Daily Traffic (ADT) and Heavy Goods Vehicle (HGV) percentage. All infrastructure objects on the selected road corridor are investigated according to their potential criticality.

Step 2: Calculation of network importance

In Step 2, the objects selected in Step 1 are ranked according to their network importance. For this step, detailed road network data is required, and a specific traffic and transport model should be applied.

The network importance is defined as the benefit which arises from the prevented non-availability of a certain infrastructure objects. The network importance of a road infrastructure object is not only reflected by the consequences of its non-availability for road transport, but by any kind of socio-economic effects. Therefore, the developed assessment procedure takes into account that road users, traffic flow, the infrastructure object itself as well as the surrounding regional economy may also be affected by the non-availability of infrastructure objects. Resulting consequences are quantified, monetised and summed up to a final importance value. This importance value describes the benefit resulting from the prevented non-availability.

Source: http://www.seron-project.eu/

[5] Security of Road Transport Networks | SERON | Project | Fact sheet | FP7 | CORDIS | European Commission (europa.eu)

1.5.4. Summary - Criticality

Recommended action

Assess criticality following the most relevant principle. Use the suggested criteria to identify which assets, operations or services are critical to the road organisation.

How can this information be used?

Road organisations to carry out some type of assessment (vulnerability assessment, risk assessment, or resilience assessment) may need to identify which assets are the most relevant or critical in their network. Since criticality was not included in the FW2015, some options for its inclusion are described in the following.

- Criticality can be one of the initial criteria for defining the scope of the risk or vulnerability assessment. One of the tasks in this step will be evaluate critical assets of great value for the transport, with the aim of prioritising, or limiting the scope of the assessment, at the very start. This is e.g. the case in FHWA framework [9].
- 'Criticality' can be assessed and scored as an element of its own, in a risk analysis and when calculating the total risk. This way of treating criticality is suitable in cases when one wishes to compare the risk scores on several road stretches within a road network. The score of total risk, defined in the FW2015 as "severity" or "consequences", would in that case get 'criticality' as an additional element.
- Criticality can be combined with other criteria into more complex parameters of the risk assessment methodology. Some frameworks /methodologies add the notion of criticality to the criteria for judging the sensitivity of a road section, or the severity of an event. Some examples are including a "Review of methods to determine criticality of roading networks" (NZTA, 2016) [39], Bles et al (2019) [40] and Bles (2021) [41].

1.6. Defining key tasks and delivery plan

Purpose of the work in this step Define the investigation lying ahead with all the elements of an executive project or task: detailed plans, responsibilities, deliveries, time plans etc.
Requirements: Identify existing programmes (e.g. maintenance programme) Map human and financial resources.
Compatibility with other processes or systems The work guided by the Framework should seek to align and integrate with other organisational delivery plans, similar investment programmes and systems where possible, if the road organisation has them.
Outcome: At the finalisation of this step of work, the road organisation will have a plan for all activities and tasks necessary for it to achieve the objective of the evaluation and obtain the product(s) derived from the climate change assessment for road adaptation to increase resilience in road networks.

By developing and defining tasks and a plan for the delivery of an assessment, the road organisation provides further details on the assessment to be carried out. The aims and scope and the context of the investigation have been defined (1.2 and 1.4), but now the tasks comprising the investigation should be described. As noted in 1.2, a major initial clarification is whether the aim is to identify the extent of the challenges, or if the assessment is action focused.

ISO 14090 (6.2.1 General) suggests it is valuable to first perform an impact assessment based upon historical climate trends, variability and events that have already been experienced. The focus can thereafter be on understanding the implications of future climate change trends and climate events over the full lifespan of a decision.

Deciding on the specific task to carry out is dependent on both needs and possibilities. One decisive factor can be the data quality and availability. Figure 7 is a schematic presentation of the possible ranges of data quality and implications on the choice of the type of assessment to be carried out. Some potential tasks are included in the figure.

Delivery plan

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). The outputs can be multiple products, which must be aligned with the objectives of the adaptation work. It is important to be clear about the intended user group of each of the final products.

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 (Sec. 1.4) 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 [FW2015].

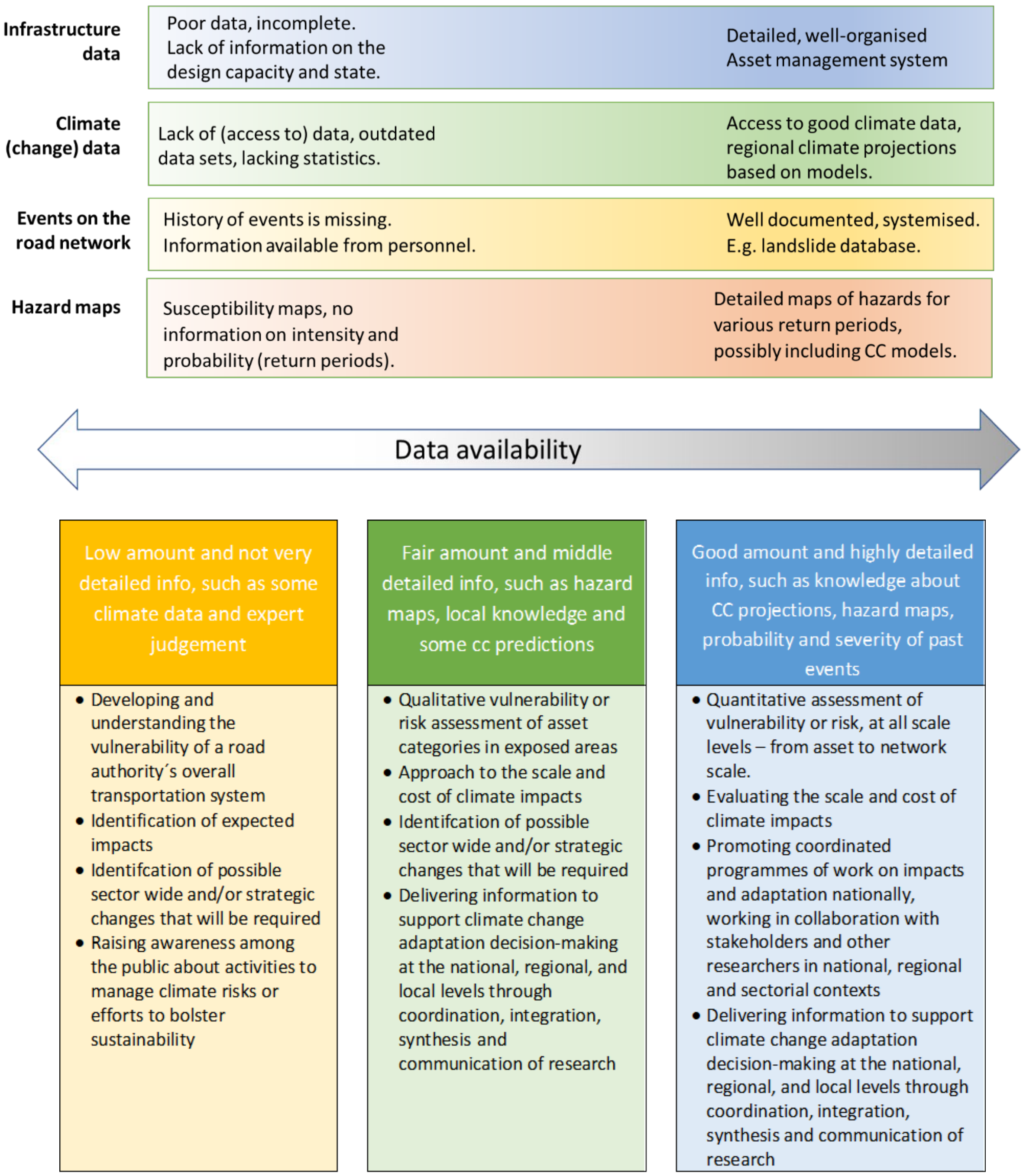


Figure 7. Schematic illustration of data quality range and what it means for the choice of the type of assessment

1.7. Outcome of Stage 1 – Continuation of the work

In Stage 1, the realistic possibilities for assessing impact of climate (change) on roads have been recognised and the goals for the work defined. Stakeholders are identified and information on climate change scenarios collected. In addition, some preliminary limitations of the work have been introduced, for example by recognising the most important climatic hazards and the most critical roads, assets or functions.

After completing Stage 1, the road organisation will have:

- assessed the baseline for adaptation in a critical way, by establishing general drivers and ambitions and assessing the available resources.
- defined the aims and scope of the specific assessment lying ahead
- detailed the climatic premises (climate projections: have them? Not? how do we get them?)
- obtained an overview of the context in which the climate change assessment will be carried out - knowing their institutional capacities, their communication strategies, the identification of stakeholders (who else is interested? who provides the knowledge or data I need? Who *has* to be involved?) and the target population, for early involvement in the adaptation process.
- considered criticality, if it was relevant for deciding on priorities or providing more input to a risk assessment. (The *most relevant climate phenomena* are chosen, based on climate knowledge. The most *critical roads or road sections* are mapped.)
- defined the key tasks and a delivery plan.

The findings from Stage 1 may motivate implementation of preliminary or immediate measures, even before vulnerability is assessed.

Examples of situations that can motivate immediate measures: lack of data and/or routine to collect them, lack of expertise or contact with stakeholders, the need for education or restructuring of resources just to be able to carry out an assessment of impact to climate change.

Relevant measures can be:
recalculate budgets, develop certain expertise, improve datasets, introduce training programmes, establish collaboration agreements with important stakeholders etc.

This is the content of Stage 3, especially "Governance measures".

The findings from Stage 1 may confirm that the scope and aims are feasible, that resources for the key tasks are available, that the internal context is defined and stakeholders recognised.

The continuation of the work may be to (here are some possibilities):

* perform an exposure assessment, to identify the assets that will be exposed to a changed climate impact; or

* map vulnerability – identify areas or assets that are likely to be impacted; or

* analyse risk of vulnerable assets or areas, to obtain an overview of priorities.

This is the content of Stage 2.
Stage 2 consists of modules, which can be combined into an assessment adjusted to the needs and possibilities.

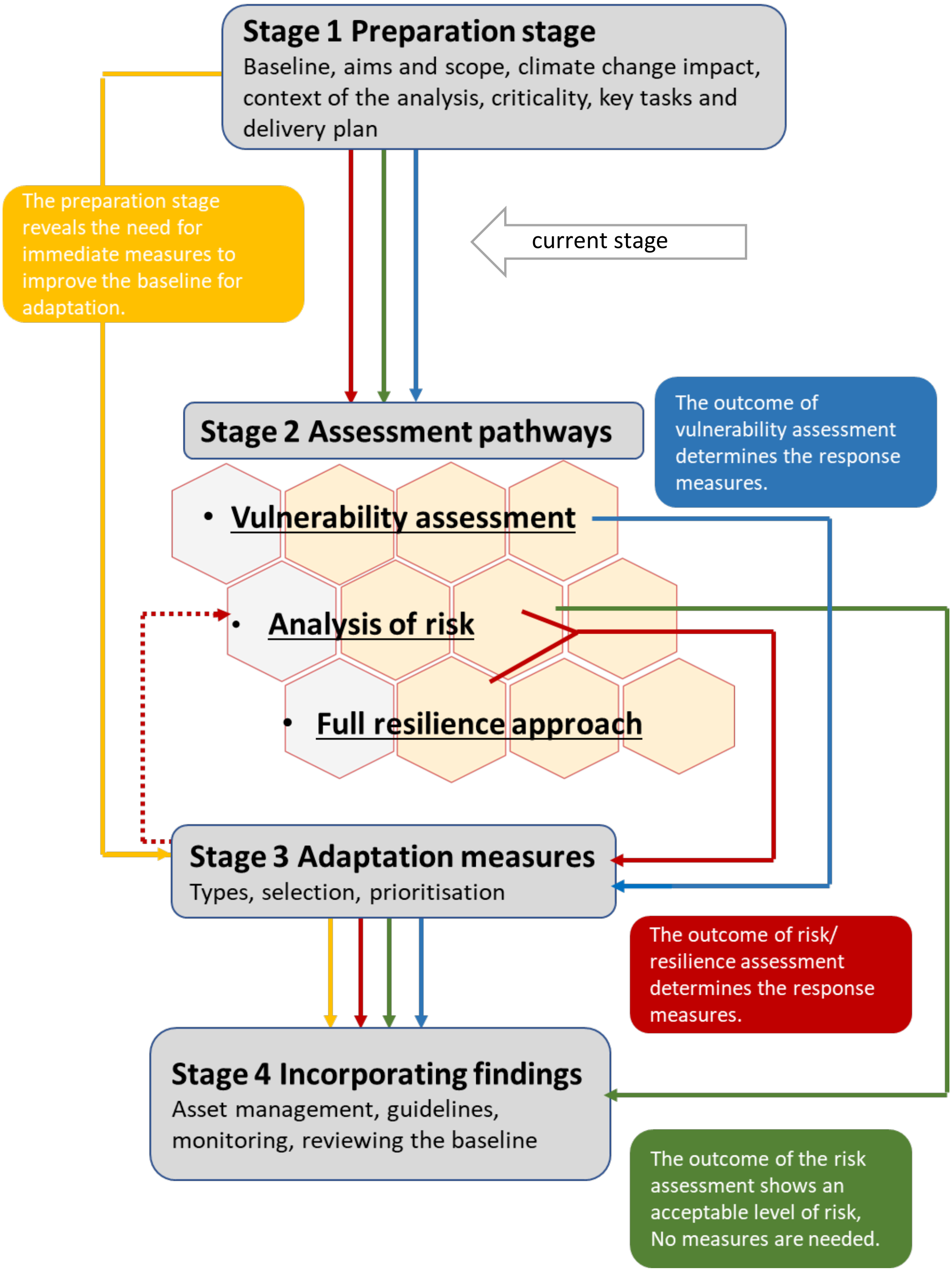


Figure 8. Illustration of the Framework: four main stages and possible assessment pathways.

Findings should be incorporated into road organisation's decision-making processes to ensure implementation, monitor progress, and develop a starting point for future assessments.

Stage 2

Assessment Pathways

2. STAGE 2 - ASSESSMENT PATHWAYS

Stage 2 describes tools, options, and process considerations for assessing vulnerability and risk/resilience of the key assets, operations and services identified in Stage 1. The contents in which these assessments are applied will depend on outcomes from Stage 1, including findings regarding the availability of data, existing expertise, resources, and decisions concerning the aims and scope of the analysis.

Stage 2 describes different approaches that can be used in whole, or in part, to assess vulnerability and risk, to prioritise vulnerable assets, or to prioritise risks for road users and communities.

The multiple tasks comprising this stage are illustrated in Figure 9, and can be divided into:

- 2.1 Assessing vulnerability
- 2.2 Assessing risk and resilience regarding damage to roads and road assets
- 2.3 Assessing risk and resilience regarding a broad range of hazards and consequences

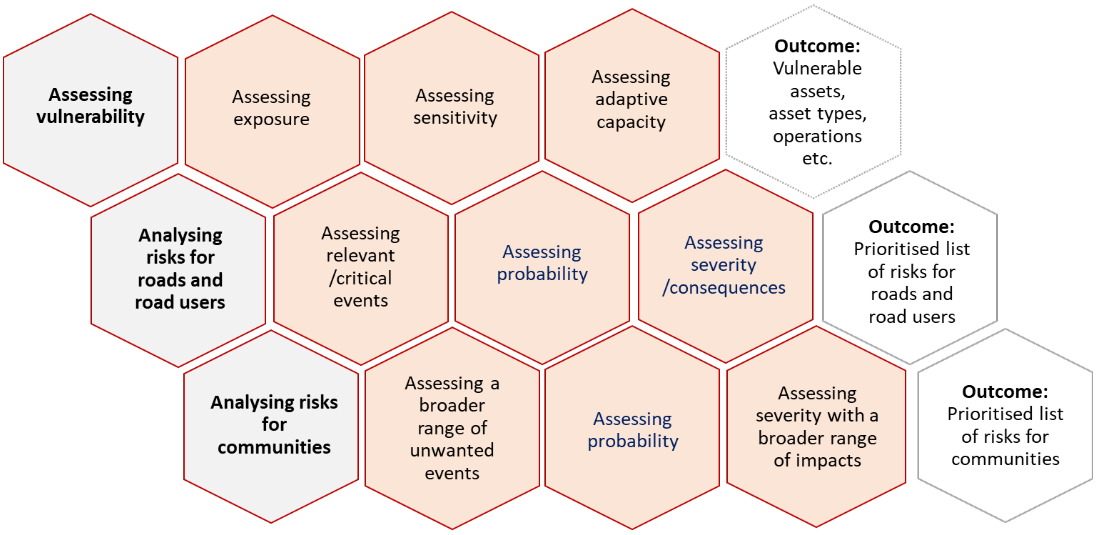


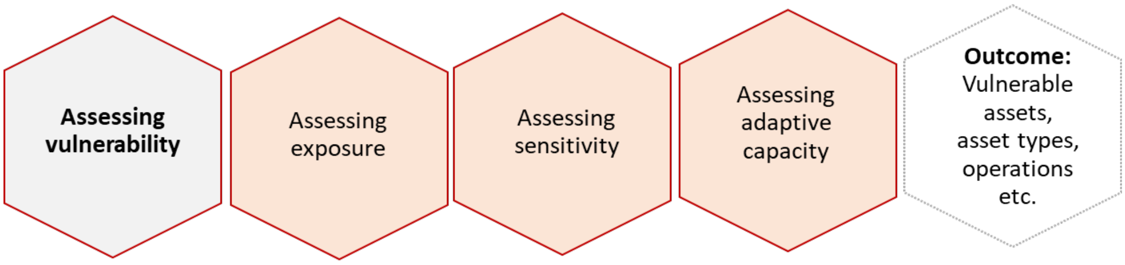
Figure 9. Structure of Stage 2 Assessment pathways. The tasks can be combined into an assessment that suits the needs and possibilities in each case.

Stage 2 is organised in modules, which correspond to steps in the assessment. The process is flexible and can be combined in different ways, according to the road organisations' needs and resources. There is no minimum or maximum number of steps that must be taken. This section walks through considerations that need to be taken in each of the steps above. Examples of vulnerability and risk assessment from around the world highlight possible combinations of steps and various approaches.

The examples provided in this section are not intended to be considered complete nor exhaustive, but are presented to enhance understanding and perhaps stimulate thinking about how a risk assessment could be made in the context of the road organisation, particularly the scale or focus of the study, and availability of data.

Section 5 of this report gives some examples of performed assessments and how they relate to the steps of this Framework.

2.1. Assessing vulnerability



Purpose

Identify assets or operations that are exposed or especially sensitive to climate impacts, due to their position, age, design capacity, condition, maintenance level, or other reasons.
Also, provide a basis for prioritising assets for further risk/resilience assessment.

Requirements

- Infrastructure data such as maps of roads, bridges, pipes, or other assets,
- Susceptibility maps for hazards such as landslides, avalanches, floods,
- Inspection data,
- Records of past events,
- Weather data and climate projections,
- Vulnerability functions, or alternative ways of collecting data on socio-economic impact.

Compatibility with other processes or systems

- Maintenance registers where needs for renewal are listed,
- Asset management database or system where known vulnerabilities are registered,
- Other government organisations' data on weather, climate, flooding, etc.

Outcome

List, database, or map that combines data to identify vulnerabilities, and supports further risk assessments or prioritisation of needs, depending on scope and scale of assessment.

FW2015 defines vulnerability as a *measure of the susceptibility of a system or asset to adverse effects of hazards, such as climate change and extreme events*. This definition is in line with IPCC 2007. Please see App. 10.2.1 for further definitions.

Vulnerability is most often expressed as a function of three factors, which can be combined in various ways to assess vulnerability.

1. **Exposure** of the system to climate threats (the character, magnitude and rate),
2. **Sensitivity**, or degree, that climate impacts affect a system positively or negatively,
3. **Adaptive capacity** or ability of the system[6] to successfully respond[7] to climate change.

Another way to express vulnerability is the estimated degree of damage inflicted on infrastructure at varying hazard levels, or "vulnerability functions". Damage is commonly expressed as a monetary value, also as the percent cost of repairing a damaged asset. A more holistic picture is obtained if one adds an estimate of the socio-economic impact of the loss of road function. The

[6] Here: the "system" can be a road network, road assets, operations, services etc.
[7] A system's response can be adjustments in behaviour, resources and/or technology.

damage and the losses are an indication of both sensitivity of the networks or assets, and the system's ability to cope with the impacts. This approach is shown in 2.1.5.

Exposure, sensitivity, and adaptive capacity are determined using information available. It can be assessed quantitatively, if data is available, or it can be based on qualitative information sourced from practitioners' or communities' knowledge and experience.

Examples of tools and information used to assess vulnerability are shown in Table 3.

Table 3. Types of vulnerability assessments, related to the type and quality of data

Quantitative	Semi-quantitative	Qualitative
Analytical models and metrics. Repair or replacement costs. Socio-economic impacts.	Combine scores of exposure, sensitivity and adaptive capacity (or their indicators). (Commonly applied to specific road sections or networks.)	Knowledge and experience in qualified judgements. Community vulnerability or non-monetised impacts. (Commonly applied to broad geographical areas or when quantitative data is lacking.)

In countries where advanced data collection systems and information (e.g., GIS formats) are not available, information provided by practitioners, communities and local representatives is especially valuable. In such cases, field visits, inspections, workshops, or brainstorming sessions can be used alone or in combination with the analysis of accessible data.

A simple way of assessing vulnerability can be comparing historical events with maintenance and repair needs. This can make it possible to estimate how well assets may withstand stressors in the future, and to think of adaptive approaches to make the structure less vulnerable. However, the future climate may bring other challenges that the ones experienced.

2.1.1. Assessing exposure

Purpose Identify road assets, operations or services that may be exposed to climate change consequences because of their location. Gain understanding of *where* the road network is exposed (without needing information on *how* the road is impacted).
Requirements • Infrastructure data, such as maps of roads, bridges or drainage structures, • Susceptibility maps for hazards, such as landslides, avalanches, flood maps, • Inspection data, • Records of past events, • Weather data and climate projections, • Socio-economic data.
Compatibility with other processes or systems • Maintenance registers where needs for renewal are listed, • Asset management database or system where known vulnerabilities are registered, • Other government organisation data on weather, climate, flooding, etc.
Outcome List, database, map, or other summary resource(s) that identify vulnerability because of location.

Exposure is the presence of people, economic activity, environmental resources, infrastructure, social or cultural assets in places that are at risk of climate impacts [42].

Exposure can apply to anything from an entire network to a single road structure. It is based on the potential for negative impacts from a hazard, now or in the future, expressed by the hazard's frequency, duration, intensity and proximity.

The task is to identify the assets or values that may be impacted by climate related events and climate change due to their location.

Obtaining data for an exposure assessment

Existing exposure levels are based on known past events and observations, technical knowledge, and research. Meteorological and historical records are common sources of this information.

Future exposure is typically based on using climate projections (see 1.3), and scenarios. In some cases, climate projections indicate that assets not currently exposed to climate impact may be exposed in the future, due to changes in precipitation or temperature, or sea level rise. In addition, predictive models including artificial intelligence could be useful. However, climate change projections based on trends established from historical events may not accurately model future extreme events.

For both existing and future exposure, any data on climate, hazards, infrastructure, and potentially impacted communities can be useful for the vulnerability assessment.

Climate data: See Sec. 1.3 for information on relevant climate data. Examples include weather records, present climatic data, climate change projections, preferably climatic hazard maps (extreme temperatures, rainfall, etc.). National meteorological organisations will be able to provide good support here.

Examples of data used to assess exposure

Hazard maps collect existing information about hazards in the assessment area by collating climate data and location characteristics (e.g., soil type, relief, land use) to help to determine relevant natural hazards. It helps to have both first-grade impacts (e.g., impact of heavy rain on roads and road assets) and second-grade impacts (e.g., impacts of flooding or landslides). The aim is to use *existing* hazard maps, but they can be the outcome of the assessment if they are not available in advance. It should be noted that hazard maps are usually made for a certain return period. This means that the likelihood of occurrence is indirectly included in the exposure assessment.

Road maps and maps of road inventory help identify which sections to assess in the hazard areas and to create exposure maps.

Information about exposed services, operation, communities will add time aspects to the dataset, since exposure can vary by time of day (e.g., morning or evening commute time) or season (e.g., tourist routes).

If data or hazard maps are missing, other sources of information may be available:

- Documented past natural hazards events,
- Interviews with personnel working in the assessment area,
- Technical expertise and judgement from the professional staff.

Methods used to assess exposure

Depending on the data and information available, the expose analysis can be quantitative, qualitative, or a combination.

Geospatial analysis can be used to visualise exposure of vulnerable assets and operations in areas based on proximity to natural hazards.

** Geospatial analysis, Mexico (→ Sec. 9.2.1)

The integration of spatial climate change data and its spatial analysis have become basic tools for climate change vulnerability assessments for almost all sectors, including transportation.

In Mexico, spatial maps of different climate threats (developed with predictive models) and climate change scenarios were used to determine the exposure levels of the road network. The results made it possible to identify potentially exposed regions of the country, and to estimate the length of roads and the number of bridges located in areas with high and very high levels of exposure, for example to flooding, sea level rise, heat waves, etc.

** Towards a more resilient Spanish road network (→ Sec. 9.1.7)

The Spanish methodology for climate change risk assessment proposes to assess exposure by using the information obtained in the assessment of climate change hazards and impacts (previous stage) and locating the different road elements in the Study Area. The exposure of different road drainage elements was assessed by the help of flooding hazard maps in the N-621 road in Cantabria (northern Spain). [34]

Some *combination of qualitative and quantitative data* (semi-quantitative) is commonly used to assess exposure. A scoring table can be useful to understand which hazards an asset or network is currently exposed to and how the exposure may evolve, see Figure 10. Using the same scoring scale for different assessments will enable comparison of the results for each assessment.

	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						

Exposure scoring:

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

Figure 10. Example of a scoring table for exposure [FW2015]

Identifying *indicators of exposure* is another assessment approach. Examples of indicators include:

- Previous road closures or other evidence of exposure
- Documented repair/maintenance costs, especially at locations where costs are higher than average
- Proximity to mapped hazards

** **Assessment of trunk roads to floods, Germany** (→ Sec. 9.2.2) In order to assess the impact of river and storm surge flood hazards on the German trunk road network, the Federal Highway Research Institute BASt estimated the exposure, based on the location of the road relative to indicated flood zones based on flood hazard maps available throughout Germany. Sections of the federal trunk road network were identified that are located in the area of influence of various flood and storm surge scenarios ("frequent", "medium", "rare/extreme").
** **Vulnerability assessment of DIR Méditerranée, Cerema, France** (→ Sec. 9.2.3) Cerema's project on risk assessment of the DIR Méditerranée network, provides good examples of scoring exposure [43].

FORESEE project – calculation of flood extent

In the FORESEE project, a novel methodology was developed for the study of floods using advanced statistical techniques to improve the calculation of flood extent for different return periods through a better exploration of the space of extremes.

Tool#4 – Learning Hub (foreseelearning.eu)

Outcome of the exposure assessment

A common outcome of an exposure assessment is a map or hazard map that identifies the assets (roads, road structures, operations, services, economic activity, or other resources) located in areas where they are exposed to the impact of climate or climate change. There is significant flexibility on scope and scale of any map-based outcome.

2.1.2. Assessing sensitivity

Purpose Identify assets, operations or services that may be impacted by climate change due to their current characteristics, such as design capacity, age or maintenance level.
Requirements • historical information about the climatic phenomena that have impacted the road, • Information on experiences sensitivity of areas to landslides, flooding etc., • hierarchy or roads, • information about the structural condition of the roads: design levels, maintenance levels, drainage conditions, slope stability, etc.
Compatibility with other processes or systems Inventory or inspection data of bridges, roads, or other assets.
Outcome An overview of assets that could be more affected by climatic impact due to their age, condition, or other structural characteristic.

PIARC FW2015 defines sensitivity as t*he degree to which a system is affected adversely or beneficially by climate-related stimuli*. Sensitivity analysis is similar to exposure assessment, but is primarily based on the current characteristics of an asset instead of its location.

Obtaining data for a sensitivity assessment

Assessing sensitivity of infrastructure assets on the basis of their characteristics can be data intensive, for example depending on the scale of the assessment. Like other steps in the assessment, there is flexibility in the assessment, based on availability of data that can be collected and collated.

Intrinsic factors that describe an assets' structural and functional behaviour include:

- Age and/or remaining service life
- Design capacity
- Condition
- Type of structure and capacity / capability for its purpose (e.g. 2-lane road in evacuation route)
- For earthworks, the height, slope, and materials.

External conditions that can influence sensitivity can be:

- *Level of maintenance* – assets that require more maintenance, which are also likely to be older, may be more sensitive to climate impacts than newer assets. Assets with inadequate maintenance budgets will be more sensitive with time;
- *Landscape* - road assets along slopes can be more sensitive to landslide and scour than those in flat areas;
- *Context* – disruptions on roads connecting large urban areas will impact more people and have a greater economic impact compared to less populated and less urbanised areas;
- *Adjacent land use* - land use in the surrounding areas can increase sensitivity of assets to hazards and climate change;
- *Societal and Community Considerations* - sensitivity of communities and businesses served by the road (should not be confused with criticality).

The road organisation may be able to obtain relevant climate change information from existing resources:

- *Database or inventory of assets* – if it exists, can provide information. However, inventories and inspections generally lack the type of data relevant for assessing sensitivity to climate change.
- *Experience from recent and historical events* – historical climate and weather information that has affected the road can help identify locations experiencing higher relatively higher impact than one would expect based on their exposure.

One can also collect new information as a substitute or compliment to historical data.

- Visual inspections (see for example ReCAP Visual Inspection Manual [44])
- Interviewing experts with experience from area as well as communities to capture undocumented events or organising brainstorming and engagement sessions with local transport authorities.
- Open-source online maps can also be a practical low-cost tool.

Methods for assessing sensitivity

Sensitivity can be assessed in several ways, depending on the type and quality of the data available, and the resources or experience available.

Quantitative assessment, including measurements, may be best suited to assessing sensitivity of individual assets.

> ** Spanish methodology for risk assessment (→ Sec 9.2.4)
>
> The Spanish methodology for climate change risk assessment proposes the use of matrices to calculate sensitivity in an objective way. These matrixes will propose different sensitivity factors (asset characteristics, such as age or maintenance) that will be ranked from 1 to 5. The higher the ranking the more sensitive the asset. These matrixes should be customised for different locations and specific assets.

Semi-quantitative assessment or sensitivity scoring, which combines analytical data and expert judgement with qualitative descriptions into quantitative scores. For example, the scoring table in Figure 11 [FW2015] uses scores from 0 – 3 to identify four levels of sensitivity. The scales developed in case studies respond to practical needs of the transport authorities, which are often based on the level of the road degradation. In order to compare sensitivity over a span of asset categories, or to compare sensitivity in a vulnerability assessment, it is important to choose a single “universal” scale.

Level of Sensitivity		Description of Sensitivity Level of 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.

Figure 11. Example of a sensitivity scale [45]

Sensitivity analysis will typically reflect current conditions and may not necessarily use future climate change projections. A sensitivity analysis can, alternatively be combined with current and future *exposure* to provide information about the potential evolution (increase or decrease) in vulnerability.

In some cases, it is more efficient to recognise *asset categories*, assess their sensitivity and further analyse *aggravating* and *adaptive factors (*App. 10.2.2). The sensitivity of two assets of the same category (e.g. same type of culvert or bridge) can differ according to their condition, their building material, their level of maintenance, etc. The sensitivity score of each asset can then be assessed as the overall scoring of the asset *category*, modified by the aggravating or adaptive factors.

Since each asset must be assessed according to its characteristic. This requires that the road network is divided into categories of assets, such as road surface, road structure, bridges, walls, small drainage systems and equipment.

** **Vulnerability assessment of DIR Méditerranée, Cerema, France** (→ Sec. 9.2.3)

This case study provides a good example of sensitivity scoring. The method recognises asset categories, assigns general sensitivity indicators and applies a scoring scale; then, aggravating and adaptive factors are defined and assessed.

Using indicators to assess sensitivity

Sensitivity indicators can be useful when specific factors appear to be deciding or critical. It may also be sufficient to distinguish between 'sensitive' or 'not sensitive' through indicators, instead of scoring and ranking. While this is a practical way of expressing sensitivity or vulnerability, indicators do not reflect the interrelation between factors or complexities such as cascading or resonance effects (discussed in Section 2.2).

Examples of situations when specific factors are critical, include:

- *Age* – year of construction or over/under a certain age-threshold
- *Design* - year of design or compliance with current design standards
- *Material* – e.g., some pavement types are more sensitive to high temperatures
- *Condition level* - existing damage /level of road degradation (e.g., rutting or cracking) or known high-damage location would probably be more sensitive to future damage
- *Existing resilience/adaptation measures* - presence or lack of protection measures.

**** Assessment of trunk roads in relation to landslides, Germany** (→ Sec. 9.2.5)
Within the climate impact assessment of trunk roads, performed by BASt in Germany, the presence of landslide protection measures was used as an indicator of sensitivity. Road sections with implemented landslide protection measures were regarded as 'not sensitive'. Road section without protection measures were regarded as 'sensitive'.

Outcome of the sensitivity assessment

This step gives us an overview of the assets, asset categories, or operations that can be more affected by climatic impact. The sensitivity can be related to characteristics such as structure, age, maintenance level etc.

2.1.3. Assessing Adaptive Capacity

Purpose of the work in this step The assessment of vulnerability is not complete unless one takes into consideration the possibilities for adaptation to unfavourable conditions. This will assist the assessment to more realistically reflect the actual effects of the disruption as a modifier on the raw impacts assessment.
Requirements Information on: • location, quantity and capability of response and recovery resources • location and capacity of key services used by affected communities • socio-economic distribution of affected communities. • financial and funding systems available • local transport system redundancies (alternate routes, modes, cost structures, stockpiles, virtual systems, destinations, etc.)
Compatibility with other processes or systems Adaptive capacity is usually assessed as an independent variable which is then applied as a modifier to other routines or calculations that are assessing basic vulnerability (usually from exposure and sensitivity). The same or consistent data sets (age, granularity, survey methods) should be used where common factors or variables are applied in the respective calculations.
Outcome An understanding is developed about where in the system and how impactful various factors or characteristics are that have an ability to reduce the effects of a disruptive event. This understanding can inform assessments of how effective various interventions can be or where the priorities for improving adaptive capacity lie.

The impacts of any natural hazard event which disrupt the transport system are affected (usually reduced) by how the receiving system is able to adjust to minimise the effects of the impacts. It is important to define ways of introducing this factor in the Framework.

In the PIARC context, adaptive capacity is the ability of a system to respond successfully and to impacts from climate phenomena. There are numerous references and papers addressing adaptive capacity in various contexts [46], [47], [48]. See also App. 10.2.3 and 10.2.4.

A successful response includes adjustments in behaviour, in resources and technologies. In this sense, adaptive capacity represents the currently identifiable scope of options for adapting to the expected climate change by means of additional measures.

It is often a non-dimensional, comparative measure or a (descriptive) rating measure, which makes it useful for integrating in a range of related assessment equations or measures. However, adaptive capacity can be difficult to quantify and assess due to various internal and external factors.

"Adaptive capacity affects a system's vulnerability through modulating both exposure and sensitivity to a hazard. That is, the higher the adaptive capacity of a system, the lower the influence of the exposure and sensitivity components, and as such, vulnerability is reduced" [49].

A capacity assessment includes an examination of the willingness and resources necessary to adapt to climate hazards. An assessment should avoid the potential pitfall of trying to identify a comprehensive list of quantitative capacity indicators. It is more important to understand and to characterise the adaptation process in a pragmatic manner [50].

How can a system adapt?

The adaptive capacity of a transport system can exist in a wide range of dimensions and components. Each can contribute to the adaptive capacity of the system individually or in combination. The adjustments can be proactive in response to potential damage, can take advantage of opportunities, or can be reactive to consequences. They can relate to:

Asset or network adaptive capacity:

- Asset and network redundancy (see Sec 8, Glossary)
- The amount of time to adjust or respond to an event
- Location factors
- Asset and network ability to absorb short term stressors
- Systems that have been previously exposed to shocks and stresses are more likely to have the experience and the ability to adapt in the face of new and emerging challenges.

Organisational adaptive capacity

- Operational flexibility, awareness and interdependencies
- Organisational capabilities, leadership, knowledge and learning culture, and flexibility of resource allocation
- Financial, funding and regulatory capacity and processes

Community adaptive capacity

- Receiving community resources and their distribution across the community, affecting equity and ability to adjust
- Social capital and community decision-making and engagement
- Impacted ecosystem capacities and characteristics

ISO 14091 "Adaptation to climate change – Guidelines on vulnerability, impacts and risk assessment", Annex G (Components of adaptive capacity) suggests the following general categories of components:

- Organisational capability
- Technical and financial capacity
- Ecosystem capacity

Obtaining data for assessing adaptive capacity

The assessment of adaptive capacity requires insight rather than data. All types of information that can describe the capability of the road organisation to respond successfully to impacts from climate-related challenges are relevant. The type of information that is necessary is indicated by <u>the factors that can reduce or enhance adaptive capacity</u>, such as:

- Resources for adjusting to climatic events (e.g. using flood barriers, developing storm water detention systems),
- Ability and /or resources to temporarily adjust or cope with a short-term change,
- Resources for quick repair (the ability of the road organisation to respond promptly and effectively to the threat and repair damage quickly).
- Redundancy (presence of viable alternative routes, modes, timing of trip, alternative destinations/services, virtual options).

Where can Adaptive Capacity be applied?

Adaptive capacity assessments are often qualitative or semi-quantitative. The nature of the assessment will necessarily impact on how (and possibly where) the results are used through the various stages of the Framework assessments.

Adaptive capacity can be used:

- in risk assessments as a modifying factor that can influence or adjust the severity or degree of impact and consequence of an event.
- In selecting adaptation measures and programmes of action, when one can choose to deliberately modify or amend factors which affect adaptive capacity.
- In the monitoring and reporting on the progress and effectiveness of the adopted programme of actions, and if factors to increase adaptive capacity have been specifically included in the adopted programme of actions.

Task and methods for assessing adaptive capacity

Adaptive capacity can be a difficult concept to quantify and evaluate due to a range of internal and external factors. Assessment of adaptive capacity is usually founded on qualitative or semi-quantitative methodologies that consider a range of factors and data sets, although processes could also be based on expert opinion.

Irrespective of the methodology used, the best results occur when the process involves and incorporates local knowledge, both organisation and the affected communities.

- **Qualitative assessment**

The FW2015 presented a series of questions related to assessing adaptive capacity, see App. 10.2.4. Associated with this series of questions, the FW2015 also proposes a simple 5-step descriptive rating or categorisation schema (from Very High to Very Low Adaptive Capacity), which could be developed to suit the wider assessments needs.

- **Semi-quantitative /scoring / using indicators**

ISO 14091 – "Adaptation to climate change – Guidelines on vulnerability, impacts and risk assessment" in its Annex E (Examples of indicators for risk and vulnerability assessments) has possible example indicators for adaptive capacity assessment and monitoring. They are framed around the risk factors of financial capacity, technical capacities, and organisational capability albeit not directly related to transport systems.

ISO 14091 in its Annex H (Assessing adaptive capacity) presents some attributes that can be measured or considered when evaluating adaptive capacity and proposes a means to determine the required adaptive capacity for various situations. It suggests three levels of adaptive capacity according to a range of organisational features, processes, commitment and leadership.

Outcome of the assessment of adaptive capacity

After considering factors that influence adaptive capacity, the road organisation will have an overview /scores or adaptive capacity to be used in an overall vulnerability assessment.

2.1.4. Assessing vulnerability by combining exposure, sensitivity, and adaptive capacity

In step 2.1, one or more of the following has been assessed:

Exposure: identifying assets, operations or services that are especially exposed to the key climate elements (e.g. heavy rain). Present or future exposure can be assessed, and it is a function of the character, magnitude, and rate of climate change.

Sensitivity: age, design capacity, adequacy of structural type, standard maintenance level, sensitivity of soil, debris transport by water etc. Sensitivity should also account for factors connected to the road users or communities benefitting from the road.
Sensitivity can be assessed for asset *categories* and then modified by adding aggravating and/or adaptive factors.

Adaptive capacity: the possibility of a system to adapt – e.g. existing alternative routes (redundancy), having resources to manage unwanted situations and recover quickly.

Vulnerability is usually assessed as combination of the assessment of exposure, sensitivity, and adaptive capacity. Figure 12 shows an example of an often-applied vulnerability matrix, where exposure and sensitivity are used to determine overall vulnerability levels. Such a matrix can also be set up for different levels of adaptive capacity. It can be done for current and future exposure.

		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)

- **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.

Figure 12. Example of a vulnerability matrix [FW2015]

The suggested categories of vulnerability are only an illustration of a possible scale. Road organisations will need to produce their own categories dependent on their requirements and data availability. Assets, locations and operations will most likely not wholly comply with chosen categories. Additionally, there is a need for additional professional judgement.

The assessed levels of exposure, sensitivity and adaptive capacity may be quantitative, semi-quantitative or descriptive. The assessment may be based on a broad analysis of all influencing factors, or they may be based on indicators. Additionally, it may be engineering informed or assessed by expert teams and personnel who have knowledge and experience from the analysed road section.

The task is then to analyse the findings or scores from the assessment of exposure, sensitivity and adaptive capacity, and to combine them into a vulnerability score.

Assessing vulnerability is usually done to provide a basis for ranking. In that case it is good to consider that also the ranking will be impacted by climate change, because climate change will have impact on the evolution of vulnerability. This can be incorporated in the assessment by combining sensitivity with the *current* and the *future* exposure.

If vulnerability or risk assessments are to be undertaken for different networks, the comparison between the assessment will be possible only if the scale of vulnerability is the same for each study. The scale should be designed together with the transport organisation.

Examples of vulnerability assessment and case studies

There are many methods and algorithms for assessing or calculating vulnerability. The list below provides some examples.

** U.S.DOT Vulnerability Scoring Tool (VAST) (→ Sec. 9.2.6) The U.S. Department of Transportation developed the Vulnerability Assessment Scoring Tool (VAST) as an indicator-based vulnerability screen assessment of transportation assets. Vulnerability is a function of exposure, sensitivity, and adaptive capacity. Certain characteristics of assets can serve as indicators of their exposure, sensitivity, or adaptive capacity. The tool is also available from FHWA's Tools website.
** Guidelines for Climate Impact and Vulnerability Assessment, Germany (→ 9.2.7) The understanding of the term "vulnerability" in these guidelines, published by the German Ministry of the Environment, is based on a combination of the vulnerability concept of IPCC 2007 and the risk concept of IPCC 2014.
** Qualitative vulnerability assessment, Spain (→ Sec 9.2.8) Due to the difficulty to obtain all the needed data, it was decided to perform a qualitative assessment by interviewing experts and personnel. The characterisation of the road network vulnerabilities was done based on a pre-established typology of impacts.
** Analysis of the dynamics of erosion Quebec (→ Sec 9.2.9) This is an example of a vulnerability assessment of coastal areas exposed to erosion. In this case study, the analysis of the dynamics of erosion focuses on the North Coast (Québec) to help identify adaptation solutions along Route 138.
** Vulnerability /resilience assessment Orange – Lunel (→ Sec 9.2.10) In this example, current and future vulnerabilities are assessed, where both exposure and sensitivity can change with time. It is more usual to see only exposure assumed changed.
** Vulnerability score – Western Australia (→ Sec 9.2.11) In this example, the vulnerability score includes a score of criticality. 'Exposure' and 'Sensitivity' are combined into 'Potential Impact', which is then combined with 'Adaptive capacity' and 'Criticality' into a vulnerability score.
Minnesota DOT – Vulnerability assessment In MnDOT, an earlier quantitative vulnerability assessment (in this case flood) was supplemented by a qualitative assessment, based on feedback from experienced maintenance staff. More information in Section 5 and App. 10.5.9

2.1.5. Assessing vulnerability by the help of vulnerability functions

Vulnerability can also be expressed as a monetary value, corresponding to the expected damage caused by natural hazards. To assess the degree of damage of the road /road asset, one can use *vulnerability functions*. Vulnerability functions are based on the statistical analysis of recorded damage values. If not available, they can be deduced from repair or maintenance records. If these records do not exist, local expert knowledge can be applied. Figure 13 illustrates the use of vulnerability functions.

The relation between expected damage and level of threat can be obtained for various probabilities /or return periods. A set of vulnerability functions will therefore also contain risk information. The monetary value of expected damage can then be related to the cost of repair or cost of replacement of the asset, in that way providing more relevant information for measures.

Finally, expressing the expected annual damage (EAD) will provide a good basis for decision-making on the network level.

How this has been applied in risk assessment, will be shown on examples in Section 2.2.5.

Box 10: Vulnerability functions in the FORESEE project

The FORESEE project developed a method that combines infrastructure, hazard and traffic data into a decision-making tool. Vulnerabilities are expressed as damages and losses caused by natural hazards and indicated by traffic disruptions. The approach based on vulnerability functions has been applied in a case study on A24 Highway Carsoli-Torano in Italy.

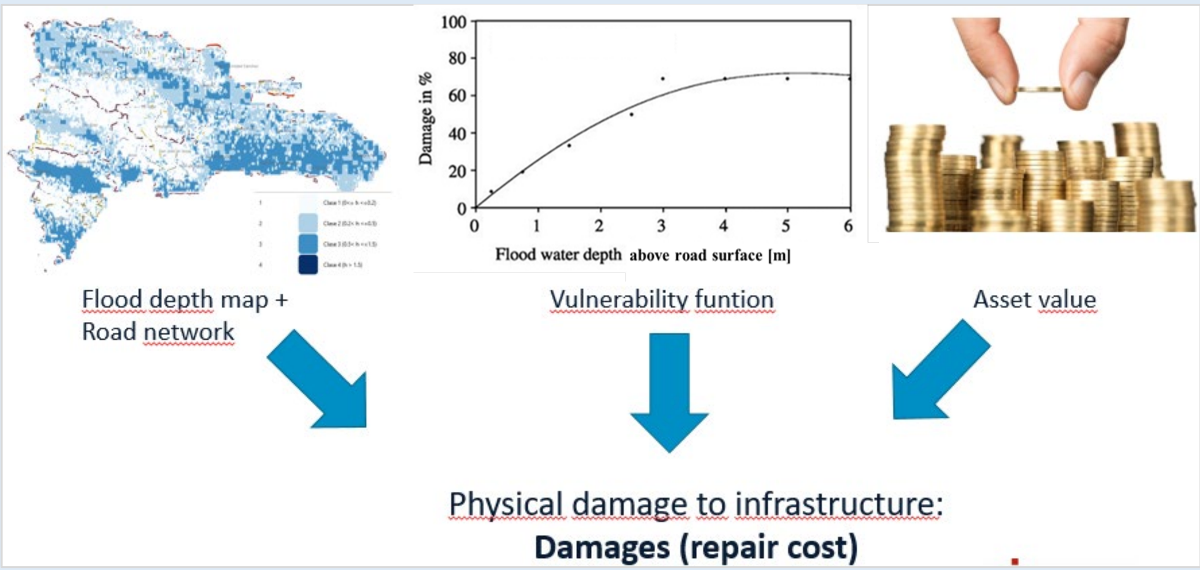
See the attached presentation "*The Fragility Functions, Vulnerability Functions and Decision Support Module Tool*", from the projects Learning Hub. It starts with a description of the different assets of the infrastructure and the hazard scenarios likely to occur in the specific site. Then, several performance indicators of the transport infrastructure are derived from the approach as:

- risk or damage probability indexes,
- possible loss indications for different hazard scenarios,
- Level of Service assessment before and after the event, and
- resilience estimation both at asset and network level

Tool#12 – Learning Hub (foreseelearning.eu)

Example: Vulnerability function for flood damage

Vulnerability functions are used to combine hazard intensity and asset value to attain the expected repair costs (see below):



The steps for a given asset/ location are as follows:

- Determine hazard intensity e.g. flood depth
- Use the vulnerability function. Determine the % of damage
- Multiply the % of damage with the asset value to gain the repair costs

Such vulnerability functions are not always readily available. However, the necessary information can often be deduced from good (historical) maintenance records if they exist. Ideally these records consist of the following data:

- Time and date
- Hazard intensity
- Location of hazardous event
- Assets involved and location of assets
- Asset characteristics (e.g. type of asset, dimensions, type of pavement)
- Duration of disruption. This information can also be used taken from ROADAPT Guidelines[8]
- Economic damages that have been observed
- Number of people affected

Sometimes these historical records are missing. In those cases, it should be considered if local expert knowledge can be used to construct vulnerability functions.

Figure 13. Example of use of vulnerability functions in the case of flood damage [Source: Deltares, Netherlands]

[8] ROADAPT_integrating_main_guidelines.pdf (cedr.eu) [31]

2.1.6. Outcome of Stage 2.1 - Assessing vulnerability

The outcome of this stage should be a map or listed overview of vulnerable areas, assets or asset categories, operations or services that can be affected by climatic impact because:

- they are especially exposed to climate parameters and climate change,
- they are especially sensitive, due to their design characteristics, maintenance level, special circumstances of the communities relying on the road etc.
- there is a lack of adequate resources to manage the relevant threats.

Summary - Recommended action:

Following the aims and scope of the analysis (formulated in Sec. 1.2), and depending on the availability and quality of data, the purpose of this stage is to assess the elements comprising vulnerability, in a quantitative or qualitative manner. Figure 7 and the examples provided in this section may provide some guidance.

- **Exposure analysis:** will identify assets, road sections, or operations that may be impacted by climate change due to their location. One will gain understanding of where the road network is exposed (without information on how the road is impacted).
- **Sensitivity analysis**: will highlight assets, road sections or operations that will be impacted by climate (change) due to their characteristics. This can be intrinsic features (such as design capacity, age, structure type) or external conditions (such as level of maintenance).
- **Adaptive capacity** is an important modifying factor of the vulnerability as it would appear based on exposure and sensitivity. It can be a property of the road organisation (resources, knowledge, preparedness), of the road network (redundancy) or the physical asset (where, for example, a tunnel is not adaptive, while open road is).

Alternatively, if vulnerability functions are available, express vulnerability by the help of expected damage level.

If the aim is to use the vulnerability scores to provide a basis for prioritising measures, risk has to be considered. This is the subject of the next step.

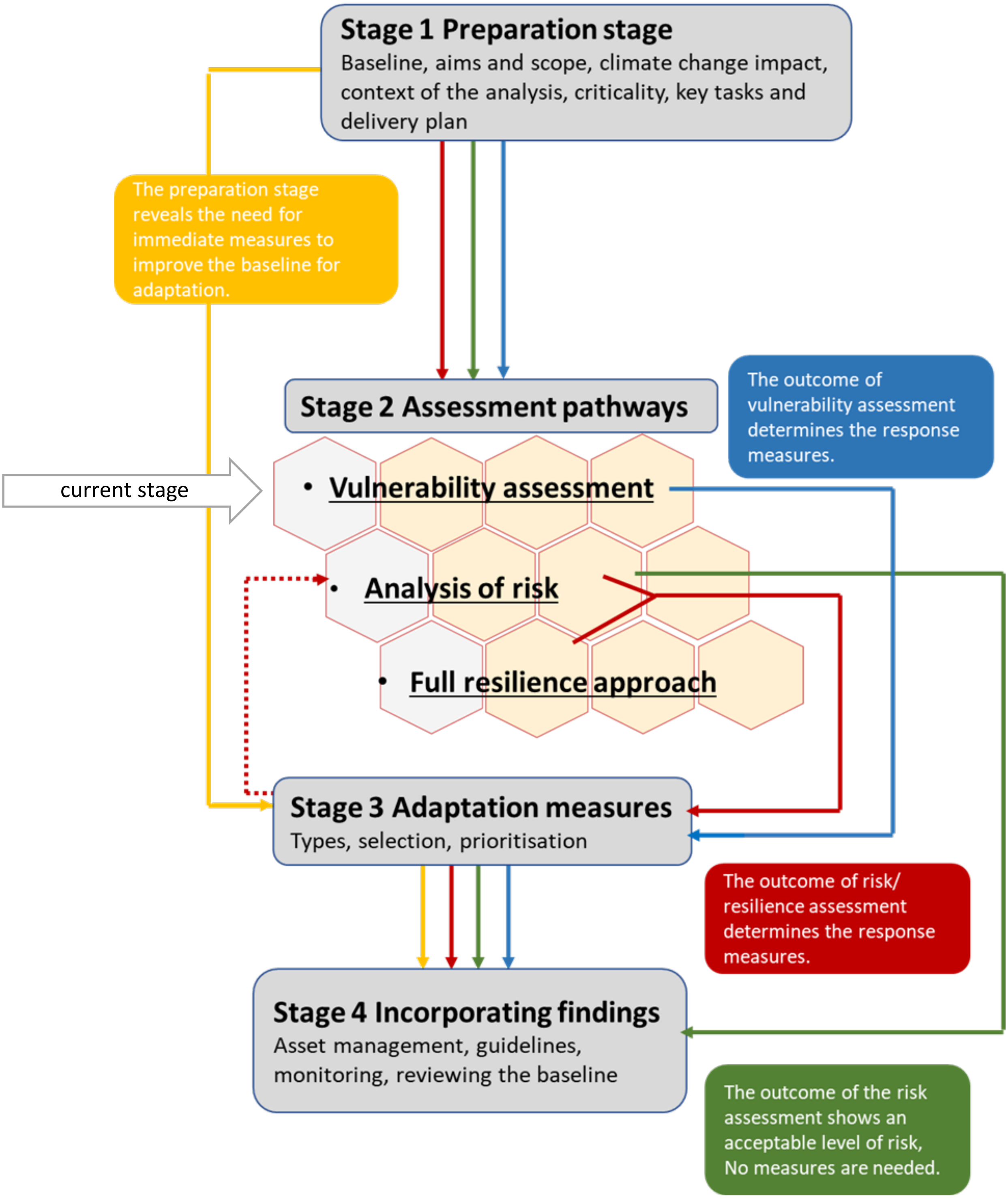
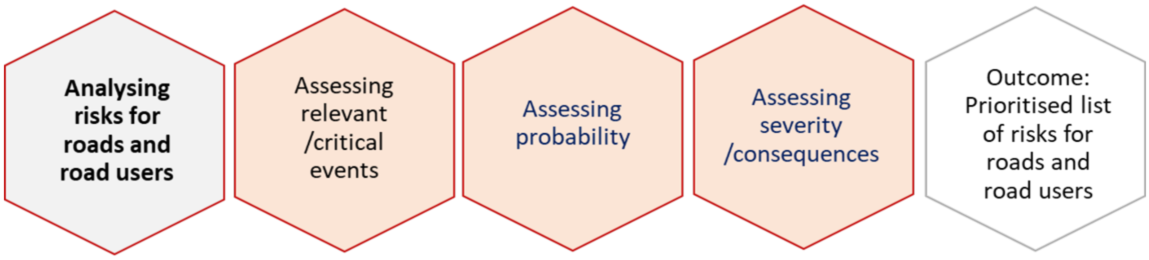


Figure 14. Illustration of the Framework: four main stages and possible assessment pathways.

Findings should be incorporated into road organisation's decision-making processes to ensure implementation, monitor progress, and develop a starting point for future assessments.

2.2. Risk Analysis to Climate Impact



Purpose

To guide the analysis of the probability and consequences of hazards to determine the risk to assets, networks or operations, and the residual risks related to potential intervention proposals

To allow the determination of relative risk to assets, networks or operations for prioritisation of responses and risk management decisions.

Requirements

- Basis for estimating probability (like hazard maps, experience from previous events)
- Traffic data
- Overview of decisions about consequences, e.g., economic and social data /losses. These can be based on previous events, or interviews with road staff, or others
- Asset data (location, form, attributes)
- Climate projections.

Compatibility with other processes or systems

- Possible existing risk assessment processes carried out for other purposes.
- Severity /consequence /damage scales used for other purposes.

Outcome

A ranked list of risks, according to their probability of occurrence and their impact (consequence related to event probability). These can be taken to Stage 3, which outlines how adaptation responses to address these risks can be identified, selected and prioritised to result in an acceptable residual risk register.

This section provides steps and considerations for performing risk analysis, and is framed around:

- Identifying the most relevant or most critical events or hazards (of interest) and confirming the type and extent of challenges
- Estimating the (changing) probability of the events of interest that are affecting the network
- Estimating the severity of the impact from the events of interest (derived from the vulnerability assessment and criticality)
- Evaluating the degree and range of risks that exist for the network from the events of interest (and establish initial content for risk register)
- Considering residual risk, risk tolerance and acceptance thresholds.

The approach outlined here should enable road organisations to understand, and where possible to evaluate or quantify, the risks posed to their networks and assets in a flexible, accessible, iterative and yet robust and holistic way following sound and established risk analysis principles and methods.

Issues of data available (asset data, network data, local knowledge and expertise, hazard data and records) strongly influence the options available, such as assessing direct impacts and costs

(Section 2.2), or extending the analysis to indirect impacts and costs such as socio-economic and cross-sectoral costs (explored in Section 2.3) for assets alone, or for the services they provide.

The nature of the available data also affects the types of assessment possible: quantitative, semi-quantitative or qualitative. These types are outlined in Table 4.

Table 4. Types of risks assessments, related to the type and quality of data [5]

Qualitative	Semi-quantitative	Quantitative
- Strategies or policy guidance - Risk assessment with various networks on broad geographical areas - Risk assessment with a few data/human/economical resources available - First step of a semi-quantitative or quantitative risk assessment	- Risk assessment on mid-geographical areas - Risk assessment focused on one specific network even if the geographical area of study is broad	- Risk assessment of specific assets for which models are available

The examples in Table 4 are not rigid in their application, and a road organisation may use more than one. Additionally, the qualitative, semi-quantitative and quantitative approaches can be combined in an iterative manner. For example, if a risk assessment is conducted on a very broad network using a semi-quantitative assessment and it shows that some specific assets are more at high risk, it might be relevant to conduct a quantitative assessment for these specific assets.

Qualitative analysis allows consideration of a wide and disparate range of factors and impacts such as social vulnerability indices, effects on strategic social and economic infrastructure (such as the urban environment, health, education, energy, communications, tourism and commerce). It can also scan and consider very quickly large geographical areas and wide ranges of impacts in ways understandable to many stakeholder groups, saving much time and cost and allowing the focussing in on the key high-risk areas quickly and effectively.

There are a number of other approaches that can be applied to a risk assessment. These include:

- Top-down approaches – taking a whole of system view, analysing macro-scale hazards and impacts and cumulative effects across a large area or domain, before progressively becoming more detailed and granular at successive iterations
- Indicator based approaches – using (and cross-referencing) indices or classification systems such as vulnerability indices related to health, social well-being or agricultural needs (rainfall, sunlight hours). This can provide an integrated perspective on the complex transport interdependencies, and provide insights on elements such as adaptability, robustness, durability, criticality and connectivity
- Quantitative risk analysis and probabilistic risk analysis - can initially appear appealing, but often it is identified that more or large quantities of information are needed which can be difficult or expensive to acquire.

2.2.1. Recognising events of concern

Purpose
Selecting realistic and relevant adverse events for analysing risk.
Determine which unwanted events are likely to happen on the road/assets - and limit challenges/unwanted events to the most important
Possibilities for early limiting of the scope: focus on the most critical events or most critical roads /road sections.

Requirements
- (Down-scaled) information and data on hazards in assessment area
- What impacts are of concern?
- Criticality and interdependence with other utilities, etc.
- Target dates for future scenario
- Asset data (location, characteristics)
- Historical events, damage and costs

Compatibility with other processes or systems
- Operation centres processes and records
- Consistency of results with partner organisations/utilities

Outcome
Clear identification of the hazard (and future scenarios to be considered) and the consequences of concern that may need to be assessed.

The need for clarity

Prior to assessing risks, it is essential that the following variables are defined and agreed that have been scoped into the assessment:

- climate hazards and impacts on the exposed assets,
- locations and operations or services at risk.

Sometimes it is necessary to estimate the most relevant or most critical events (of interest), depending on the type and extent of challenges present or predicted to occur. The adaptive capacity of the assets, network or community/users could allow some form of (re-)prioritising of the events of interest if required.

In order to confirm the matters for assessment (from Stage 1), a series of further questions could be useful, such as:

- What are the current characteristic climate/s of the geographical area/s where the network or the road assets are located, e.g. mean temperature, mean precipitation, wind patterns?
- Which climate hazards have already occurred in this area, and which have or have not impacted the network: flooding, heat wave, freeze-thaw cycle?
- What kind of hazards could affect a road network/asset (by deteriorating it sooner than expected, destroying it, or causing traffic failure) even if these hazards have not occurred yet in this area, e.g. freeze-thaw cycle, coastal flooding?
- How will these hazards evolve in the future?
- Will the transport network have to face new hazards in the future, in a context of climate change?

- Will changes to the transport network change the risk from existing hazards (e.g. new links in hazardous locations or growing traffic demands change exposure)
- What types of disruption or consequence are of interest e.g. precautionary closure of bridge/tunnel/road or closure due to damage or operational facilities are not working such as traffic signals or scada systems[9] are unavailable?

The above questions need to be considered in the light of what the future context will be. This is a significant source of uncertainty, as it is not known how fast change will occur in the future, particularly in terms of the mean and distributions of climate parameters.

Assessing a broad(er) range of unwanted events

It is possible that from the assessment in the previous section, additional matters are identified for potential assessment in the risk analysis. Careful consideration should be given to the necessity and added value of including these matters, but irrespective of the decisions on the matters, it should be documented and potentially reported (however briefly) to the project's governance and/or decision-makers. In some places, however, available data might not allow for a broader analysis of additional events.

There are many examples where a series of events have occurred in close succession, causing compounding consequences (e.g., New Zealand had a major earthquake (Kaikoura 2016) which was followed a few days later by heavy wet weather over affected areas, causing much more complexity and cost to the response and recovery activities).

Potential reasons for wishing to consider a broader range of unwanted events may be:

- to allow consideration of various Annual Exceedance Probabilities[10] (AEP's) or hazard return periods and the impact of the alternatives on design or operational standards.
- to promote discussion on acceptable risk threshold and tolerance in scenarios of compounding events.
- to assess as part of the wider risk analysis, a range of event types for example to identify where vulnerability scores are high, yet the adaptive capacity is low, as that combination may be a key situation for focus in the responses assessments.

If more than one relevant or critical (design) event is agreed to be included in the project, then a range of follow-on considerations will need to be resolved including:

- Can the assessments of the events use the same data (repair costs, historical weather records, future climate predictions, asset condition and vulnerability functions)? It is advantageous if the same data and underlying context can be used, both in terms of efficiency of analysis and reducing the complexity of decisions at the end.
- If different data sets are used for the different events, are they available at similar levels of detail, comprehensiveness and time periods? If not, how can the analytical processes

[9] SCADA (supervisory control and data acquisition) is a category of software applications for controlling industrial processes, which is the gathering of data in real time from remote locations.

[10] AEP – the likelihood of exceeding a certain level annually

be modified so that the results can have similar levels of detail, error, confidence and content for decision-makers?

- Will the events be assessed and decisions made on them in isolation to other events, or will there also be some level of combinations of events (considering likely combinations of events, compounding and interdependency effects, local knowledge and cultural history)?
- In presenting the results of several event assessments what common factors/variables will be reported and how will it be displayed, particularly for decision-making purposes?
- How would a decision-making framework be structured to allow consideration of the priorities and trade-offs in deciding between recommendation options related to several individual event results or any event combinations assessed?

In many instances, comparing multiple and different events results in assessments and results that are more focussed on qualitative analysis or perhaps semi-quantitative analysis. They could also be reported both separately by event and in frameworks for combinations, as well as using "traffic light scoring" for diverse factors or multi-criteria type tabulations.

"Unknown unknown" events and deep uncertainty

Some may wonder about whether in identifying the most relevant and critical events thought should be given to preparing for unknown events or for decision making under deep uncertainty.

Unknown "unknown" events are also commonly known as Black Swan events. They are typically a surprise at least to an observer. More information can be found in App. 10.2.5.

2.2.2. Assessing probability

Purpose To determine the various likelihoods for hazard events of interest based on key/critical event from previous section.
Requirements Hazard event severity distribution data.
Compatibility with other processes or systems Any other existing maps of events where probability is indicated.
Outcome An understanding of the likelihood profiles for the various severities of hazards of interest.

The Briefing Note "Terminology on Resilience and Coordination with related PIARC Technical Committees" [6] describes Probability as "impact probability relates to the likelihood of an impact occurring within a given timeframe [FW2015]. Measure of the chance of occurrence expressed as a number between 0 and 1, where 0 is impossibility and 1 is absolute certainty[11]." It has a very similar meaning to both "Likelihood" and "Frequency".

Hazard event probability relates to the likelihood of a hazard of particular severity occurring within a given timeframe. Due to the uncertain nature of climate change (pace, range and scale), assessing probability of impacts occurring can be difficult. However, approximations can be made using climate change projections, evidence of past events, local experience, and information of similar situations.

It is important to recognise the difference between the probability for a certain climate phenomenon and the probability of an unwanted event caused by this phenomenon. For example, a 1 in 100-year precipitation event will not cause a 1 in 100-year drainage failure if the drainage system was appropriately designed, constructed and maintained.

Generally, probability of the hazard event is inversely related to its severity. So, a range of probability: severity scenarios or combinations can be assessed for a particular hazard, should data and need allow. Probability should be scored for a specified point in time or timeframe (e.g. present day, 2040 or 2030-2050).

Obtaining data for the probability assessment

Sources of probability data can include:

- Local and professional knowledge from experience (limited to lifetimes or cultural stories)
- Information about past events, including geological records
- Historical information on impacts (associated with climate change) on the road network, such as emergency works records or physical asset condition inferences
- National, regional, and local risk maps
- Local or regional climate change projections for the future (e.g., IPCC projections)

[11] ISO 31000 (2009) Risk Management – Principles and guidelines

Particularly where there is a lack of information and data, considerations can be made to either interpolate between data points/sets available, undertake approximations using (climate change) projections, or revisit the nature or detail of the hazard events of interest to see if a modified target hazard event may have more data associated or available.

If the transport service, area, road section or asset has pre-existing mitigation measures and/or adaptive capacity in place, this should be recorded with the probability information as modifying factors which should be recognised in the later risk analysis. Notwithstanding these situations adding extra data points and richness to the assessments that can be used in understanding the existing and future risks, so should not be discarded as potentially contaminating the risk analysis.

When analysing the probabilities of events of interest identified in previous stages, it is important to remain alert to the possibilities of concurrent events or cascading events (requiring additional scenarios or maps, etc.). It is also important to keep in mind that probabilities and probability distributions can change over time. These matters add complexity and quantum to the data and information needs, costs and collection challenges for the project. This is described in App. 10.2.6.

Methods for assessing probability

Depending on the type and quality of available data, probability assessment can be qualitative or quantitative or semi-quantitative, as the case studies in 2.2.5 will show.

In cases of quantitative risk assessments, risk probability should be assessed in terms of Annual Exceedance Probability (AEP), such as a 1% AEP being the probability of an equal or larger event per year is 1 per cent. The term AEP is often (but incorrectly) interchanged with return period, such as a 1 in a 100-year flood, which is a particular frequency of event rather than equal or greater than a frequency.

Risk probability can be assessed as a semi-quantitative description of the chance of the risk event occurring, while considering the effectiveness of existing controls. Often a 5-point scale is used, but shorter or longer scales can be used; this should be informed by the level of detail in the data available, and the potential granularity that may be wanted at the end of the assessment. A standard time horizon is used, often related to the strategic planning or funding cycle, such as three years. As with risk consequences, the time periods for each probability level may be adjusted to align with the relevant operating context.

There are also models to predict the probability of occurrence of some phenomena, such as floods or hurricanes.

The time and place

Sometimes the risk analysis scope is to only analyse the current situation. This is relatively straightforward as contemporary data can be collected and consultation can occur with those immediately affected.

In many projects the analysis needs to consider current and future situations, in which the risk will be calculated for different times and in the associated different settings. This raises the challenge of changing probability over time.

As well as contextual changes, the changing climate means that the hazard statistics are also changing over time. There are well known future scenarios for climate change produced by the IPCC, which are progressively being refined in detail and scale (e.g. the Representative Concentration Pathways (RCP's) or Shared Socio-Economic Pathways (SSP's)).

The future variable values or scenarios should be based on the best projections and scientific information available (e.g., the RCPs, and national census information and projections), and if that is limited, use of projections from historic records could be suitable if not projected too far into the future.

Assessing how the risk level varies over time can be basically achieved through undertaking the same analysis for different timeframes (for example, 2040-2050, 2080-2090). Severity score will remain largely unchanged (subject to other factors varying such as age and maintenance of asset), but probability is likely to vary over time. This can be established through the review of climate change projections data – taking particular notice of the potential variations in the future so considering scenarios that represent different mixes of potential future outcomes.

Key controls considered as part of the probability assessment should be recorded in the risk register, along with associated control owners.

Examples of standard likelihood levels are defined below, firstly a semi-quantitative scheme followed by a qualitative example.

Probability Level	Definition
Almost Certain	The risk event has a >85% chance of occurring over the next three years.
Likely	The risk event has a 55-85% chance of occurring over the next three years.
Possible	The risk event has a 30-55% chance of occurring over the next three years.
Unlikely	The risk event has a 5-30% chance of occurring over the next three years.
Rare	The risk event has a <5% chance of occurring over the next three years.

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 that 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

The lower table could also be modified slightly to be used in a qualitative assessment, for example where expert opinion is being relied upon rather than scientific or surveyed data.

Outcome of probability assessment

The outcome of a probability assessment is information or data which can be used in the risk analysis methodology. This could be in numerical form (to be used in a mathematical calculation) or descriptive (to be used in risk tables) - see Section 2.2.5 on risk analysis.

The probability assessment will estimate the (changing) probability of the events taking place and affecting the network at a set of future dates associated with particular levels of severity of event or size of consequence. Alternatively, and often, the road organisation picks a target Annual Exceedance Probability (AEP – for example, say 0.01, or roughly 1:100-year event) as a design demand or minimum service level to use in analysis, design and operations, recognising the broadly inverse relationship between probability and hazard severity.

2.2.3. Assessing severity

Purpose To determine the severity of key consequences for hazard events, focussed on the critical event(s) of interest from previous section.
Requirements Hazard event severity distribution data Vulnerability information for assets, services or impacted communities
Compatibility with other routines or systems Operational forecasting tools and processes
Outcome Information on potential range of severities and related consequences for various potential hazards

Severity can relate to either the magnitude or intensity of natural hazard event (such as the Richter Scale of an earthquake), or the size of an impact caused by the event (such as flooding of a road, heat damage to a bridge, a landslide in a particular location etc.) or the consequences, if it were to be realised, regardless of the probability of occurrence. If relating to impacts, it usually is assessed by the adverse effects on a system, community or environment, rather than on an individual or individual component.

The Briefing Note on terminology [6] describes *consequence*, rather than using the term severity specifically, as the "*Outcome of an event affecting objectives or system. An event can lead to a range of consequences. A consequence can be certain or uncertain and can have positive or negative effects on objectives. (ISO 31000) [53].*

Additionally, impacts are described in ISO 14091 within *"the context of climate change, the term 'impact' is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate change or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes."*

As with probability assessments, there is often much uncertainty driven from the variations in the hazard event (duration, peak strength, area of impact, etc.) and assessing the impacts can be difficult. Those different future settings can also involve changes to demographics of affected groups, urban development, surface water catchment changes, and road network development. There is inherent uncertainty in defining the different future settings, which grows the further into the future the analysis attempts to assess.

This challenge is subject of research in "Decision-making under deep uncertainty". This decision-making under deep uncertainty approach continues in the Framework activities in Stage 3 and 4, where techniques such as Real Options Analysis and Dynamic Adaptive Pathways can be used.

However, the two simplest means of dealing with the uncertainty about the future is to use ranges for the key analytical variables, or to develop a set of possible future scenarios.

The key initial focus for the assessment of the severity, impact or consequence should be on the direct implications or size of the event based on information and data available, with cascading or compounding effects being considered later. This breadth of the event's impact assessment may vary from simple road closure assessments to an elaborate list of various asset, systems or outcome impacts.

Previous experience with and reviews of the Framework have identified two aspects of risk assessment which should be better recognised and utilised, if possible, in the calculation of total risk: adaptive capacity and criticality of the assets/importance of the road. These can be used as additional factors in the risk calculation beyond probability and consequence or used as modifying factors in assessing consequence/severity. These factors are written about in Section 2.1.3 and 1.5, respectively.

However, in assessing the severity (additional costs and impacts) to the user, the road organisation needs to consider likely user responses to a disruption. For example, just because a disruption has occurred to a user's normal route does not mean that the purpose of the trip is prevented until the normal route is restored. Consideration is needed as to whether there is:

- An alternative route
- An alternative mode to make the trip (e.g., boat, walking, train)
- An alternative destination with similar offerings to the original destination
- A virtual alternative (e.g., remote schooling)

These considerations (and which are often what the users actually consider) can result in a reduction of the user costs and impacts of a disruption and lowering the risk by reducing the consequence even if not the likelihood.

In considering road users in the risk analysis, attention should be given to all modes present and affected – are there pedestrians or cyclists, are there elderly or mobility impaired users, are there over-dimension or over-weight vehicles present in addition to the "normal" vehicle mix. The impacts and consequences of these other groups will be different to vehicular traffic, and the solutions or interventions to address them may be specific to them, both in temporary measures to re-establish basic availability as well as the permanent solution or recovery works.

Obtaining data for the assessment

Available data affects what impacts or consequences can be assessed, potentially constraining the scope from Stage 1 and consequently influencing what the risk assessment focuses on. The sources of severity, impact or consequence data are largely the same as for other parts of the assessment. These include for past or present information:

- local or indigenous expert knowledge,
- operational databases,
- ongoing monitoring of key factors
- historical records of previous events and damage effects (and repair costs),
- socio-economic studies of impacts on and from the road network associated with previous events
- impacts on highway operation (including economic losses in logistics changes or travel time losses and crashes)

For future year assessments, data for assessments would be based on two main areas: climate projections (such as the RCP projections and associated implications or disaggregation) and future scenarios and related sensitivity scenario sets, focussing on the events and locations of interest.

The severity of the impact should be estimated using available data (drawn from sources noted above, as well as from previous stages such as the vulnerability assessment, the exposure / location and sensitivity). The estimation of the severity or impacts will require an agreed criteria or indicator (or set of indicators), for example:

- a metric for intensity or magnitude of hazard (mm/12 hrs of rain)
- cost to repair,
- cost of disruption/impact of loss of road;
- duration closed with/without alternate route
- number of trips or population directly affected
- days isolated from key destinations and services

Data needs will be shaped by the chosen criteria and the associated metrics (perhaps using a Severity Scale) and should be tailored according to availability, local needs and priorities, determined from considerations in Stage 1.

As with probability assessments, when assessing future states of roads, recognition and appropriate adjustments should be made to inputs for changing severity of the hazard through time and changing impacts or consequences. However, adjusting for these changes would not usually be needed for variables where the changing context/factors are the same for counterfactual (base case) and the options.

Due to the uncertainty associated with the changes in the future, it is also recommended that either sensitivity or scenario testing is undertaken to determine the key variables and distribution of initial results that most influence the results for this stage. In both cases this gives the analysts and decision-makers better information on which to make better decisions in light of the uncertainties being confronted.

Interdependent impacts, compounding and cascade failures

Once the direct effects of a hazard event have been considered, thought should be given to whether wider matters and effects should be or could be included in the assessments, such as interdependencies with other utilities and services, compounding events or cascading failures. More guidance and comment can be found at App. 10.2.7.

Methods for severity assessment

The severity/consequence assessment should be based around consideration of the key performance indicators identified in Stage 1. These could relate to direct transport system costs, indirect transport system costs, intangible matters or organisational risks. There could be very few (perhaps just looking at repair costs or number of disruptions) through to a comprehensive list considering a wider range of potential impacts from across several domains (economic, social, infrastructure performance, environmental, cultural).

When assessing a network or corridor, it is usual practice that the assigned “Severity Score” is that corresponding to the highest rated indicator. For example, if a Severity-related indicator is scored as 5 (Very High) and all other Severity-related indicators are scored as 4 (High), then the overall “Severity Score” would be 5 (Very High) for that section or network. Where there are multiple potential consequences for an event, the most significant consequence should be used for the assessment summary.

It is recommended that the basis for the scores assigned during the assessment is recorded for both future reference and/or moderation across all assessments that may be compared in later decision-making.

The assessment should also take into account any in-built mitigation measure, but should not include any measures that are not currently in place.

Some road organisations will have an enterprise-wide risk policy, framework and practice. These can include a general scale of consequences or criteria for assessing severity of unwanted events in their risk assessment process. These may be also present in other transport outcome disciplines in the organisation such as road safety or asset management. It is worth considering how applicable the scale or framework may be for the climate change risk assessment, and possibly incorporate it directly or with suitable adjustments. This can both assist the risk conversations in general at the organisation especially in their decision-making, as well as save project time and debate in setting up a bespoke indicator assessment framework for the climate change project.

There is value in establishing a table or data base of all possible impacts and consequences to identify objectively and rationally as many impacts as possible (constrained by the data and information available to assess them), and to manage them during the assessment and subsequent evaluations of potential response strategies.

Quantitative, semi-quantitative and qualitative assessment

Some consequence criteria are appropriate for quantitative assessment (e.g. economic impacts) whereas others are difficult to quantify (e.g. management effort). Hence the criteria used for assessing the consequence drives the nature of the assessment – whether it be quantitative, semi-quantitative or qualitative, or even a hybrid (for example reporting through a Multi-Criteria Assessment table with a mix).

Consequence categories

While assessment categories can be fairly standard, the definition of each level (for example, an “Extreme” Financial impact) may vary depending on the road organisation or function conducting the assessment and the specific nature and project objectives and structures of the risk assessment project.

As with Probability, often a 5-point scale is used, but shorter or longer scales can be used; this should be informed by the level of detail in the data available, and the potential granularity that may be wanted at the end of the assessment. See example in Table 5.

Table 5. Example Impact Severity Scale (other criteria can be used as necessary) [FW2015]

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

Risk consequences should be assessed against standard levels within a project, and the level assigned should explicitly consider the effectiveness of existing controls. For example, while a malicious cyber-attack could disrupt a road organisation's operating system, consideration should be given to what processes and systems are already in place (and how effective they are) when assigning a risk level.

Key controls considered as part of this assessment should be recorded in the risk register, along with associated control owners.

Please see App. 10.2.8 for examples of:

- template for quantitative assessment of direct transport system costs with possible indicators (such as number of affected vehicles, duration of disruption and repair costs). The severity is scaled from 'insignificant' to 'extreme'.
- examples of standard consequence tables for semi-quantitative assessment of indirect transport system cost (such as affected population, society, supply chains etc.), with corresponding consequence criteria for assessing strategic or organisational risk.

Two factors that can modify the result of consequence in a risk assessment are *criticality of the assets* (importance of the road) and *adaptive capacity.* They have been discussed in Sections 1.5 and 2.1.3, respectively. They can be used as factors in the calculation of vulnerability (see 2.1.4) and risk (2.2.5) or be used as modifying factors for criteria for assessing consequence /severity.

Outcome of the severity assessment

The outcome of a severity/consequences assessment is information or data which can be used in the risk assessment methodology. As with the probability assessment, this could be in numerical form (to be used in a quantitative mathematical calculation) or descriptive (to be used in semi-quantitative or qualitative risk tables), dependent upon the indicator sets and data agreed and available for the assessment – see Section 2.2.5 on risk assessment.

The severity/consequences assessment for climate change assessments needs to estimate the (changing) magnitude or intensity of the events taking place and affecting the network at a set of future dates associated with particular return periods. Alternatively, and often, the road organisation selects a target Annual Exceedance Probability (AEP – for example, say 0.01, or roughly 1:100-year event) as a design demand or minimum service level to use in analysis, design and operations.

2.2.4. Assessing risk

Purpose To quantify the risks posed to networks and assets in an effective, accessible, iterative, robust and holistic way. To combine the findings of the probability and severity assessments to determine the risk for the element(s) of focus.
Requirements Assessments of probability of (a range of) hazards of interest; Assessments of level of consequence, disruption or damage from various hazards of interest; Geospatial information for the assets, links, corridors of focus.
Compatibility with other processes or systems Schemes for probability and consequence descriptions that may exist in asset management plans or system operations management plans.
Outcome Risk scores for items of interest related to various hazards or combinations of hazards; for Business As Usual and alternative future scenarios, for use in investment prioritisation and programming and emergency response priorities.

Analysing risk is at the core of the full Climate Change Adaptation Framework methodology.

'Risk' can be seen as a combination of probability and severity. It is where the road organisation brings together all the previous information and assessments into a summary form. This is to gain insights and understanding about the focus of the project as determined in Stage 1 and provides the launch point for the work of Stage 3, which considers how best to respond to risks of concern.

A risk assessment involves the identification, analysis, and evaluation (grading and prioritisation) of risks relevant to an asset/project/service (ISO 31000 "Risk Management"). The analysis involves some means of combining the level of risk probability (likelihood of future impacts on the asset) and severity (consequence of the impacts on the asset) – see previous sections. The risk assessment also aims to evaluate to provide a list of prioritised risks, in which the highest/extreme risks would likely be the focus of a subsequent adaptation response.

This section covers the following:

- Data needs
- Methods for risk analysis and related case studies a risk register
- residual risk and risk registers
- Outcomes and uses of the risk analysis

The means of analysing risk needs to be able to both assess:

- a base case or the current situation or a do-nothing future scenario, and
- the various potential response programmes or interventions (various future alternative scenarios)

The Briefing Note "Terminology on Resilience and Coordination with related PIARC Technical Committees"[6] defines risk using the ISO 31000 (2009) definition, as *"Effect of uncertainty on objectives. Risk is often characterised by reference to potential events, consequences, or a* *combination of these and how they can affect the achievement of objectives. Risk is often expressed in terms of a combination of the consequences of an event or a change in circumstances, and the associated likelihood of occurrence."*

The Briefing Note goes on to define 'risk analysis' as a "Process to comprehend the nature of risk and to determine the level of risk. Risk analysis provides the basis for risk evaluation and decisions about risk treatment." (ISO 31000 Risk management – Principles and Guidelines). See App. 10.2.9 for more discussion on risk analysis.

2.2.5. Risk Analysis Methods and case studies

Focus of analysis: assets and networks

The assessment and prioritisation of risks within Stage 2 of the PIARC Framework is based on risk being a function of probability and severity. The risk analysis also aims to provide a list of prioritised risks, whereby higher risks would be the focus of an adaptation response.

A road organisation may not yet have a specific process to address climate change in its risk assessment processes, yet it may have an existing general method for risk assessment of roads or assets. In such cases, it is only reasonable to expand the existing methodology by introducing aspects of climate change, instead of developing a new method for risk analysis.

The road organisation needs to develop a method of assessing risk through combining in in a tailored approach, the assessments of probability and severity which has been undertaken in previous sections. The method will need to be able to assess and demonstrate the current or anticipated future base case as well as be able to reflect and indicate the change to impacts or risk which occurs due to proposed interventions or strategies. It also needs to be able to recognise existing mitigations and risk controls.

Focus of analysis: road users

Work undertaken in Stage 1 of the Framework should have identified the focus of the risk analysis: that is to say which receptors of the consequences of a hazard event are of main concern such as asset, user or community well-being related.

Often road authorities focus on principally the costs and impacts on their assets and networks, and how to return them to normal functionality as efficiently as possible. There are three main user groups affected when road infrastructure performance is disrupted. They are the user, the owner, and the operator. For the user, owner and operator, resilience refers to the availability (and safety) of roads for travel and the services they provide. However, in many cases, the larger costs and impacts are experienced by the users and communities (lack of access to services, impacted livelihoods, higher transport costs) rather than the owner and/or operator (asset damage costs and impacts). The users' costs include their direct transport costs of additional travel time costs, additional vehicle operating costs (extra distance, travel on rougher roads, etc.) and risk of personal harm, freight losses and property damage

Broader costs and impacts related to community and wider economic issues such as value of quality of life, access to critical services, productivity and competitiveness are covered under Section 2.3.

A factor for risk analysis to consider with the time and place of the analysis are the annual distributions of demand and users. For example, at certain times of a year, there may be a peak of tourists in an area who have particular profiles which make them particularly vulnerable to hazard risks. Equally changing exposure of children may occur depending on whether it is school term or holidays. And at a fine-grained daily level, at night-time people tend to be in suburban areas rather than central business or other employment zones so the distribution of where people are during an event can vary on a broadly regular basis.

Focus of analysis: Communities

An important user group that usually bears the full brunt of the adverse climatic events, particularly in LMICs, is the communities (principally rural). The communities that live along the influence area of the road, or are being serviced by the asset, tend to get impacted negatively in the event of the asset being damaged and/or services disrupted. The situation is worse for those living in the hinterland where access is difficult if not impossible during and after these events.

There is evidence that loss of life and livelihoods is exacerbated by delayed and ineffective recovery efforts because of poor access, lack of early warning systems, among other reasons. These communities are also particularly vulnerable due to non-adherence to land use best practices that increases their exposure to climatic hazards.

The negative impact is compounded by destruction of their source of livelihood in the form of agricultural activities such as cropping and livestock.

Residual risk

Residual risk is the risk that remains after actions or interventions to modify and/or eliminate some or all the targeted risks have been made. It is not the change in risk between the counter-factual and option scenario (which represents to benefit or cost stream of the changes in risk from the changes in context or due to intervention programmes).

Residual risk is important because it is the remaining risk “left over” after interventions or improvements have been applied. It is a key consideration for decision-makers in Stage 4 in determining whether the proposed resilience or risk strategy proposed is successful and meets the aspirations set out in Stage 1. There will always be some level of residual risk, however small, but the desired outcome should be to reduce the residual risk to an acceptable (and manageable) level, i.e. below the thresholds and tolerance levels used elsewhere.

If residual risk is above the thresholds or tolerance levels (from Stage 1), then decisions (Stage 4) will be needed about how to respond to this situation. Considerations would include

- Reviewing the threshold or tolerance level (is it too aspirational or too high a standard?)
- Are there further intervention options available which could get the risk within the target levels?
- Does the road organisation accept the risk identified?
- Are there priority areas or actions which could bring (critical) parts of the affected location, assets or operations within tolerance and accept the balance do not meet the targets?

Whatever the situation related to residual risk results, the project should explicitly communicate the situation (results and implications) to the decision-makers, users and those impacted so that they are aware of the ongoing risk profile in the various situations or scenarios, however nominal or not.

Summing them all up

Depending on the scope of the framework analysis determined in Stage 1, it is possible that the road organisation will have many risks assessment scores. Risk calculations (for locations, assets or operations) are repeated several times in this Framework, starting with a base case, then potentially the future scenarios (Business–As-Usual and/or potential alternative futures), and finally for the impacts of potential intervention programmes.

These could relate to risk scores:

- along a corridor or through different parts of a region
- for different hazards at a site or affecting a suite of assets
- for different future scenarios (at different times and/or different projections of changes to climate)
- for different return periods of a hazard

The potential array of risk assessment scores could be difficult to manage and interpret. The presentation of the results of the risk analyses in a way that is easily understood and informative is a key input to the work of Stage 4 – Decision-making, especially to compare and contrast the different effects of various optional programmes of potential interventions. There are several ways that these results could be presented and interpreted, again depending upon the decisions of the scoping undertaken in Stage 1. These include:

- a colour coded table of risk scores
- sum the scores to get a total for all the test scores for each location, asset or operation
- identify and use the highest risk score from across the tests for each location, asset or operation
- a multi-criteria assessment table with weightings and summed results for each location, asset or operation
- graphing the results (over time) and assess the trends of change and pace of change (particularly in relation to tolerance thresholds and triggers)

Recording the results – use of risk register

Communication and good recording is fundamental to a successful adaptation plan both during its development and later with its implementation, with road users, stakeholders and decision-makers. Communication with stakeholders has been the subject of 1.4.2, while communicating the findings of the assessment will be described in 4.2.

An effective way of recording key results of the analysis is to use a form of risk register. A risk register is essentially a table of project risks that allows the tracking of each identified risk and any vital information about it. It is used to identify potential risks in a project or an organisation or a domain of interest to stay on top of potential issues that can derail intended outcomes.

Its key function is to provide the road organisation, governance groups and key stakeholders with significant information on the main risks faced. The risk register also gives the risk managers a clear view of the current status of each risk, at any point in time.

A risk register is where all the identified risks from hazards are contained. It is a key means of communicating risks with the governance, management team, co-workers and organisations that are interacted with.

For each register there will be fields with identifying details, which will describe and determine the risk rating, as well as show any the actions taken and actions required to ensure this risk is being managed appropriately and who is assigned responsibility for those actions.

Risk registers are particularly useful and important for the risks which are accepted and not taken through to Stage 3 of the Framework for further analysis and response. Those accepted should be documented for later addressing or ongoing management, as well as for future reference about why others were taken forward and these ones accepted at the time of assessment.

Options and Case Studies

As detailed in the above sections, 'Risk' can be seen as a combination of probability and severity. Dependent on how criticality and adaptive capacity are dealt with in the consequence calculation, they could also be added to the calculation process for a risk score. This is similar to the assessment of vulnerability (Section 2.1.4).

A simple method for assessing risk for a qualitative analysis is to apply the probability and consequence scores to a Risk Score Matrix like in Figure 15.

The probability and consequence scores can be combined (i.e. multiplied) to give a range of scores from 1 to 25 (a Risk Value), which could then also be applied to the Risk categories (a rating or grading scheme) and responses table. These can be colour-coded, and outline levels of action and attention can be determined, such as indicated in Table 6.

	Severity/Consequence				
Probability	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

Figure 15. Examples of risk score matrix [FW2015]

Table 6. Example of table of risk categories vs. responses [FW2015]

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 can be acceptable without treatment.

These methods of assessing 'Risk' show the risk at a point in time and place that it might occur, but does not show the trend in risk over time or between scenarios. A series of risk analyses will need to be undertaken to evaluate various future scenarios or potential intervention programmes of interest to see how much chance occurs or how effective they are in achieving the desired outcomes or target thresholds for the key indicators (and get a sense of the possible residual risk which would need to be accepted with each decision).

In ISO standards, a methodology for assessing vulnerability and risk can be found in:

- **ISO 31000:2018** – "Risk management guidelines" – as part of its 5-step process (context, identification, analysis, evaluation, response + monitoring/review)
- **ISO 14091: 2021** "Adaptation to climate change – Guidelines on vulnerability, impacts and risk management" chapter 6 (Implementing a climate change risk assessment)

There are many methods for assessing transport system risks from climate change. They differ in the ways elements are put together, or the algorithms for calculation of risk scores. Here are some examples.

**** ROADAPT – assessing risk** (→ Sec. 9.2.12)

In the ROADAPT methodology, risk is assessed from scores of probabilities and consequences. The consequence estimates are weighted, so that the calculation of risk score is adjusted to each specific case. Also, the concept of criticality is introduced, called 'importance of the road' and based on redundancy, economic importance of the road and traffic intensity. By estimating the current and future probability, one gets current and future risk scores, in that way illustrating the impact of climate change.

**** Methodology for analysing risk – Cerema, France** (→ Sec. 9.2.13)

The report "Vulnerabilities and risks: Transport infrastructure in the face of climate change" [54], proposes a ten-step procedure for analysing risk on infrastructure network. It starts with defining the climatic loading, analysing the infrastructure, and analysing criticality.

**** Increasing resilience of earth structures on roads in Northern Spain** (→ 9.2.14)

This case study includes the process of selecting the main climate variables based on experience from weather-related events on the road [55].

**** Criticality including the aspect of vulnerability** (→ Sec. 9.1.12)

.. a three-step framework to prioritise road segments for climate-resilience investments. Vulnerability is an element of 'composite criticality', which is a criterion for prioritising resilience strengthening investments [56].

**** VegROS Norway** (→ Sec. 9.2.15)

.. is an example of a simple and practical scoring system for risk assessment of roads that has been used for periodic risk assessment. The risk score includes a score for level of threat, importance of the road, and the adaptive capacity. (NPRA, 2023)

**** A Framework for Informed Choices – Transport Research Board** (→ Sec. 9.2.16)

This report provides an overview of practice and research relevant for introducing resilience into asset management and investment plans [57]. A multi-step and multi-hazard approach is suggested, where criticality, vulnerability and potential damage are combined.

**** New Zealand - National Resilience Programme Business Case** (→ Sec. 9.2.17)

The purpose of this project was to provide an evidence base of the nationally important risks posed to the New Zealand land transport system from natural hazards. This project is an example of how to undertake a pragmatic risk assessment of a significant length of network (11,000km), using the consistent data sets available at such a scale.

**** Coastal prioritisation index for erosion (IPIC-E) - Quebec** (→ Sec. 9.2.18)

The Action plan for infrastructure management in the context of climate change (PAGI3C) was adopted by the Ministère des transports et de la Mobilité durable du Québec (see 1.2).
One of the first structuring actions of PAGI3C was the development of indices for prioritizing coastal interventions (IPIC-E). An initial index for erosion (IPIC-E) has been developed, while indices for marine flooding and for landslides are under development.

**** Mondego Mobility System Climate Assessment** (→ Sec. 9.2.19)

This case study from Portugal is an example of risk assessment in the urban environment.

2.2.6. Outcome of Stage 2.2 – Assessing risk

The outcomes of this risk analysis phase are to have identified and enabled risk calculation method(s) for testing the natural hazard (climate change) and scenario risks confronting the location, assets or operations as identified in Stage 1 as the focus of the project.

There are many ways to conduct a risk analysis, even within the principles of this framework, which can depend on scope requirements and the data or resources available. However, it is essential to be consistent in each risk analysis run. The results can be qualitative, semi-quantitative or quantitative, and the scoping and reporting of results needs to recognise which is the case.

This risk analysis approach is based on the risk definition of Risk = Probability * Consequence, where consequence can be assessed using exposure, sensitivity, adaptive capacity, and criticality.

As with the probability and severity assessments, the risk assessment results could be in numerical form (using a mathematical calculation) or descriptive (using risk tables /matrixes), dependent upon the indicator sets and data available and used for the assessment.

It is suggested to do sensitivity tests (i.e. multiple runs with key factors varied) to develop ranges and distributions of results, rather than relying upon a single fixed number or narrow rating. This also gives a better understanding of the key issues which will influence the resilience of the location, assets or operations.

The risk analysis framework will enable the impacts and risks of the base-case (as identified in Stage 1) to be rated and prioritised for action. Road organisations should decide, using the evidence gathered through the risk assessment, which impacts to address and take forward to the next stage.

Prioritising these base-case risks in this way will subsequently aid the development and prioritisation of adaptation responses and strategies for targeting the priority risks within Stage 3 of this Framework. The risk analysis framework would then be applied to the proposed programmes of adaptation responses and strategies to test the effect of the proposals on the priority risks (what would be the residual risk?). If necessary, this process can be iterated to target certain results and refine the Stage 3 proposals and compare the results against the original project objectives from Stage 1. These rated and prioritised impacts and risks can be used to develop a Risk Register.

Summary - Recommended action:

Following the aims and scope of the analysis (as formulated in Section 1.2), focusing on the most relevant events (2.2.1), and using the outcome of the vulnerability assessment (2.1.6) to limit the scope, assess elements of a risk score:

- **Probability:** obtained from risk maps, or from history of events, or assessed by the help of indicators, will give us an idea of what is most likely to happen.
- **Consequences:** which can be expressed by a whole range of factors, from simple road closure (Y/N) to non-quantifiable consequences (such as loss of reputation) will give us an idea of possible outcomes of unmanaged threats.
- **A combination of probability and consequence** will highlight the situations that need to be mitigated first.

Alternatively, estimate the expected damage of the infrastructure and the expected losses for road users, and in that way highlight the points that should be priorities for action.

Document the results in a risk register.

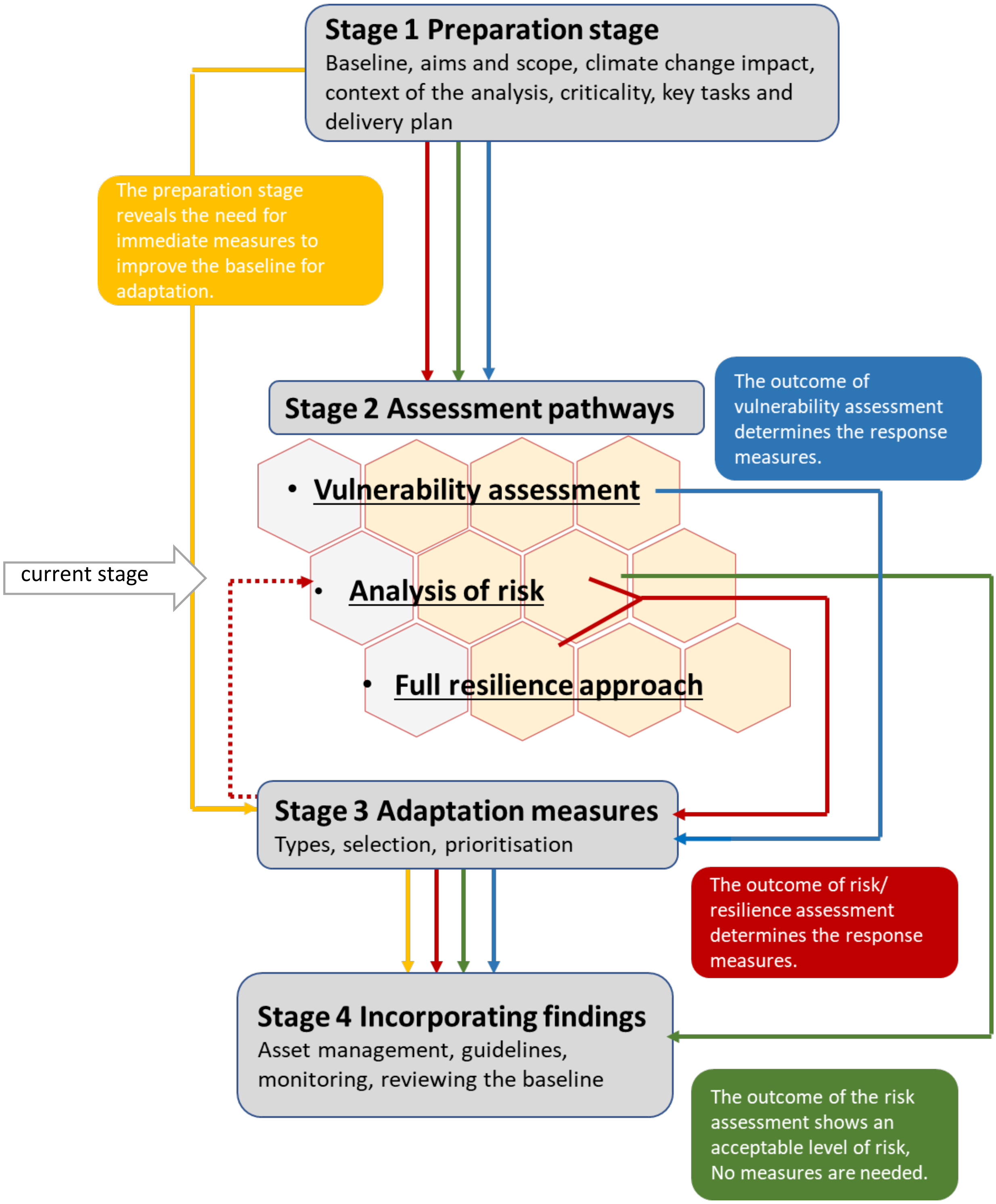
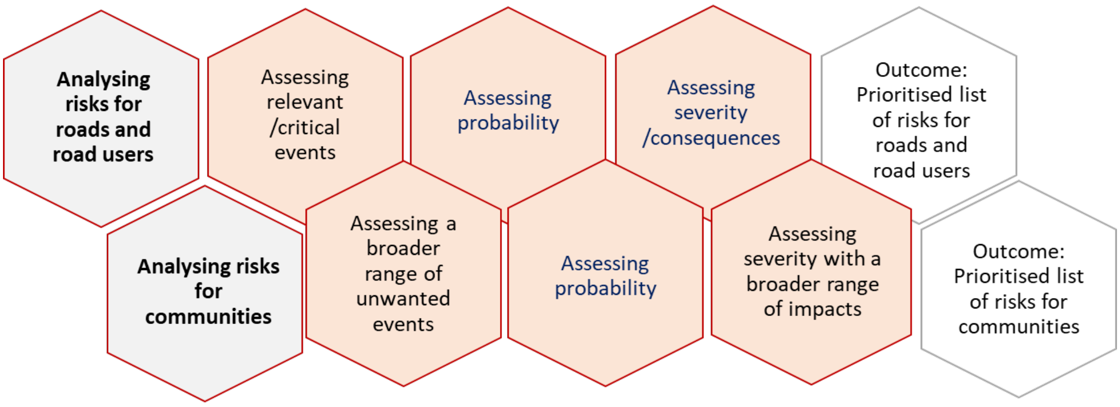


Figure 16. Illustration of the Framework: four main stages and possible assessment pathways.

Findings should be incorporated into road organisation's decision-making processes to ensure implementation, monitor progress, and develop a starting point for future assessments.

2.3. RESILIENCE APPROACH TO CLIMATE IMPACTS



2.3.1. Overview

Much of the above content has been focussed on the risks to asset or network condition and functionality, with a view to guiding adaptation actions to reduce the risks to the assets and networks. Resilience is greater than this risk assessment process, which can be seen in the various definitions which are used. For example, the current (2019) PIARC definition for resilience is "*the ability to <u>prepare</u> and <u>plan</u> for, <u>absorb</u>, <u>recover</u> from, or more successfully <u>adapt to</u> actual or potential adverse events*".

Increasingly road organisations are asking the "why?" question around resilience i.e., "Why are we wanting to make the system more resilient?". The transport system provides services to enable strategic social and economic infrastructure. It is also dependent upon a range of services from strategic social and economic infrastructure to operate. Strategic social and economic infrastructure is the infrastructure (and services) which enable the urban environment, health, education, energy, communications, tourism and commerce. These collectively support community resilience.

Resilience seeks to focus on effects on services provided and potential socio-economic impacts to the customer or communities. The road organisations are increasingly focusing on minimising any adverse impacts on customers and business from disruptions of the services being provided by the transport system for which they are responsible, rather than just focussing on the condition and functioning of their assets. With regard to the socio-economic context, it is about how the adaptation project addresses the existing communities' vulnerabilities and climate resilience, and potentially where it is exacerbating them.

For example, in a flooding adaptation project, the possible socio-economic impacts of such an adaptation project can go beyond and be separate from simply considering the cost as damage cost and assets repair value and consider matters such as: 1) Will the new asset cause communities to move or move their livelihood? 2) Will the diverting of the flooded water endanger other communities? 3) Will it adversely impact the ecological systems?

Undertaking a resilience assessment or programme, therefore broadens the scope beyond the risk analysis focus on assets and networks to a wider ranging set of issues and impacts that cover more complex target levels of service analysis, distributions of effects (and equity) and multi-system and service-provision thinking.

This leads to the interest in a more comprehensive and complex scope that could be established in Stage 1 which could be described as a Community-Impacts (or Full Resilience) Approach. Such an approach is much more complex, and resource and information intensive. It would consider the risks of impacts to the functioning of the communities exposed to the hazards of interest and are affected by disruptions to the transport system services that support those community functions. These assessments can consider a wide range of potential risk domains (but may not consider all) such as:

- Access to critical services and functions (e.g. hospital, food, energy, firefighting, etc.)
- Access to community functions and services (schools, work, voluntary services, etc.)
- Business and local economic impacts
- Reputational and community trust/social licence impacts
- Media and information risks
- Legal and compliance risks/requirements
- Environmental impacts
- Funding, revenue and financial risks

This would result in quite a different set of indicators to be reported on and used in subsequent decision-making. It also opens up a range of additional potential solutions or interventions to explore and implement in addressing the new performance indicators and impacts of interest.

2.3.2. Data and information needs

A Full Resilience Approach will need additional information above and beyond that of the standard asset and network risk analysis approach. This would be required to support a range of different indicators, and would cover extra data and information areas such as:

- macro and local economic,
- socio-demographic,
- sites of cultural significance,
- records and mapping of indigenous information
- environmental condition and monitoring
- geospatial information and resources (business locations, public and community facilities)

It is likely that some surrogate information sources will be required as direct information for indicators of some outcomes and community concerns may not be available or directly measurable.

There will need to be information and knowledge developed to show the relationships and their nature between the community indicators and the services provided by the transport system.

Additionally, greater recognition, understanding and assessment of the interdependencies (and consequently related potential cascade failures) across network utilities would be needed, such as transport system reliance on communications networks and vice versa.

2.3.3. The RA2CE modelling framework

Resilience of infrastructure, or rather lack of resilience and the need for action, can be assessed by combining expected damages from climate related events and expected losses for the users of the infrastructure. This is embodied in the RA2CE framework, developed by Deltares, Netherlands.

The RA2CE modelling framework [58] - Resilience Assessment and Action perspective for Critical Infrastructure – has been developed by Deltares in the Netherlands to support road organisations take decisions concerning resilience assessments and adaptation. It provides a basis for producing resilience maps for infrastructure networks.

The framework covers all steps from exposure, via vulnerability and criticality to risk and resilience, see Figure 17. Outputs are expressed as exposure, criticality, annual expected damages for operator costs (direct) and annual expected losses for road users for societal costs (indirect) and can be used for identification of hot spots. The network criticality analyses are based on graph theory using single and multiple link disruption analyses and have been used widely in climate-adaptation planning studies. For further assessment of indirect impacts, inclusiveness and equity principles can be applied. In adaptation and planning studies, this platform enables cost-benefit assessments to be performed including for an uncertain future.

The use of vulnerability functions for assessing expected annual damage (EAD) was described in 2.1.5. The monetary value of expected damage can be related to the cost of repair or cost of replacement of the asset.

If the aim is to include the socio-economic impact of disruptions, the losses for road users should be included. The estimate of losses can be done by assessing criticality of the roads or road sections, combined with exposure data and with additional time costs due to longer travel routes. The losses can be expressed as expected annual losses (EAL) – to provide input for decision-making on the network level. The calculation of EAL can be done for a variety of probabilities, in that way incorporating information of *risk*.

In this way, all aspects of impact that cause economic consequences are included, giving this approach a broader value. Non-tangible consequences, such as fear of hazards, inconvenience, other aspect of quality of life are currently not included.

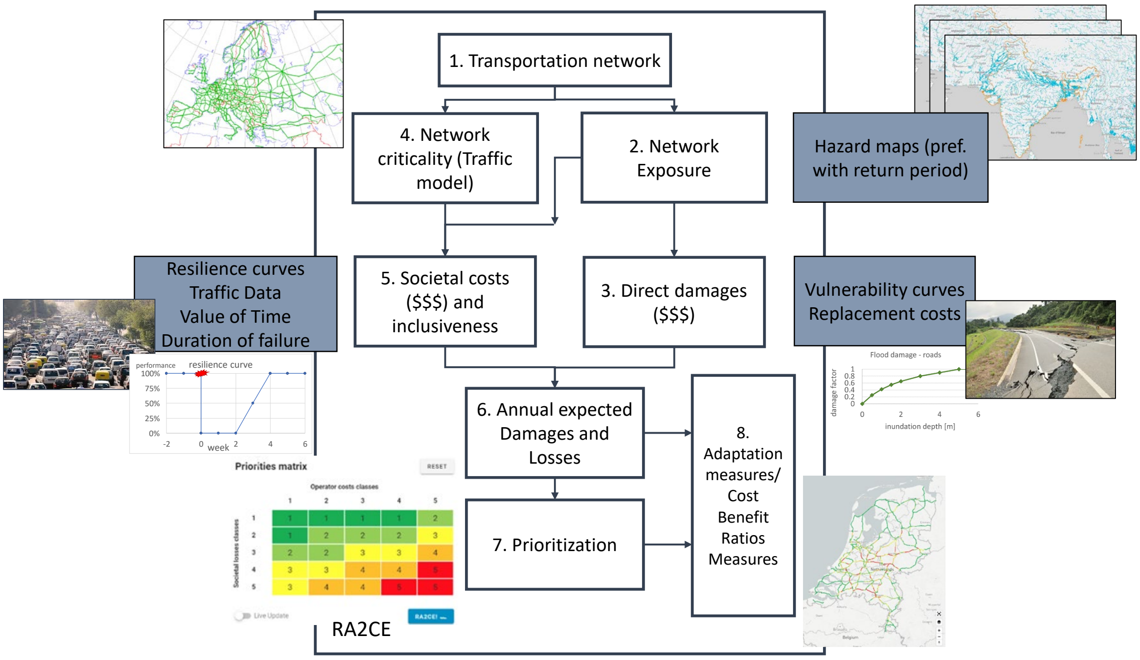


Figure 17. The RA2CE Framework (Deltares, NL)

Examples are the Netherlands (see 9.0.5), Philippines (se example below), Myanmar, Dominican Republic and Albania.

** **Vulnerability and resilience assessment in the Philippines (Deltares, NL)** (→ Sec. 9.2.20)

In the Philippines, there was a need to assess the resilience of the provincial road network and suggest an adaptation strategy. In this case study [59], vulnerability and resilience were assessed by the help of expected annual damage of the road network and expected annual losses for road users. All aspects of consequences that have a socio-economic impact are included. Non-tangible impacts are not included.

An adaptation strategy was developed that corresponds to DMDU approach (Decision Making under Deep Uncertainty) however adjusted to a basic level.

** **FORESEE: CEN workshop agreement – Assessing resilience** (→ Sec. 9.2.21)

The FORESEE project developed CEN Workshop agreement CWA 17819 “Guidelines for the assessment of resilience of transport infrastructure to potentially disruptive events”.

** **Norway: 3R method, simplified resilience approach** (→ Sec. 9.2.22)

The 3R-method is a simplified resilience assessment of roads, where the main elements are robustness, redundancy, and recovery. For a certain road project / alternative, the impact on these three factors is scored. Combined with a score of the “importance of the road”, one gets a final “consequence score”, which can be used for comparison of two options [60].

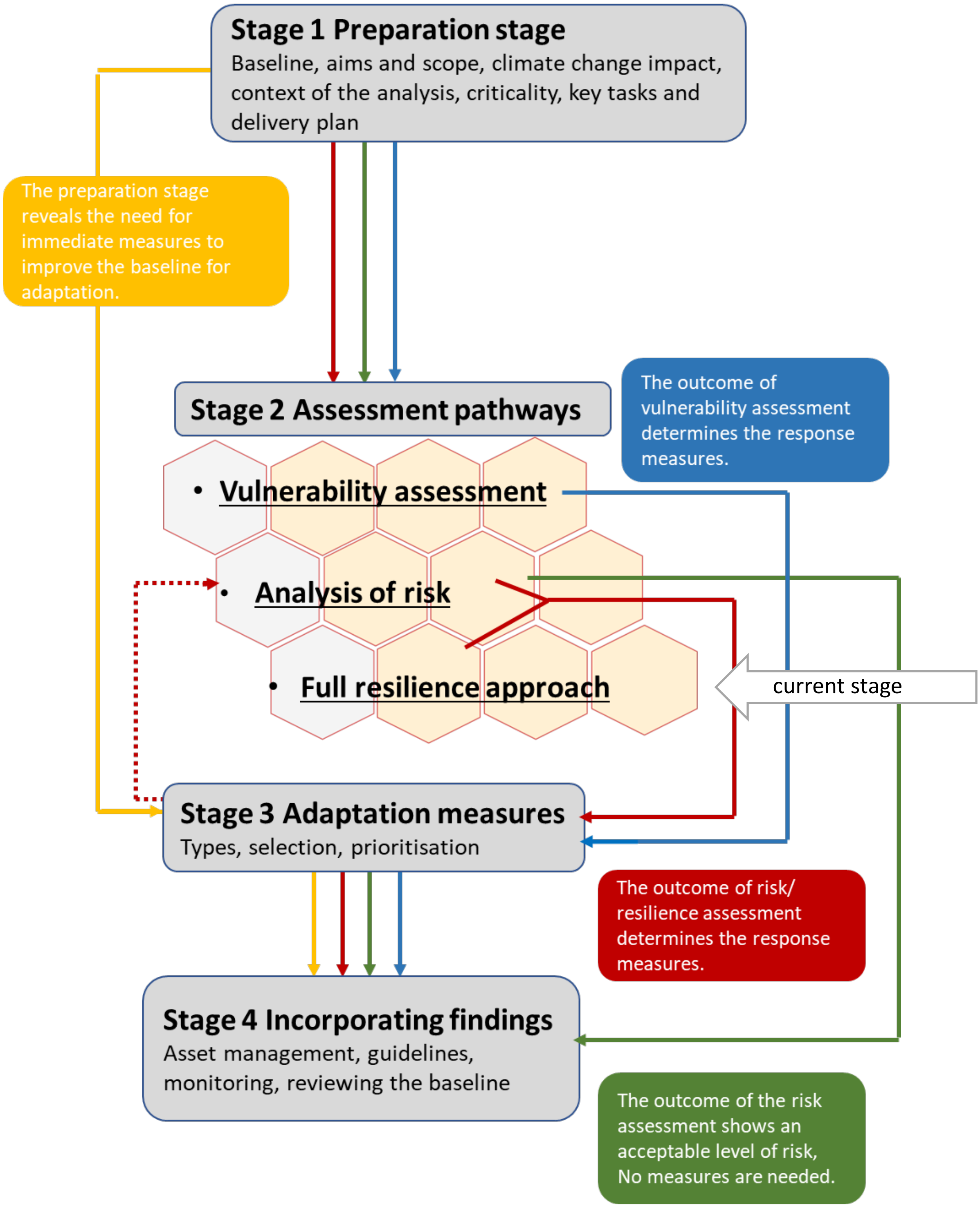


Figure 18. Illustration of the Framework: four main stages and possible assessment pathways.

Findings should be incorporated into road organisation's decision-making processes to ensure implementation, monitor progress, and develop a starting point for future assessments.

2.3.4. Community Resilience

Land transport systems and networks provide services to different kinds of 'communities' and stakeholders. The way these are defined combined with the different views that exist on 'resilience' increase the complexity when trying to build 'community resilience'. Effort should be made to establish a common understanding and expectation of these terms should a road organisation wish to undertake a full and comprehensive resilience assessment.

For instance, 'community' is a term that may encompass many different definitions, ranging from geographical location to similar organisations and to all types of groups of people with common characteristics. Similarly, 'resilience' has been defined differently by different organisations, and even definitions provided by the same organisation have undergone modifications over time. PIARC is no exception to this.

With further discussion and research it can be concluded that there is no common, agreed definition of "community resilience" [62].

As such, initial efforts (in Stage 1) must concentrate on harmonizing the 'resilience' and 'community' concepts among involved stakeholders since their definition may ultimately affect the way that stakeholders attempt to measure a community's 'resilience' and enhance it. See further discussion for a proposed 4-step approach for narrowing down and harmonizing the approach to 'community resilience' in App. 10.2.10. However, this proposed approach does not aim at quantitatively or qualitatively establishing or measuring some pre-defined 'resilience' metric. Rather it proposes an approach for establishing a stakeholder understanding and agreement on basic principles and definitions and enabling relevant targeted insights so that these can be duly considered in the adopted 'resilience' quantification approach or method [65], [66].

2.3.5. Taking the Full Resilience Approach forward

Full consideration of the Community Impacts/Full Resilience Approach goes beyond the scope of this Framework update as outlined in the PIARC 2019-23 Strategic Plan and the recommendations of the 2019 report "Refinement of PIARC's International Climate Change Adaptation Framework for Road Infrastructure".

Box 4 (Risk and Resilience) presents thoughts on the difference between risk and resilience. It notes that Risk can be characterised by reference to the likelihood of potential events, consequences, or a combination of these and how they can directly (usually) or indirectly affect the achievement of objectives or system operation. Risk is often expressed in terms of a combination of the consequences of an event or a change in circumstances, and the associated likelihood of occurrence. Resilience is described as focusing on minimising impacts on services provided to users and communities through the restoration of initial conditions or the adaptation to a new operating scenario. A resilience assessment looks at the (range and distribution of) impacts from natural hazards on the services provided for users and community and interdependencies with other utilities; and provides recommendations to maintain the essential function, identity and structure of the system's services.

The PIARC Technical Committee 1.4 Working Group 1 report "Uniform and holistic methodological approaches to climate change and other hazards resilience" (2023) includes a chapter covering the difference between resilience and risk management; how the level of resilience can be understood; and how can it be measured or visualised. It outlines the need for road network resilience in ensuring reliable operations, mobility, supply chain movements with the ultimate goal to enhance the resilience of society which depends on the road network. Resilience is about providing services during and after transport system disruptions.

In the Working Group 1 report forthcoming in 2023, risk is noted as assessing the possible threats and opportunities from a hazard and the potential consequences of the hazard. It also notes that there are many definitions for resilience used across the various PIARC Technical Committees and reports, and proposes one for the purposes of that report:

> "The ability of a system, exposed to a hazardous event, a trend or a disturbance, to resist, absorb, accommodate, adapt to, transform, learn and recover from the induced effects in a timely and efficient manner that maintain their essential function, identity and structure" (adapted and slightly amended …. from IPCC, 2019 and UNDRR 2017).

From the above, it may be concluded that a resilience assessment starts with the risk assessment, but needs to take into account a wider range of actions (perhaps grouped under Resilience Cycle structures such as Robustness /Resourcefulness /Recovery /Adaptability or Reduction/ Readiness /Response /Recovery) to minimise the impacts (reduced effects, faster recovery, social dislocation, economic disruptions, etc.) at a community level from hazards. It also potentially gives more consideration to distributional effects, interdependencies, cascading and compounding events, and a wider range of consequence domains (economic, social, environmental, cultural).

Guiding a Full Resilience Approach could form a part of the next key update in future PIARC work cycles. This could align the Framework more with the UN's Agenda for Sustainable Development, in which the principles of the resilience of transport systems are included in some of the 17 SDGs to be achieved by 2030 to make the future of our communities more sustainable. These include the following goals:

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation;

Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable;

as well as

Goal 13. Take urgent action to combat climate change and its impacts.

The content of a future Strategic Plan that scopes such a project could suggest sections to address, including

- the purpose and value of choosing a Full Resilience Approach over a standard asset or direct user risk assessment,
- the differences to a standard risk assessment,
- the additional data needs
- engagement and stakeholder involvement,
- criteria and potential issues of interest,
- guidance concerning methods, and
- differences in reporting and decision-making.

Stage 3

Developing and Selecting Adaptation Responses and Strategies

3. STAGE 3 - DEVELOPING AND SELECTING ADAPTATION RESPONSES AND STRATEGIES

3.1. IDENTIFICATION OF ADAPTATION RESPONSES AND STRATEGIES

Purpose of the work in this step Assess possible and relevant adaptation options as per the needs of the road organisation.
Requirements: Details of available human, material, technological resources, technical and organisational capacity of the road organisation.
Compatibility with other processes or systems Active reaction strategies (for managing disruptions), existing emergency and incident management plans, maintenance plans and budgets.
Outcome Possible adaptation measures and strategies are identified, to be assessed closely and prioritised.

In this stage of the work, the tasks are to:

- Assess technical capacity from the road organisation to identify the adaptation actions.
- Collect additional input from individuals and groups who hold local knowledge and experience;
- Assess options for adaptation measures /strategies.

This section will explain how to identify adaptation responses or strategies, depending on the purpose or phase of activity a road organisation is undertaking, or according to the role of a practitioner within a road organisation. Ultimately, a climate Adaptation Plan should be developed for the full breadth and scope of a road organisation's role or function (see 3.5). However, constraints exist, such as technical capacity, funding and resources, and as a result this is not always possible.

The ROADAPT project developed a database of adaptation techniques, which lists over 500 measures, their applicability and effectiveness. The database is available from the CEDR website Call 2012 Climate Change (cedr.eu).

More information:
** ROADAPT – Database of adaptation techniques (→ Sec 9.3.1)

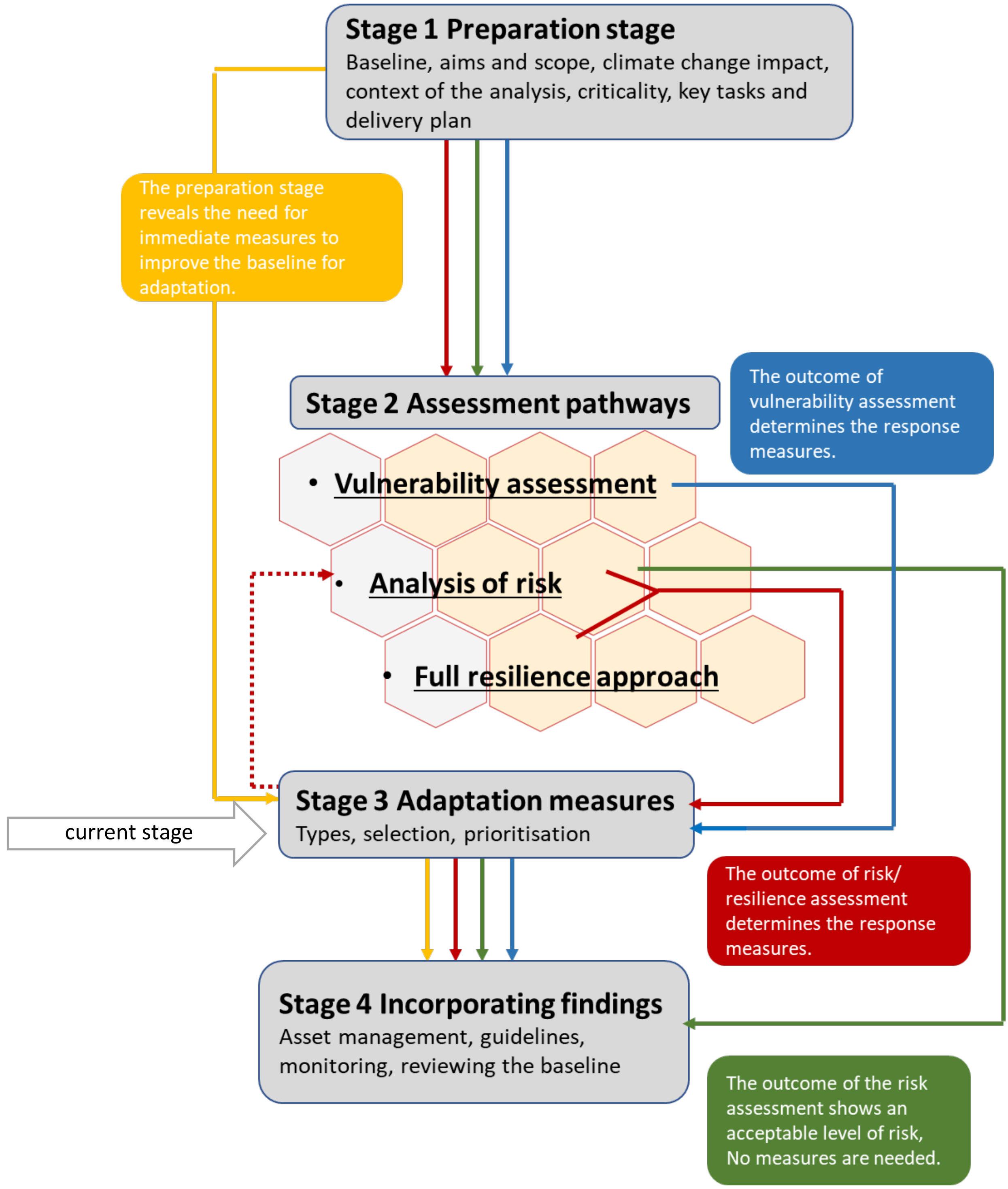


Figure 19. Illustration of the Framework: four main stages and possible assessment pathways.

Findings should be incorporated into road organisation's decision-making processes to ensure implementation, monitor progress, and develop a starting point for future assessments.

3.1.1. What are adaptation responses and strategies?

Adaptation responses are any actions, or a combination of actions that constitute a strategy a road organisation may take, either coordinated or ad-hoc, that addresses any element of a resilience cycle (prepare, prevent, respond or recover etc) and reduces a road organisation's vulnerability to climate change risk or natural hazards.

A number of adaptation responses and strategies exist which are appropriate to different contexts. Some are only appropriate for particular climate change hazards, while others introduce a systematic approach to climate adaptation, and improve overall organisational capability to implement measures on an ongoing basis.

Road organisations should refer to their own technical or engineering approaches and standards and seek input from stakeholders with relevant local knowledge when selecting adaptation responses or strategies. Individuals and groups who hold local knowledge are most likely to know which options are the most feasible, realistic and have the biggest potential to be effective and successful.

3.1.2. Importance of (selecting the right) adaptation responses and strategies

The selection of adaptation responses and strategies is influenced by a number of factors and the context which the road network is in. This includes the assessed level of redundancy, reliability, resistance or ability to recover a particular road network. A practitioner needs to consider the stage within the asset or project lifecycle that they are in, such as governance or strategic level, project planning or development, road design, construction, maintenance or operation of the road network itself. Different adaptation responses or strategies are relevant to the different stages. Similarly, where within a resilience cycle a road network may be, will impact the selection of which adaptation response or strategy is relevant, or possible to implement.

Adaptation responses can vary widely in terms of ease of implementation, costs, resources and technical feasibility, so it is important to consider which response is appropriate for a particular adaptation scenario, for the road organisation itself, and for who is undertaking the response or strategy. The responsible organisation will need to consider its capability, including the availability of resources, for the strategies it chooses to implement, and effort may need to be focused on developing organisational capability including a structured approach to decision making [67].

The responses or strategies that a road organisation selects from may result in different outcomes for adaptation, such as differing levels of service or differing levels of risk mitigation. Community expectations for levels of service and acceptable standards of safety need to be considered when selecting adaptation responses and strategies. Road infrastructure is considered vital to society, thus timely adaptation to climate change is warranted and which techniques to apply, when and why.

3.2. TYPES OF ADAPTATION RESPONSES AND STRATEGIES

Adaptation responses and strategies can be categorised into various types and levels, or against an infrastructure project life cycle, the functions of a road organisation and against the phases of a resilience cycle. To assist road organisations to develop comprehensive approaches to climate change adaptation, all elements should be considered.

Adaptation solution types, or measures, can include natural, structural, or policy-based and can range from site-specific to regional [68]. Within a road organisation, the typical functions, or the phases of infrastructure project lifecycle, for which adaptation responses can be attributed against includes:

- Governance including policy, capacity building, research, strategic or organisational level actions,
- Network and Operational Planning including transport network planning, strategic asset management,
- Infrastructure related including design standards, construction,
- Traffic and hazard management adaptation measures including incident response, network operations and monitoring,
- Maintenance adaptation responses.

This Framework uses a resilience cycle to further categorise responses. It is recognised that there are multiple other resilience models or cycles that align with this type of categorisation, such as the 4Rs of resilience: reduction, readiness, response, and recovery, or the PPRR spectrum: prevention, preparedness, response and recovery. The PIARC Working Group 1 Technical Report ‘Uniform and Holistic Approaches to Resilience: Case Study Approach Addressing Climate Change and Other Hazards’ characterises resilience across four categories: *robustness* as the ability to withstand shocks, *resourcefulness* as the skilful management of a disaster as it occurs, *recovery* as the ability to restore or normalise as quickly as possible, and *adaptability* as the ability to learn and improve from disasters. The intent is ultimately the same across the following components of resilience:

- **Prevention** through risk avoidance and risk reduction strategies – all activities concerned with minimising the occurrence of incidents. **Protection** measures are included here as they reduce or nullify the impact of events/incidents.
- **Preparedness** through strategic and/or policy solutions – all activities undertaken in advance of the occurrence of an incident to decrease the impact, extent, and severity of the incident and to ensure more effective response activities.
- **Response** strategies for disaster management – all activities undertaken immediately before, during and after an incident to ensure that its effects are minimised and that those immediately affected are given relief and support.
- **Recovery** strategies for improvement or adaptation in post-disaster recovery – all activities undertaken after the occurrence of an incident to provide ongoing support to affected communities in reconstruction of the physical infrastructure and restoration of emotional, social, economic and physical wellbeing.

Adaptation responses and strategies may also be implemented over different timeframes or terms and can be defined as interim, intermediate or long term.

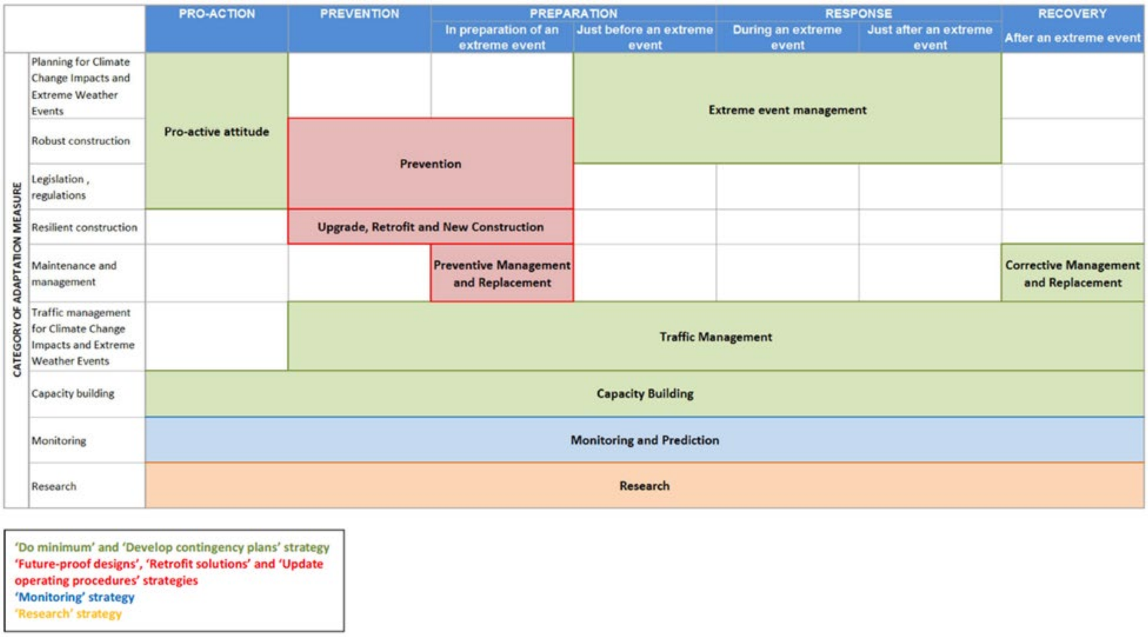


Figure 20. Policy matrix: combining response measures into strategies (ROADAPT [31])

The schematic in Figure 20 demonstrates various categories of activities against the resilience cycle. It indicates actions considered ongoing versus those done at specific times or during specific phases.

** ROADAPT 10-step approach (→ Sec. 9.3.2)

According to the ROADAPT methodology, the procedure for the selection of a response strategy can be organised in ten main steps:

- Steps 0 – 3 is about road owner's needs, impacts and current and future resilience of the assets;
- Steps 4 – 8 deal with the selection of adaptation measures and strategies, and their ranking according to their consequences for operation and sustainability.
- Steps 9 – 10 deal with the knowledge base, availability of data and techniques, and time-to-market assessment.

Practitioners may need to consider the stage within the asset or project lifecycle that they are in, in order to develop appropriate response measures, see *Table 7*.

Table 7. Response measures reference matrix

Type of adaptation measure	**Infrastructure related**	**Traffic and hazard management related**	**Maintenance**	**Network and Operational Planning**
Governance: Organisational policy, strategic planning, community readiness, capacity building, critical link analysis, stakeholder engagement, research				
Stage in the resilience cycle	**Design & Construction**	**Operation (and Incident Management)**	**Maintenance**	**Planning**
Prevent & protect	Design standards and design strategies Protection Measures Upgrading Infrastructure or structural adaptation	Guidelines and Frameworks	Asset Management	Road planning
Prepare	Strategic network management and increasing redundancy	Operational management or master planning Monitoring	Preventative maintenance Contract amendments Vulnerability assessments	Critical link analysis Strategic network management and increasing redundancy
Respond	Emergency Repairs and Maintenance	Road user awareness and behaviour Traffic management & Detours	Emergency Repairs and Maintenance	Road user awareness and behaviour
Recover	Build back better	Monitoring, evaluation and feedback	Road Maintenance	

3.2.1. Governance Measures

Governance measures typically cover the entire spectrum of a resilience cycle and help define how a road organisation, on the whole, will implement adaptation responses. They may be strategic in nature and provide overall direction. For road organisations, governance measures for adapting to climate change may include:

- Organisational Policy
- Strategic Planning
- Community Readiness
- Capacity building
- Critical Link Analysis
- Stakeholder engagement
- Research.

These actions and measures are discussed further below.

Organisational Policy

There are aspects of uncertainty when it comes to making decisions for road infrastructure based on climate change projections. Setting organisational policy helps to overcome uncertainty by providing an understanding of the extent of risk or vulnerability mitigation that is acceptable, or expected, and who is responsible for making decisions as to what action to take and when. In some cases, adaptation measures may be undertaken by organisations external to a road organisation and the roles and responsibilities may need to be clarified to maximise the effect or adaptation responses [69].
See sections 1.1.1, 1.1.4 and 1.4.1.

Strategic Planning

Strategic planning supports the overall defining and understanding of success for implemented climate adaptation strategies and will ultimately inform organisational policy, roles and responsibilities, resource requirements and capabilities needed by a road organisation. Prior to commencing any actions in relation to the prevention of, preparedness for, response to or recovery from climate change events or scenarios, the strategic objectives of the tasks should be identified [70]. This includes articulating what functions the road organisation want the road network to perform before, during, and after an event, and how these functions contribute to public safety; what conditions need to be in place for the road network to effectively perform each of these functions and what can be practically done to increase effectiveness; and what the cost-benefit relationship is and the management practicalities of implementing solutions [71].

** Incorporating Bushfire Impacts into Road Design: Literature Review (→ 9.3.3)

According to the Australian developed framework that imbeds the consideration of bushfire prevention, preparedness, response and recovery into the planning, design, construction and maintenance of transport infrastructure, setting strategic planning objectives needs to occur prior to the implementation of resilience measures.

** [RESOLUTE project](→ 9.3.4)

According to the European Resilience Management Guidelines, strategic planning is critical in aligning the performance of operational assets with institutional missions and objectives, in particular, the identification of potential adaptive capacity needs.

Community Readiness

Community adaptation or readiness refers to increasing community self-reliance or influencing the behaviour of the general public in response to events or scenarios. For example, people in vulnerable communities may ensure that they have sufficient food and other resources, in preparation for inaccessibility, or they are aware of their personal responsibilities in various scenarios. Community or stakeholder engagement may be required for this adaptation technique. See also Section 1.4.2.

Capacity Building

Additional procedures or processes may be introduced within an organisation to enable climate change vulnerabilities within the road network to be identified, assessed, addressed or responded to. Training may be required for various staff including those responsible or involved in assessments and other activities related to adaptation [69].

Of particular importance, emergency, incident or response measures and procedures may need to be updated, or introduced, in cases where hazards are newly experienced. Staff training, contract or supplier agreements, contracting procedures, and supplier and market development (availability of multiple suppliers or contractors within the supply chain) all may need to undergo review, or development, as an adaptation measure [71]. See also Section 1.4.1.

Critical Link Analysis

To plan for events and prioritise resilience measures or strategies, critical routes may need to be identified. Important locations or areas prone to events can be identified through undertaking a critical link analysis [70]. For a full explanation of criticality please refer to Section 1.5.

Stakeholder engagement

Stakeholder engagement can be leveraged to assist with developing and implementing a comprehensive and coordinated approach to adaptation strategies. It is also recognised that some organisations may be better places to undertake certain adaptation actions than a road organisation and engagement needs to occur to facilitate and coordinate these activities [68]. For a full explanation of stakeholder engagement please refer to Section 1.4.2.

Research

A focus on ongoing research, including developing methods and knowledge about climate change, natural hazards and adaption, may assist road organisations in being better prepared for climate related events. Closely aligned to developing institutional capacity, research builds information related to climate change and adaptation relevant to a road organisation and enables a strong foundation for delivering responsive adaptation actions. A centralised organisation may be delegated responsibility for undertaking research. Please also refer to Sections 1.1.3 & 1.3.3.

3.2.2. Prevention Measures

For road organisations, prevention measures for adapting to climate change include all activities concerned with minimizing the occurrence of incidents, regulatory and physical measures to ensure occurrences are prevented or mitigated or measures to eliminate or reduce the incidence or severity of events. The types of prevention measure can include:

- Road planning
- Design Standards and Design Strategies
- Asset Management
- Upgrading infrastructure or structural adaptation
- Protection measures

These actions and measures are discussed further below.

Road Planning

Planning related adaptation strategies can help to mitigate or lower the risk of increasingly harmful climate hazards through supporting the appropriate placement of new infrastructure that avoids prone areas. Within road planning activities, road organisations can embed practice that supports the systematic development of resilience of the road network by considering climate hazards in alignment selection, the prioritisation of network upgrades or the realignment of the road infrastructure at vulnerable locations. More broadly, while often outside the control of road organisations, land-use restrictions, such as the where residential and commercial land-use occurs, could be considered as part a wider adaptation strategy. Improving access to alternate modes of transport could also be considered from a planning perspective [72].

Design Standards and Design Strategies

The review and potential modification of existing standards, specifications or technical regulations is an important organisational adaptation measure for road organisations. Existing approaches to standardised designs may not be adequate to appropriately accommodate climate change hazards. Historical data, used as a basis for various designs, may not adequately represent climate trends and projected climate change. There may need to be flexibility for design standards, specifications or technical regulations to enable future proofed designs, or support innovative project delivery, such as the use of alternative materials or construction methods.

Design strategies may integrate adaptation response measures into the planning and design phase of road construction. The aim is to avoid excessive vulnerability by adequate planning and design, whereby likely climate change scenarios are considered as early as possible when developing a project so that potential treatments can be integrated into the built infrastructure. Important considerations for infrastructure may include the critical components, such as road pavement, bridges and structures or design life, exposure to hazards and the ease of future intervention.
See Section 4.1.3, Amendments to design rules.

Asset Management

Vulnerability registers, and the prioritisation of road infrastructure upgrades, may need to be reviewed as part of an adaptation strategy. The sequencing of adaptation responses can be integrated into a road organisation's overall asset management strategy. The management of an existing asset may see adaptation responses applied at different times as responses to key triggers, thresholds or future decision points [59]. These responses may need to be tracked and managed within an asset management system. An asset management adaptation strategy should be informed by a vulnerability assessment that enables a systematic approach to be adopted. Asset management systems may need to be flexible to accommodate different inputs or responses as new data becomes available. See Section 4.1.2, Asset management as a tool for climate change adaptation.

Upgrading Infrastructure or structural adaptation

Infrastructure and critical assets identified as being sensitive or vulnerable to climate change can be upgraded or strengthened to accommodate a particular changing hazard. This may include minor enhancements, strengthening works or improvements within projects already underway or under planning. The ultimate goal of structural adaptation is to increase resilience by adapting infrastructure or the surrounding system directly to climatic and weather events using engineering solutions [72], [73]. See also Protection Measures.

Guidelines and Frameworks

The development of context specific guidelines to embed climate change adaptation response measures into road organisation processes is a method to address identified climate change risks or vulnerabilities systematically and consistently. Guidelines can assist in simplifying adaptation responses and clarify what steps officers are to take at the various stages of the resilience cycle. Guidelines may also be appropriate where there are knowledge gaps, a lack of existing procedures, uncertainty in climate scenarios, or standards and specifications may not have been formally updated to accommodate anticipated climate change. In cases that road organisation developed guidelines are addressing knowledge gaps, it may suggest national guidelines are needed, or require amendment.

Protection Measures

Protection measures for infrastructure are often applied to mitigate the impacts of a particular hazard or a vulnerability of a road asset. It can relate to a physical reinforcement of interrelated components of road infrastructure and includes the retrofit of existing assets to accommodate impacts i.e. adding barriers to protect an asset from a particular hazard [69].

Protection measures, in some cases, may not be directly applied to the infrastructure itself [68]. Grey Infrastructure and Green Infrastructure are adaptation category types that may also be used as a protection measures. Grey infrastructure are the physical interventions or construction measures to make infrastructure more capable of withstanding extreme events. Example actions include beach nourishment and reinforcing natural defences such as dune systems. Green infrastructure contributes to the increase of ecosystems resilience, such as revegetation of dunes and wetlands, and use the functions and services provided by the ecosystems to achieve a more cost effective and sometimes more feasible adaptation solution than grey infrastructure [74].

Some examples of prevention measures are provided below.

Box 11: Nature-based solutions for coastal highway resilience (FHWA)

Nature-based engineering structures mimic characteristics of natural features and processes. Examples include dunes, wetlands, maritime forests, beaches, and reefs. These features can protect coastal highways from the brunt of storm surges and waves.
For more information refer to the Implementation Guide and pilot projects at: Green Infrastructure - Ongoing And Current Research - Resilience - Sustainability - Environment - FHWA (dot.gov)

Box 12: Design and implementation of green road infrastructure (Mexico)

This planning manual provides guidance for the design and implementation of green road infrastructure, which can help reduce climate risks, support sustainable adaptation to climate change, and provide co-benefits such as greenhouse gas reductions.

Some of the examples allow to reduce flooding, erosion control, slope stability, etc. Source: https://www.sct.gob.mx/fileadmin/DireccionesGrales/DGST/Manuales/Manual_de_Planeacion/Manual_Infraestructura_Verde_Vial.pdf

Box 13: Good Practice Guide for Roads Adaptation to Climate Change

The Latin American Development Bank (CAF) has developed a guide for Latin American and Caribbean countries to ensure that investments are oriented towards less vulnerable infrastructure, including the sustainability of projects and the efficiency of investments aimed at making transport infrastructure more resilient.

The guide provides a series of measures to adapt the road infrastructure to climate change, which can be consulted at the following link: Guía de Buenas Prácticas para la Adaptación de las Carreteras al Clima (caf.com) / https://scioteca.caf.com/handle/123456789/1221

** **Submersible pavement design, Quebec** (→ 9.3.5)
This is an example of research work aimed at specific measures to achieve robustness. It explored the possibilities of using submersible pavements in flood-prone areas. The aim of the study was to identify design parameters and formulate methods for design and construction that are suitable for typical cross-section adapted for Quebec.

** **Intensive Maintenance Work Closure of All Lanes - example from Japan** (→ 9.3.6)
There are several advantages to intensive maintenance works requiring all lanes to be closed as opposed to regular maintenance works with traffic control. These include: adequate workspace, a shortened work period, and an improvement in the quality of work by securing a path for work vehicles in and out of the workspace.

3.2.3. Preparedness Measures

Preparedness measures are applied in preparation of expected climate change events. The aim is to reduce the consequence of such events[12]. Activities to support this phase can include establishing well-prepared command and management structures, providing appropriate information systems or training personnel (for managing incidents or catastrophes), or the implementation of strategies and planning measures. Preparedness measures can be integrated into a Road Asset Management System (RAMS), see also 4.1.2.
For road organisations preparedness measures for adapting to climate change may include:

- Strategic Network Management and Redundancy
- Operational Management or Master Plans
- Critical Route Analysis
- Preventative Maintenance
- Monitoring

These actions and measures are discussed further below.

Strategic Network Management and Increasing Redundancy

Strategic network management can include climate change interventions such as long-term integrated planning or introducing new infrastructure. Long term integrated planning includes the development of alternate routes for road transport, while introducing new infrastructure considers new routes or alternate transport access [72].

Improving the redundancy of the road network, through providing more alternate routes and route connections, helps to mitigate impacts to road users if the preferred road section becomes impassable during climate related events [59]. It may be possible to achieve this through the targeted upgrade of lower tier roads, which may be outside of the jurisdiction of a road organisation. The overall transport system should also be considered as part of efforts to improve or increase road network redundancy [9]. Transportation services provided by road infrastructure may be able to be provided by other means or alternative modes.

Operational Management or Master Planning

The operational plans and procedures for the road network need to consider regular operations, as well as during, and after, times of incidents or disruptions. The ongoing and continuous assessment of network conditions is an important preparedness action to assist in response efforts including appropriately allocating network resources. Ensuring organisational and operational procedures are updated and improved on a regular basis enables adaptation to any changing conditions and flexibility should be considered for implementing local or centralised approaches and restructuring response teams.

In some cases, operational management or master planning will interface with actions considered under the governance section. This includes elements of community readiness and stakeholder engagement, but also emergency planning. Emergency response plans, hazard reduction plans

[12] ROADAPT Guidelines - Part E, Selection of adaptation measures, pg.8: Overview of Research Programmes Operations (cedr.eu)

(i.e. bushfires, avalanche, flood risk, coast management etc.) and agreements to respond to natural hazards or events may be undertaken by relevant service providers including road organisations.

Critical Route Analysis

Critical and evacuation route analysis should be undertaken in conjunction with relevant emergency services so that overall preparedness activities are targeted for the greatest mitigation outcome. Important locations, or areas prone to events, can be identified through a risk or vulnerability assessment process. Key aspects which may lead to a route being critical include if it: is designed for emergency vehicle access; is designed for hazard mitigation or reduction i.e. firebreaks can be easily maintained; provides access for evacuations; or is the only link between a community and the goods and services that it may require.

Preventative Maintenance

Climate change can emphasise the need to perform effective preventative maintenance or to alter preventative maintenance routines. In contrast to construction or engineering-based adaptation measures, the management of climate change risk through altering maintenance regimes can be achieved in a relatively short period of time. This may be particularly important in areas where the infrastructure is considered to be particularly vulnerable to various climate hazards. Maintenance activities can be targeted at hazard reduction (i.e. reducing bushfire fuel availability) or to accommodate expected events (i.e. cleaning drains)[13]. Through effective preventative maintenance, the consequence from various events can be reduced and impact mitigated or avoided.

Maintenance or operational contracts can be long term in nature; thus, mechanisms may need to be introduced that accommodate observed climate trends and the uncertainty of weather events, which may alter over the contract period. Contracts may need to be formulated in a flexible way in order to take into account unpredictable elements such as unusual weather combinations, increased vegetation at roadsides, temperatures around freezing point, drifting snow and increase debris on the road etc. [72], [73]

Monitoring

The monitoring of various hazards and conditions on the road network provides road organisations with information on potential emergent conditions that may need to be responded to or require an organisational intervention. Monitoring may be provided through systems installed on the road network i.e. sensors or CCTV, by other organisations i.e. weather or by road users themselves. The types and extent of monitoring systems a road organisation has at its disposal for various hazards is a consideration for climate adaptation.

Vulnerability assessments by inspection may be implemented to collect data on component health on the road asset. They can potentially be carried out simultaneously with routine road condition assessments. The climate sensitivity of all components would need to be determined

13 ROADAPT: Roads for today, adapted for tomorrow. Guideline part E, pg8 [29]

prior to implementation of this procedure. This style of assessment may be useful in contexts where there is limited asset inventory data compiled of accessible [69].

Examples of Preparedness Measures

Examples are provided below sourced from a Scanning tour to South Korea and Japan and report on Infrastructure Resilience, and examples through various PIARC case study publications developed.

** **Early Warning Against Floods - Japan** (→ 9.3.7)
This is an example of flood risk assessment that involves an assessment of various experimental scenarios and basin scale rainfall information; flood evaluations and projections for present and future climates according to projections of variations in discharge, water level and water depth. Based on this uncertainty assessment, a socio-economic assessment is undertaken.[14]

** **RESPONS(e) portal – Norway** (→ 9.3.8)
RESPONS is a web-based mapping solution that combines static information from maps of natural hazard in a contract area with dynamic data on weather, avalanche hazard and other events. In this way, one can relate current threats to earlier mapped vulnerabilities and decide how to act.

** **National warning system for landslides and avalanches - Norway** (→ 9.3.9)
The Norwegian Avalanche Warning Service is a collaboration platform that provides information about natural hazards in Norway, with a particular focus on avalanches, but also flood and landslide hazards. The warning service is a collaboration between stakeholders, suppliers of data and expertise.

Box 14 : **Cost-Efficient and Storm Surge-Sensitive Bridge Design for Coastal Maine (bts.gov)**

The general goal is to address cost and risk issues associated with projected sea level rise and threats to state infrastructure elements that are also designed to pass freshwater streams and rivers. More specifically, this project aims to help develop storm surge-sensitive design standards and approaches for large, tidally influenced transportation structures along the Maine coast.

[14] Evans, 2018 REAAA Technical Report: Infrastructure Resilience Scanning Tour of South Korea and Japan, FEHRL

Box 15: National Emergency Plan for Seismic and Tsunami Risk - Portugal

Portugal has been strengthening alert mechanisms and emergency plans for a tsunami (earthquake) scenario and coordination at various levels - from national to local - to deal with the potential occurrence of this phenomenon. This is one of the phenomena included in the National Strategy for a Preventive Civil Protection 2030, which will include a National Emergency Plan for Seismic and Tsunami Risk.

According to the National Risk Assessment, mainland Portugal has a high risk of tsunamis, and they are considered a HILP (High Impact - Low Probability) phenomenon.

The National Authority for Emergency and Civil Protection has been mapping the seismic and tsunami risk and working with municipalities, which also develop studies and define local actions.

Notification procedures have already been developed to disseminate tsunami alert messages to civil protection authorities, in order to ensure timely information to the population in potentially affected areas. On the other hand, several municipalities have been installing tsunami warning signs and sirens in risk areas, which will be activated in case of a tsunami alert, complementing the national SMS warning system in place.

For the Algarve region - one of the main risk areas in Portugal - a Special Emergency Plan for Seismic and Tsunami Risk has been drawn up, bringing together more than a hundred entities. These emergency plans are regularly tested in regional and national exercises.

Conferência dos Oceanos: Risco de tsunami incluído na Estratégia Nacional para uma Proteção Civil Preventiva 2030 - XXIII Governo - República Portuguesa (portugal.gov.pt)

3.2.4. Response Measures

Response measures are implemented during an event, or immediately after an event. They may need to be coordinated with impacted communities, or with emergency services. Depending on the hazard or event that is being responded to, a different approach may need to be implemented from a road management perspective. Effective response strategies aim to minimise stoppages and disruptions due to congestion or damaged infrastructure, but also ensure safety of users including emergency services. For road organisations response measures to be considered for adapting to climate change include:

- Road User Awareness and Behaviour
- Traffic Management / Detours
- Emergency repairs and maintenance

These actions and measures are discussed further below.

Road User Awareness and Behaviour

The communication of information [71] and the management of road user behaviour, during and after times of disruption or incidents can improve outcomes for the road user, i.e. improved safety and reduced delay, and for the road organisation, as less resources may be required to manage such events, and damage to the asset may be reduced. Typically, communication takes the form of warnings, road condition status updates or suggestions for transport alternatives.

Options for improving the delivery of information on the road network in a major hazard event, such as early warning systems, intelligent transport systems or variable message signs, should also be considered as part of preparedness activities and master planning. Real-time context aware and personalised communication may enable greater numbers of individuals and communities to act in sufficient time when threatened by a hazard. Smart technologies such as mobile and wearable smart devices and communication infrastructure such as Wi-Fi, LTE/4G, Bluetooth, capillary network, Delay Tolerant networks etc may be utilised through using pre-scripted messages [72].

Traffic Management/ Detours

Implementing detours or the rerouting of freight and passenger networks (short term and planned), including modal shift, can help manage the road network in response to climate change events [59] [31]. Whilst the redirection of traffic has benefits to road users by way of allowing journeys to be completed safely and with minimal delays, there can be a direct financial aspect to rerouting traffic by protecting infrastructure from damage, such as the damage from loading from the weight heavy vehicles causing stress to road pavements when they are wet or saturated. Detours may need to be managed carefully as increased traffic on lower standard roads may, in itself, result in a safety hazard. Congestion, driver unfamiliarity of the road, combined with the potential increased exposure to road hazards (even though the road is still passable) may lead to decreased safety environment for all road users.

Traffic management may need to be implemented in conjunction with emergency services. In scenarios where emergency services are responding to an event, such as a bushfire, a decision support system may need to be implemented. Roadblocks set up by emergency services can become a traffic hazard if poorly placed or communicated and emergency vehicle access may also need to be implemented as part of traffic management [70].

Emergency Repairs and Maintenance

Emergency repairs or maintenance may need to be implemented at the time of events to protect infrastructure from further damage, enable the road network to be reopened in a safe manner and to minimise delay for the road user. This can include the temporary repair of the infrastructure itself, the removal of debris and other hazards or the emergency construction of side tracks or temporary structures. Implementing processes and procedures to ensure that the 'design, build and contracting' process is streamlined during an event should be considered by road organisations to reduce risk [59].

3.2.5. Recovery Measures

Recovery refers to the strategies which can be implemented as part of the recovery effort following an event. This includes reconstruction activities such as how to maintain and rehabilitate damaged infrastructure, and how to upgrade or improve assets to build resilience against future events. For road organisations, recovery measures for adapting to climate change may include:

- Road maintenance - Medium to long term works
- Monitoring, evaluation and feedback
- Build Back Better

These actions and measures are discussed further below.

Road Maintenance

It may not be immediately apparent the impact certain climate related events have had on road infrastructure i.e. from bushfires or heatwaves. A condition and structural assessment may need to be conducted, after even minor events which did not result in significant or easily observable damage. This is to identify issues in the road asset that may need to be addressed as part of immediate recovery activities, in scheduled routine maintenance or ongoing maintenance activities [70].

Monitoring, evaluation and feedback

When disruptive events occur and affect critical infrastructure, emergency management or services may be impacted in various ways. Collecting data on the impacts through the various systems, formal reports or by informal observations can assist with future response or adaptation efforts [71]. Establishing monitoring, evaluation and feedback processes helps to inform future adaptation efforts. It can also inform cost-effectiveness evaluations of the adaptation measure implemented. Feedback and data can be used to inform road organisation policy including design standards, maintenance regimes or response efforts and adapt to changing conditions [69]. 'Unstructured' data such as social media may be considered as a source to evaluate and establish insights, particularly if there are gaps in the collected or observed data of the road organisation.

Build back better

During reconstruction efforts, particularly following events in which infrastructure has been damaged or destroyed, road organisations may implement a practice of building back the infrastructure to an increased design standard [59]. To reduce downtime, designs for infrastructure identified to be vulnerable, based on updated design standards could be made beforehand to make the rebuilding effort more efficient. There may be some barriers to implementing this adaptation practice if natural disaster funding requires like for like replacement of infrastructure [75].

** **NEXCO Urgent Repair Operation Standard** (→ 9.3.10)

The Urgent Repair Operation Standard was implemented by NEXCO (one of the main operators of expressways and toll roads in Japan), following the 2011 Great East Japan Earthquake. Recognising the importance of functional roads in emergencies, the system is set up for three stages of recovery.

3.3. Selection and prioritisation of adaptation responses and strategies

Purpose of the work in this step Select adaptation response measure that: • suits the aims and scope (from Stage 1) • suits the outcome of the assessment (from Stage 2) • are feasible and comply with the capacity, resource constraints, and other work in the road organisation (from Stage 3.1)
Requirements: An overview of relevant adaptation responses – for the assets, operations and services. Knowledge about the use of tools for prioritising options. Information required as input to the tools.
Compatibility with other processes or systems Technically feasible, socially accepted in (local) communities. Offers synergy with national policies. Compatible with government planning periods and budgets.
Outcome Selected series of measures, i.e., a strategy for increasing or maintaining climate resilience.

This stage of the Framework provides guidance on how to prioritise among relevant response measures and strategies. It sets out criteria and methods to assist in prioritising a long list of options into a number of options which improve effectively the climate resilience the network, assets, operations and services.

The following methods will be described:

- Cost-benefit analysis
- Multi-criteria analysis
- Life cycle costing analysis
- Probabilistic analysis

This stage also provides an outline of approaches for selecting an adaptation strategy and preferred level of resilience.

3.3.1. Criteria for prioritisation

Prioritisation of adaptation measures often requires the use of economic techniques to determine which adaptation options are most appropriate for selection and prioritisation. For example, not all adaptation measures are suitable for certain locations, or from an economic, social or environmental perspective, and maladaptation should also be considered. The options selected may only be appropriate for a particular location (urban, regional or rural) or type of road (sealed or unsealed), and their selection may also be determined by matters such as the frequency intervals of events, or possible accelerated asset deterioration e.g. aged seals on roads.

Adaptation responses that best meet the scopes and aims should be selected for further consideration. As part of the selection process the following factors should be considered:

- Does the adaptation response fall within the scope and expected outcome of the assessment (as perceived in Stage 1)?
- Are adequate resources (economic, financial and organisational) available to implement and sustain the adaptation response?
- Is the adaptation response technically feasible?
- Is the adaptation response acceptable to local communities?
- Will implementation of the adaptation response offer synergies with national policies?

An adaptation response may not fully comply with each of the above factors, however there should be a degree of compliance with each. Responses with high to moderate level of compliance with the above factors should be selected as potential adaptation responses and scoped into further assessments. After selecting the best-fitting adaptation responses, road organisations are likely to have identified a manageable, condensed list of potential adaptation responses.

Once adaptation measures have been selected, economic assessment methodologies can be used to assist in sizing and prioritising adaptation measures for potential implementation. To determine the monetised and non-monetised impacts of climate change upon assets, operations and locations, a range of scenarios can be considered:

1. The expected impacts **with no adaptation responses (the "do-nothing" option)**. The following should be considered:

    - The damage which may arise to the assets, operations and locations in question as a result of climate variability,
    - Is the damage repairable, and how much would the repair cost?
    - How often such repairs would be required (as a function of climate variability)? In a do-nothing option.

    Note that there may be existing commitments to be carried out, and will therefore create a new starting point - a "base case" option.

2. The expected impacts **with implemented adaptation responses (the "do-something" options)**. The following should be considered:

    - The total cost of adaptation responses (as a proportion or incremental cost of existing network upgrade costs if adaptation responses include retrofitting/maintenance of the existing network)
    - The damage which may arise to the network assets, operations and locations in question as a result of climate variability (in spite of the included adaptation responses)
    - How much this damage would cost to repair
    - How often such repairs would be required (as a function of climate variability).

An overview of economic decision-making methodologies and approaches are shown in Figure 21.

	APPROACH	SUMMARY	POTENTIAL USE
Traditional economic decision support	Cost-Benefit Analysis	Values all costs and benefits to society of all options, and estimates the net benefits/costs in monetary options	To identify low- and no-regret options in the near future. As a decision support tool within iterative climate risk management
	Cost-effectiveness analysis	Compares costs against effectiveness (monetary/non-monetary) to rank, then cost-curves for targets/resources	As above, but for market and non-market sectors where benefits are not monetised
	Multi-criteria analysis	Allows consideration of quantitative data together for ranking alternative options	As above, but for scoping options. Can complement other tools and capture qualitative aspects
Uncertainty framing	Iterative risk management	Uses iterative framework of monitoring, research, evaluation and learning to improve future strategies	For appraisal over medium-longer term. Also applicable as a framework at policy level
Economic decision making under uncertainty	Real-option analysis	Allows economic analysis of future option value and economic benefit of waiting / information / flexibility	Economic analysis of major capital investment decisions over the medium term. Analysis of flexibility within major projects
	Robust decision-making	Identifies strategies which are optimal (robust) against a large number of plausible scenarios	Identifying combination of strategic (long-term scenario-independent) and operational (short-term scenario-dependent) decisions
	Portfolio analysis	Economic analysis of optimal portfolio of options by trade-offs between return (net present value) and uncertainty (variance)	Project based analysis of future combinations. Designing portfolio mixes as part of iterative pathways

Figure 21. Table of economic decision-making approaches [76]

3.3.2. Cost-Benefit Analysis

Cost-Benefit Analysis (CBA) is a common method to compare and prioritise the economic efficiency of adaptation responses and can be used to assess and compare different adaptation responses or groups of adaptation responses.

A CBA focuses on benefits and costs associated with the adaptation responses.

> **Benefits** are related to the avoided damage costs or the accrued benefits following implemented adaptation responses [76]. Benefits of adaptation responses can be measured by the reduction in costs caused by climate change induced damages between now (where no adaptation has been undertaken) and a time in the future (when the adaptation response has been implemented).
>
> **Costs** are related to planning, preparing, implementing and maintaining adaptation responses. The costs are discounted to current values to provide an estimate of the present value of costs from implementing options.

The Asian Development Bank's 'Climate Proofing ADB Investment in the Transport Sector'[15] provides a comprehensive overview of applying economic analysis techniques to climate change adaptation responses. The method provides decision makers with indicative information relating to the expected costs and benefits of each adaptation response. Subsequently, responses can be ranked according to net total benefit or benefit/cost ratio. Ranking adaptation responses with this method may help to determine which adaptation response to undertake first when improving the adaptive capacity of road infrastructure.

In addition to the CBA results, indirect and intangible impacts (which may not be monetised) should be incorporated. Indirect impacts can, for example, include reduced access to a road network link, which may limit tourism or freight, while enhanced road access through the provision of more links may enhance tourism. Intangible losses are those which are difficult to quantify and can have impacts on nature, culture and heritage.

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, hence sensitivity analysis can be beneficial.

An example of a CBA which followed this approach is the World Bank's Road Upgrade Project in Timor-Leste [ADB report], as shown in Box 16.

Box 16 : World Bank – Upgrade project in Timor Leste

Economic Analysis of Road Upgrade Project in Timor-Leste is 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 monetised 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 monetise the impact of the identified adaptation measures on the "cost of climate change." This monetised impact (change in cost from climate change adaptation measures) will represent the present value of the expected benefits of the adaptation measures.

Step 6: Assess the present value of the incremental 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.

Source: World bank (2014) Timor-Leste: Building Climate and Disaster Resilience in Communities Along Dili-Ainaro and Linked Road Corridors | GFDRR

3.3.3. Multi-criteria analysis

PIARC (2019) [5] identified that Multi-Criteria Analysis (MCA) is a comparative assessment of options that accounts for several criteria simultaneously (and consequently can be a useful allocative or prioritisation tool). Whilst CBA assesses costs and benefits in monetary terms, the MCA enables assessment of many environmental and social impacts more qualitatively. Hence, MCA offers a methodology for the assessment of climate change impacts that are not able to be valued in monetary terms (non-tangible values), such as political sensitivity, public acceptance, sustainability and some environmental impacts. The disadvantage of MCA is that it is comparative (not determinative), does not provide easy comparison of projects when multiple benefits arise, can be subjective, and can lead to inappropriate trade-offs.

As adaptation responses often are difficult to value monetarily, and usually involve a lack of quantitative information, Multi-Criteria Analysis (MCA) is often used. MCA can be undertaken in various forms; it can be as simplistic or complex as required by road organisations and can be conducted without specialist software or techniques. MCA can be used by all road organisations irrespective of resource availability, as the information required to conduct a MCA is likely to be readily available internally within the organisation. For example, the Ethiopian National Adaptation Programmes of Action evaluated adaptation responses 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 [77].

Evaluation criteria and ranking

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 list of 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 but should take care to not create double counting or correlated criteria. The criteria should contribute to the achievement of the objectives set out in original project and organisational aims [77].

<u>MCA evaluation criteria can also be ranked/ weighted in order of importance.</u> Using a scale to rank the evaluation criteria or weighting them allows for a relative internal assessment of the responses to a criterion to be conducted and subsequently an aggregated evaluation score to be established for each adaptation option. Looking at the evaluation criteria in this way allows for a realistic representation of the most effective responses to be made and allows for the decision-makers to have an ongoing input into adaptation development [77].

It should be noted that, as auditable monetary values are not applied, there is the risk that a MCA analysis can be subjected to bias and personal opinion, which may influence the evaluation criteria applied and lead to unrealistic weighting of the criteria being carried forward to the evaluation stage. Hence it is strongly recommended that sensitivity testing is conducted by varying the weightings and scoring schemas of criteria to assess the sensitivity of the results.

3.3.4. Life-Cycle Costing

A widely used measure of the economic impacts of climate change is the application of Life-Cycle Costing (LCC) assessments, which estimate road organisation costs and road user costs based on the prediction of, and changes in, road condition and traffic use. In undertaking these assessments, organisation costs represent the savings made resulting from the adoption of more effective pavement maintenance, repair, rehabilitation and resealing practices. Under the projected climate change impacts, organisation costs are expected to increase unless more climate resilient measures are considered. Other costs include accident costs, vehicle operating costs, travel time delay costs, and the costs associated with delays in the delivery of freight [5].

LCC analysis allows for a flexible range of inputs and variables, in order to best-model the life-cycle effects of climate change on assets. This method applies a number of alternative options and involves testing the sensitivity of the model to changes in key inputs e.g. the frequency of events. LCC analysis considers the damage itself, its immediate recovery time and cost, its eventual reconstruction and the cost of repairs, community and industry delays, and other road user costs, as an overall change in net present value (NPV) for all options. It includes the life-cycle costs of 'what actually happened' (base case) and two possible alternatives, a preventative maintenance approach, and a full resilience approach [5], [112]. These can be used and compared for an analysis of the costs and benefits of adaptation initiatives for improved resilience. This also assists with the identification of optimal solutions applicable under different operating circumstances, with current traffic levels being the main driver of the solutions, having accounted for disruption impacts [PIARC 2019]. This methodology has proven to be very effective in the prioritisation of adaptation measures and maximising the return on investment for road organisations [5], [112].

** **Accounting for Life-Cycle Costing Implications and Network Performance Risks of Rain and Flood Events, Queensland, Australia** (→ 9.3.11)
Implemented adaptation responses should be monitored and evaluated with regards to effectiveness. An example of this is the foam bitumen stabilisation used in Queensland, Australia. The performance of these pavements was tested through numerous flood events.

3.3.5. Probabilistic Analysis of Adaptation Responses

Attempting to quantify costs and benefits of adaptation responses can be challenging as climate change projections and risks are associated with large uncertainties. Consequently, risk and uncertainty must also be accounted for; this can be achieved through methods such as probabilistic analysis [77].

As a result of uncertainties in climate change projections and climate change risks, accounting for variabilities of costs and benefits can sometimes be challenging. Probabilistic analysis involves attaching a probability distribution for the possible value of any given specific cost or benefit component of an adaptation response, rather than a single deterministic value. The outcome is a probability distribution which represents a possible range of new present values. The new present value distribution is used to estimate the net present value for an adaptation response [5].

3.3.6. Selecting adaptation strategy related to the acceptable level of risk

The selection of the adaptation strategy will depend on the type and quality of information obtained in the assessment. For example, a qualitative vulnerability analysis will provide a basis for ranking vulnerability, but not for prioritising action. For that, risk needs to be considered. A qualitative risk assessment will provide the basis for prioritising action. But a quantitative risk assessment will provide the basis for both prioritising action and identifying measures that will be cost effective, i.e. where the cost of the measure is lower than the benefit, in terms of lower risk or higher resilience. In some cases, based on a range of factors including the cost of the measure and the impacts of failure, it may be acceptable to allow an asset to fail and then rebuild.
Ideally, a road organisation should establish an **acceptable level of risk** and use it as guiding input to the assessment of costs and benefits. This is illustrated in Figure 22.

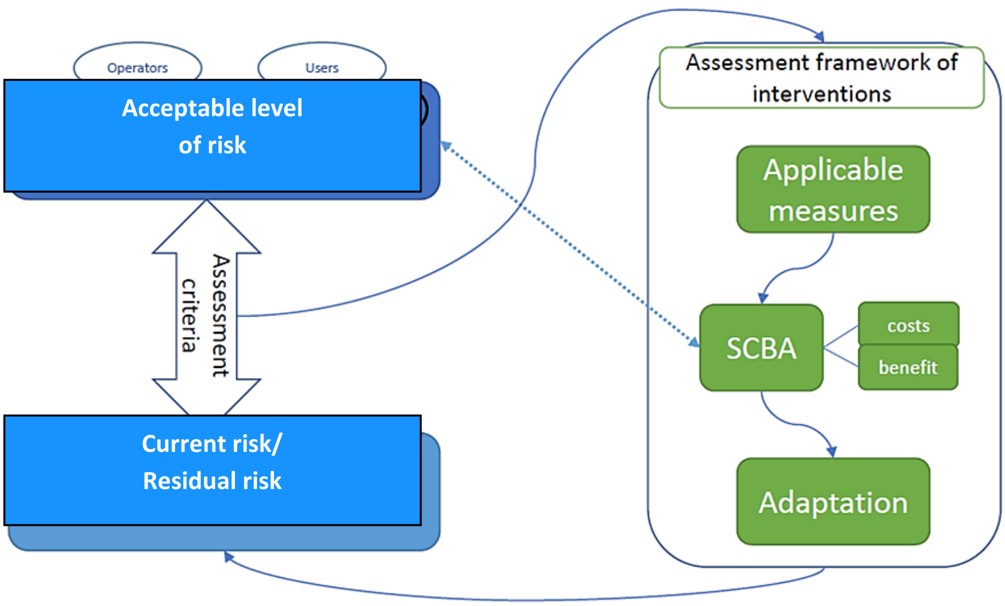


Figure 22. Process of selecting a response strategy in accordance with the preferred resilience level [Deltares]

A research project carried out at Deltares and Eindhoven University [78] offers a method to quantify the current level of resilience by analysing the users' perspective. The process that is recommended in this research is as follows:

a) Assessed risk can be compared to an acceptable level of risk. In cases when the risk is higher than the acceptable level of risk, adaptation measures need to be considered.
b) If the benefits of the identified set of measures outweigh the costs, they can be assumed implemented, and one needs to assess the residual risk with the new measures.
c) This new (residual) risk level (with the measures assumed implemented) can again be compared with the acceptable level of risk.
d) Then it should be decided whether or not the measures should be taken, whether alternative measures should be proposed (go again though the circle), or whether the ambition should be changed.

If the risk of our system remains within the acceptable level, there may be no need to implement measures. However, one should bear in mind that this may require repairs or maintenance that may be unaffordable in the medium or long term.

A possible strategy from this process is that lower-cost measures may enable us to aim for a lower acceptable risk level. Alternatively costly measures may require a higher level of acceptable risk.

Indicators and thresholds have been discussed in 1.2. After carrying out the assessment, and based on the results, it may be necessary to review and modify the selected indicators, to assist the evaluation and selection of response options.

The level of acceptable risk is a matter of decision of the road organisation, ministry, etc. It is not easy to define. An ongoing CEDR project, ICARUS [79], is addressing this, using the term "required resilience", which can be interpreted as the opposite of "acceptable risk". Required resilience can be formulated in many ways and at different levels: the network, for road links /connections, or for individual assets. Requirements should be considered for ensuring resilience is included in design rules, functional contracts, etc. Nevertheless, it is a complex issue to determine how the resilience requirements combine into a desired level of resilience /acceptable risk.

Some general advice is to:

- ensure that there is an explicit step on assessing how resilient certain objects/connections are, as well as agree whether adaptation makes sense.
- relate the evaluation and criteria as much as possible to the general decision-making context of the road administration.

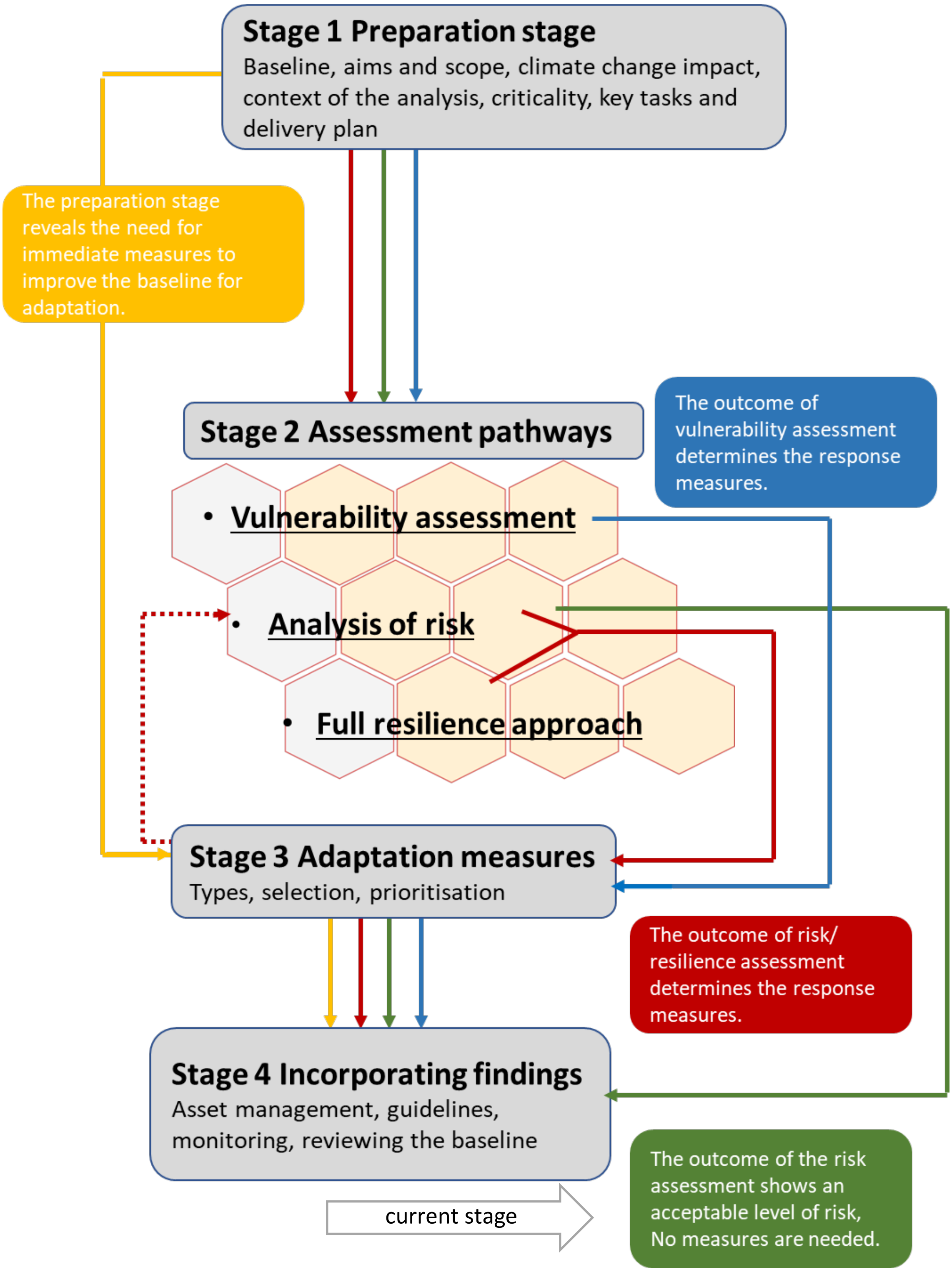


Figure 23. Illustration of the Framework: four main stages and possible assessment pathways. The green line corresponds to the situation where the assessed risk is within the limits of acceptable risk. Adaptation measures are not needed. The red stippled line shows the iterations for achieving an acceptable level of risk.

Findings should be incorporated into road organisation's decision-making processes to ensure implementation, monitor progress, and develop a starting point for future assessments.

3.4. Approaches for Assessing Deep Uncertainties – Adaptation Pathways and Real Option Analysis

Purpose of the work in this step Identify approaches for assessing deep uncertainties through economic assessments that can augment economic analysis approaches (from stage 3.3).
Requirements: An overview of relevant adaptation responses – for assets, operations and locations. Knowledge about the use of tools for prioritising options. Information required as input to the tools.
Compatibility with other processes or systems Technically feasible, socially accepted in (local) communities. Offers synergy with national policies. Compatible with government planning periods and budgets.
Outcome Identification of selected future scenarios for implementing adaptation measures.

Deep uncertainty, in relation to climate change, stems from its long timescales and complexity. It occurs when decision makers and stakeholders do not know, or cannot come to a consensus on, how likely different future climate change scenarios are, or decide what the consequences are from decisions made today. A number of tools or methods are available to road organisations to improve investment decision-making under deep uncertainty.

3.4.1. Real Option Analysis

When investments are nearer term (especially high upfront capital irreversible investments), there is potential for learning as new climate risk information becomes available, and where there is an existing adaptation deficit, Real Options Analysis (ROA) is a potentially useful tool [76]. It is most applicable when there is significant uncertainty in proposal assumptions or future states (such as shocks or stresses). A “real option” provides the ability to undertake a different action in the future to alter a project pathway (scope) when uncertainty impacts project scope and performance [80].

The ROA is an extension of a CBA and quantifies the investment risk associated with uncertain future outcomes and is used when considering the value and flexibility of investments. It can be used to inform how a project can adapt, expand or scale back in response to unfolding events (Watkiss 2013, cited [81]). Identifying and assessing options over time can be a way of addressing downside risk (the risk of a bad outcome). A real option is a decision taken today that makes it possible for policy makers to take a particular (new) action in the future. Options are explored that involve adopting a ‘wait and see’ approach until a major uncertainty is resolved or lessened and the project pathway choice is more clearly going to be successful [82].

The advantage of the real options theory approach is its ability to take into account uncertainty and flexibility, compared to the Net Present Value (NPV) theory or Cost Benefit Analysis (CBA) that assume a deterministic trend [83].

Challenges exist in applying a CBA of transport projects. This is where CBA’s often rely on projections and forecasts that estimate the impact of changes decades into the future, often at least 30 years into the future, and in many cases beyond: up to 100 years (depending upon discount rates) to account for the full life of the assets and their use [114]. Climate change is particularly challenging in infrastructure where the 'sunk cost' associated with assets can also exaggerate the desirability of additional projects, hiding their true cost in previously completed CBAs. A benefit of real options analysis is that it augments traditional CBA applications to enable decision makers to incorporate these risks and uncertainties, instead of simply applying the most likely forecast or projection [114].

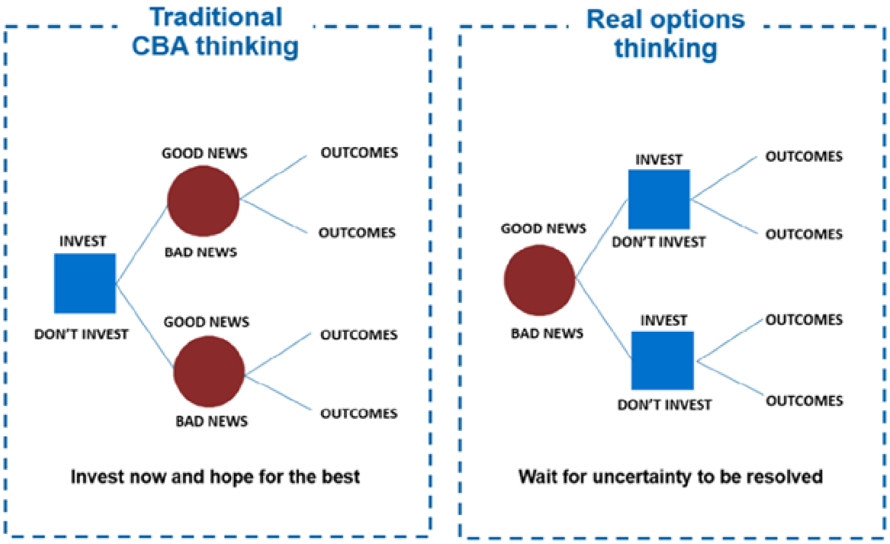


Figure 24. How real option analysis improves traditional CBA (Source: Department of Treasury and Finance, Victoria, 2018 cited in [114])

** Example of real option analysis in a road renewal project (→ 9.3.12)

A case study example of the widening and strengthening of a sealed road using a real options assessment is identified ([84] cited in [114]). This is based on a decision tree analysis used to calculate the value of the real option.

** The "real option triage" (→ 9.3.13)

The 'real options triage' enables organisations to identify the uncertainties that could impact their investment, the vulnerability of the investment to those uncertainties, and the level of flexibility within the investment to adapt its strategy to mitigate those impacts ([84] cited in [114]).

A real option analysis triage by the Victorian Government, Australia is shown in Figure 25.

Source: Department of Treasury and Finance 2018, *Investing under uncertainty: real options analysis technical supplement – investment lifecycle and high value high risk guidelines*, Victorian Government, Figure 9.

Figure 25. Real Options analysis framework [84]

3.4.2. Adaptation Pathways

Adaptation Pathways is a similar approach, whereby once risk treatments have been determined they are often arranged into a sequence in order to be responsive and flexible to changing circumstances. This sequence of risk treatments can be termed as an adaptation pathway. Each adaptation pathway that is formed, can be considered to be an adaptation option [85].

Adaptation pathways can be short and once-off, or more commonly can be more complex, particularly for larger assets where managing the risk is a process of adaptive decision making over time. Adaptation Pathways generally establish a structured, continuous process of assessing and implementing risk treatments in response to new information and changing circumstances [85]. This approach is formed of sequential actions that are instigated on the basis of changes to risk, with early actions not compromising future actions. By considering scenarios from low-regret to worst-case, adaptation pathways negotiate potential stagnation in decision-making due to deep-uncertainty [115].

A key element of Adaptation Pathways is the consideration of tipping points to establish different pathways with different costs and benefits. Buurman & Babovic (2016) [83] note that rather than taking different climate scenarios as a starting point and analysing the impacts of changes, it assesses current policies and management strategies and determines when they no longer meet the objectives. At this stage, a tipping point is triggered leading to changing paths to alternative policies and management strategies that will support the same objectives, as the climate scenario materialises. It is an approach to assist policymakers in determining how different climate change adaptation strategies can be adjusted and sequenced over time [83].

Timescales or tipping points of when a certain adaptation measure is not effective anymore or will become effective can be determined through the Risk Management for Roads in a Changing Climate (RIMAROCC) Framework method as shown in Figure 26.

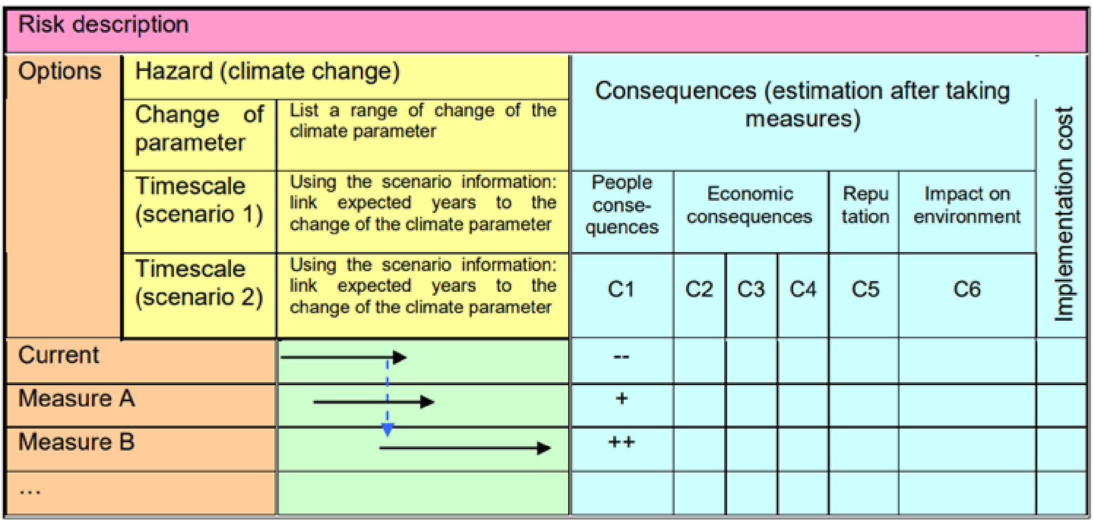


Figure 26. Illustration of the effectiveness of measures (RIMAROCC [30])

Adaptation pathway approaches can also be considered together with Adaptive Policy Making (APM) approaches and Dynamic Adaptive Policy Pathways. APM can be used to provide the policymaker with a stepwise approach to develop flexible, resilient plans. The APM provides the structure to develop adaptation pathways and select promising pathways with the aid of a real options analysis [83].

Examples of adaptation pathway approaches have been developed by the French Agency of Ecological Transition, ADEME. They have developed a tool called TACCT ("Trajectoires d'adaptation au changement climatique des territoires", Adaptation pathways to climate change in territories, https://tacct.ademe.fr) to help local and regional authorities build adaptation pathways.

An application of adaptation pathways for addressing uncertainty in climate projections has been developed, see Figure 27 (Adapted from [86]). This is a five-step cyclic process, developed to identify different levels of risk and opportunity to encourage different levels of adaptation.

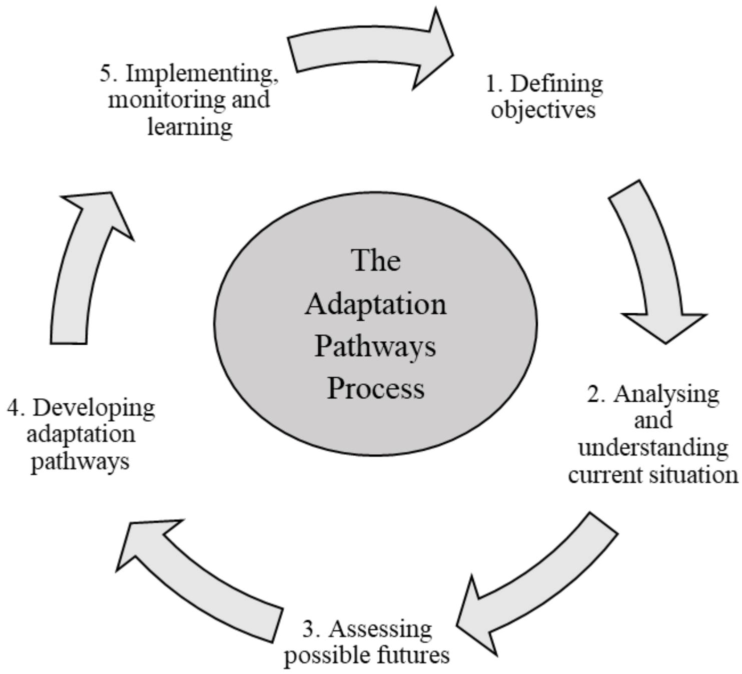


Figure 27. Steps to develop climate change adaptation pathways (a*dapted from [86])*

Adaptation pathway approaches have also been developed by the Environmental Agency to manage flood risk in the Thames Estuary, UK (TE2100) (see FW2015). Additionally, the Eyre Peninsula, South Australia released its Adaptation Plan for the region in 2014. The plan outlined adaptation pathways for the next fifty years across nine areas including maintenance of road infrastructure. A range of adaptation options for maintenance of road infrastructure outlining the time periods, decision points and emerging pathways are presented in Figure 28.

Issue

Roads

Key decision

How will bitumen and unsealed roads respond to an increasing frequency of extreme events (e.g. hot weather and higher intensity storm events)

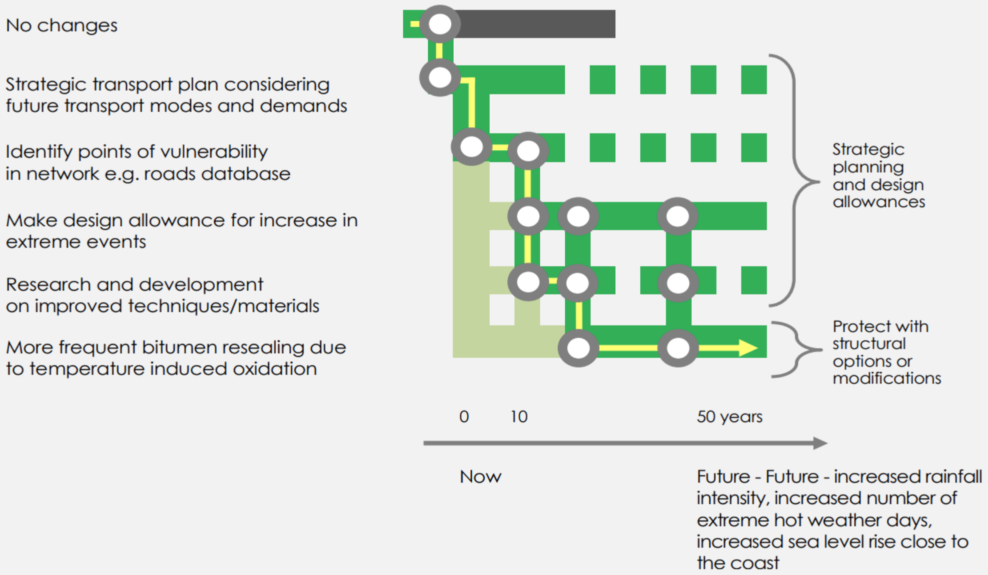


Figure 28. Adaptation options for maintenance of road infrastructure [116]

**** Climate Adaptation Strategy for InnovA58**

A further example is the Development of a Climate Adaptation Strategy for the InnovA58 highway in the Netherlands [87]. The strategy comprises several selected measures, implemented over time. Dynamic Adaptation Policy Pathways was used to visualise the potential measures. The effectiveness of a measure is plotted against a normative climate parameter, for example, a precipitation intensity, see Figure 29. By means of the overview thus created, different paths become visible that may be taken in order to be ready for future climate change.

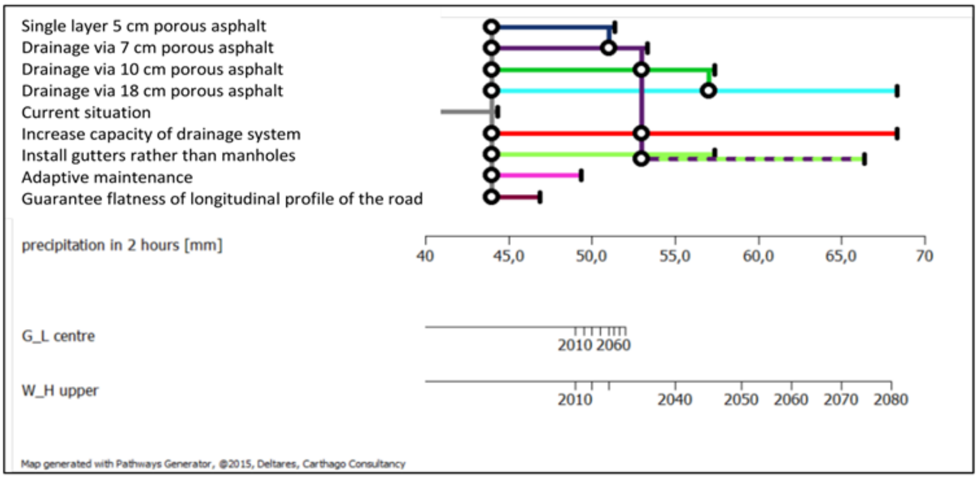


Figure 29. Example of adaptation pathway for pluvial flooding, from InnovA58 [87]

3.5. DEVELOPMENT OF AN ADAPTATION PLAN OR STRATEGY

Purpose of the work in this step Provides details necessary for developing an adaptation plan or strategy of the selected adaption measures.
Requirements: Starting point from the previous steps: a ranked list of adaptation measures that the road organisation has decided to implement.
Compatibility with other processes or systems Budget /resources. Other existing strategies or action plans within maintenance, renewal, capacity building, education, etc. Possible procedures for execution of public works with climatic considerations.
Outcome Document containing a detailed plan or strategy of work to achieve the aims of adaptation work, ref. Stage 1.

After identifying and prioritising adaptation responses, road organisations will need to develop a plan or strategy to carry out the selected measures. A number of actions, priorities, timescales and responsibilities will need to be determined and assigned.

3.5.1. Contents of an Adaptation Plan

An Adaptation Plan should provide details relating to the selected adaptation measures, such as actions and sub-actions (and linkages or interdependencies), timescales, priorities, necessary resources and responsibilities. It should also explain why some actions are adopted and some not.

According to ISO 14090, each planned climate change adaptation action shall include: an objective, its description, indicators and timescales. It should also include an estimate of costs and expected benefits, an assessment of the threats to its effective delivery, its current and required organisational capability, and any dependencies on regulatory/economic instruments.

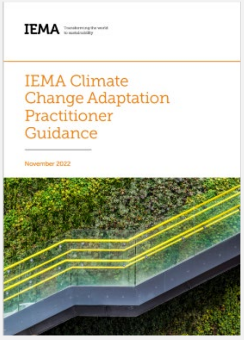
The grade of detailing can vary. Possible contents are:

- **Measure / Scheme:** Details on the action, what it is trying to achieve, and the risks it is 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.
- **Funding:** Estimated costs and funding source(s).
- **Priority and dependencies:** 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.

3.5.2. Tracing the Adaptation Plan

An Adaptation Plan should be seen as a live document. There should be a mechanism for monitoring and tracing the plan. A review of the plan on a regular basis is recommended. The adaptation plan shall provide a basis for following changes (a monitoring plan), by describing past, present and future impacts. As far as possible, indicators identified in Stage 1 should be used (see 1.2).

Ongoing monitoring and review of climate change risks, vulnerabilities and the effectiveness of adaptation initiatives is essential. This involves a review of findings, strategies and plans as more information becomes available and as new risks become apparent. Monitoring is a part of Stage 4 (Section 4 of this report).



Box 17

“**Climate Change Adaptation Practitioner Guidance’**, published in 2022 by the Institute of Environmental Management and Assessment (IEMA) provides information for practitioners dealing with adaptation to climate change.

The guidance addresses the whole process of assessment and adaptation. However, it may be especially useful for its practical approach to planning actions, based on a ‘maturity matrix’, comprising resources and possibilities. The report is available from:

IEMA - IEMA publishes guidance on climate change adaptation – November 2022

Box 18 : Scottish Government National Transport Strategy
- Delivery plan 2022-2023

”We will publish Transport Scotland’s Approach to Adaptation and Resilience. This will address the risks associated with changing weather patterns attributed to climate change and provide a strategic overview to our approach to adaption”

Climate Ready Scotland: Second Scottish Climate Change Adaptation Programme 2019-2024 (www.gov.scot)

Box 19: Adapting Victoria's Infrastructure to Climate Change, Australia

Infrastructure Victoria is completing a project on adapting Victoria's infrastructure to climate change. The project advances a recommendation from *Victoria's infrastructure strategy 2021-2051* to assess climate risks to Victoria's infrastructure. The project examines opportunities and develops the evidence-base for adapt Victoria's infrastructure to climate change. It identifies priority measures to improve infrastructure resilience, and evaluates the return on investment for adaptation measures.

The project considers different climate hazards including increased temperature, heatwaves, extreme rainfall and flooding, coastal flooding. It aims to show more resilient infrastructure can reduce the costs and impacts of future damage related to climate change.

The analysis includes a high-level risk assessment of climate impacts across selected infrastructure sectors, including a geospatial exposure mapping of assets to climate hazards. Its economic analysis includes:

- Identifying quantitative and qualitative upstream and downstream costs and benefits of investing in climate adaptation measures for roads, and the potential costs of no or limited action when factoring in the growing risks from climate change.
- Determines return-on-investment for selected adaptation actions when considering increasing climate risks over time.
- Present a replicable, robust, and scalable methodology for measuring and valuing investment in climate adaptation for infrastructure.

This component also includes assessment of direct tangible, indirect tangible, and intangible costs. It also captures some wider values of resilient infrastructure for the surrounding environment, communities, and economy, and considers avoiding maladaptation.

The project identifies opportunities for bundling and sequencing measures by considering adaptation measures holistically and examining their potential interactions. Instead of implementing measures in isolation, they can be strategically combined and implemented in a specific sequence to achieve greater overall resilience and deliver on broader objectives.

Ref: Infrastructure Victoria, forthcoming report

3.6. Outcome of Stage 3

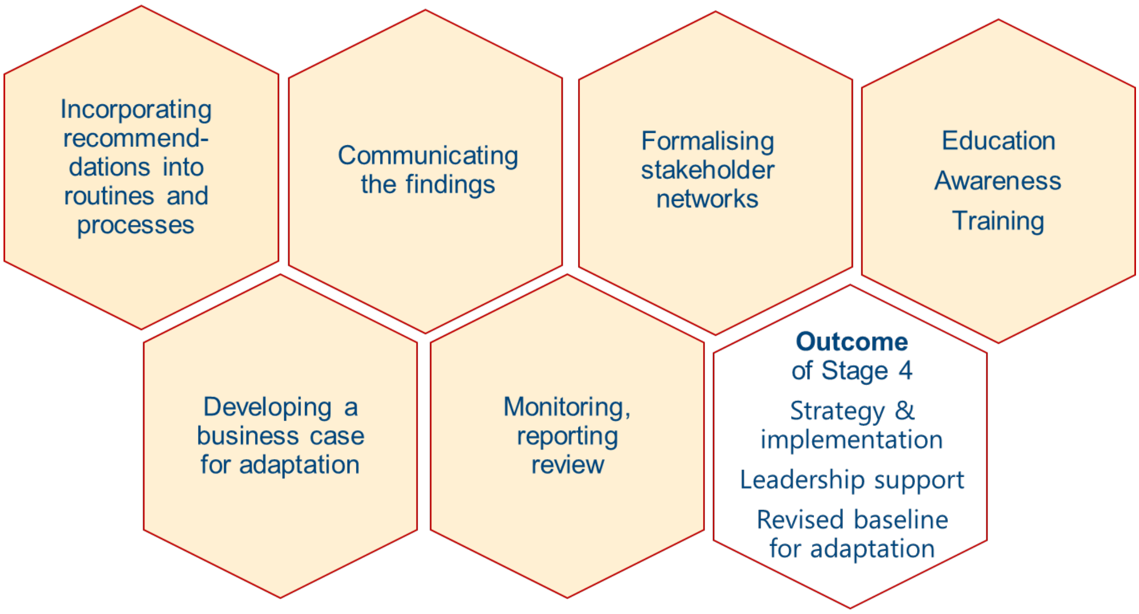
At the end of Stage 3, the road organisations will have:

- a list (or programme) of possible adaptation responses; or
- a list (or programme) of prioritised adaptation measures, with an idea of the benefits of each of the adaptation measures; or
- a response strategy – combining response measures in a way that the resources are used in accordance with the current knowledge and accompanying uncertainty; or
- an Adaptation Plan in order to facilitate the delivery of the adaptation actions. The plan should contain details about actions, teams, time schedule, funding and priority. Regular reviews of the adaptation plan are recommended.

Stage 4

Integrating Findings into Decision-Making Processes

4. STAGE 4 - INTEGRATING FINDINGS INTO DECISION-MAKING PROCESSES



This stage provides guidance on how to incorporate assessment findings from Stages 1 – 3 into the decision-making processes and systems, such as road infrastructure programmes, investments and wider plans, programmes, strategies, and policies. It also provides guidance on developing effective communication strategies for sharing information about climate change adaptation and resilience, developing a business case for action, and for strengthening collaboration with stakeholders. Finally, developing a business case and monitoring, evaluation and reporting of adaptation is included.

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

- Is there still a need to motivate decision-makers and explain the importance of implementing adaptation to climate change?
- Who do I need to engage with to ensure the Adaptation Plan developed during Stage 3 is implemented and monitored?
- In 1.4.1, plans, programmes, strategies and policies that could support findings of this assessment were identified. Is there anything to amend?
- Do the key stakeholders currently have the required level of education, awareness and training to support and implement climate change adaptation responses?
  Is there a mutual understanding between stakeholders of the differences in challenges and roles in adaptation to climate change at their level of focus?

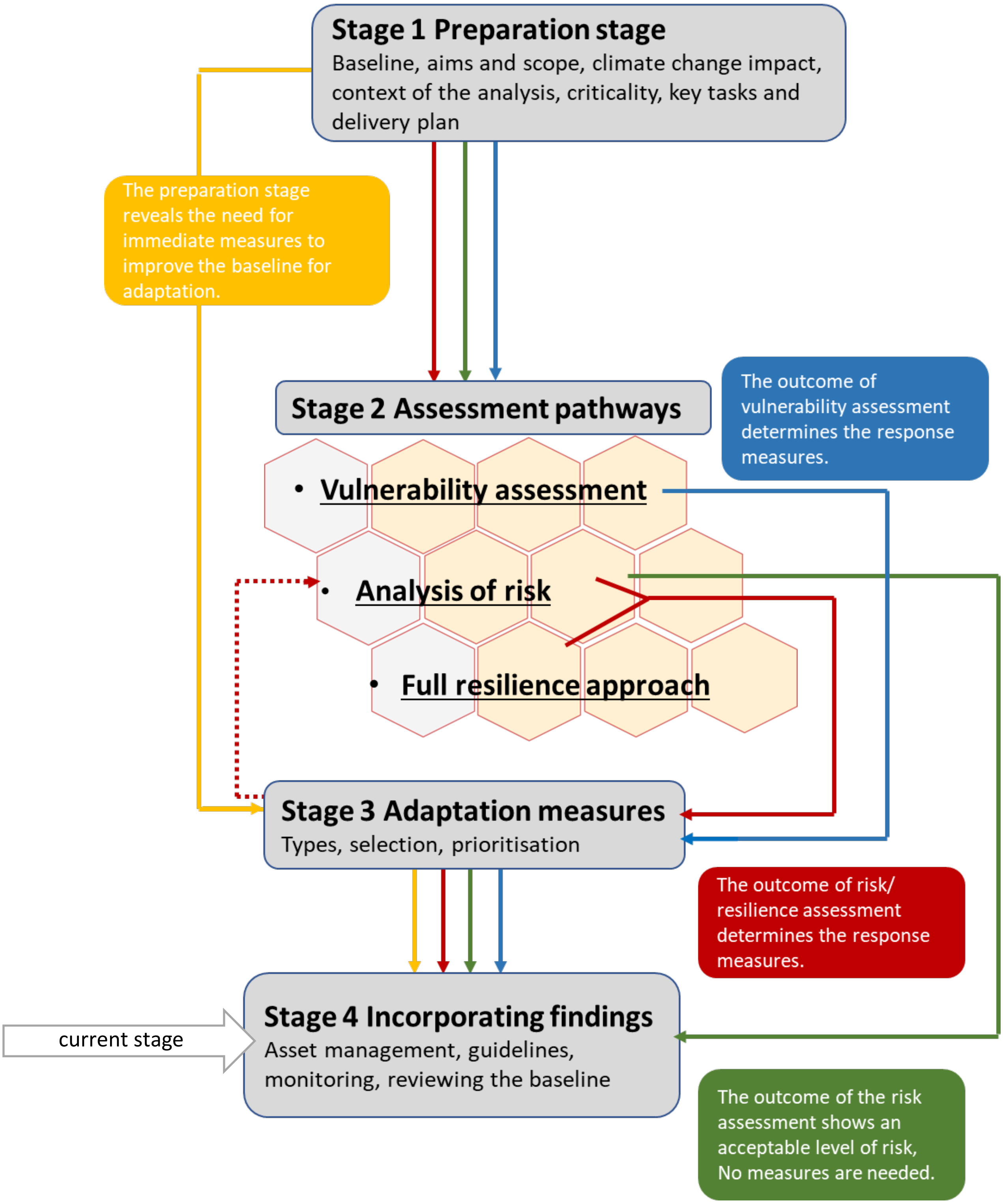


Figure 30. Illustration of the Framework: four main stages and possible assessment pathways.

Findings should be incorporated into road organisation's decision-making processes to ensure implementation, monitor progress, and develop a starting point for future assessments.

4.1. INCORPORATING RECOMMENDATIONS INTO ROUTINES AND PROCESSES

Purpose of the work in this step Provide conditions for incorporating findings and decisions into existing systems, programmes, processes and investments. Compose an implementation plan to ensure that the adaptation plan is carried out. An implementation plan is needed for the delivery of the adaptation plan and the preparation of a monitoring and evaluation plan.
Requirements: It is helpful if Section 1.4.1 already identified systems and processes that can be adjusted to incorporate climate change adaptation.
Compatibility with other processes or systems Almost any system or process can be influenced by adaptation measures. Some examples are: long-term planning and budgeting, asset management, quality systems, inspections and control.
Outcome Plans for implementation, monitoring and reviewing adaptation work, which ensure successful, sustainable adaptation and development towards a more resilient road network and system.

4.1.1. Mainstreaming climate change adaptation

Climate change risks should not be treated as a separate standalone issue [FW2015]. Findings from the vulnerability and risk assessment, the selected measures and strategies should inform the development of all other policies and practices of the road organisation. This step of integration is vital to ensure future climate resilience of road infrastructure networks and assets.

Mainstreaming adaptation to climate change implies that all levels, from decision-makers to practitioners, need to be aware of their role and make adjustments to contribute to the whole organisation being more resilient.

Climate change adaptation measures are relevant for many areas of work of an organisation. Table 8 shows some examples of processes that are influenced by climate change, and how they can be amended to incorporate adaptation measures.

FHWA's Vulnerability Assessment and Adaptation Framework includes a systematic overview of possible strategies to effectively incorporate results into transportation planning and project prioritisation, environmental review, engineering design, transport systems management and operations, maintenance and emergency management, and asset management. The section concludes with steps agencies can take to monitor adaptation strategies and revisit study assumptions and data. Asset management and monitoring are the subject of 4.1.2 and 6.5, respectively.

7. Incorporating Assessment Results in Decisionmaking - Adaptation Framework - Resilience - Sustainability - Environment - FHWA (dot.gov)

** **New Zealand's National Infrastructure Plan** (→ Sec. 9.4.1)

… is an example of successful incorporation of climate change risk assessment into whole of government planning and investment. The plan was developed in 2010, updated in 2011, 2015, and most recently in 2022 (as the New Zealand Infrastructure Strategy 2022 – 2052). The most recent update recognises that New Zealand will need to rebuild, strengthen, or relocate infrastructure in response to the changing climate and to recover from natural disasters, like volcanic eruptions and earthquakes. As an example, adapting New Zealand's infrastructure to climate change and repairing infrastructure after earthquakes will cost at least 0.2% of GDP every year over a 30-year period.

In parallel with the Infrastructure Plan, New Zealand has also created a whole of Government "National Climate Change Risk Assessment" (NCCRA, 2020, to be renewed every 6 years) and a National Adaptation Plan (NAP, 2022) to help the Government identify where it needed to prioritise climate adaptation action.

Table 8. Examples of processes influenced by adaptation measures, and how they can be amended to incorporate adaptation to climate change

Examples of programmes, processes, and investments	**Possible amendments or products**
Transport asset management system /programmes	Better inclusion of information regarding climate change vulnerability, providing a better basis for the assessment of necessary protection-, repair- and preparedness measures.
Asset inventory plans and policies	Aligning inventory plans with risk assessment of climate change hazards. Integrate meteorological and climatic information.
Maintenance programmes	Considering climate change vulnerability in the prioritised maintenance programmes.
Landscape strategies	Opening waterways for better flood resilience, forest management, water transport with respect to landslide hazard, urban flooding. Improved collaboration with other area and infrastructure owners.
Traffic management strategies	Ensure flexibility, and redundancy, with special consideration of climate-related hazard events. Address vulnerability of remote management, high-tech solutions and automatisation.
Investment plans	Plans that incorporate possible additional investments for climate change adaptation, which are carried out as a part of other planned work. Formulating investment plans with a flexibility to incorporate future adjustments in adaptation strategy, future insights and improved datasets.
Design standards and specifications	Implementing amendments regarding the most important hazards and risks (see 4.2).
Emergency and risk management processes	Base decisions on dynamic weather data and forecasts, develop thresholds based on earlier experience, learn from each event. Cross-sectoral collaboration is critical for coordination and collaboration to ensure effective implementation and management of interdependencies.
Hazard mitigation plans	Protection measures with capacity for additional impact from climate change, planned together with preparedness measures.
Transportation planning - project selection criteria	Natural hazard risk reduction should be among the central criteria for the selection of project alternatives. Redundancy and options for fast and simple recovering after disruptions should be considered already in the planning phase of a road project.
Environmental reviews and strategies.	Integrate climate considerations, both adaptation and mitigation, in all environmental reviews, specifically for ecosystem-based adaptation strategies.

4.1.2. Asset management as a tool for climate change adaptation

Road Asset Management (RAM) systems typically include data on location, criticality and the physical condition of road elements, such as pavements, bridges, slopes, and drainage structures. RAM can therefore be valuable for road organisations in understanding which assets are most vulnerable and at risk from climate change and extreme weather events.

A road organisation in the early stages of developing an asset management system could begin by using the collected and systemised data to document, analyse, and better understand the nature and extent of impacts of climate change and extreme weather on specific assets and on the network as a whole [88]. With time, consideration of weather and climate risk can inform the data collection and resource allocation decisions.

Countries that have implemented good asset management can use information on the assets' condition to assess sensitivity, and directly inform the vulnerability assessment. If the quality of data is good, thresholds for a quantitative rating can also be obtained.

Using a RAM system makes it possible to optimise investments in road maintenance. Integrating information on climate impact into a RAM system or strategy will ensure that resilience to climate change and extreme weather events is considered in maintenance and renewal prioritisation decisions.

Comprehensive asset management will make it possible to protect and maintain road assets at a desired level, above the critical thresholds for the different climate hazards, and thus ensure safe and effective performance under conditions of climate stress.

RAM can also make it possible to adequately programme maintenance actions based on deterioration models adapted to future climate conditions. Software tools, such as the Highway Development and Management System (HDM-4), can forecast the evolution of the condition of the asset. The incorporation of the expected changes in temperature and/or precipitation due to climate change will help to schedule more timely maintenance of the road network.

Asset management has historically focused on pavement maintenance management and bridge management, and therefore has not comprehensively incorporated other elements of the road, such as slopes, and drainage structures. However, the trend is to strengthen asset management with a holistic approach and the integration of climate change risks.

Integrating the issue of resilience is more complicated. The key question is how to agree upon a set of quantifiable indicators and related targets of resilience. The PIARC asset management manual[15] addresses this issue in a chapter dedicated to resilience.

[15] Asset Management Manual - World Road Association (PIARC) | Asset Management Manual guide for practitioners

Box 20 : Risk-based transportation asset management plans (FHWA)

The FHWA Resilience Framework advises the development of risk-based Transportation Asset Management Plans (TAMPs) [89]. TAMPs help organisations answer five core questions:

1. What is the current status of our assets?
2. What is the required condition and performance of those assets?
3. Are there critical risks that must be managed?
4. What are the best investment options available for managing the assets?
5. What is the best long-term funding strategy?

State Departments of Transportation (DOTs) are required to address resilience in their asset management plans, in:

- the risk sections and development of risk registers;
- their "life cycle planning" analyses, supported by another 2017-report "Using a life cycle planning process to support asset management [90], also mentioning climate risk.

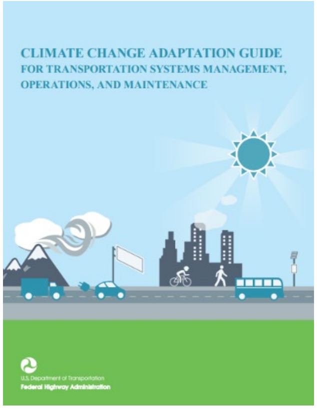
Pilot projects, supported by FHWA, can provide more information on this topic.
https://www.fhwa.dot.gov/asset/pilot/

Box 21 : Implementation of action through RAMS (National Highways)

National Highways (until 2021 'Highways England'), in their third adaptation report (ARP3) of 2022, put forward as the main outcome the inclusion of actions resulting from ARP3 within their **Asset Management Transformation Programme**, to allow for identification of the most effective way of advancing progress and monitoring.

National Highways will "strive to ensure that climate risk will be effectively governed through the Asset Management Transformational Programme. Better governance and ownership of climate risks and actions will contribute to more effective implementation and more efficient progress." [91]

Box 22:

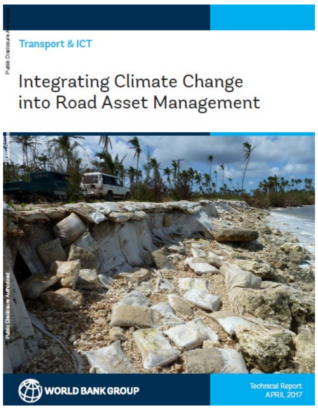


[Climate change adaptation guide for transportation systems management, operations, and maintenance], AASHTO, 2015

This document, developed by The American Association of State Highway and Transportation Officials (AASHTO) in 2015, examines how Transportation Asset Management (TAM) provides a mechanism for integrating consideration of extreme weather risk into decision-making.

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.

Box 23 :



[Integrating Climate Change into Road Asset Management], World Bank 2017

«The main conclusion of this report is that asset management, when undertaken according to best practice, is already one of the most significant climate adaptation strategies. There are many processes and techniques that are used to develop optimal maintenance and renewals programmes that result in more resilient road networks. However, so much more could be done in order to effectively integrate climate adaptation into business-as-usual asset management. »

4.1.3. Amendments to design rules

Making changes or adjustments to design rules is one of the most efficient ways of achieving resilience of new infrastructure. Amendments to requirements for operation and maintenance will help ensure that existing infrastructure is maintained and managed in a way that contributes to overall resilience.

An important factor for achieving these changes is where the responsibility for providing and amending regulations lies.

- In cases where the road organisations do not have the mandate to amend regulations, they will need to pursue an informed case for the amendments by another pathway, for example the responsible transport ministry. **See Example 1** BASt Germany, App. 10.4.1 and Figure 31.
- In cases where the road authorities have the ability to amend regulations, the priority task is to deal with the regulations that are most relevant for the identified hazards or risks. **See Example 2** NPRA Guidelines, App. 10.4.2 and Figure 32.

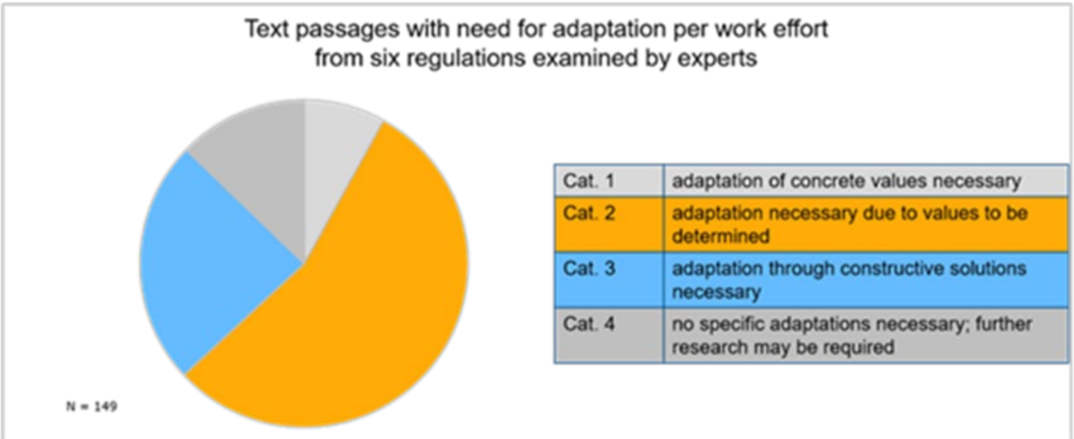
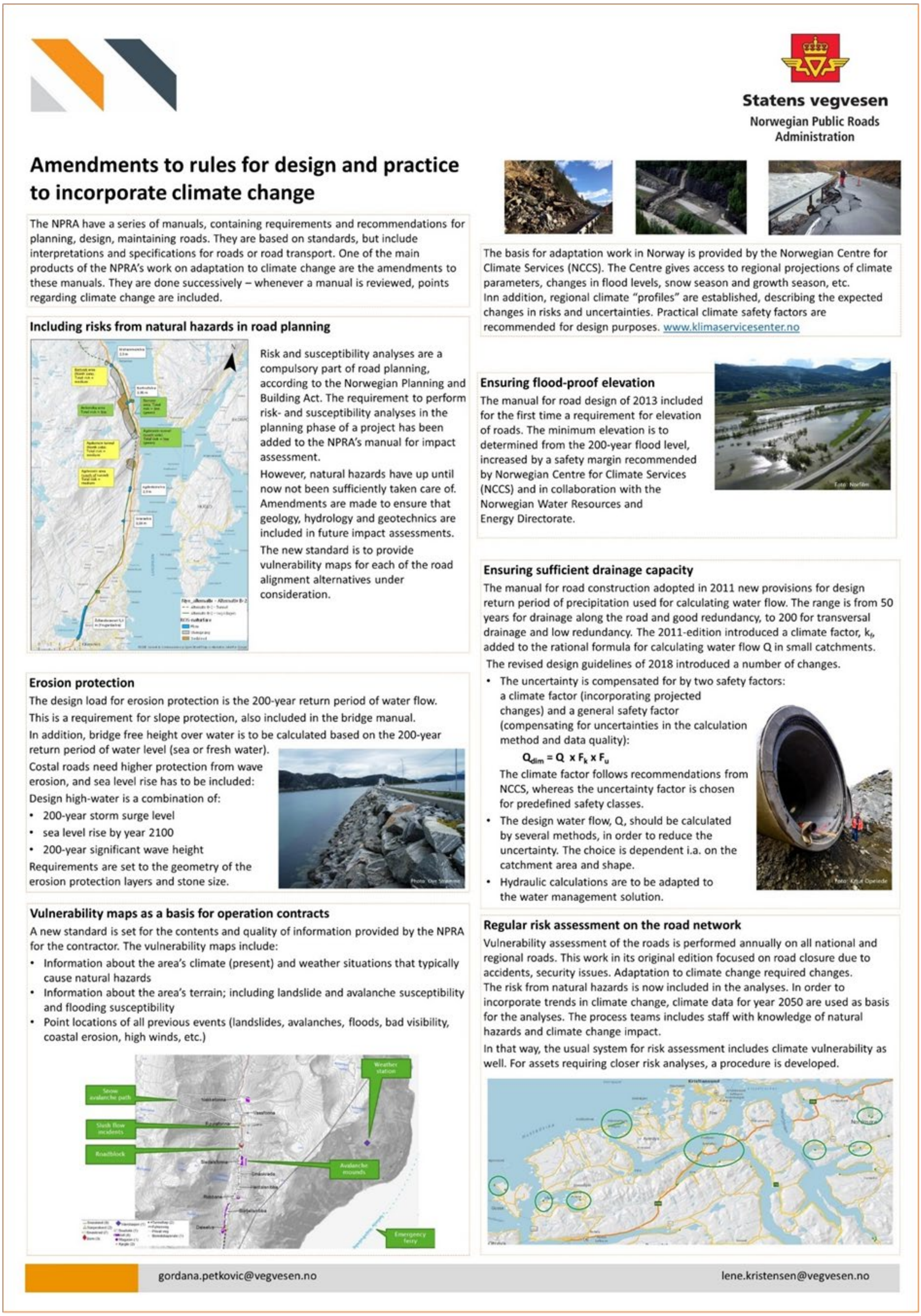


Figure 31. Results of the overview of the investigated standards and regulations concerning the need for amendments.

** **Adaptation of Road Standards, Guidelines and Regulations to Climate Change, France** (→ Sec. 9.4.2)

In this study carried out by Cerema (France), one of the outcomes is a list of documents that are commonly used to design, maintain and operate roads, and that need to be amended to incorporate the impact of climate change. To establish the list, a group of experts assessed over 130 documents with references to climate parameters and sorted them by priority of adaptation.



Statens vegvesen
Norwegian Public Roads Administration

Amendments to rules for design and practice to incorporate climate change

The NPRA have a series of manuals, containing requirements and recommendations for planning, design, maintaining roads. They are based on standards, but include interpretations and specifications for roads or road transport. One of the main products of the NPRA's work on adaptation to climate change are the amendments to these manuals. They are done successively – whenever a manual is reviewed, points regarding climate change are included.

The basis for adaptation work in Norway is provided by the Norwegian Centre for Climate Services (NCCS). The Centre gives access to regional projections of climate parameters, changes in flood levels, snow season and growth season, etc. Inn addition, regional climate "profiles" are established, describing the expected changes in risks and uncertainties. Practical climate safety factors are recommended for design purposes. www.klimaservicesenter.no

Including risks from natural hazards in road planning

Risk and susceptibility analyses are a compulsory part of road planning, according to the Norwegian Planning and Building Act. The requirement to perform risk- and susceptibility analyses in the planning phase of a project has been added to the NPRA's manual for impact assessment.

However, natural hazards have up until now not been sufficiently taken care of. Amendments are made to ensure that geology, hydrology and geotechnics are included in future impact assessments.

The new standard is to provide vulnerability maps for each of the road alignment alternatives under consideration.

Ensuring flood-proof elevation

The manual for road design of 2013 included for the first time a requirement for elevation of roads. The minimum elevation is to determined from the 200-year flood level, increased by a safety margin recommended by Norwegian Centre for Climate Services (NCCS) and in collaboration with the Norwegian Water Resources and Energy Directorate.

Erosion protection

The design load for erosion protection is the 200-year return period of water flow. This is a requirement for slope protection, also included in the bridge manual.

In addition, bridge free height over water is to be calculated based on the 200-year return period of water level (sea or fresh water).

Costal roads need higher protection from wave erosion, and sea level rise has to be included:

Design high-water is a combination of:

- 200-year storm surge level
- sea level rise by year 2100
- 200-year significant wave height

Requirements are set to the geometry of the erosion protection layers and stone size.

Ensuring sufficient drainage capacity

The manual for road construction adopted in 2011 new provisions for design return period of precipitation used for calculating water flow. The range is from 50 years for drainage along the road and good redundancy, to 200 for transversal drainage and low redundancy. The 2011-edition introduced a climate factor, k_f, added to the rational formula for calculating water flow Q in small catchments.

The revised design guidelines of 2018 introduced a number of changes.

- The uncertainty is compensated for by two safety factors: a climate factor (incorporating projected changes) and a general safety factor (compensating for uncertainties in the calculation method and data quality):

  $Q_{dim} = Q \times F_k \times F_u$

  The climate factor follows recommendations from NCCS, whereas the uncertainty factor is chosen for predefined safety classes.
- The design water flow, Q, should be calculated by several methods, in order to reduce the uncertainty. The choice is dependent i.a. on the catchment area and shape.
- Hydraulic calculations are to be adapted to the water management solution.

Vulnerability maps as a basis for operation contracts

A new standard is set for the contents and quality of information provided by the NPRA for the contractor. The vulnerability maps include:

- Information about the area's climate (present) and weather situations that typically cause natural hazards
- Information about the area's terrain; including landslide and avalanche susceptibility and flooding susceptibility
- Point locations of all previous events (landslides, avalanches, floods, bad visibility, coastal erosion, high winds, etc.)

Regular risk assessment on the road network

Vulnerability assessment of the roads is performed annually on all national and regional roads. This work in its original edition focused on road closure due to accidents, security issues. Adaptation to climate change required changes.

The risk from natural hazards is now included in the analyses. In order to incorporate trends in climate change, climate data for year 2050 are used as basis for the analyses. The process teams includes staff with knowledge of natural hazards and climate change impact.

In that way, the usual system for risk assessment includes climate vulnerability as well. For assets requiring closer risk analyses, a procedure is developed.

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Figure 32. A summary of the amendments of guidelines for design and practice in the NPRA (CEDR Final conference of the Climate Adaptation Programme in 2018)

4.1.4. Developing an implementation plan

Implementation means transforming the climate change adaptation plan into a programme or suite of activities [ISO 14090]. The role of the **implementation plan** is to:

- define conditions for the delivery of the adaptation plan,
- guide on how adaptation actions should be embedded in policies, strategies, activities,
- establish roles and responsibilities,
- establish contingencies,
- provide adjustments where new learning or circumstances are recognised,
- specify barriers and report on strategies to address them,
- document capabilities and resources.

Adaptation is iterative work. That is why it is important to ensure a mechanism for taking in learning, making useful adjustments, absorbing input from partners /stakeholders, etc.

ICAO – Climate adaptation in aviation organisations [92] The 2022 report 'Climate Risk Assessment, Adaptation and Resilience: Key Steps for Aviation Organisation Climate Change Risk Assessment and Adaptation Planning', from The International Civil Aviation Organisation (ICAO), covers the whole adaptation process, but provides a particularly good overview of adaptation, implementation and monitoring plans. The report is available from: Climate Risk Assessment and Adaptation Report_Key Steps Risk Assessment_final.pdf (icao.int)

4.2. Communicating the findings

This section provides guidance on how to communicate the main conclusions from the Strategy or assessment developed by this Framework to three important groups:

- Senior or executive management, and decision-makers (national policy, strategy) who are in the position to ensure that the adaptation work is implemented and that it builds upon the findings of the assessment
- users of the road network, or recipients of the communication regarding risk and emergency measures in case of hazard events.
- affected communities who may be impacted severely (in terms of accessibility and possible isolation) by damaged infrastructure.

The aim is to communicate the relevance, purpose and importance of the selected adaptation measures. The communication plan described in Sec. 1.4.2, which focused on stakeholders and target audiences, can also be used in this stage of work.

4.2.1. Communicating with senior or executive management

Effective communication with senior or executive management and decision makers is important because it provides possibilities for mainstreaming adaptation to climate change, i.e. embedding resilience within business-as-usual planning, design, construction, operation and maintenance of the road system.

It supports the delivery of implementation plans (which help carry out adaptation plans), especially by securing resources and priority. It is also important for efficient and high-level collaboration with other stakeholders.

The key findings from risk assessments and key recommendations to senior managers should be communicated in a concise way. Suggested main elements of such communication are:

- summary of obligations and relevant high-level organisational strategies,
- outline the risks of failing to adapt to climate change,
- what progress already has been made, the key conclusions and recommendations,
- cross-sectoral issues, and the organisation's role in that setting,
- what is required/requested from senior management in order to progress further with adaptation measures.

4.2.2. Communicating with users of the road network

Having means to communicate with users before, during and after a disruptive event can help minimise the consequences of the impacts and duration of emergency and recovery works.

The two key pieces of information most users wish to have are the availability of the network (current or anticipated), and regular updates of a disrupted network returning to functionality following a major event (including information on alternatives available). Proactive engagement with users can assist them to make better decisions and reduce their risk of being involved in an incident.

Means of communication with users is constantly evolving with new options regularly becoming available to road organisations on a regular basis. Some well-established options include:

- Variable Messaging Signs (VMS)
- Mobile Phone apps/social media
- Television and radio broadcasts
- Use of a dedicated website to inform the public
- Freephone numbers and broadcast emails
- Supplying providers of navigation systems services with data about incidents, road closures, roadworks, and traffic conditions, for the benefit of end-users.
- Ongoing educational and awareness-raising campaigns to discourage unnecessary travel during extreme weather events and encourage safe driving.
- Disseminating summary notes and newsletters, etc.

See App. 10.4.3. for more information on studies in road users' perceptions.

4.2.3. Communicating with local communities

Local communities need to be involved during the process of defining and designing adaptation measures. Local knowledge is often overlooked and yet it can provide a crucial input into effective and sustainable design and implementation of adaptation measures.

To that end, communication with local communities before, during and after a disruptive event can help to minimise the consequences of the impacts and duration of emergency and recovery works. There are examples of where communities are only informed of the need to evacuate at short notice and this has contributed to unnecessary loss of life and property in addition to damaged infrastructure.

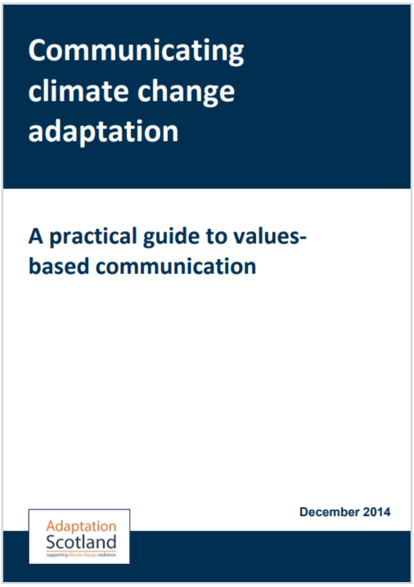
The target audience should be considered prior to developing communication channels and tools. Common means of communication with communities include:

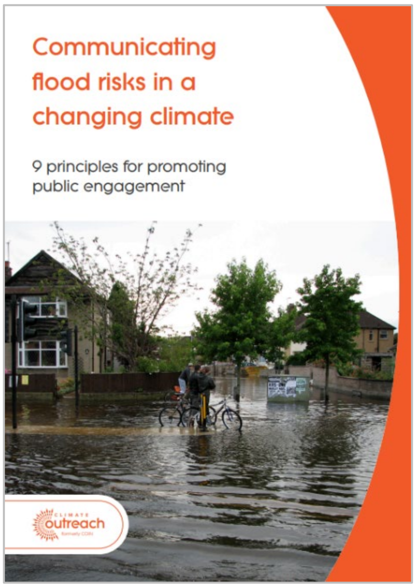
- Television and radio broadcasts
- Mobile Phone apps/social media
- Local and traditional personal engagement

4.2.4. Examples of communicating adaptation

The weADAPT platform (an online 'open space' on climate adaptation that allows practitioners, researchers, and policy makers to access credible high-quality information and to share experiences and lessons learned) is sharing some good references on the topic of communicating climate change and risk. Some central issues are ensuring a balance between consequences and opportunities, finding the right types of examples, and communicating uncertainty in the right way.

Two suggested resources from weADAPT are:





- Communicating climate change adaptation: A practical guide to values-based communication

- "Communicating flood risks in a changing climate: nine principles for promoting public engagement", available from: https://www.weadapt.org/knowledge-base/climate-services/communicating-flood-risks-in-a-changing-climate-0

4.3. Formalising stakeholder networks

In many countries, the cross-disciplinary nature of climate adaptation and management of natural hazards has motivated the founding of cooperative networks. The exchange of expertise and data is extremely beneficial for building capacity for adaptation to climate change.
Some examples are given below, see Box 24 – Box 26.

Box 24 : Network of Experts of the German Federal Ministry for Digital and Transport (BMDV)

The BMDV Network of Experts (NoE) is a cross-modal format of departmental research. In 2016, under the leitmotif "Knowledge – Ability – Action", seven departmental research institutes and specialist authorities within the portfolio of the Federal Ministry for Digital and Transport (BMDV) joined forces to form the BMDV Network of Experts.

The network's objectives are to address pressing and future-oriented questions in the field of transportation and, by means of innovations, to enable a resilient and environmentally sound transport system.

Seven federal agencies are involved in the BMDV NoE: The Federal Highway Research Institute (BASt), Federal Institute of Hydrology (BfG), Federal Waterways Engineering and Research Institute (BAW), German Meteorological Service (DWD), Federal Logistics and Mobility Office (BALM), Federal Maritime and Hydrographic Agency (BSH) and the German Centre for Rail Traffic Research at the Federal Railway Authority. [93]

The NoE covers six topic areas. Topic area 1 "Climate Change Impacts and Adaptation" aims at "Adapting transport and transport infrastructure to climate change and extreme weather events". Actions under this topic should provide answers to questions such as:

- What is the significance of climate change?
- Which climatic changes are relevant to transport and infrastructure in Germany?
- How strongly, where and by which mechanisms will climate change and weather extremes affect the German federal transport infrastructure and its use?
- How do infrastructure-specific characteristics increase the sensitivity to climate impacts?
- Which adaptation strategies and options exist?
- How are traffic flows influenced by climate-induced functional impairments or outages?
- Which measures exist to minimise potential damages?
- Which adaptation measures are available or can be developed?
- How can the transport sector be designed to increase its climate resilience?
- How to integrate results from exposure, sensitivity and criticality analyses?

During the network's first research phase (2016-2019), specific climatic influences and impacts on the federal transport infrastructure were investigated. These activities resulted in a methodology to analyse impacts of climate change on transport infrastructure – the 'climate impact analysis'. The steps of the climate impact analysis provide a structure for the activities within the current research phase, which started in 2020. Thus, the researchers are building a comprehensive understanding of the impacts of climate change and adaptation measures within the context of climate resilient transport infrastructure development.

Networking activities and exploiting synergies from the cooperation with infrastructure operators, federal/state-level authorities, research institutions and neighbouring countries are key to answering numerous research questions within this topic area. The outcomes contribute to the ongoing development of the DAS core service “climate and water”, which was founded by the Federal Government within the German strategy for Adaptation to Climate Change (DAS). The service makes the topic area’s research results permanently available for political and operational decision-making and planning processes. The findings can also be accessed via the federal and state governments’ Climate Preparedness Service, the German Climate Service or the BMDV’s mCloud. [94]

BMDV, 2022

Box 25 : Natural Hazard Forum (Norway)

The Norwegian **Natural Hazard Forum** was established in 2016 as a collaboration forum for preventive work on natural hazards. Its purpose is to strengthen cooperation between national, regional, and local actors in order to reduce society’s vulnerability to natural hazards. It works to identify deficiencies or improvement potential in society’s prevention and management of natural hazards and propose appropriate measures. The forum initiates and focuses on projects in areas where there are cross-sectoral challenges. It is also the national platform for the Global Disaster Prevention Framework (Sendai Framework), which Norway has committed to follow.

Governing board: The forum has a governance board drawn from the Directorate for Social Security and Emergency Planning (DSB), Energy and Water Resources Directorate (NVE), Norwegian Public Roads Administration, Bane NOR (state-owned company responsible for the national railway infrastructure), the Directorate for Agriculture, the Norwegian Association of Local and Regional Authorities (KS), Norwegian Environment Agency, Meteorological Institute, and the county governors’ chiefs of civil protection.

The Knowledge Bank is a project which aims to contribute to the general efficiency of data-sharing across the public sector. The project will establish a single platform containing all relevant available data on natural hazards and climate change. Having a single platform improves data sharing, data analysis, and mapping. The Knowledge Bank currently prioritises data related to natural hazards, but will be expanded with other available data. The project is led by the Directorate for Social Security and Emergency Planning (DSB). Partners include Finance Norway. Finance Norway’s presence will add insurance data, which can be highly valuable for evaluating the relationship between damage costs and protection measures.

Norwegian Public Roads Administration, 2022

Box 26 : Your Peak Body for Engagement | IAP2 Australasia

As the peak body for the community and stakeholder engagement sector, IAP2 Australasia believes that engagement, when done well, improves social, environmental and economic outcomes and increases trust in the democratic process.

IAP2 is the preeminent international organisation advancing the practice of public participation. Its mission is to promote and advance public participation / community engagement globally through targeted initiatives that are guided by culturally adaptive standards of practice and core values.

It advocates for genuine community and stakeholder engagement in alignment with the IAP2 Quality Assurance Standard for Community and Stakeholder Engagement.

As a not-for-profit organisation, its aim is to advance the community engagement profession by providing training in, and communicating the principles of, public participation and how to achieve effective community and stakeholder engagement (or public participation).

Its activities include developing publications. IAP2 has developed the three Pillars of Public Participation – the Core Values, Code of Ethics, and Spectrum of Public Participation – to create a shared framework to differentiate public participation from other forms of civic engagement. IAP2 also operates a Professional Certification system and runs Professional Certification programs.

IAP2 has developed tools that are widely used and acknowledged. These include the **Core Values for Public Participation** for use in the development and implementation of public participation processes; the **IAP2 Public Participation Spectrum** which assists with the selection of the level of participation that defines the public's role in any community engagement program; and the IAP2 Code of Ethics which guides the actions of those who advocate including all affected parties in public decision-making process.

Finally, the **Quality Assurance Standard for Community and Stakeholder Engagement**, is recognised as the international standard for public participation practice.

4.4. Education, Awareness, Training

Purpose of the work in this step How can an organisation incorporate climate change knowledge in staff training and education?
Requirements: Common understanding and internal agreement in the road organisation regarding issues and priorities about climate change education, research and awareness programmes.
Compatibility with other processes or systems It is an advantage if knowledge about the impacts of climate change is mainstreamed into other training courses in road planning, design etc.
Outcome Improved awareness within an organisation or sector about the impacts of climate change in all relevant settings and areas of expertise.

Road organisation employees need more knowledge of climate change risks, resilience, and adaptation methods. Incorporating climate change adaptation into a road organisation's education and training will have a significant role in the success of the adaptation processes. Access to robust information, tools, and guidance will further improve employee capacity to make informed decisions [FW2015].

Potential actions:

- internal climate change impact training. Courses should aim to improve and update employee knowledge of current and developing information on risks and opportunities
- collaboration with other government organisations with common interest in adaptation to climate change, to provide cross-disciplinary training programmes, and exchange of lessons learned and best practices
- collaboration with experts from academia and education centres
- integrating climate change into other training programmes, for example planning, design, operation, maintenance, for internal or external partners.

Box 27 : Workshops on PIARC Climate Change Adaptation Framework

The Mexican Institute of Transportation in collaboration with the World Road Association has implemented several workshops on the use of the International Framework for the Adaptation of Road Infrastructure to Climate Change, which were held in Mexico, Paraguay and Cuba.

As part of the implementation of the Framework and the national work for the adaptation of road infrastructure to climate change, workshops were held in the state offices of the Ministry of Transport, Infrastructure and Communications.

The objective was to provide participants with knowledge on the “International Framework for Road Infrastructure Adaptation to Climate Change”, so that this tool can be an effective and useful mechanism for the identification of risks associated with climate change. It enabled these risks to be evaluated and prioritised, so that those that are determined to have a high impact on the transportation network can be addressed through the development of adaptation strategies and responses., Such actions can then be incorporated into the investment programmes of road organisations.

The main content was:

- Overview of the impact of climate change on road infrastructure (main hazards, effects on road infrastructure, etc.)
- Terminology and concepts
- PIARC Framework
- Identification of sites at risk.
- Vulnerability assessment (exposure and sensitivity) and Risk assessment (probability and severity).
- Identification and development of adaptive responses.
- Prioritisation of adaptation measures

The workshop was targeted to decision-makers and technical experts from any road organisation, whether at the national or regional level, who are closely involved in the operation and maintenance of roads, particularly in dealing with risks associated with climatic phenomena.

In addition, as part of the work of the PIARC technical committee on climate change, workshops were held at the world congresses in Abu Dhabi (2019) and Prague (2023).

The Mexican Institute of Transportation & PIARC 2022.

Box 28 : Mandatory training programme for contractors in operation contracts

A large number of road stretches in Norway are exposed of natural hazards like landslides, avalanches and flood events. To operate these road stretches safely, the Norwegian Public Road Administration developed a mandatory training programme for contractors operating those stretches. The road organisation organises this training programme which teaches about:

- relevant natural hazards in the contract area,
- meteorological factors relevant for the natural hazards,
- how to recognise early warning signs in the weather-, snow-, or ground-conditions,
- the contingency plan for natural hazards,
- how to report early warning signs of potential natural hazards, signs of hazards and hazard assessments,
- how to operate the road stretch safely (both for the operating personnel and users),
- how to clean up after a slide or flood event,
- search and rescue

The content is adjusted to the relevant hazards in the contract area. This training programme makes sure that:

- private suppliers/contractors are more capable of safely operating road stretches exposed of natural hazards
- reporting of events is standardised. This provides efficient communication between the contractor and the road organisation, such as observations of natural hazards. These observations are saved in an open database that can be uploaded to various map solutions.
- a larger group of private suppliers/contractors have the necessary knowledge, rather than relying on a few expensive specialist private suppliers/contractors. This allows for a more robust operation and good communication between private suppliers/contractors and road organisations.

Norwegian Public Roads Administration, 2022

Transportation Engineering Approaches to Climate Resiliency (TEACR) Study

In 2017, US Federal Highway Administration (FHWA) published the report "Synthesis of Approaches for Addressing Resilience in Project Development" with lessons learned and innovations from different FHWA studies and pilots. The report helps transportation organisations address resilience at the asset level, using engineering-informed studies on hydraulics, riverine flooding, pavements and soils, and mechanical and electrical systems.

The project also developed engineering assessments of options for adapting transportation assets (e.g., roadways, bridges, pavements, culverts, and slopes), to changes in precipitation, sea level, storm surge, heat, drought, and wildfire.

4.5. DEVELOPING A BUSINESS CASE FOR ADAPTATION

Purpose of the work in this step To define the rationale behind an adaptation strategy/measure. What are the problems and drivers behind adaptation to CC? What are the potential benefits?
Requirements: From previous steps: strategy aims and scope, problem definition, optioneering, action plan, implementation roadmap, communication strategy. Road organisation's strategy, main goals etc. will provide guidance.
Compatibility with other processes or systems • Road organisation's strategy, main goals etc. • Road maintenance and investment programmes, • Technical capacity of the road system.
Outcome A document summarising the rationale for investing in adaptation to climate change. If possible, this should be related to established strategies and goals, or motivate establishing new goals, strategies and programmes.

Engagement and support from senior managers and decision-makers is vital to the successful implementation of any climate change risk assessment findings and adaptation responses. A business case for adaptation should document the rationale behind the implementation of an adaptation strategy or initiation of a particular action or measure. A solid business case gives the key stakeholders a document relevant to their real-world situation. Such practical documentation helps to build engagement and improve investment decision-making, by making the issue relatable, compelling and justifiable.

A business case requests approval to invest money. It outlines the reason for the investment, its costs and its benefits, and the options with a preferred programme for delivery.

The Five Case Model originated in the United Kingdom as an approved standard for the production of public sector business cases. In August 2018 the G20 adopted this as the standard for all infrastructure projects. It comprises five dimensions and answers the following key questions:

- **Strategic Case** – Why is this needed? What is the case for change and how does it provide strategic fit?
- **Economic Case** – what is the best choice for optimising value to the organisation?
- **Commercial Case** – is the proposed deal commercially viable? Who will deliver it?
- **Financial Case** – is the investment proposal affordable? How will It be funded?
- **Management Case** – are the necessary arrangements in place for successful delivery?

The business case planning process provides a framework for the systematic and holistic development and application of policies, regulations, organisational strategies, programmes and projects. The Business Case Approach supports planning and investing for outcomes, ensures early collaboration between stakeholders and the development of a robust, evidence-based investment case. It is a principles-based approach that clearly links strategy to outcomes, and defines problems and their consequences thoroughly before solutions are considered. This principles-based approach ensures a shared view of problems and benefits early in the transport planning process without requiring that the work has to be done in a particular way.

A key aspect of the Business Case Approach is that a case for investment is built progressively with decision points along the way that determine whether the investment is worthwhile to continue or requires re-directing in relation to the desired outcome.

4.5.1. Case studies and examples

** **Business case approach – Waka Kotahi New Zealand** (→ Sec. 9.4.3)
Waka Kotahi New Zealand Transport Agency has developed a comprehensive business case approach to be used in the development and approval of transport programmes and projects which are seeking funding (Processes | Waka Kotahi NZ Transport Agency (nzta.govt.nz)). This business case approach is applicable to projects that are pursuing any key outcome, including climate change adaptation or other responses. It is intended to be scalable and useable with a wide range of sizes and types of initiative.

An example outline guide for business case process as evolved from the 5 Case Model and developed for a road organisation is: https://www.nzta.govt.nz/assets/Highways-Information-Portal/Processes/Business-case-phases/NZTA-BusinessCaseApproach-final.pdf. It is structured on three main phases of developing a case for change, optioneering (development and assessment) and developing and documenting a preferred option (including procurement strategy, risk management and delivery activities).

** **Wellington Regional Land Transport Resilience Programme** (→ Sec. 9.4.4)
The Wellington Region is vulnerable to a range of natural hazards, including earthquakes, tsunami, major storms, floods and landslips. Waka Kotahi, in collaboration with local councils and KiwiRail, identified the most-at-risk locations in the land transport system, and recommended a long-term programme of interventions to address the risks at these locations.

The project was based on the application of the Waka Kotahi Business Case Approach and applied the Strategic Case and Programme Business Case stages.

This case study is an example of joined-up use of MCA and Cost-Benefit Analysis approaches and was used as input to a wider integrated multi-sector plan. Although this study is an excellent example of a region-wide application of the business case process to transport system risk, optioneering and evaluations, its primary focus and the maximum credible event used for planning was not climate change related!

Box 29: Coastal Climate Adaptation Decision Support – CoastAdapt (Australia)

There has been increasing recognition by businesses that the Australian economy is affected by climate change, which has led to organisational imperative to develop business cases for adaptation. The rationale for building a business case needs support from decision-makers, meaning that it is important that the business case reflects the risks and economic costs identified in the organisation. One example of risks is that the topmost severe risk on a global scale for the next 10 years is climate action failure (World Economic Forum Global Risks Perception Survey 2021-2022). Another study showed that Australian estimated future costs of natural hazards would reach $2.3 billion by 2050, and adaptation measures could reduce these costs by 50 % (Deloitte Access Economics 2013). Such information can create consensus that it is important to investigate and manage climate change risks and ensure the long-term viability of business in the face of adverse climate change impact.

Effective business cases for climate change adaptation can be a valuable tool to ensure organisational support, access to required resources and achieving action. Based on experience from the business cases for adaptation, a procedure and a template has been developed for such business cases. An analysis of the business cases showed that there are several success factors, some listed below:

- structured and informative documents,
- strategic approach and leadership involvement, for progressing the business case through the organisation,
- integrating the business case into overall business case decision framework in the organisation
- the business case identifies the pathway of adaptation, planning for infrastructure in long and short term
- develop shared value for adaptation, monitoring adaptation outcomes
- using extreme events as a critical component of the business case,
- using visual and local context to demonstrate the need of adaptation measures

Guidance on how to build a business case for climate change adaptation: Lessons from coastal Australia | CoastAdapt

Box 30: The United Nations Framework Convention on Climate Change (UNFCCC) secretariat issued in 2019 «The Business Case for Adaptation», a short overview of the main risks of climate change to businesses and how they can be addressed: https://unfccc.int/sites/default/files/resource/businesscase.pdf

Several examples from FW2015, with some updates, of guidance documents relating to the development of a business case for climate change adaptation, are provided in App. 10.4.4.:

** **A.** Welsh Government: Public Sector: “The Business Case for Action on Climate Change” (2012) followed by a 2019-report

** **B.** IEMA (2013) ‘IEMA Climate Change Adaptation Practitioner Guidance’, with key principles in building a business case for climate adaptation**.**

** **C.** Innovate UK (2014)

4.6. Monitoring, reporting, review

Purpose of the work in this step: Improve adaptation planning and implementation by assessing effectiveness of interventions. Ensure new knowledge and data are integrated in adaptation responses.
Requirements: Tools to monitor and evaluate the effectiveness, accountability and technical capacity of an adaptation plan. Suitable resources, methods and indicators to assess the success of an intervention.
Compatibility with other processes or systems: Any other monitoring efforts or systems such as asset management programmes or incident control and recording databases.
Outcome: A set of documents or routines that efficiently and effectively ensure knowledge and insight gained in one round of adaptation work will provide a better starting point for the next round.

4.6.1. Monitoring and evaluation – needs and contents

Monitoring and evaluation of projects, policies and programmes forms an important part of the adaptation process as adaptation is a continuous, learning and evolving activity. 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. (United Nations Framework Convention on Climate Change, UNFCCC [95]).

Monitoring and evaluation (M&E) are used to analyse and evaluate adaptation plans to ensure progress, inform stakeholders, and reveal obstacles (ISO 14090). This step helps ensure long-term success, effectiveness, and accountability of resilience programmes. Regular monitoring and reporting to stakeholders and decision-makers improves implementation.
There are three main differences between M&E of traditional management vs adaptation planning:

1. Time frames for climate change adaptation outcomes tend to be longer;
2. Higher levels of uncertainty about the likelihood and magnitude of climate changes, particularly at the local level;
3. Traditional approaches to measuring change, such as comparing monitoring results to baseline conditions may not be possible and a moving baseline must be considered.

Monitoring and evaluation (M&E) is critical in ensuring the long-term success of climate adaptation initiatives, plans and actions[16]. It plays an important role in three aspects of adaptation.

- Tracking the performance of activities undertaken or agreed during the development of an adaptation plan (e.g. stakeholder engagement activities).
- Tracking indicators in relation to pre-identified risk thresholds/trigger levels which identify when new adaptation actions should be undertaken.

[16] Monitoring and Evaluation in climate change adaptation | CoastAdapt

- Determining whether planned outputs and outcomes from adaptation actions have been achieved.

Other factors to consider for M&E (ClimateAdapt[17]):

- *Acknowledging trade-offs*: accounting for trade-offs or surrogates in the design of the M&E approach is important as sometimes it can be very time- or resource intensive to gather certain types of information and there should be consideration if these are justified.
- *Defining the baselines as reference for M&E*: baselines should be defined for all components of M&E, including assumptions for autonomous adaptation taking place without any intervention.
- *Considering the unintended and unexpected*: the M&E approach should go beyond a simple checklist of indicators and be flexible enough to explore the unintended and unexpected, which is where some of the most important adaptation lessons can be learnt.
- *Communicating and agreeing on the purpose for monitoring and evaluating*: it is important to take the motives for M&E efforts into account and to communicate them to all involved, e.g. in order to account for public funds, to learn what works (or not) and why; to track progress; to ensure equity and social justice, etc.

4.6.2. Identifying indicators

There are challenges around developing indicators and measures for monitoring climate change adaptation performance. However, monitoring and evaluation should be embedded into the adaptation plan development process, allowing for iterative, ongoing learning and opportunities to modify, change and improve responses to climate change [96].

As mentioned in 1.2, ISO 14090 states that indicators should be quantitative, where possible. Measurable indicators have the advantage of providing quantifiable "evidence" of impacts, progress and performance. However, it can be a challenge to identify robust, appropriate and practicable indicators. This is due to factors such as data availability, but also because of the difficulty of measuring actual progress towards increased resilience.

A successful M&E procedure relies on indicators that measure and reflect the adaptation initiative. Identification of good indicators therefore relies on:

- clear and specific adaptation objectives, and
- that the desired outcomes are defined.

Here are some additional criteria that may be useful when considering indicators (modified from ClimateADAPT and RESIN [97]):

- The total set of indicators should allow consideration of all (influential) aspects that affect the adaptation objectives and desired outcomes;
- The identified indicators should be capable of being measured, preferably as objectively as possible. The indicators should include effects of future climate change, such as investments in road infrastructure;

[17] ClimateAdapt, European Environmental Agency, Home — Climate-ADAPT (europa.eu)
6.1 Developing the monitoring and evaluation approach — Climate-ADAPT (europa.eu)

- Evaluate existing indicators, they can be reused;
- The indicators should be easy to understand by the users;
- Develop a combination of process and outcome indicators, and acknowledge that some outcome indicators will not be determined for many years;
- Data for the indicators should be easily available, i.e. gathering data should not be more costly than the value of the information provided;
- Be aware that many indicators are also subject to other influences. The results of the indicators should have a limited degree of uncertainty and margin of error. Factors that increase reliability are; good quality of the underlying data, clear and specific definition of the indicator and a transparent and direct calculation methodology;
- Indicators within a framework should not measure the same aspect.

If threshold values of indicators are identified or estimated, they will provide additional information for estimating progress.

Two examples of indicators from FW2015

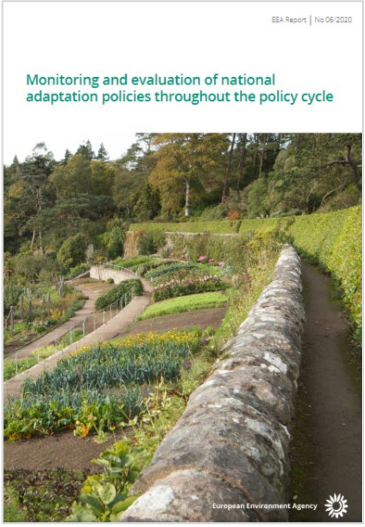
1 Example of indicators that can be included within a monitoring and evaluation assessment include:

- 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,
- Awareness of climate risks and impacts among employees, users of the network and other stakeholders.

2 The United Nations Development Programme (UNDP) developed a set of indicators to measure success of a policy, action, investment, or strategy [98]:

- **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.

[Indicators for adaptation to climate change at national level - Lessons from emerging practice in Europe — Eionet Portal (europa.eu)] [99]



[Monitoring and evaluation of national adaptation policies throughout the policy cycle — European Environment Agency (europa.eu)] [100]

Figure 33. Two useful references from European Environmental Agency (EEA) on indicators and monitoring

Two useful references are shown in Figure 33. The Eionet Portal 2018-paper from the European Environmental Agency (EEA) summarises efforts several European countries have put into identifying indicators for adaptation. The 2020-report from EEA described the needs for and contents of monitoring and evaluation. Here are some important points:

- Monitoring, reporting and evaluation of adaptation can support the process across all levels of governance. The scope and objectives vary from the international to the national and further to the local level. Indicators are useful but are not necessarily directly transferable across levels and policy domains;
- Evaluation of adaptation policies and their implementation benefits from the use of mixed methods: quantitative and qualitative information, with evidence from multiple sources;
- Stakeholder engagement is crucial, both for better quantitative and qualitative data for monitoring adaptation, and for better interpreting of the result and deriving relevant messages from it.

4.6.3. Developing a monitoring and evaluation plan

Based on the selected indicators, the road organisation shall prepare a monitoring and evaluation plan (M&E plan), which assesses progress and success of the adaptation plan (or adaptation and implementation plan, see Box 31.)

The M&E plan should include an assessment of actions, inputs, outputs, resources, roles and responsibilities, processes, capacities and any other relevant aspects (ISO 14090).

Box 31: A summary of "plans" in the FW

Adaptation work is iterative. It is important to establish means of taking in learning, adjusting the plan to accommodate for new circumstances, including input from stakeholders, etc.

Following ISO 14090 (adopted in this framework), the road organisation could develop several types of plans. Not all will be necessary or possible in each case, but here is a short overview of the purpose and contents of each of the document types.

The Adaptation Plan (Sec 3.5) describes in a more detailed manner the selected adaptation measures. It contains a list of actions and sub-actions, timescales, priorities, and responsibilities. Each planned action shall include: an objective, its description, indicators and timescales, estimate of costs and expected benefits, etc.

The Implementation Plan (Section 4.1.4) (or Project Plan) supplements the adaptation plan with specific activities that will ensure that the adaptation actions are really carried out. It defines conditions for the planned deliveries, contingencies, possibilities for adjustments to new knowledge or circumstances, specifies how barriers will be addressed, etc.

The Monitoring and Evaluation Plan (Section 4.6.3) is meant to assess progress against the Adaptation Plan and its implementation. The plan should include an assessment of actions, inputs, outputs, resources, roles and responsibilities, processes, capacities and any other relevant aspects.

** **The UK Climate Impacts Programme** (→ Sec. 9.4.5)

An example from 2011, but a useful tool for organisations starting the work on adaptation. The UK Climate Impacts Programme (UKCIP) developed the 'AdaptME Toolkit' for practical support in evaluating adaptation progress and performance.

Other useful sources of information and examples are given in Box 32.

Box 32: M&E - Sources and examples

ADEME - Guiding principles

ADEME, French Environment and Energy Management Agency (2016) presents the main guiding principles to be followed when setting up a plan for monitoring and evaluation of adaptation policies. It gives examples of four evaluation processes, supplemented by four families of monitoring indicators.

Monitoring and evaluating climate change adaptation at local and regional levels: Learning from international experience to develop an M&E methodology — Climate-ADAPT (europa.eu)

CoastAdapt Australia

… is an information delivery and decision support framework, focusing on Australia's coast, the risks it faces from climate change and sea-level rise, and what can be done to respond to those risks. Some useful information on monitoring and evaluation can be found here:

Monitoring and Evaluation in climate change adaptation | CoastAdapt

ICAO – Climate adaptation in aviation organisations

The 2022 report 'Climate Risk Assessment, Adaptation and Resilience: Key Steps for Aviation Organisation Climate Change Risk Assessment and Adaptation Planning' [92], was mentioned 4.1.4, and is applicable here as well.

ClimateLinks USAID

See also 'Climatelinks' on the USAID website with more sources :

Monitoring, Evaluation, and Learning | Global Climate Change (climatelinks.org)

4.6.4. Using the findings /Reporting /Review

The M&E findings should be used to progressively update, revise and readjust the adaptation strategy.

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

The monitoring process helps fill gaps in the baseline process (Section 1.1) or confirms what should be continued as good practice. It thus provides a better basis for planning the next round of work.

Useful ways of documenting the findings from monitoring and evaluation (ISO 14090:2019):

- determine whether the adaptation approach and its implementation are still valid;
- update policies, strategies and plans based on the findings;
- revisit the assessment with periodicity of monitoring and evaluation that suits the organisations policies, strategies and plans
- evaluate the outcomes of monitoring at appropriate stages during the implementation cycle.

It can be a challenge to make an M&E procedure of integrated activities because the performance must be assessed across multiple sectors. It is common to engage experts to assist at the M&E procedure.

It should be noted that some issues are not easily or quickly changed or reviewed in the short-term perspective. Especially organisational structure issues may take longer to address completely but still benefit from monitoring (e.g., improved understanding of assets, better understanding of climate and weather risks, and higher-quality data).

Box 33: New Zealand: Mandatory disclosure of climate -related information

Although it focuses mainly on GHG emission, this example shows the use and value of reporting requirements for large organisations and could be expanded further for adaptation to climate change.

Until recently the majority of large New Zealand entities involved in significant financial investments provided limited or no information or reporting on what climate change might mean to them or were reporting in inconsistent ways. This could lead to an overvaluation of carbon-intensive activities. In response, the New Zealand Government created a reporting framework and required its application by specified reporting organisations. Its purpose is to manage risks, identify and seize climate-related business opportunities, and disclose reliable information about the risks and opportunities to investors. This reporting standard was published in 2022, framed around reporting on questions covering Governance, Strategy, Risk Management and Metrics and Targets.

Whilst not obliged to, Waka Kotahi New Zealand Transport Agency is voluntarily reporting under this framework in its organisational Annual Plan [111] and includes activities related to climate change adaptation in its responses. The initiative to make disclosure of climate change-related information mandatory for key organisations is valuable for improving processes, keeping accountability and strengthening focus on decision-making and implementation of adaptation strategies.

Mandatory climate-related disclosures | Ministry of Business, Innovation & Employment (mbie.govt.nz)

The TEACR Study, see Box 34, is a good example of compiling the results of different approaches to climate resilience, with lessons learnt and synthesis of several studies.

Box 34 : Transportation Engineering Approaches to Climate Resiliency (TEACR) Study

In 2017, US Federal Highway Administration (FHWA) published the report “Synthesis of Approaches for Addressing Resilience in Project Development” with lessons learned and innovations from different FHWA studies and pilots. The report helps transportation organisations address resilience at the asset level, using engineering-informed studies on hydraulics, riverine flooding, pavements and soils, and mechanical and electrical systems.

The project also developed engineering assessments of options for adapting transportation assets (e.g., roadways, bridges, pavements, culverts, and slopes), to changes in precipitation, sea level, storm surge, heat, drought, and wildfire.

TEACR - Ongoing And Current Research - Resilience - Sustainability - Environment - FHWA (dot.gov)

Summary - Recommended action:

- Review the indicators identified in Stage 1.2 (in defining the aims of the investigation). Can these indicators help evaluate the effect of the measures? Should they be adjusted to give better insight in the adaptation process?
- Prepare a monitoring and evaluation plan to assess outcomes against the goals. Assess the actions, inputs, outputs, resources, roles and responsibilities, processes, capacities, and any other relevant aspects.
  Have they provided the insight needed?
  Do they seem adequate for achieving the aims set in 1.2?
  Have they motivated improvements in the baseline for adaptation, such as data availability, resources, capacity, contacts with stakeholders?
- Document and report, for use in the next round of adaptation work.

4.7. Outcome of Stage 4

By finalising Stage 4 of the Framework, the threats and risks have been recognised, response measures selected and implemented, and the road organisation has found ways of including the findings of the whole process in the established working processes and systems that will ensure that the adaptation is sustainable.

This adaptation work is now back at the starting point - a reviewed baseline for adaptation. The baseline does not have to be significantly changed. But the insight and knowledge gained during the work will reduce the uncertainty in the next round of adaptation work.

Box 35 : Example of a repeated "adaptation effort" UK National highways

Preparing for climate change on the strategic road network, Third adaptation report (2021)

Climate change adaptation is an iterative process and needs regular reporting on progress. Under the Climate Change Act 2008, the UK National Highways was required to produce reports detailing their climate change adaptation. The first report was published in 2011, and the following reports are published every five years afterward. The reports show progress towards adaptation, what is new since last report and what to do the next five years.

The most recent 3rd report could identify actions underway, new actions that build on past progress and identify new areas to explore. Actions set out are measured through internal processes. In the first period standards and design manuals were updated to include climate risk and resilience. They established a series of goals for sustainable development. These standards were updated to include new knowledge from the following reporting periods. Other actions towards climate change adaptation have been establishing monitoring processes, update data on key risks, pilot projects and research projects. The 3rd report shows that repeated adaptation effort provides more defined risks and focus areas to develop further.

The 3rd report developed an experience-based list of prioritised risks that require more action, with two types of actions: those that are sufficiently mature to take forward and those that need more development and will be actively pursued. There is also a need to understand interdependencies, which can be complex and difficult to identify. A repeated adaptation process seems to provide better understanding of the strength of the interdependency and existing processes. New interdependencies can be identified, and for external interdependencies, organisations can be engaged in forum that share information and exchange good practice.

Preparing for climate change on the strategic road network - third adaptation report under the Climate Change Act (nationalhighways.co.uk)
ARP 1, 2, 3 (2022)

5

Examples of Adaptation Assessments

5. EXAMPLES OF ADAPTATION ASSESSMENTS

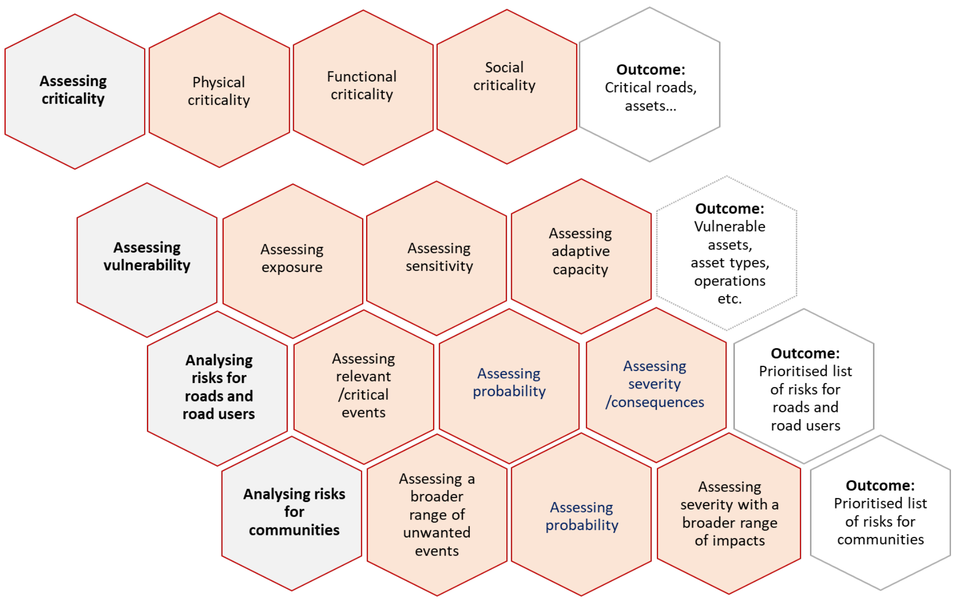
This Framework has been composed in modules, each corresponding to a task in the assessment. The idea is that the users of the Framework should be able to combine the modules in a way they find practical and select the assessment pathway that is suitable for their needs and possibilities.

While is it useful to go through all the steps of Stage 1 /Preparation stage, it is usually neither practical nor necessary to carry out all the steps of Stage 2. The preparation work (Stage 1) should provide a basis for deciding upon the best way to proceed and for selecting the tasks to include in the assessment of interest. This will be dependent on available resources, knowledge, data etc.

There are no clear borders between assessment types. By combining the tasks comprising Stage 2, one should be able to perform an exposure assessment, vulnerability assessment, and an assessment of risk/resilience regarding damage to roads and road assets, and assessment of risk/resilience regarding a broad range of hazards and consequences.

Criticality assessment is often a part of vulnerability or risk assessments, see 1.5 and 2.2.5. It is a good way of introducing priorities at an early stage of the work, and limiting the scope of work.

Therefore, the whole of Stage 2 "Assessment pathways", preceded by a criticality assessment (Step 1.5), could be illustrated as in the Figure below.



The present Framework has yet to be implemented. However, since it is a generic tool and provides structure rather than step-by-step guidance, it is possible to test it against assessments performed following other frameworks or guidelines. This section will illustrate the main elements of a selection of performed assessments of vulnerability, impact or risk, and how they correspond to the steps of the PIARC Framework.

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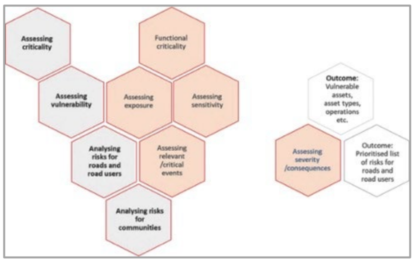

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BASt Germany: assessment of climate impacts for trunk roads

Three climate related threats were chosen for the analysis: landslides, floods and storms. The assessment of criticality was based on traffic-related indicators. Indicators of exposure and sensitivity were: proximity to hazard lines and existence of protections measures respectively. Adaptive capacity was not assessed. Risk was not specifically assessed. However, an estimate of the type and possible extent of consequences for the main climate related threats was a part of the impact assessment. **Read more**: **Climate impact assessment of the German trunk road network**

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Deltares Netherlands: risk assessment of regional roads in the Philippines

Example where vulnerability was assessed by the help of annual expected damages and losses. The assessment of damages uses vulnerability functions, the assessment of losses includes the criticality of the road sections. The threats and locations of highest score on both parameters were prioritised. Relevant adaptation measures were assessed by the help of cost-benefit analysis.

Read more: Vulnerability and resilience assessment in the Philippines

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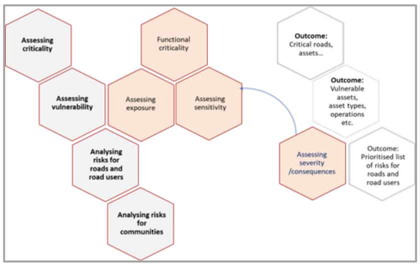

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MOEI in UAE: study of potential impact of climate change on asphalt pavements

The Ministry of Environment and Infrastructure investigated the relation between changing climate parameters on one side and pavement design and pavement performance on the other. The vulnerability of today's pavement design was tried against projected future air temperatures, and the maintenance intensity was estimated. The conclusions led to amendments of design requirements for asphalt pavements.

Read more: U.A.E.: Potential Impact of CC on Materials Selection and Asphalt Pavement Performance

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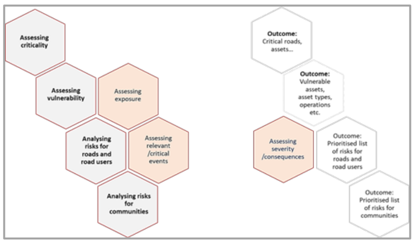

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MoEI in UAE: study of potential impact of climate change on traffic safety (exposure analysis)

This study investigates the impact on traffic safety from the future climatic conditions. The aim was to develop a safety statistical model to predict future accidents under different climate change projection scenarios, with focus on rain, dust and fog events.

Read more: UAE: The effect of climate factors on traffic safety and transportation system performance

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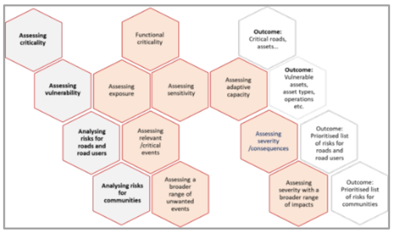
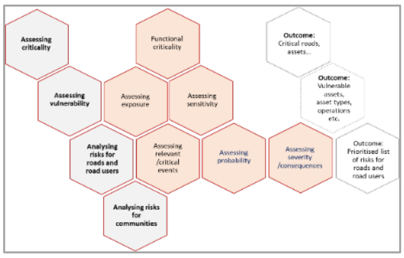
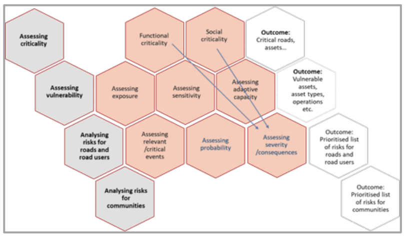
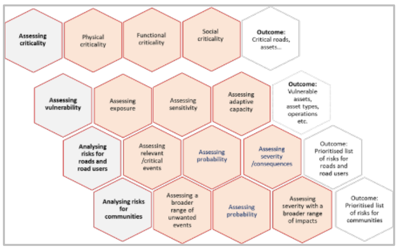
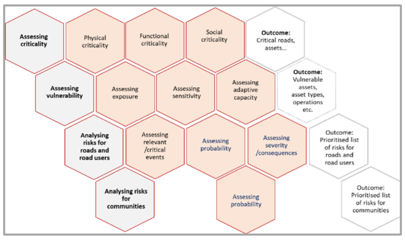
	**Western Australia: Road network vulnerability to climate change** An example of the piloting of a data driven methodology for calculating vulnerability based on indicators of criticality, exposure, sensitivity and adaptive capacity. The methodology was tested on to sections of the State controlled road network in Western Australia and found practical as a first pass assessment to identify sections of a road network that warrant further follow up. **Read more: Western Australia**: **Assessing network vulnerability to future climate risks and natural hazards: An applied approach**
	**Assessment of A2 Guadalajara – Alcolea del Pinar** This risk assessment was performed for a specific road stretch. Earlier events showed that temperature and rain intensity data were important. A projection of the climate conditions for the studied road stretch was provided by using the ClimateAdapt methodology and data from the publicly available database. Sensitivity was assessed by interview with expert staff, who had knowledge of the road. Adaptation measures were identified and for each measure, the expected costs and efficiency was estimated. The measures were selected by the help of a simple cost-benefit analysis. **Read more: Assessment of A2 Motorway Guadalajara – Alcolea del Pinar**
	**Mexico – Implementing the International Climate Change Adaptation Framework for Road Infrastructure in Mexico** This case study implemented the PIARC Framework. Under a bottom-up process, sites at risk associated with hydrometeorological phenomena were identified, their vulnerability and risk were assessed, and adaptation measures proposed. The measures were prioritised under a multi-criteria evaluation. The results allowed adapting the PIARC FW and tailoring a version suitable for any road organisation in Mexico. **Read more: Mexico – Implementing the International CC Adaptation Framework for Roads**
	**ReCAP Methodology applied in Mozambique** Applying procedures outlined in the ReCAP Climate Adaptation Guidelines, climate threats and impacts and vulnerability were assessed on a rural road that had consistently been subjected to flooding for 3 consecutive years. Possible interventions and their priorities were also assessed. **Read more: ReCAP Methodology - Mozambique**
	**Mn DOT Assessment of climate change impact** The Minnesota DOT explored the opportunities to prepare for and adapt to our changing climate by identifying measures of resilience and factors to considered with network criticality. **Read more:** **MnDOT: Assessing Resilience and Criticality in a Changing Climate**

6

Recommendations

6. RECOMMENDATIONS

6.1. RECOMMENDATIONS FOR USERS OF THE REPORT AND DECISIONS MAKERS

6.1.1. Invest in good preparations work

Adjust the ambitions to the level of data and resource availability.
Use the findings of the preparation work as an indication of what should be improved for the next round of work. Especially, which data should be recorded in a better manner.
Climate change adaptation should be part of a functional asset management system to facilitate prioritisation and performance review of measures for effective use of scarce resources.

6.1.2. Adjust /tailor your assessment

Tailor the assessment selecting the steps that are most important for your needs and resources.
Adjust the assessment depending on the driver for adaptation (in general) and the motivation for the specific assessment to be carried out.
See Section 5 for examples.

6.1.3. Provide the basis for an iterative process

Provide sustainable institutional setup and capacity to carry out planning and implementation of adaptation work.
Anchor climate change adaptation capacity development in institutionalised planning systems and processes for sustainable implementation.
Ensure good documentation of all work processes to provide a better starting point for the next round of work. Communicate the findings to senior management in an adequate way, to make sure that the major actions and successes are understood. It is recommended to develop a summary of the main findings, and update it regularly, when possible.

6.1.4. Share and publish your experience

Share and publish results. Experience from the use of the Framework is valuable for others.

- Firstly, disseminate information on climate change adaptation priority interventions (case studies) nationally incorporating designs, expected performance and subsequently, outcomes of monitoring and evaluation processes, lessons learnt, among others.
- Secondly, share experience of applying Framework on case studies regionally as many adverse climatic events affect more than one country in the geographic region.

6.2. Recommendations for PIARC

6.2.1. Develop an all-hazard framework

Technical Committee 1.4 recommends the development a more general resilience framework, including other hazards (in line with the scope of the Working Group 1 report in this cycle). Although limitation in hazard types and sources would need to be considered to make the work feasible, the resilience framework should address complexities, such as coinciding events and amplifying effects, interdependencies and cascade effects, etc. General instability because of climate change challenges may add to aspects of vulnerability.

6.2.2. Support implementation and feedback

It is important to assess the value of a product developed and prepared through the current Technical Committee process. This includes:

- Defining the process for dissemination and endorsement of the product. Following publication, actively encourage application by member states and establish mechanisms to collect feedback from implementation.
- PIARC may want to conduct a series of seminars and workshops for structured implementation. Other avenues could be for PIARC to consider providing technical assistance on specific aspects to LMICs and LICs with clear implementation plans and funding.

7. GLOSSARY

Term	Definition
Adaptation	Adaptation is adjustment within natural or human systems in response to actual or projected (usually climatic) stimuli or their effects, which aims to moderate harm or exploit beneficial opportunities (PIARC Framework, 2015).
Adaptation assessment	An adaptation assessment is the practice of identifying options to adapt to climate change and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency, and feasibility. (OECD, 2006, Adaptation to CC – Key terms)
Adaptive Capacity	The ability or potential of a system to respond successfully to impacts of environmental (often climate) variability and change, and includes adjustments in both behaviour and in resources and technologies (PIARC Framework, 2015).
Consequence	Outcome of an event affecting objectives or system. An event can lead to a range of consequences. A consequence can be certain or uncertain and can have positive or negative effects on objectives (ISO 31000, 2009).
Community Impacts	The impacts (social, economic, cultural, etc.) affecting a group of people who: • live in a particular area or place ('geographic' or 'place based' community); • are similar in some way ('relational' or 'population based' community); or • have friendships, or a sense of having something in common ('community of interest'). People can belong to more than one community, and communities can be any size. With increasing use of social media and digital technologies, communities can also be virtual. (Derived from New Zealand "National Disaster Resilience Strategy" 2019)
Critical Assets	Critical assets (physical, data/information, intellectual, process, technology) are those that are essential for supporting the social and business needs of both the local and national economy (PIARC, Asset Management Manual, 2017).
Criticality	The relevance of an infrastructure element or section to the availability of a transport infrastructure system. Note: Based on All-Hazard Guide for Transport Infrastructure, 2015.
Disaster	Situation where widespread human, material, economic or environmental losses have occurred which exceeded the ability of the affected organisation, community or society to respond and recover using its own resources (ISO 22300:2012, (2.1.11). A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts. (United Nations Office for Disaster Risk Reduction)
Disruption	An event that considerably interrupts normal life, business, functions, operations, or processes, whether anticipated or unanticipated. (New Zealand "National Disaster Resilience Strategy" 2019)
Event	An incident, man-made or from natural causes, that has an impact on infrastructure, such as the state highway network, for example earthquakes, tsunami, floods, sea level rise (as a result of climate change), extreme weather, road traffic accidents, terrorist act, vehicles striking structures (State Highway Network Resilience National Programme Business Case - 2014).

Exposure	The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected by a hazard (Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, IPCC, 2012).
Frequency	Measure of the likelihood of an event expressed as an expected number of events or outcomes per defined unit of time (31000). See "Likelihood" and "Probability"
Hazard	A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. (UNDRR) A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. Hazards can include latent conditions that may represent future threats and can have different origins: natural or induced by human processes. (Sendai Framework 2015)
Level of service	Level of service (LOS) is a mechanism used to determine how well a transportation facility is operating from a traveller's perspective. Typically, six levels of service are defined, and each is assigned a letter designation from A to F, with LOS A representing the best operating conditions, and LOS F the worst.
Likelihood	Chance of something happening (ISO 31000, 2009). ISO uses the word "likelihood" is used to refer to the chance of something happening, whether defined, measured or determined objectively, subjectively, qualitatively or quantitatively, and described using general terms or mathematically (such as probability or a frequency). See "Frequency" and "Probability"
Probability	Impact probability relates to the likelihood of an impact occurring within a given timeframe (PIARC Framework, 2015). Measure of the chance of occurrence expressed as a number between 0 and 1, where 0 is impossibility and 1 is absolute certainty (ISO 31000, 2009). See "Likelihood" and "Frequency"
Readiness	Developing operational systems and capabilities before an emergency happens, including making arrangements with emergency services, lifeline utilities, and other agencies, and developing self-help and response arrangements for the general public. (New Zealand "National Disaster Resilience Strategy" 2019)
Recovery	The coordinated efforts and processes used to bring about the immediate, medium-term, and long-term holistic regeneration and enhancement of a community following an emergency. (New Zealand "National Disaster Resilience Strategy" 2019)
Redundancy	The extent to which elements, systems, or other infrastructure units exist that are substitutable, i.e., capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality (AECOM, 2013 Resilience Research report).
Resilience	The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation (Arctic Council, 2016). See also Hazard, Risk and Vulnerability.
Response	Actions taken immediately before, during or directly after an emergency to save human and animal lives and property, and to help communities begin to recover. (New Zealand "National Disaster Resilience Strategy" 2019)

Risk	Effect of uncertainty on objectives or system operation. Risk is often characterised by reference to the likelihood of potential events, consequences, or a combination of these and how they can affect the achievement of objectives or system operation. Risk is often expressed in terms of a combination of the consequences of an event or a change in circumstances, and the associated likelihood of occurrence (ISO 31000, 2009).
Risk Analysis	Process to comprehend the nature of risk and to determine the level of risk. Risk analysis provides the basis for risk evaluation and decisions about risk treatment (ISO 31000, 2009). According to UNDP: an assessment of the nature and extent of such risk, by analysing hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend
Risk Evaluation	Process of comparing the results of risk analysis against risk criteria to determine whether the level of risk is acceptable or tolerable (ISO 31000, 2009).
Risk Management	Coordinated activities to direct and control an organisation with regard to risk (ISO, 2009). Disaster risk management is the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses. (UNDRR)
Risk Treatment	Process of developing, selecting and implementing controls (ISO 31000, 2009).
Robust	Strength or the ability of elements, systems, and other units of analysis, to withstand a given level of stress or demand without suffering degradation of loss of function (AECOM, 2013 Resilience Research report).
Sensitivity	The degree to which a system is affected, either adversely or beneficially, by hazard-related stimuli (PIARC Framework, 2015). Sensitivity determines the degree to which a system is adversely or beneficially affected by a given climate change exposure (IPCC 2007b).
Threshold	Measure of the level of uncertainty or the level of impact at which a stakeholder may have a specific interest. Below that risk threshold, the organisation will accept the risk. Above that risk threshold, the organisation will not tolerate the risk. Condition that triggers some stakeholder action. (ISO/IEC 16085:2006 Systems and software engineering — Life cycle processes — Risk management)
Vulnerability	The degree to which a system is susceptible to, or unable to cope with, adverse effects of hazards, including climate change, variability and extremes (PIARC Framework, 2015). The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. (UNDRR) The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. (Sendai Framework 2015)

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9

Examples and Case Studies

9. EXAMPLES AND CASE STUDIES

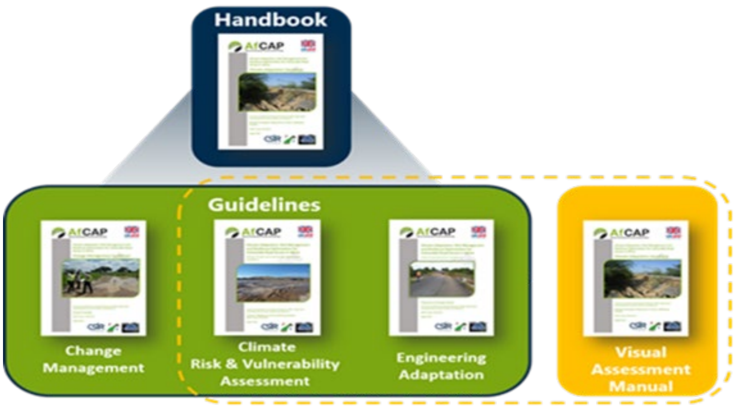
9.0. CASE STUDIES – GENERAL REFERENCES, PROJECTS, FRAMEWORKS

9.0.1. The Research for Community Access Partnership (ReCAP)

Back

To help address the significant threat of climate change to Africa's development, the Research for Community Access Partnership (ReCAP), a research programme funded by UKAid, commissioned a project in April 2016 to produce regional guidance on the adaptation of rural access roads to climate change. The project aimed to provide pragmatic, cost-beneficial engineering and non-engineering, adaptation procedures and guidance to road sector institutions, through research and knowledge sharing within, and between, participating African countries. See also [14].

The study covered climate threats and adaptation for both existing and new infrastructure. It addressed the issues of appropriate and economic methodologies for vulnerability and risk assessments; prioritisation of adaptation interventions; and optimisation of asset resilience in the context of low-volume rural access roads. In addition, it provided evidence of cost-, economic- and social-benefit links to rural communities arising from more resilient rural access to support wider policy adoption across Africa.



This Climate Adaptation Handbook provides a methodology for carrying out a climate adaptation assessment for rural access to assist socio-economic development. It also focuses on those activities and actions that conventional engineering standards and procedures do not necessarily cover. The Handbook is supported by three separate guideline documents, and an associated manual, that cover the following:

Change Management – this guideline covers, inter alia, policy and planning, stakeholder and asset management, and provides recommendations for the formulation of strategies and programmes for improvement.

Climate Risk and Vulnerability Assessment – this guideline takes users through the steps involved in conducting a risk and vulnerability assessment at national-/district-level, as well as a local-

/project-level risk and vulnerability study when implementing new or maintaining/retrofitting existing infrastructure.

Engineering Adaptation – this guideline introduces primary climatic attributes and the potential effects of these, followed by the provision of suggested adaptation measures for each infrastructure component, also highlighting the critical importance of effective drainage provision and of timely and appropriate maintenance of road assets.

Visual Assessment Manual – The manual describes the nature, and collection methodologies, of the type of data which is normally not part of the routine data collection for asset management. This includes issues such as erosion, problem soils, drainage from the road and its surrounds as well as from outside the road reserve, instability of embankments and cuttings, construction issues and maintenance problems.

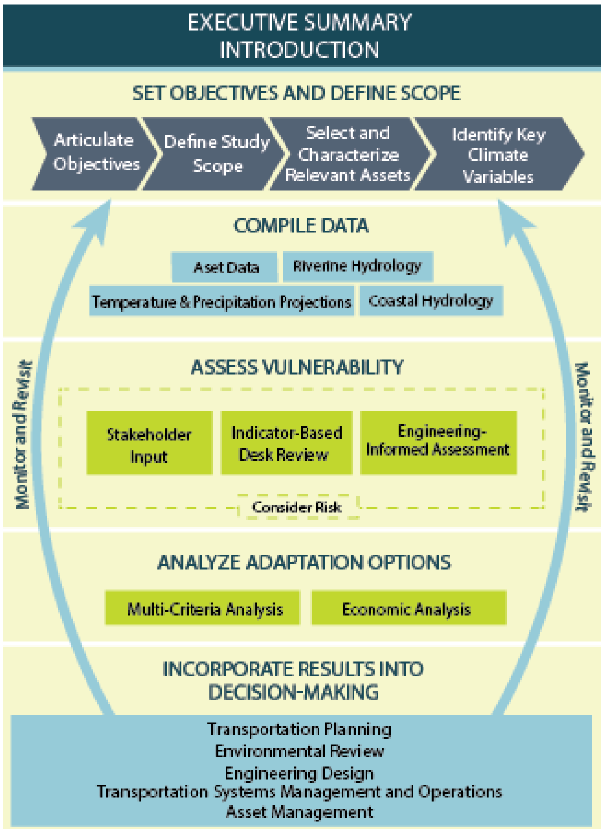
9.0.2. The Federal Highway Administration's (FHWA) Framework

Back

The Federal Highway Administration's (FHWA's) Vulnerability Assessment and Adaptation Framework [9] is a manual for any road organisation that is responsible for managing road networks, to assess the vulnerability of road infrastructure to extreme weather and climate impacts.

FHWA has partnered with State Departments of Transportation (DOTs), Metropolitan Planning Organizations (MPOs), and others, to develop and implement resilience solutions, see 'Resilience pilots'[18].

The Framework provides a structured six step process, including examples and tools. The first steps to doing a vulnerability assessment are to set objectives, and determine the scope of the assessment. Establishing the objectives early, and clearly, helps to define the scope, the type of data needed, and the expertise of the team, etc. Defining the scope requires selecting and characterizing the relevant assets, and identify the key climatic variables.



Step 2 seeks to obtain data for conducting the vulnerability assessment. In this step, the asset must be characterised according to the corresponding transport infrastructure.

In addition to the asset data, climate data for the study area must be obtained in Step 3. This step allows the incorporation of future climate projections of variables such as temperature and precipitation. River and coastal hydrological data are very useful for assessing the vulnerability of bridges or port infrastructure.

The vulnerability assessment of the transportation infrastructure is performed in Step 4. Climate change and extreme weather vulnerability is a function of a transportation asset's or system's exposure to climate effects, sensitivity to climate effects, and adaptive capacity. Exposure refers to whether an asset or system is located in an area experiencing direct effects of climate change; sensitivity refers to how the asset or system fares when exposed to a climate variable; and adaptive capacity refers to the system's ability to cope with existing climate variability or future climate impacts.

[18] Pilots - Resilience - Sustainability - Environment - FHWA (dot.gov)

Additionally, a risk assessment can be considered, which includes measures of the likelihood of a particular impact occurring, and the consequences (severity) of the impact. Risk is often represented by a matrix that classifies climate stressors into categories (i.e., low, moderate, or high) based on their likelihood and consequence.

After identifying vulnerable assets at the network level, engineers must identify adaptation options to address these vulnerabilities. Depending on the scope or size of the network, the list of adaptation actions can be very long, so through Step 5, an analysis can be performed to prioritise adaptation measures. A multi-criteria analysis or an economic analysis can be used.

Step 6 seeks to incorporate the results into transportation plans and programs. The plans allow decision makers to take proactive adaptation action to climate change, and provide a forward-looking vision for transportation projects. It allows the consideration of climate change impacts and adaptation early in the project development process to help ensure climate resilience infrastructure is delivered. The Framework also provides advice on how to incorporate and make use of results from assessments for project design, transportation management systems, and asset management.

Adapting to climate change is an iterative process that requires monitoring and evaluation to keep adaptation efforts on track with the evolving understanding of climate risks. Conducting a climate change vulnerability assessment will inform organisations about the threats to their assets and provide vital information to effectively address those vulnerabilities.

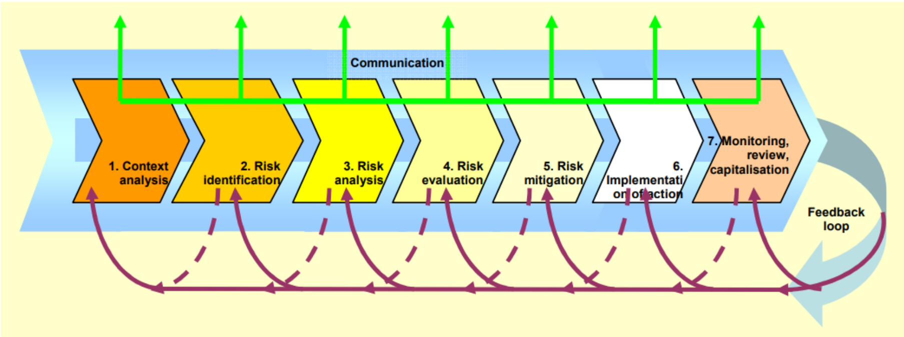
FHWA has carried out a large number of resilience pilots, where the framework was implemented and reported. They are available from: Pilots - Resilience - Sustainability - Environment - FHWA (dot.gov)

9.0.3. RIMAROCC and ROADAPT risk assessment framework

Back

RIMAROCC (Risk Management for Roads in A Changing Climate) was carried out with the framework of ERA-NET ROAD, a European initiative for cooperative financing of research and development programmes. The objective of the project was to develop a common method for risk analysis and risk management with regard to climate change, in order to support decision making in the road sector. The project collated existing methods, analysed possibilities and needs. The developed methodology is summarised in "Risk Management for Roads in a Changing Climate - A Guidebook to the RIMAROCC Method". The applicability of the method is demonstrated in three case studies, on the territorial, network, and structure scale, and reported in project reports.

"Risk Management for Roads in a Changing Climate - A Guidebook to the RIMAROCC Method" is available from the CEDR website.



ROADAPT (Roads of Today Adapted for Tomorrow) built further on the RIMAROCC approach (therefore it is often called RIMAROCC-ROADAPT). The project was financed by the Conference of European Directors of Roads (CEDR) programme "Road Owners Adapting to Climate Change". ROADAPT developed a set of practical tools for risk assessment of roads – from acquiring climate data to selection of adaptation strategies.

The output from the ROADAPT project consists of:

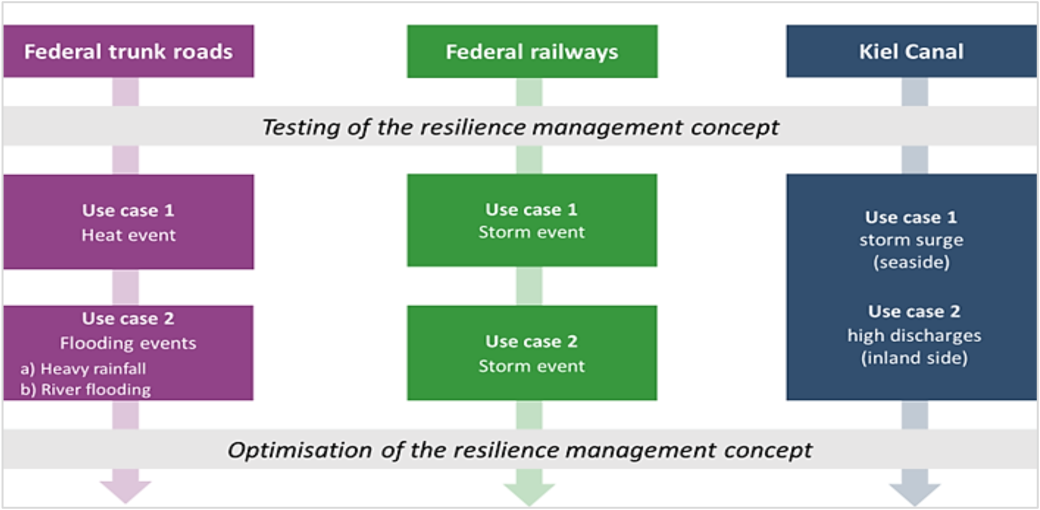
A summary report: ROADAPT_integrating_main_guidelines.pdf (cedr.eu) and specific guidelines:

A. Guidelines on the use of climate data for the current and future climate
B. Guidelines on the application of a QuickScan on climate change risks for roads
C. Guidelines on how to perform a detailed vulnerability assessment
D. Guidelines on how to perform a socio-economic impact assessment
E. Guidelines on how to select an adaptation strategy, including a database of more than 500 techniques.

Database of adaptation techniques is also available from the CEDR website: https://cedr.eu/call-2012-climate-change-road-owners-adapting-climate-change
See also [101].

9.0.4. Resilience management concept Germany

Back



Extreme weather events, natural hazards, and changing climatic conditions, pose operational and strategic challenges for transport infrastructure owners, and operators. Resilience management, as an integrative management approach, offers diverse practical application potential to address the impacts of climate change across the different areas of transport and infrastructure management, (e.g. traffic control, operation, maintenance planning) under the objective of a reliable and functional transport infrastructure.

After the general concept of a resilience management for road transport was developed in a previous project, the research project FE 69.0010 "Testing and optimisation of a resilience management concept – case study-based investigations for the road, rail and waterway transport modes in the context of climate change", takes a cross-modal perspective and is the basis for the elaboration of a detailed concept, which is to be anchored in the planning processes of the transport modes [12]. The main objective of the project is to increase the resilience of the federal transport infrastructure through practical case studies, especially against the background of climate change and extreme weather events. Along with the testing of resilience as a concept, its practicability will also be determined given the data that is available.

The testing of the resilience management concept is undertaken by means of specific use cases. These use cases are covered by three mode-specific case studies that relate to the existing network of federal transport routes. In the first use case, the resilience management is tested using a heat event for a selected section of the federal trunk road network. Selected stretches of road will also be examined in a further use case in the event of flooding events, differentiated according to river flooding and heavy rainfall. The second case study deals with two use cases in the form of storm events for the rail transport mode. In the third case study, the use cases of storm surge on the seaside as well as high discharges on the inland side are examined in more detail at the Kiel Canal (see figure).

The aim is to develop a concept that can be integrated by the various stakeholders of the road, rail and waterway transport field into the climate adaptation efforts of their transport and infrastructure management. Thus, it contributes to making the federal transport infrastructure more resilient to climate change and extreme weather events.

9.0.5. Towards a resilient infrastructure in the Netherlands

Back

The Dutch National Road Authority (Rijkswaterstaat, NRA) has the ambition to establish a resilient road network by 2050. To reach that objective, a stress-test was developed, and applied, in 2019 to identify the effect of future climate conditions and associated weather extremes on the Dutch highway network. This stress-test provides the information needed to establish an Implementation Agenda that links to all the processes that Rijkswaterstaat uses for the management of the road network, being design, maintenance, renewal and renovation.

- In the first phase of the stress-test, hazards were identified and the corresponding exposure of the road network and vital elements, like bridges and tunnels, was assessed and mapped.
- In the second phase the vulnerability of the road network was assessed (assessing the damage and recovery costs) as well as the societal impact for the road users (losses due to delays of road users due to partial or full obstruction of the road).

This forthcoming information has been used by Rijkswaterstaat in several so-called ‘risk dialogues’.

These dialogues have the following objectives:

- raising awareness,
- validation of stress-test results,
- identification of hotspots,
- discussing the level of acceptable risk / desired level of resilience,
- identifying steps needed to act where and when necessary, and
- Identifying and assessing adaptation measures to identify suitable and effective action perspectives.

Hazard assessment

In total, the stress-test covered 13 hazards, including pluvial flooding of the road due to intense rainfall, uplift of tunnels and lightweight materials, dike breaches (river and coastal flooding), heat expansion of bridges, heat effects on road foundations, drought-, nature- and roadside-related fires and road deformation caused by soil subsidence. See Table 1.

Table 1. Overview of the climate change related hazards divided in four climate related impacts

Drought	Heat	Extreme precipitation	Groundwater related	Fluvial floods
Unequal settlements due to drought	Thermal expansion of the pavement	Puddles on the road	Uplift of tunnels	Dike breaches (River and coastal flooding)
Wild- and verge fires	Heat expansion of bridges	Poor visibility during intense precipitation	Uplift of light-weight materials	
		Erosion and instability of road embankment		
		Erosion and instability aside the road		

There were some challenges regarding the availability of data. For dike breaches (river and coastal flooding), hazard maps with related return period and intensity already exist based on modelled data. However, most of the hazards are too specific to model. To overcome this, innovative solutions based on the ROADAPT [31] methodology were used for vulnerability assessments. The susceptibility maps were subsequently validated based on a historic events database and expert session including the Dutch National Road Authority.

From exposure to impact

The developed hazard and susceptibility maps were projected on the road infrastructure, at a 100 m level, and its relevant assets (e.g. tunnels for uplift of tunnels and heat expansion of bridges). This resulted in exposure maps.

For evaluating the risk, insight in the impact of events was needed. Information on risk was then obtained by the combination of likelihood, multiplied with the impact. Impact results were split in the expected damages to the road and the potential losses for the road user (socio-economic losses). Table 2 provides an overview of the data used to identify likelihood and subsequently calculate the damages and losses.

Damages were quantified at a 100 m level for the road network. For this, an overview was used of the costs that would be involved per event at asset level or per 100-meter road stretch. These costs were determined based on expert and experience by the national road authority and included costs for cleaning of the road and reconstruction costs. To include uncertainty, both a low- and high-end scenario were considered.

Socio-economic losses were calculated per event and per road stretch starting from ramp to exit of the road stretch. To do this, traffic data delivered by a traffic model was used that included traffic intensities and distribution per vehicle type per time of the day, as well as the potential capacity of each road stretch. Using a single link disruption approach (i.e. a criticality measure), this traffic data was converted to vehicle loss hours per event type by multiplying the traffic vehicle mix with the value of time, the value of reliability and the duration of the event. A low- and a high-end scenario were used by varying the duration of the event.

By combining the damages and losses per event occurring, with the likelihood of the event occurring, an estimation could be made of the annually expected damages and losses. The likelihood has been determined in several ways. For fluvial floods the return periods were available with the hazard maps, but for the other hazards an estimation was made. Climate change effects were considered by keeping the damages and losses per event equal, but by changing the return period based on climate statics data delivered by the Royal Netherlands Meteorological Institute (KNMI) Dutch meteorological institute.

Table 2. Overview of the data used to identify likelihood for calculating damages and losses

Damages	Costs per event	Low- and high-end scenario (Euro per event)
Socio-economic losses	Duration of event	Low- and high-end scenario (hours per event)
	Traffic data	Number of vehicles Vehicle type (freight, business, leisure, other) Capacity Redundancy (hr detour)
	Partial/full road closure	Percentage per hazard stating the percentage of people that would make a detour
	Vehicle loss hours	Value of time * Occupation * Value of reliability *duration of event
Likelihood estimates	Return period	Low- and high-end scenario
	Climate change effects	Factor change in return period between now and 2050

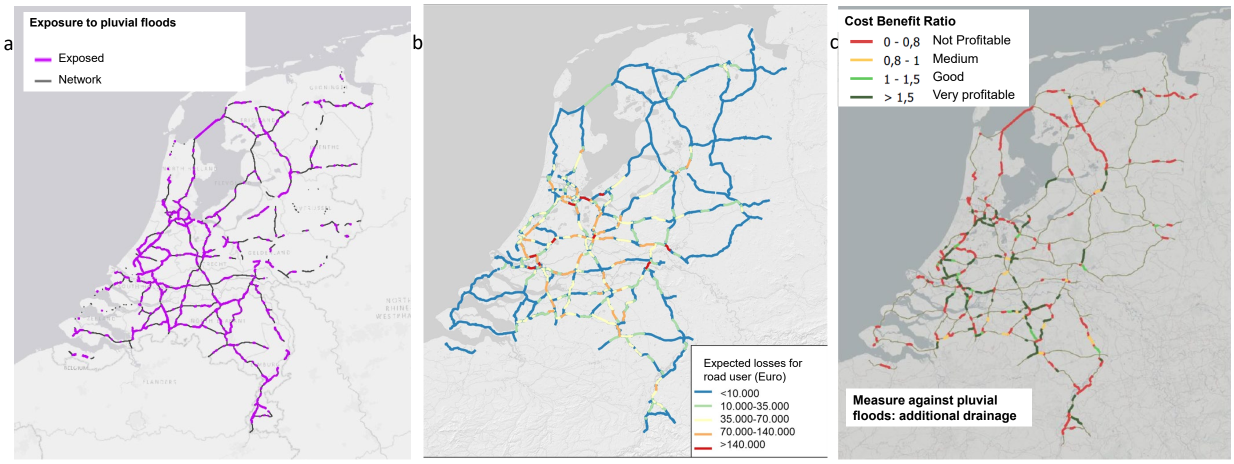
Providing an action perspective: towards an adaptation strategy

An overview or long-list of possible measures per threat was made. Measures from the ROADAPT project was used as a starting point and supplemented during interviews with experts from Rijkswaterstaat and Deltares. These measures were evaluated using a multi criteria assessment, and linked to the main processes at Rijkswaterstaat, being maintenance, renovation and construction.

A semi quantitative cost benefit assessment of the measures in the long-list was undertaken. For that purpose, a cost estimate of the measures was made by using of key cost drivers. Also, a general estimation of the effectiveness of the measures has been made. The effectiveness was scored against criteria that are applied in the asset management of Rijkswaterstaat; being availability, safety for road users, sustainability, and image/politics.

Finally, other criteria were scored in order to gain better insight in the applicability of the measures. These criteria were; robustness for various future developments, flexibility to change to other measures when needed, possibility to connect with other measures, and feasibility in terms of governance aspects. By conducting a multi criteria analysis it was possible to select promising measures from the long-list of measures.

Consequently, for two hazards, a quantitative cost benefit assessment has been made. This has been modelled in the RA2CE framework (see 3.3.6). For that purpose, the effectiveness of the measures was needed to be determined, and new hazard maps and forthcoming exposure maps were needed to be developed for each measure. This made it possible to conduct a cost benefit assessment per 100-meter segment of road for the entire road network. The assessment accounted for the expected change of likelihood of events due to climate change, the frequency of application of the measures (and thus cost) and a discount rate. This has resulted in maps and tables showing the economic feasibility of the various measures.



The figure above contains results of the assessments for pluvial flooding showing the (a) exposure to pluvial flooding, (b) the impact in terms of expected losses for the road user in case of flooding and (c) the appropriateness of one measure being additional drainage, in terms of the cost benefit ratio.

In collaboration between the ministry and Rijkswaterstaat, the preferred level of resilience is being established. This proves to be a challenging discussion, for which insight is needed; costs on the one hand, and the ambition at the other hand. They are, however, related to each other. A higher ambition will lead to higher cost and vice versa.

In dialogues with the regional asset managers the results of the stress-test are being validated, and plans for implementation of measures are being made. The stress-test results are connected to the asset management system called RAMSSHEEP. The impact of failure due to natural hazard events is being scored in the same risk-based approach as other threats are being scored. This provides an indication on whether risks are acceptable, undesirable or unacceptable from an asset management perspective.

Information from the stress-test has been integrated into the Rijkswaterstaat Klimaateffectatlas (Atlas of Climate Effects): Rijkswaterstaat Klimaateffectatlas (rws.nl)

The implementation agenda is available (in Dutch): Uitvoeringsagenda Klimaatbestendige Networking | Tweede Kamer der Staten-Generaal

9.0.6. Plan for Resilience of Infrastructures to Climate Change (PRIAC), Portugal

Back

The effects of climate change on transportation infrastructure can be significant - most notably, landslides and material washout due to flash floods, damage and wear and tear to materials and equipment, falling trees, and fires – causing disruptions in the provision of services, with economic, social, and environmental consequences.

In Portugal, Infraestruturas de Portugal, S.A. (IP)[19] is the company responsible for the management of road and rail infrastructures, ensuring the provision of a safe, efficient, and sustainable service and, in this context, it has an ongoing Plan for Infrastructure Resilience to Climate Change (PRIAC).

The PRIAC covers rail, road and telematics networks and aims to assist Infraestruturas de Portugal understand the risks associated with the effects of climate change, assess their impacts on the infrastructure, develop measures for prevention, and adaptation, to climate change, in a succinct, organised and coherent way for the three networks, making them more resilient.

PRIAC will be a strategic document, identifying vulnerabilities and risks for the various areas of Portugal, proposing mitigation and adaptation measures to climate change for the Railway Network, the Road Network and the Telematics assets that support operation, and translating these into investments to be included in modernisation projects and in the construction of new infrastructures, as well as the respective economic effects.

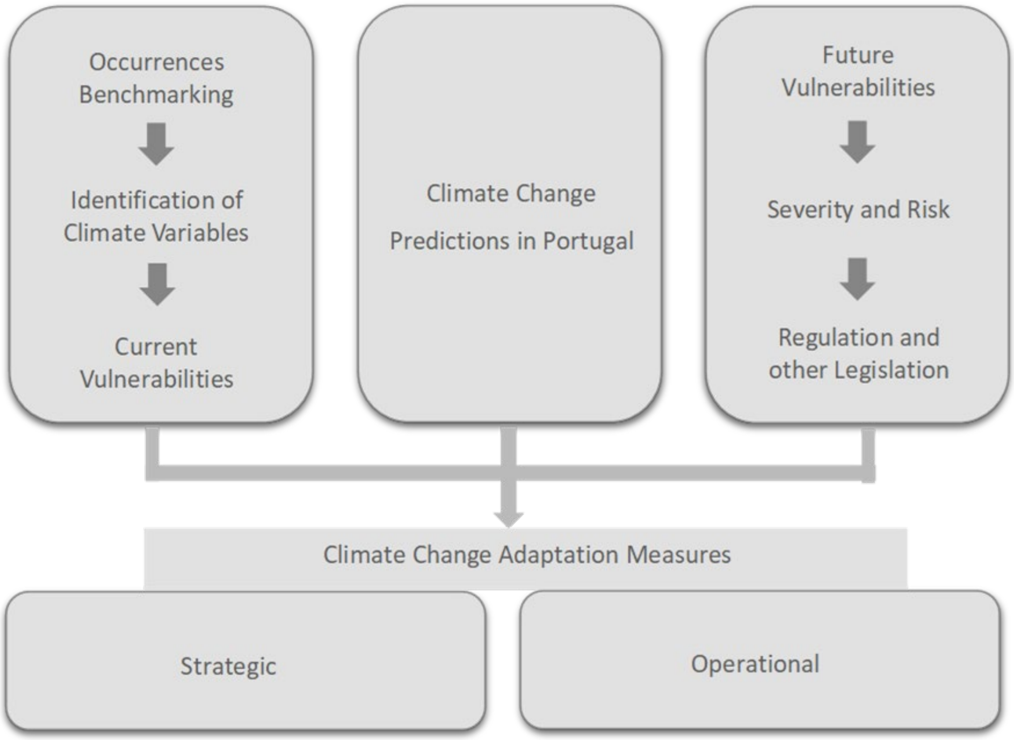
PRIAC will be carried out in two phases, where Phase I focuses on the identification and assessment of vulnerabilities and risks, and Phase II, will add value by proposing adaptation measures to be included in projects, and the quantify the economic benefits related to the increased resilience of infrastructure and the reduction of disruptions caused by extreme weather events.

The methodology for PRIAC is based on official documents published by JASPERS (“JASPERS Guidance Note – The Basics of Climate Change Adaptation Vulnerability and Risk Assessment”, 2017) and the European Commission (“Technical guidance on the climate proofing of infrastructure in the period 2021-2027”, 2021), plus information from benchmarking and other published documents that complement the work.

In Phase I, the following is carried out: characterisation of the current and historical situation, and quantification of the economic costs associated with the impacts caused by extreme weather phenomena recorded in the infrastructure; presentation of climate scenarios for the variables considered as relevant, such as temperature, precipitation, winds, humidity, mean sea level, landslides, and others that may be applicable; benchmarking on documents with the same content developed for other countries; assessment of vulnerabilities for the three networks, by relevant asset, identified by zone of the country, in the present and in the 2040/2050 and

[19] IP,SA is responsible for the management of road infrastructures (NRA), under the terms of the General Concession Contract of the national road network signed with the State and provides the public service of managing the infrastructure of the National Railway Network (RFN), under a regime of delegation of powers by the Portuguese State, through the execution of a Program Contract for the railway sector.

2080/2100 time horizons, according to RCP4. 5 and RCP8.5; elaboration of risk maps for each of the networks, for the years and level of RCP Identified; inventorying of economic impacts caused by disruption in the operation of transport due to climate change and extreme weather events, and; recommendations for the next phase.



Source: Infraestruturas de Portugal (IP, SA) / NRA
https://www.infraestruturasdeportugal.pt/pt-pt/sustentabilidade-ip/alteracoes-climaticas-ip

Phase II of PRIAC aims to obtain: specification of concrete climate change adaptation measures to be incorporated in the projects, both operational and strategic, by time horizon and RCP; investment forecast for each scenario and time horizon associated with the proposed measures, staggered in time, to maximise the efficiency of decisions for adaptive management; quantification of economic costs associated with the impacts caused by climate change and extreme weather phenomena, in each horizon and scenario considered; assessment of IP regulations that may need to be adjusted to climate change and proposed updates, and; recommendations for future monitoring of the efficiency of the measures implemented Since climate risks evolve and it will be necessary to periodically assess whether the adaptation measures introduced continue to be adjusted to the needs, respecting the life cycle of assets in road, rail and telematics infrastructure.

9.0.7. European Union Adaptation Strategy

Back

The European Commission’s strategy for adaptation to climate change (2021) sets out how the European Union can adapt to the impacts of climate change. The aim is a climate resilient European Union by 2050. [13]

The Strategy has four principal objectives: to make adaptation smarter, swifter and more systemic, and to step up international action on adaptation to climate change.

Smarter adaptation will be achieved by developing robust data and risk assessment tools that are available to all. The platform Climate-ADAPT shall be the authoritative European platform for adaptation knowledge. Providing research and development programmes, and sharing knowledge and data will increase the level of knowledge in Europe.

Faster adaptation is necessary because the effects of climate change are already being felt. An increase of targeted spending is recommended, and adaptation solutions are developed to help reduce climate-related risk, increase climate protection and safeguard the availability of fresh water.

More systemic adaptation means integrating /mainstreaming climate resilience considerations in all relevant policy fields, all levels of the society and across all sectors. The European Commission will support the further development and implementation of adaptation strategies and plans with three cross-cutting priorities; integrating adaptation into macro-fiscal policy, nature-based solutions for adaptation, and local adaptation action.

Stepping up international action for climate resilience will be done through the scaling up of international finance and through stronger global engagement and exchanges on adaptation.

Information from the European Commission’s web site: EU Adaptation Strategy (europa.eu)

9.0.8. HTV Asia Applied Research Programme – State of Knowledge Report

Back

The High Volume Transport (HVT) Applied Research Programme, which is funded with UK Aid from the UK Government, published STATE OF KNOWLEDGE REPORT Adaptation for Transport Resilience to Climate Change (AfTR-CC) for LICs in Africa and South Asia–- HVT (transport-links.com). The report summarises challenges, barriers, interest and gaps in knowledge and/or capacity building related to climate change adaptation for transport resilience. This includes:

- a review of how the climate has and is projected to change across LICs in Africa and South Asia;
- physical, social and economic impacts of weather and climate upon transport infrastructure;
- extent of national adaptation ambitions;
- extent of action taken and planned by transport stakeholders;
- challenges and barriers in achieving transport resilience;
- knowledge gaps and needs that have to be addressed in order to facilitate increased transport resilience for climate change adaptation.

The project team collected and analysed primary data through stakeholder interviews and literature reviews.

Some of the key findings from the report include:

- Insufficient data is an obstacle for LICs to analyse the impacts of weather on transport infrastructure.
- The tools being developed for adapting transport to climate change may not be suitable for the technical capacities of LICs, limiting their use and/or effectiveness.
- Transport maintenance budgets take precedence over enhanced resilience, much of which is due to weather-related impacts in some countries.
- Transport stakeholders do not explicitly link impacts of weather on transport infrastructure to wider socio-economic issues;
- Monitoring and evaluation processes require improvement, and could be influenced by reframing the way adaptation options are implemented. Stakeholder and local community engagement at all stages of transport resilience for climate change adaptation is crucial.

Concerning future directions, the key ideas are: improved government coordination, capacity building and stakeholder engagement.

https://transport-links.com/download/state-of-knowledge-report-adaptation-for-transport-resilience-to-climate-change-aftr-cc-for-lics-in-africa-and-south-asia/

9.0.9. ADB 2011 “Guidelines for Climate Proofing Investment in the Transport Sector”

Back

The publication «Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects» aims to present a step-by-step methodological approach to assist road organisations to incorporate climate change adaptation measures into transport sector investment projects. The focus is on the project level.

The figures below illustrate the methodological approach presented in the report.

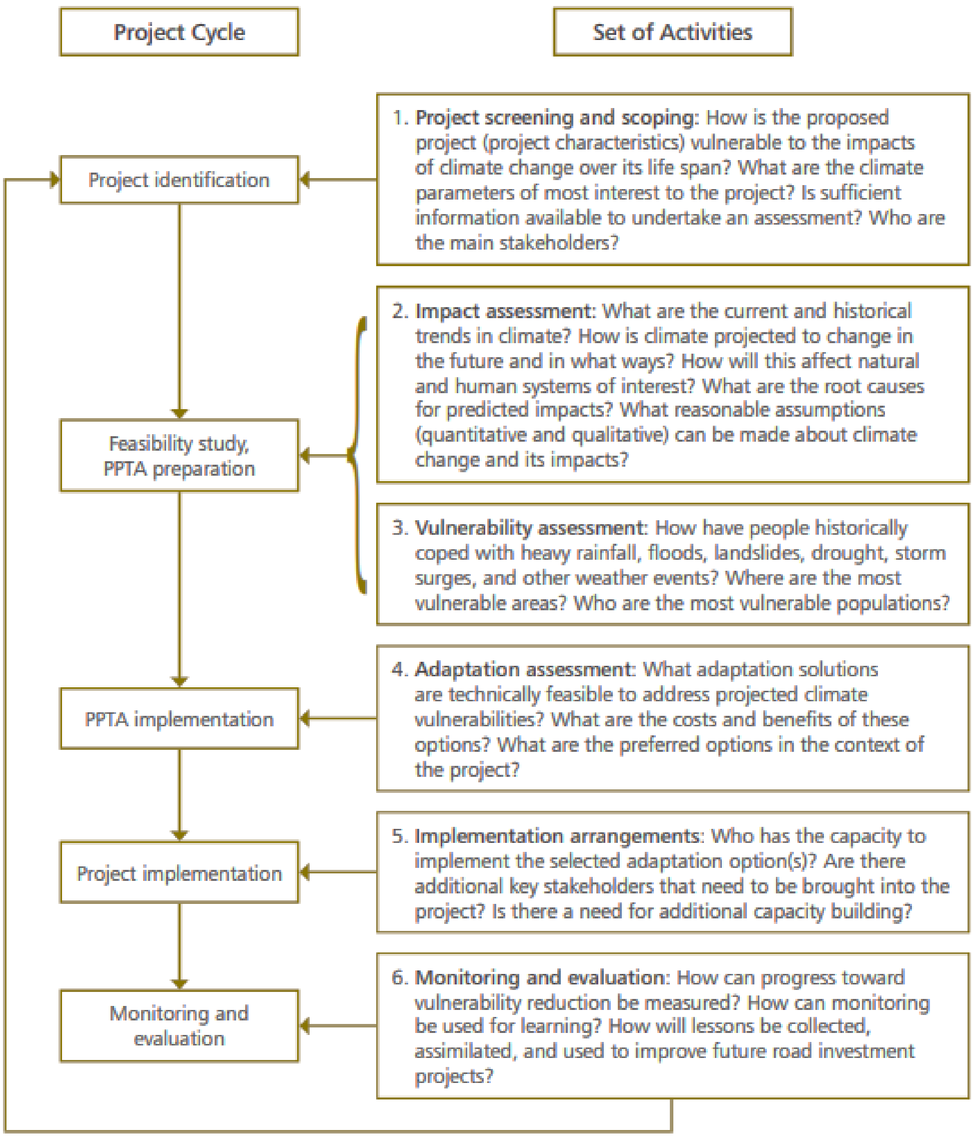
Figure 1 presents six different sets of activities. The process begins with scoping the project and defining the assessment and its objectives. The core activities related to project design fall under impact assessment, vulnerability assessment, and adaptation assessment. Finally, the process ends with defining implementation arrangements and monitoring frameworks.

In Figure 2, the six sets of activities are broken into 20 steps. A climate change assessment is best integrated into the activities of the project preparation technical assistance, following the identification of climate change as a potential risk/opportunity factor to the project at the concept stage. A risk screening tool Climate Risk Management in ADB Projects was developed for this purpose.

The report can be downloaded from here:

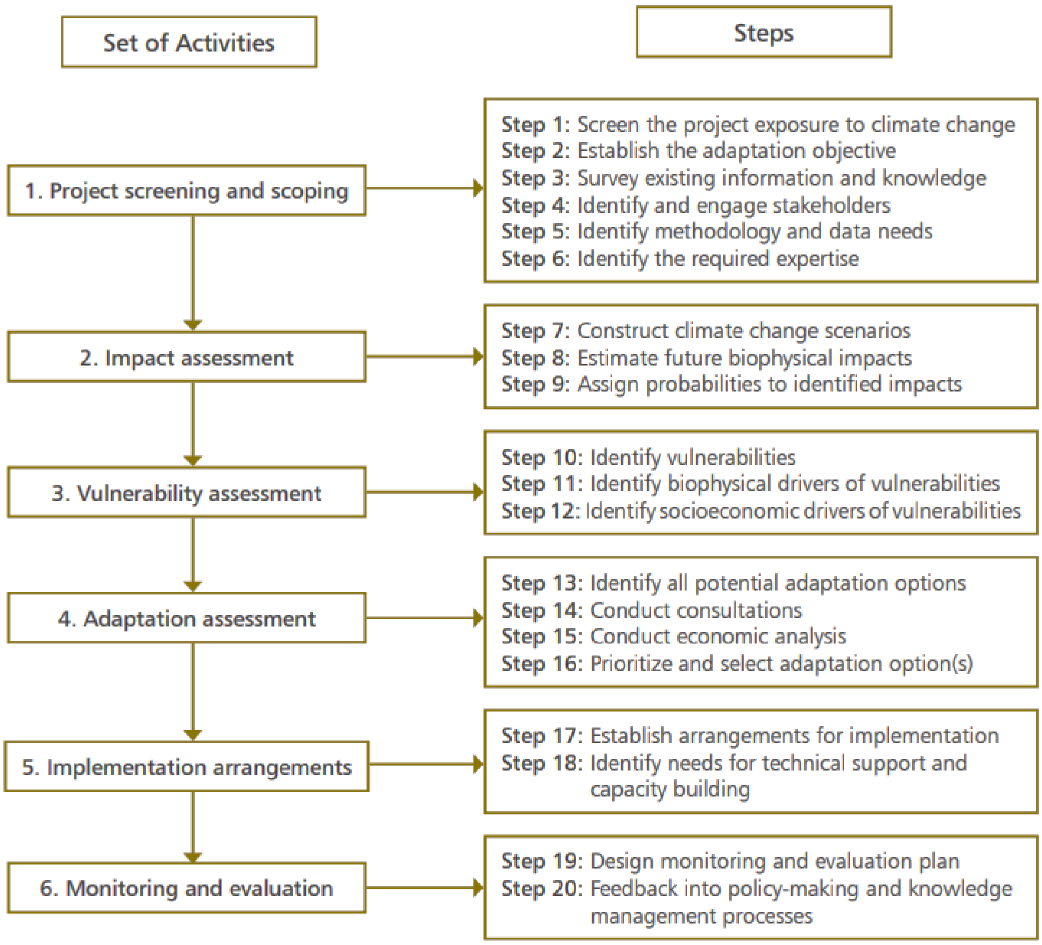
Guidelines for Climate Proofing Investment in the Transport Sector: Road Infrastructure Projects | Asian Development Bank (adb.org)

Figure E1 **Assessing Adaptation Needs and Options: 6 Sets of Activities**



PPTA = project preparation technical assistance.
Source: ADB.

Figure E2 **Assessing Adaptation Needs and Options: 6 Sets of Activities and 20 Steps**



Source: ADB.

9.0.10. The FORESEE project

Back

The FORESEE project is an interesting reference for those road administrations that already have some experience in CC. FORESEE is an EU collaborative research project funded by Horizon 2020. The overall objective of the project was developing a toolkit to improve road and rail asset management schemes for authorities and infrastructure operators with the following goals:

- Establish preventive maintenance and upgrading strategies able to improve resilience of transport infrastructures towards human (accidents) and natural hazards (extreme weather events, landslides and earthquakes);
- Predict and alert of potential risk scenarios at different time scales considering age, conditions and residual life of engineering components;
- Reduce the social and economic impact on critical transport assets (bridges, tunnels, pavement, slopes, terminals) when those disruptive events happen;
- Facilitate the deployment of mobility contingency protocols for citizens and freight in such critical situations to ensure safe and efficient evacuation including emergency operations and contingency plans;
- Demonstrate positive costs and benefits balance associated to resilience investments during the full lifecycle of the infrastructure.

As a result of the project, several tools were developed that might be of help for road owners in the situation of implementing a climate change assessment, at different stages (vulnerability, risk and resilience assessments):

- Traffic Module Tool
- Fragility Functions, Vulnerability Functions and Decision Support Interpreter Module Tool
- Virtual Modelling Platform Tool
- Alerting SAS platform Tool
- Governance Module
- Risk Mapping Tool
- Bridge Flooding Model Tool
- Command and Control Center
- A Fully Stochastic Flooding Prediction Methodology
- Hybrid Data Assessment for Diagnosis and Prognosis Tool
- Cyber-attack assessment

9.1. Case studies – Stage 1 Preparation stage

9.1.1. The Road Preservation Pyramid – ReCAP project

Back

The ReCAP research project "Economic **G**rowth through **E**ffective Road Asset **M**anagement", or "GEM", promoted a change in the approach of rural road organisations towards the management of their road networks. Traditional approaches focus on technical aspects such as network management systems and contracting modalities for road maintenance works. However, the GEM project encouraged a holistic approach, where road organisations consider all six building blocks of the Road Preservation Pyramid (see below). Particularly important of these building blocks are the **external/political** and the **institutional** building blocks. The reputation of the people that determine the political and institutional environment for roads depends on whether they manage to keep these two blocks, upon which all the other building blocks rest, intact!

The **operational** building block is a small part of the pyramid, but it represents the aspects of road asset management that road users come into contact with on a daily basis. The importance of maintenance is often underestimated in the preservation of the road infrastructure asset. Timeous maintenance of roads, using accurate data collected through regular monitoring, contributes to their longevity and is an effective use of limited financial resources. Maintenance operations are an important component of rural road asset management upon which the socio-economic development in rural areas rests.

The Road Preservation Pyramid

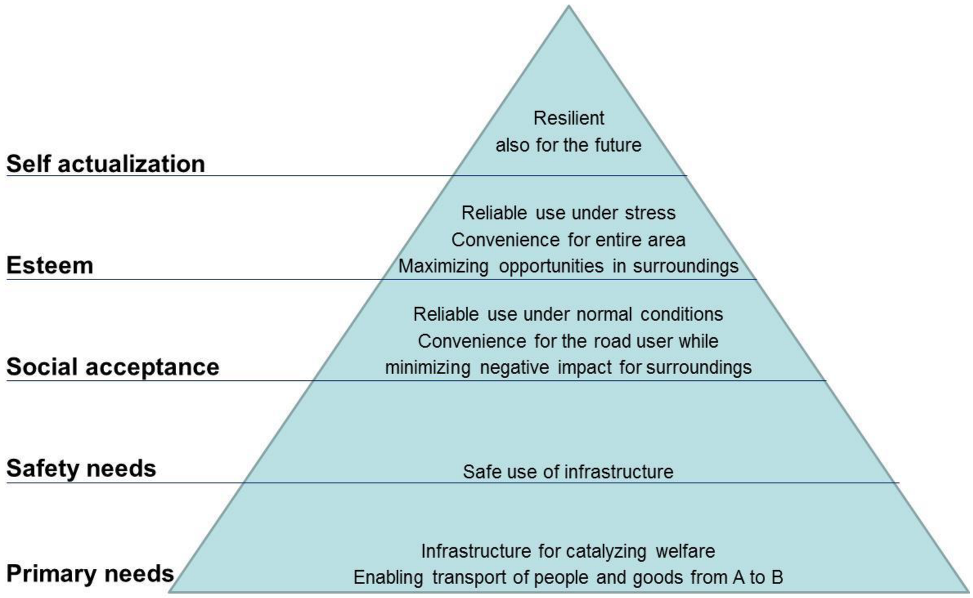
It is anticipated that once the GEM methodology is adopted by roads organisations, the planning, prioritisation, financing and implementation of climate adaptation interventions would be done on the basis of the precepts of the Road Preservation Pyramid to enhance resilience of road networks.

A baseline indicating the status of each of the building blocks is established through self-assessment based on questionnaires developed for the purpose and responses moderated by an external or internal party. The process is repeated at least once a year and results reflected on a Radar (Spider) diagram for a visual depiction of progress. The frequency with which a road organisation should undertake the process of self-assessment depends on the intensity of on-going activities towards self-improvement.

9.1.2. The Critical Infrastructure Development Pyramid

Back

The needs of road organisations vary largely. Although the aim may be the same – ensuring resilient infrastructure – the starting points may be so different that np single methodology will be applicable and appropriate for all cases. There seem to be different levels at which road operators are operating. Deltares identified that applying the Maslow pyramid (Maslow 1943) for the case of infrastructure operations provides clear insights in this respect. The road operators or road owners' needs can be recognised within the Maslow levels (the names of the levels are slightly adapted to accommodate the use for road infrastructure):



Here are some possible interpretations of the levels:

Primary needs	being able to transport people and goods from A to B.
Safety needs	providing safety for the road users.
Social acceptance	a sufficient functional and convenient use of the infrastructure is possible, which is in balance with acceptable impacts on the surroundings.
Esteem	achieving the infrastructure users' trust in the system, by achieving reliability, predictability and comfort, even in situations when under stress.
Self-actualisation	the operators are fully aware of all levels down the pyramid. They interact with all stakeholders in the environment. And they are fully aware of the fact that the system they are operating is not static and will change towards the future. This includes climate change, socio economic developments, technical and juridical developments.

9.1.3. The Maturity Index – Scotland

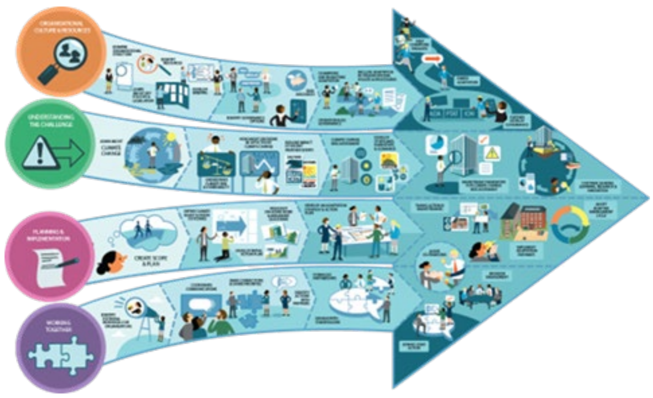
[Back]

Transport Scotland, the Scottish Government and our partners at Adaptation Scotland and Sniffer, as well as the wider public sector organisations collaboratively created the Adaptation Capability Framework. This is a pioneering new resource for use in the public sector at any stage of their adaptation journey. While this has been developed for public bodies in Scotland, the methodology and framework could be applied in essence to any region to understand your adaptation maturity level.

The framework supports climate risk assessments, whilst recognising that they belong in a broader scope adaptation, ensuring supporting guidance was holistic, outcomes focused, practical and supported organisations at different stages of adaptation. The input of the Adaptation Capability Framework, is based on local experience, embedding a pioneering capability – maturity approach that aims to support organisations to adapt to climate change. There are three main components of the Framework, starting with the capabilities. The Framework is based on the idea that an organisation has adaptation capability that determines its ability to deliver adaptation. This capability is multi-faceted and, in the Framework, categorised it into four adaptation capabilities. As adaptation requires sustained, long-term commitment from organisations and adaptation capability will develop over time, this is represented in the Framework as maturity stages. There are four maturity stages which illustrate how an organisation evolves from starting to mature. The Framework includes recommended tasks for each capability and at each maturity stage. By completing these tasks your org will be developing capabilities and delivering adaptation.

Through an expert working group and practitioner experience four overarching adaptation capabilities were identified:

- Organisational Culture and Resources;
- Understanding the Challenge;
- Planning & Implementation
- Working Together



To support organisations in understanding, utilising and measuring progress with the Framework Adaptation Scotland has developed a suite of supporting resources, ranging from an interactive online version that details all the tasks to a Starter Pack to specifically help organisations just starting out to a Benchmarking tool to evaluate and track adaptation progress.

Read more: [Adaptation Scotland: The Framework]

9.1.4. Resilience of SANEF Road network

Back

Following the publication of the first French National Climate Change Adaptation Plan (PNACC), Cerema has been involved in developing tools and supporting transport managers to help them improve the resilience of their networks to climate change.

In particular, in 2019 Cerema developed a 10-step resilience approach, which includes an analysis of the physical and functional vulnerabilities of the network and the definition of an adaptation strategy with prioritised solutions. The methodology for vulnerability assessment, entitled 'Vulnerabilities and risks: transport infrastructure in a changing climate', was published in 2019 [54]. It is available at the following link:

Vulnérabilités et risques: les infrastructures de transport face au climat | Publications du Cerema

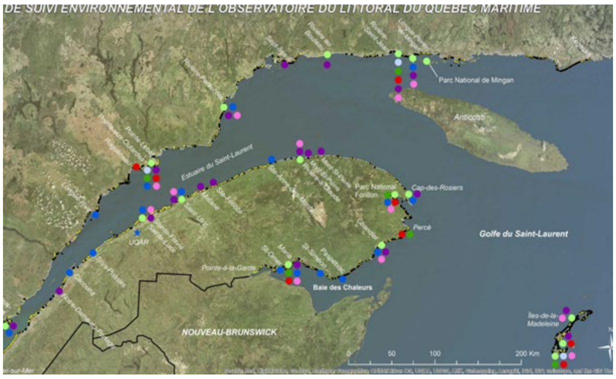
The SANEF Group is a highway concession company that finances, operates and maintains 2071km of networks including around 2000 engineering structures. For several years now, the group has been working to improve the resilience of its network to climate change. In this context, it wished to mobilise Cerema's expertise in this field to identify its vulnerabilities and define adaptation strategies.

Cerema implemented the first stage of its resilience improvement approach, which enabled the SANEF group to define and prioritise its resilience objectives, the physical, functional, geographical and climatic study scopes and finally, to identify the appropriate governance for carrying out the resilience study.

9.1.5. Action plan for coastal zones Quebec

Back

In Quebec, Canada, one third of the population and nearly 60% of national roads are located in coastal areas. In these areas, many public buildings and infrastructures are increasingly exposed to intensification of erosion processes caused by the rise in sea level, the decrease in ice cover, the increase in freeze-thaw episodes and the variations in storm patterns.



The road administration in Quebec (Ministère des transports et de la Mobilité durable du Québec) identified the need to enhance risk and asset management in coastal areas. To do so, a characterisation of coastal geomorphological dynamics has been initiated since early 2000, with major studies on vulnerability and economic impacts in 2015. To strengthen the resilience of transportation networks, the Department adopted an action plan on infrastructure management in a climate change context (PAGI3C). The action plan focused on addressing coastal hazards (erosion, flooding, and associated landslides). Other natural hazards will be incorporated, including fluvial erosion and fluvial flooding. Integrated into the 2019-2023 Strategic Plan, this action plan is structured around objectives that aim to: i) improve governance and management practices, ii) develop expertise and improve knowledge transfer, iii) analyse and assess risks, and iv) implement adaptation solutions to improve the resilience of the network. The four main objectives aim to change the Quebecian risk management orientation from reactionary to preventative.

Toward an integrated and concerted management of coastal areas

The coastal zone is a coherent area for reflection and activity. The long-term objective is to achieve integrated management of coastal territories and rally coastal communities around common issues.

The following structure ensured a successful project:

- Mobilise and include stakeholders to ensure a shared vision and the integrated management of the coastal zone
- Interdepartmental cooperation committee implemented
- Collective approach to implement solutions and carry out projects
- Social acceptability of project / stakeholders, local and regional population
- Research partnerships: creation of a research chair in coastal engineering

The following actions were taken to move from a reactionary to a preventative orientation

- Characterise the evolution and dynamics of coastal systems
- Assess the vulnerability of transportation networks and risks in coastal zones
- Develop coastal intervention prioritisation indices (IPIC)
- Create decision support tools and implement appropriate solutions for the sustainable development of the maritime environment
- Implement an asset management system to ensure the sustainability of coastal protection works, and a coastal bank monitoring system
- Develop a regional intervention plan based on integrated asset management principles in risk areas
- Conduct an environmental impact study for each region rather than for each project, including an extensive coastal community consultation program

The text below elaborates on these points.

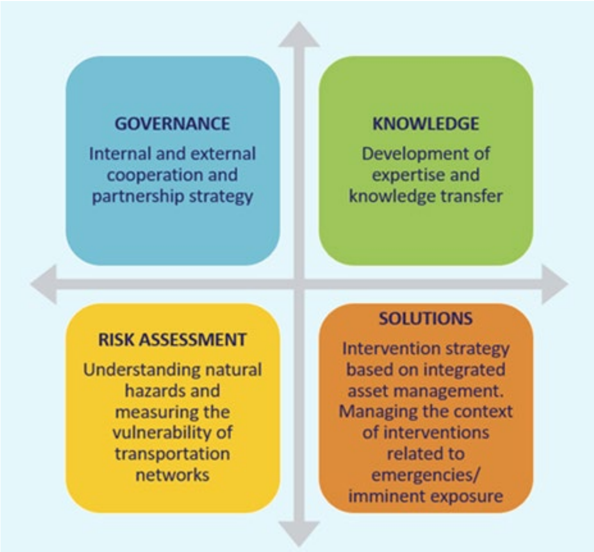
Among the structuring actions, let us mention the importance of major research partnerships to ensure the development of knowledge, to understand the evolution and dynamics of coastal systems, assess the vulnerability of transportation networks, and implement adapted solutions (providing input/data/ to develop tools and strategies, help to prioritise intervention, to review conception guidelines, etc). In the long term, the objective is to deploy an intervention strategy and public investments to improve the resilience of transportation networks.

The project developed The Coastal Intervention Prioritisation Indices for coastal erosion (IPIC-E). These indices include several parameters to assess the likely exposure to erosion and its consequences (impacts on mobility, ability to restore service, presence of service, presence of utilities within the road right-of-way), thereby produce a criticality level for the 2775 kilometres of the road network along the coastline.

The methodology behind the Coastal Intervention Prioritisation Indices for coastal erosion (IPIC-E) is one of the case studies included in Section 2.2.5 ‘Risk analysis methods and case studies’ and is explained in detail in Section 9.2.18.

To measure the vulnerability of the road network to coastal hazards, knowing the conditions of the protective structures was a priority. An asset management system of protective structures was added to ensure the durability/sustainability of structures and right safety level on the banks over time. An inventory and inspection manual was developed to establish the baseline condition of the armour stone revetment structures park. The inventory component defined the condition at installation time. The inspection component made it possible to monitor the evolution over time (a riprap condition index [SCI]). This manual is accompanied by a training and accreditation program for the Department’s inspectors and external firms. A second manual is being developed to monitor natural shorelines.

Many initiatives have been undertaken to date and many actions are still being carried out in a sectoral manner. To address the need to rally the other players involved and the need to develop a concerted governmental vision, an interdepartmental governance committee on interventions in coastal environments was set up in 2021 by the MTQ. Three subcommittees will be created by the end of the year to (1) develop a governmental vision for coastal zone management, (2) ensure the development of knowledge and expertise, and (3) improve the legislative and regulatory framework.



An action plan based on 4 main objectives:

1. Improve **governance** and infrastructure management practices in a context of climate change
2. Develop expertise and improve **knowledge** transfer
3. Understand natural hazards, measure the vulnerability of transportation networks and **assess the risks**
4. Implement adaptation **solutions** to improve the resilience of the network and develop an intervention and investment strategy

A detailed article, and poster, are available on the conference proceedings page of Calgary Congress 2022, IP0101–- Resilience of transport networks affected by erosion and marine submersion: towards an integrated and concerted management of infrastructures in coastal areas, Available from: [8. Best practices for increasing resilience in road networks (piarc.org)]

Management of coastal protection works

In order to measure the vulnerability of the road network to coastal hazards, having a good knowledge of the riprap revetment park under its management, the Ministère des transports et de la Mobilité durable du Québec developed inventory and inspection methodologies, documented in a riprap revetment inventory and inspection manual.

Figure. Cover page of the new riprap revetment inventory and inspection manual

The inventory consists of establishing the baseline condition of the riprap revetment at the time of construction or inventory in order to track the evolution of the revetment over time through inspections. The inventory includes design documents, plans, revetment geometry and site description.

The inspection consists of an on-site examination of the riprap revetment section in order to detect defects, determine their significance and extent, and assess their impact on the capacity and stability of the revetment as well as the safety of users of the infrastructure that the structure protects.

Each of the defects is rated from A to D, where A is for no defects and D is for major defects. Based on the ratings assigned to each category of defects, the riprap condition index (RCI) is obtained for each section. This condition index, which varies from 0 to 100, is a decision-making tool that allows not only to assess the structural condition of the riprap revetment section, but also to determine the required intervention and predict the frequency of inspection needed. This numerical index is converted into a letter to obtain the revetment condition class.

Condition index	Revetment condition class	Meaning	Inspection frequency (years)
≥ 85	A	Very good condition	3
70 to 84	B	Good condition — Moderate level of deterioration and defect	3
55 to 69	C	Fair condition — Significant defects	2
40 to 54	D	Poor condition — High level of deterioration and defect, which requires the engineer's advice	1
≤ 39	E	Very poor condition — requires the engineer's advice (inspection to be prioritized following a storm)	1

Figure 12. Revetment condition class

A training system with an inventory accreditation program has been implemented for inspectors from the Ministère and consulting engineering firms.

As an extension of this riprap revetment manual, a second manual is also being developed to address the need for monitoring natural shorelines at risk. Ultimately, the goal is to develop an integrated asset management and risk monitoring system for all vulnerable transportation infrastructure in the coastal zone[20].

Regional environmental impact assessment

In the province of Québec, the *Environment Quality Act* is the cornerstone of the environmental authorisation system and, through the Regulation respecting the *environmental impact assessment and review of certain projects,* provides a framework for projects that are subject to the Act due to their environmental risk and impact.

The environmental assessment focuses on:

- preventing the deterioration of environmental quality and maintaining the biodiversity, connectivity, productivity and sustainability of ecosystems;
- respecting the sensitivity of the physical, biological and human components of the receiving environment;
- protecting the life, health, safety, well-being and comfort of people;
- promoting and supporting the population's participation in the evaluation of projects that impact their living environment.

This procedure includes, for projects subject to it, the completion of an environmental impact assessment and, usually, extensive public hearings.

[20] All coastal protection structures have been inventoried. However, inspection methodologies for other types of structures will be developed progressively, taking into account their current low representation.

Considering the amount of projects to carry out, most of them being subject to this requirement, a solution has been developed to conduct a regionalised environmental impact study, with an approach that was developed in cooperation with the provincial and federal ministries involved[21]. Its implementation will allow to address the problem of erosion by providing a global vision of the territory, conduct a strategic reflection on solutions and thus reduce the impacts caused by carrying out individual projects. In addition, the study will allow for a better consideration of environmental issues, including those related to adaptation to climate change, the health of human beings or other species, and cumulative impacts. The figure below shows the extent of the territory that will be affected by this regionalised impact study.

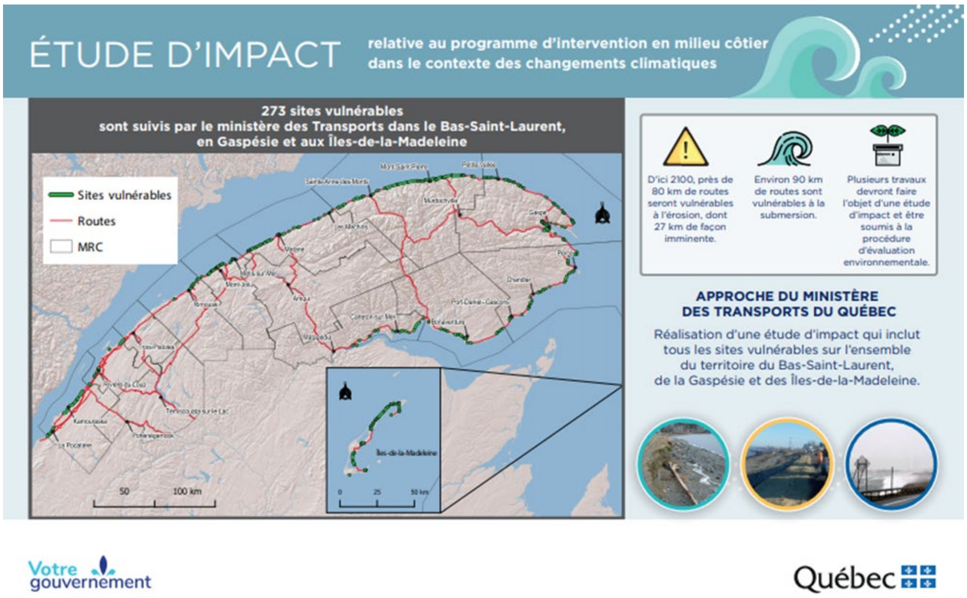


Figure. Regional impact assessment presentation document for municipal information sessions

However, in order to compensate for the lack of precision of an impact study conducted on a regional scale and meet environmental requirements, solutions had to be proposed, including the implementation of an ongoing stakeholder consultation strategy, the development of a decision-making tool, a method for estimating the encroachment of projects into wetlands and waterways, and an approach to compensate for residual impacts.

[21] Ministère de l'Environnement et de la Lutte contre les changements climatiques (MELCC), ministère de la Faune, des Forêts et des Parcs (MFFP) and Fisheries and Oceans Canada (DFO).

9.1.6. DESINVENTAR database

Back

Natural disasters have historically had a large and widespread impacts on infrastructure. Therefore, Mexico use the DESINVENTAR [22] database, which has helped identify these effects and impacts and their geographical location.

DesInventar is a conceptual and methodological tool for the generation of National Disaster Inventories and the construction of databases of damage, losses and in general the effects of disasters. These methodologies and software have been developed by the DesInventar Project team with support from different institutions as UNDRR, UNDP, etc.

The reference information makes it possible to identify the type of phenomenon that affected the infrastructure and the damage caused. Specific impact information can be obtained for transportation infrastructure.

The database can be a useful source for identifying historical impacts to select key climate variables. It only collects information from some Latin American countries, and can be consulted at: https://db.desinventar.org/

In the implementation of the Framework in Mexico, the risk assessment was carried out through the methodologies and maps developed by the National Center for Disaster Prevention, for the different types of climatic hazards, such as floods, heat waves, hydrometeorological phenomena, etc. [23]

- Centro Nacional de Prevención de Desastres. (2012). Mapas de índices de riesgo a escala municipal por fenómenos hidrometeorológicos (Maps of risk indexes at municipal level due to hydrometeorological phenomena). México, DF
- www.anr.gob.mx/Descargas/Metodologias/Hidrometeorologico.pdf
- Centro Nacional de Prevención de Desastres. (2016). Metodología para elaborar mapas de riesgo por Temperaturas máximas (1ª etapa ondas de calor) (Methodology to prepare risk maps for maximum temperaturas). México, DF
- http://www1.cenapred.unam.mx/COORDINACION_ADMINISTRATIVA/SRM/FRACCION_XLI_A/33.pdf

[22] Sistema de inventario de efectos de desastres, http://www.desinventar.org/es/

[23] http://www.atlasnacionalderiesgos.gob.mx/archivo/visor-capas.html

9.1.7. Towards a more resilient Spanish road network

Back to 1.3 Climate change impact

Back to 2.1.1 Exposure assessment

It is useful to develop a methodology that help road administrations to identify which road sections that are vulnerable to climate change and which road sections to prioritise for implementation of adaptation responses. Spanish road owners are looking to the development of such a methodology.

The first step to develop such a methodology is to give special attention to the definition and implementation of the exposure and sensitivity stages.

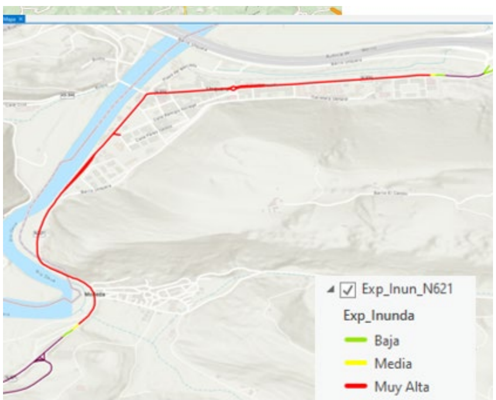
In the case of the **exposure**, one of the main hazards that are being studied are intense heavy rainfall events. Every year several dozens of road sections in Spain suffer from some kind of impact due to floods, including road closures.

The two main inputs to assess the exposure to heavy rainfall were (1) rainfall over a 24 hour-period (P24), provided by Adaptecca (web), and (2) flooding zones for different return periods, provided by the SNCZI (web) and the Ministry of Ecological Transition and Demographic Challenge. The exposure data were included in GIS based maps, used to visualise the most exposed road sections to intense rainfall.

As one of the objectives was to include semi-empirical results some thresholds were proposed:

- In the case of already existing maps from the SNCZI, the thresholds were linked to different return periods. The smaller the return period the higher the level of exposure.
- In the case of maps made up from P24 data, thresholds were defined after studying records of past vents (amount of rainfall that caused harm to road sections in the area).

Some case studies were used as a validation of the methodology. The figure below shows a very good connection between map results of flooding and registered flooding on the road.



The map on the left presents the exposure map developed, with the different levels of exposure defined for different return periods. The picture on the right shows an episode of heavy rain on N621.

In the case of **sensitivity**, matrixes were proposed for each of the considered main assets. Sensitivity matrixes define different sensitivity factors and a proposal for scoring. For example, the asset “state of maintenance of road drainage” received a low score if it was well maintained and a high score if it was a poorly maintained. By considering the different sensitivity factors, an estimation of the overall sensitivity of the asset was calculated.

One of the most difficult parts in this work was the definition of the matrixes (sensitivity factors and scores). Input to the definition was obtained from previous work developed by the Mexican Institute of Transportation (IMT)[24] along with information from experts of different disciplines (bridges, geotechnics, etc.). It has to be said that scores can change depending on the geographical area and typology of the assets under assessment. Therefore, the proposed matrixes and results obtained by using them needs validation.

Finally, vulnerability is calculated by means of tables that assign a certain value depending on the exposure and the sensitivity.

[24] “Marco Metodológico para la Adaptación de la Infraestructura Carretera ante el Cambio Climático en México”, 2019

9.1.8. Bruce Highway Link Flood Study

Back

The Bruce Highway Flood Study is a project initiated and managed by the Department of Transport and Main Roads (TMR), Queensland. It utilises a hydrologic technique known as continuous simulation which is being used in a completely new way to assess the long-term flood reliability of the Bruce Highway link from Brisbane to Cairns. The study is looking at the flood performance of the whole Bruce Highway over the last one hundred years using rainfall records to generate stream flows at every crossing (there are over 500 of these) – this data is combined with hydraulic assessment to determine when each crossing is cut from flooding. This procedure effectively simulates the long-term performance of each link of the Highway over the last hundred years.

Having established this, the study then looks at upgrading the key segments of the Highway and re-simulating performance to quantify the level of reliability improvement. The level of improvement achieved can be quantified in economic terms (that is, reduced disruption), which then forms the basis of a consistent and transparent upgrade works prioritisation programme.

This was the first time a holistic assessment of the Bruce Highway has occurred and is the largest single length of flood link study ever completed in Queensland.

More information:

Bruce Highway Upgrade program | Department of Transport and Main Roads (tmr.qld.gov.au)

Source: Department of Transport and Main Roads, Queensland

9.1.9. The Portuguese Climate Portal

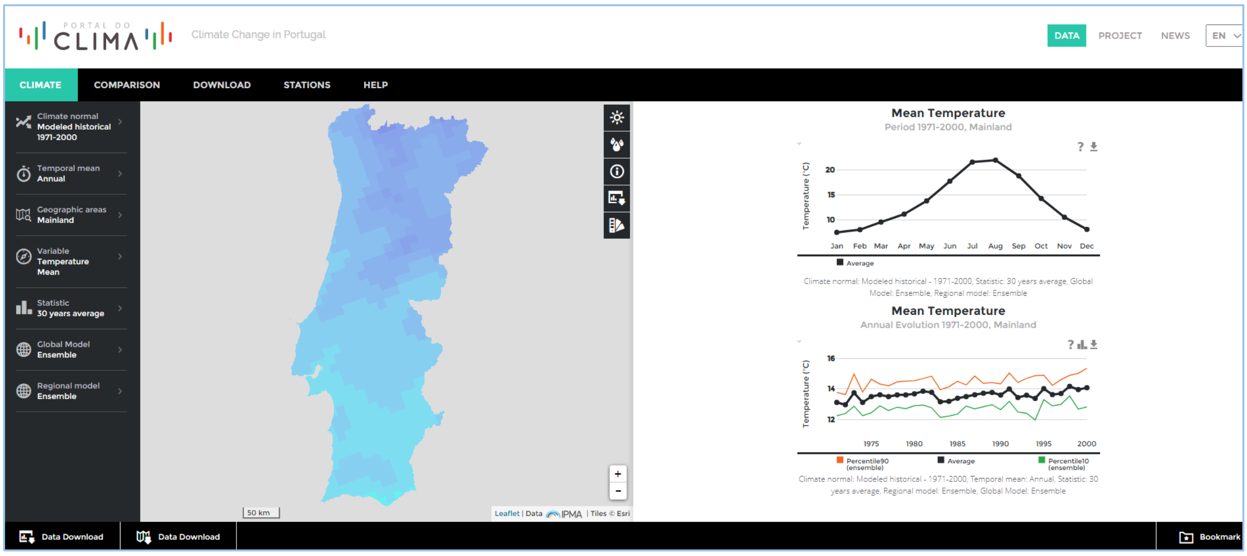
Back

In Portugal, the Climate Portal, a project under the responsibility of the Portuguese Institute of Sea and Atmosphere (IPMA), with the collaboration of the Portuguese Environment Agency (APA), disseminates a wide range of climate data in an easily accessible platform, freely available for the general public, namely: historical series, climate change scenarios at regional level and climate indicators for specific sectors in Portugal.

This project thus contributes to increasing awareness and education on climate change.

The project used past climate data and climate projection data from IPCC AR5 (CORDEX project) for dissemination through the website. This task involved all necessary calculations for the disaggregation of data at different levels of the territory (PT NUTS3 level) and at different time periods, and the (eventual) estimation of aggregate indicators (e.g. drought index, meteorological fire risk, etc.).

http://portaldoclima.pt/en/

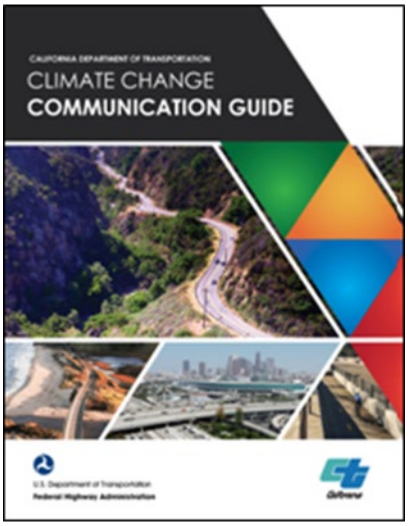


9.1.10. Climate Change Communication Guide (California Dept. of Transportation)

Back

The primary objective of the pilot was to evaluate the District-level vulnerabilities of the State highway system in California to climate change and develop a tool that Caltrans and other transportation agencies can use to **communicate** these climate risks. Caltrans sought to produce a communication guide that presents strategies for communicating with internal staff and external partner agencies as well as with the broader public on the topic of climate change to educate, inform, and strengthen collaboration.

An overarching Caltrans **objective** with the guide was to facilitate the conversation of climate change efforts with internal and external partners. This will help Caltrans to proactively plan and incorporate mitigation and resilience into its planning, design, maintenance, programming, and operations.



California Department of Transportation (Caltrans) Climate Change Communication Guide

Caltrans' pilot project took place between May 2019 and December 2020 and culminated in a 60-page Climate Change Communication Guide. The communication guide is intended to be used by Caltrans and each of its Districts. The guide can also be adapted and applied by other agencies and organisations around the US that aim to enhance resilience and climate change communications. This guide also provides best practices for agencies interacting with members of the public who may not necessarily be familiar with the underlying science of climate change or the importance of taking action to address impacts.

To inform the development of the communication guide, Caltrans conducted interviews and surveys with staff from headquarters, all twelve of its Districts, and various divisions. Caltrans engaged representatives from key external partner agencies who contributed valuable input and ideas to the guide. External stakeholders that were engaged included tribal partners, transportation agencies, permitting agencies, metropolitan planning organisations, the California Air Resources Board, the California Coastal Commission, the California Environmental Protection Agency, and the California Natural Resources Agency.

These individuals shared strengths, challenges, and concerns that helped the authors of the communication guide select a focused set of strategies to address the unique challenges of communicating about the range of expected changes in climate in a State as geographically, politically, and culturally diverse as California. The goal was to integrate these perspectives so that as Caltrans continues to develop new climate change tools and guidance, reaching a broad range of audiences will remain at the forefront. Individuals were engaged in routine working group meetings, at conferences, and through information-sharing opportunities such as peer exchanges.

Some lessons learned:

- Connecting with multiple stakeholders to inform the making of the Caltrans Climate Change Communication Guide was key for ensuring that the product would be useful and widely applicable.
- Caltrans engaged internal and external partners in regular forums such as the Climate Change Branch Quarterly Workgroup, District- and headquarters-level communications mediums, and at conferences.
- Another lesson learned was to frame concepts using language that is familiar to the audience it is intended to reach. This is important because the department developed the communication guide to engage people from several different regions of the State and beyond.

9.1.11. Indicator based criticality analysis – BASt

Back

The road network is essential to supply the society with important goods and services. A longer disruption of network elements can have serious consequences, which is why it is important to know the most critical road sections and objects (e.g. bridges, tunnels). Criticality, in this context, is defined as measure for the significance of a road section with regard to the consequences in case of a disruption.

To assess the significance of road sections of the German trunk road network, an indicator-based criticality analysis approach was chosen. This approach is comprised of four steps: After the indicators have been selected, they are assigned to four different indicator groups. The subsequent weighting of the indicator groups then allows the calculation of the overall criticality and its cartographic visualisation.

The four indicator groups include: traffic indicators (e.g. annual average daily traffic for workdays), economic indicators (e.g. annual average daily heavy traffic for workdays), spatial planning-related indicators (e.g. links between metropolitan regions) and geographical indicators (e.g. topological aspects). Further examples for the different indicator groups and their subsequent weighting factors can be seen in the table below.

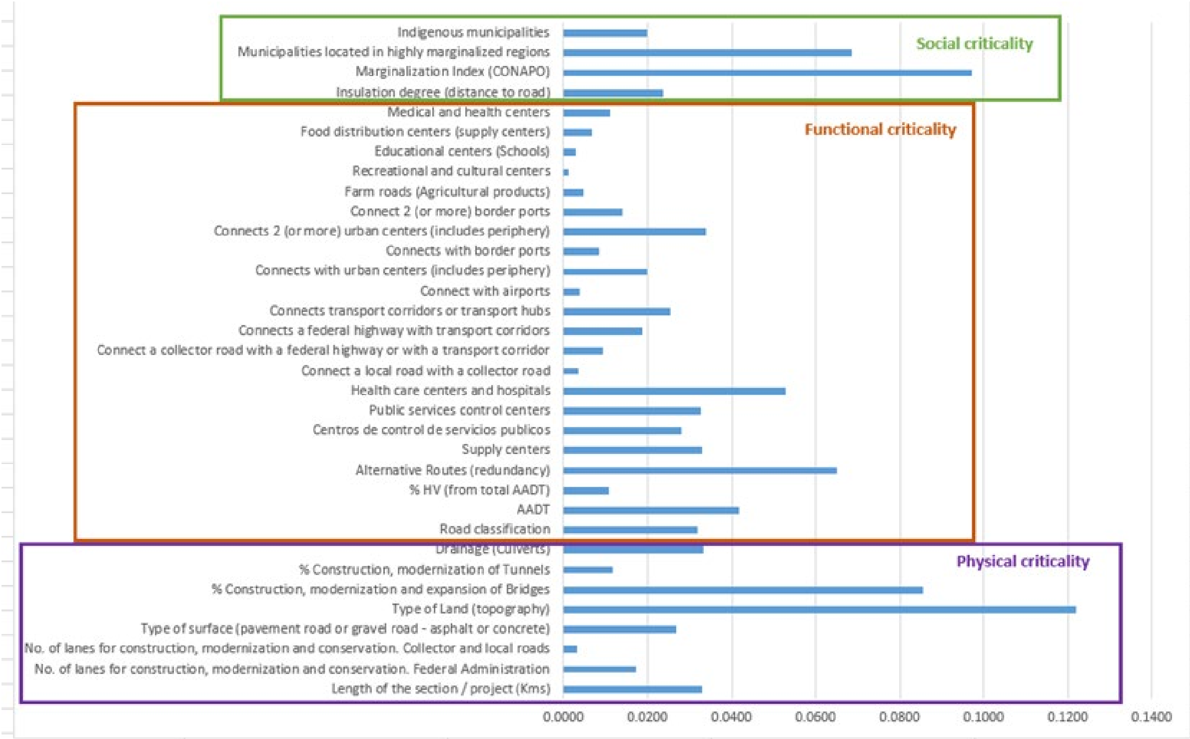
Indicator group	Weighting of the group	Indicator	Weighting of indicators
Traffic indicators	1.0	Annual average daily traffic for workdays	1.0
		Travel range for workdays	0.125
Economic indicators	0.5	Annual average daily heavy traffic for workdays	1.0
		Travel range heavy traffic for workdays	0.5
Spatial planning (system of central places)	1.0	Links between metropolitan regions	2,0
		Connections to metropolitan regions and links between higher-order centres	1.0
Geography	1.0	Topology	1.0
		Network density	0.1

Not only do the different indicator groups enable a differentiated view – suitable for the respective research question – on the criticality of the German trunk road network but can be combined to derive an overall criticality assessment by weighting them differently beforehand. It should be noted though that the selection of indicators is subject of an expert-based decision-making process which does not claim to make an irrefutable and exhaustive compilation of indicators for criticality considerations.

9.1.12. Establishment of criteria that allow determining the criticality of public investment projects for network infrastructure in Mexico

Back

This project establishes criteria to determine the criticality of public investment projects for highways in Mexico, under a hierarchical structure with three strategic criteria called Physical Criticality, Functional Criticality and Social Criticality, and several sub-criteria.



This project establishes criteria to determine the criticality of public investment projects for highways in Mexico, under a hierarchical structure with three strategic criteria called Physical Criticality, Functional Criticality and Social Criticality, and several sub-criteria.

The project seeks to increase the resilience in roads investment projects (new and existing). The process is established in two stages, the first one performs a criticality assessment to identify relevant projects of the road network, and the second stages consists of a disaster risk assessment, on which adaptation and improvement actions must be implemented into the road project to increase resilience.

For stage 1 on the evaluation of criticality, a spreadsheet tool was developed to qualify each of the criteria for a particular project, to obtain a level of criticality.

CALCULATION OF THE CRITICALITY INDEX FOR NEW ROAD PROJECTS - MEXICO-2019

CRITICALITY THRESHOLDS		
VERY HIGH > 0,571	1	1= Selectec
HIGH (0,519)		
MEDIUM > 0,484	0	0= No selected
LOW (0,440)		

Critical Project | Moderate Criticality Project | Low Criticality Project

Number of criticality criteria = 54

ROAD ID	TOTAL	Physical Criticality: Length of the section / project (Kms)	No. of lanes for construction, modernization and conservation. Federal Administration	No. of lanes for construction, modernization and conservation. Collector and local roads	Type of surface (pavement road or gravel road - asphalt or concrete)	Type of Land (topography)	% Construction, modernization and expansion of Bridges	% Construction, modernization of Tunnels	Drainage (Culvert
		0.0329	0.0174	0.0031	0.0268	0.1220	0.0855	0.0117	0.0332
Casas Grandes-Pto.Palomas	**0.3906**								
CG-Janos	0.3804	Alta 21-40	Muy alta > 4	Alto 2c de 3.5m	Revestimiento	Lomerio	Baja 0.5-2%	Medio 2.1-3.5%	4 o más od/km
Janos-LosTrios	0.4531	Muy alta > 40	Media 2 (c/acot)		Pav. Asfáltico convenc	Plano	Muy baja < 0.5%		3 od/km
LosTrios-Pto.Palomas	0.3383	Alta 21-40	Media 2 (c/acot)		Pav. Asfáltico convenc	Plano	Muy baja < 0.5%		3 od/km
Los Herrera-Tamazula	**0.6210**								
Modernizacion (alimentador)	0.6210	Muy alta > 40		Alto 2c de 3.5m	Pav. Asfáltico convenc	Montañoso	Baja 0.5-2%		4 o más od/km
Entronque Reforma-Villa Hermosa	**0.4804**								
Km148+840: 157+500	0.4804	Baja 3-10	Muy alta > 4	Medio 2c de 3m	Pav. Asfáltico convenc	Plano	Muy alto > 5%		2 od/km
Km160+700:165+740	0.4804	Baja 3-10	Muy alta > 4	Medio 2c de 3m	Pav. Asfáltico convenc	Plano	Muy alto > 5%		2 od/km
Chinà-Haltunchèn-Cayàl (moderniza)	**0.4709**	Muy alta > 40	Media 2 (c/acot)	Alto 2c de 3.5m	Pav. Asfáltico convenc	Plano	Muy alto > 5%		2 od/km
	0.0000								
	0.0000								
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INSTRUCCIONES DE USO | PROYECTOS

Criticality thresholds are used to classify projects according to their degree/level of criticality (high, moderate or low) and are obtained from a theoretical-empirical process, that is, applying aspects of statistics, distribution and calibration on the evaluation scales of the terminal criteria.

If a project exceeds the severe threshold, it is clear that it is a critical project and requires greater attention, if it exceeds the laid-back threshold, it is a project that (depending on the budget), specifically if it has a high impact on the economy.

Source: GIZ, 2019.

9.1.13. A methodology to identify the networks that must be protected: RESAU²

Back

RESEAU² (Résilience des Acteurs de l'Urgence et Réseaux) is an approach to identify the most important networks in order to define those one that must be open for rescue services transport or to provide an access to inhabitants to essential services such as hospital or supply centres (e.g. for food) is the RESAU² approach, its process is explained below:

- the first step is to identify the critical centres (hospitals, fire stations, etc., i.e., centres that must remain operational in order to limit and quickly resolve a crisis);
- this is needed to deduce which networks, and transport networks in particular, are essential for these critical centres to function; and
- and the last step is to identify the measures that will enable these networks to remain in operation under any circumstances.

This approach is particularly interesting when the number of hazards is large, or hazards can disrupt a large part of the network, and for hazards where the occurrence and consequences are difficult to predict. This approach can be based on expert judgements, or better, if feedback from past events is available, data such as the disruption duration of a network or the number of vehicles that have been rerouted may be useful to identity the critical networks and/or the adaptation measures.

Source: Cerema, France, 2009.

9.1.14. Assessing regular travel criticality: an example of multi-criteria methodology

Back

The criticality assessment may also focus on the performance of the network for regular travels of persons and goods. As models may not be available for each network, and as it is time-consuming and costly to design models, a multi-criteria method may be used.

A multi-criteria method has already been applied to assess the criticality of a network in a French conurbation. Therefore, the network has been divided into road sections. For each section, the following indicators of criticality have been assessed: the traffic, its structure (internal, junction, transit, or a combination of the three), the alternative roads and their capacity to absorb the traffic that may have been rerouted from the section that is assessed (if this section would have been cut). The sections were categorised into four groups:

- “low importance”: At least one of the alternative roads has a high available capacity;
- “moderate importance”: the alternative roads only have a moderate available capacity;
- “high importance”: An alternative road with a low capacity is available, and one or two alternative road have a moderate available capacity; and
- “very high importance”: The alternative roads have very low available capacity, or there are no alternative roads.

Source: Cerema, France, 2016.

9.1.15. Criticality including the aspect of vulnerability

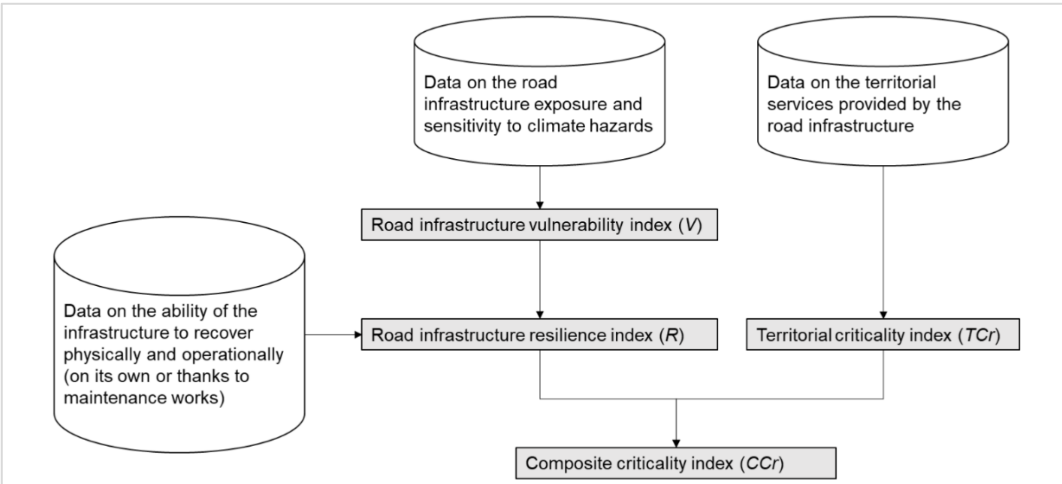
Back to 1.5 Criticality

Back to 2.2.5 Risk Analysis

'Resallience' in France developed a three-step framework to prioritise critical road segments for climate-resilience investments [56]. "Criticality" is in this case a measure of *importance of action* and *priority*. "Critical roads" are defined as roads whose unavailability would result in the highest impacts on the transport system and surrounding territory), which should be given priority for resilience strengthening investments.

"**Composite criticality**" includes the aspect of vulnerability. The three steps of the framework are:

- Divide the road network into segments
- Assess the criticality components:
    - Vulnerability – the degree to which the infrastructure is likely to experience harm due to exposure to a hazard.
    - Resilience – the ability of the infrastructure to continue to deliver or rapidly recover its functionality
    - Territorial criticality – the importance of the infrastructure for functioning of the territory
- Assess the composite criticality – calculate a composite index integrating the three components. The formula is adapted to reflect the scale of the dispersion of the scores and stakeholders' preferences.



9.2. Case studies – Stage 2 Vulnerability and risk assessment

9.2.1. Geospatial analysis, Mexico

Back

The management of risks associated with climate change has encouraged the actors involved to make use of geographic information systems (GIS) as a technological tool to understand the problem of climate change and, based on it, to assist in obtaining information.

Through GIS it is possible to build various maps, including vulnerability maps. Mapping is useful because climate variability and extreme weather can be represented spatially, including the sensitivity of populations/services/infrastructure, and their systems due to various climate stressors, as well as adaptive capacities.

Spatial data analyses generally aim to identify areas with potentially high risk associated with climate impacts, which are called climate change "hotspots."

In Mexico, geospatial analysis was carried out using hazard maps of different climatic threats (developed under predictive models), which were superimposed on the road network with the aim of identifying those areas where road infrastructure is exposed to different hydrometeorological hazards. and that, in the future, may compromise its integrity. These analyses included the estimation of the length of road sections, both state and federal network, that were in the areas with the highest danger index due to floods, heat waves and other threats.

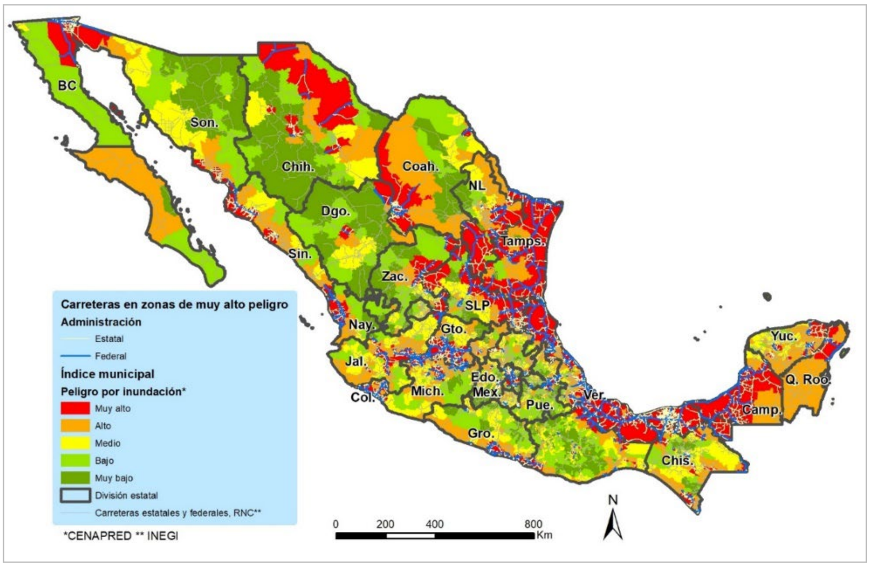


Figure. Flood hazard map on the road network in Mexico

Geospatial analysis includes maps that model future climate events, such as sea level rise, and future temperature and precipitation climate scenarios. The first approximations of this analysis allow us to estimate the future threats to the federal and state highway network, to climate change in the near future (2015-2039) and far future (2075-2099). In this way, it was possible to estimate the number of road kilometres that could be exposed in the future, as well as the bridges that are located in those highway sections.

Spatial vulnerability assessment can be a useful entry point for setting adaptation priorities, but it is not a substitute for rigorous vulnerability assessments based on field studies, which deepen knowledge of impacts of climate change on road infrastructure.

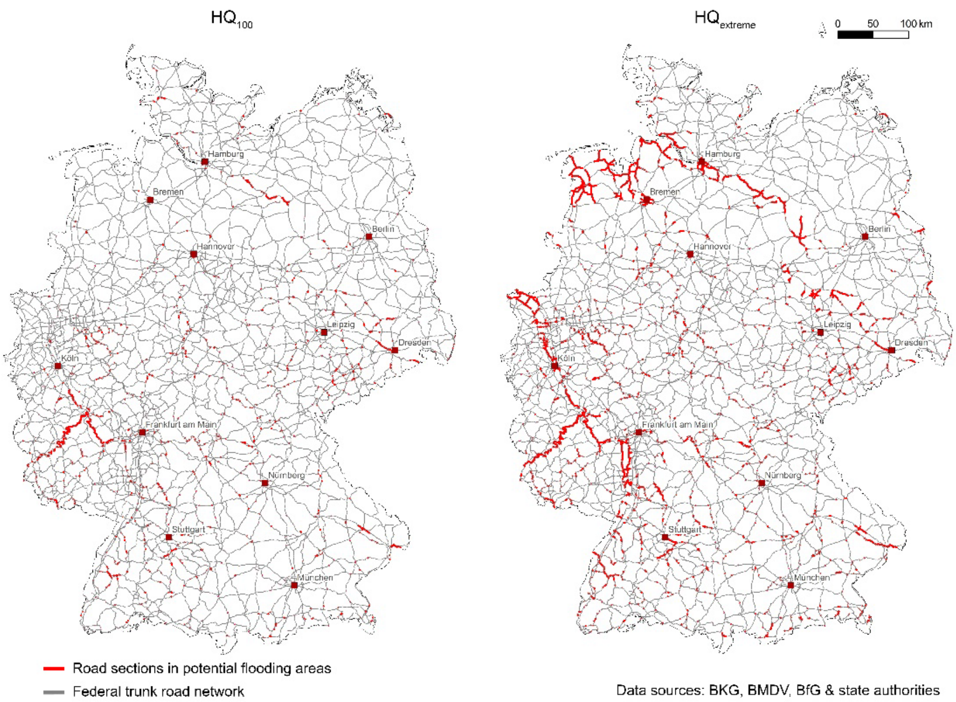
The use of GIS is recommended for geospatial analysis of and thus assist strategic decisions in the continuous process of adaptation to climate change. It is an advantage to use maps. Maps can display a large amount of information in a simplified way that can be more visually appealing to the stakeholders involved.

9.2.2. Assessment of trunk roads to floods, Germany

Back

The exposure assessment was carried out based on river and storm surge flood hazard maps available throughout all federal states of Germany. The combination of these flood hazard maps and the federal trunk road network resulted in exposure maps for medium and extreme flood scenarios. The “medium” scenario has a statistical recurrence interval of 100 years and is defined with the same recurrence interval in all federal states and is thus particularly well suited for a nationwide analysis. The “extreme” scenario, on the other hand, was derived differently in different federal states, so that there is no uniform nationwide data basis for it.

To get an estimation of the future exposure and the influence of climate change, the recurrence intervals of the present flood scenarios were recalculated on the basis of projections of future flood discharges. The spatially differentiated analysis of the projected recurrence intervals of the hundred-year flood peak allows for a rough and preliminary assessment of the future flood-related exposure of the road infrastructure in the area of today’s flooding zones.



Sections of the federal trunk road network in the area of potential river and storm surge flood areas for the medium (left) and extreme (right) scenario.

9.2.3. Vulnerability assessment of DIR Méditerranée, Cerema, France

Back to "Sensitivity"

Cerema, France, published in 2015 and updated in 2019 a methodology for analysing the risks for transport infrastructure and services from climate change. National Strategy PANCC /Action 3 [38].

Cerema and Carbone 4 applied this innovative method to the 750 kilometres of the national network operated by the Mediterranean Interdepartmental Road Directorate (DIR), by assessing

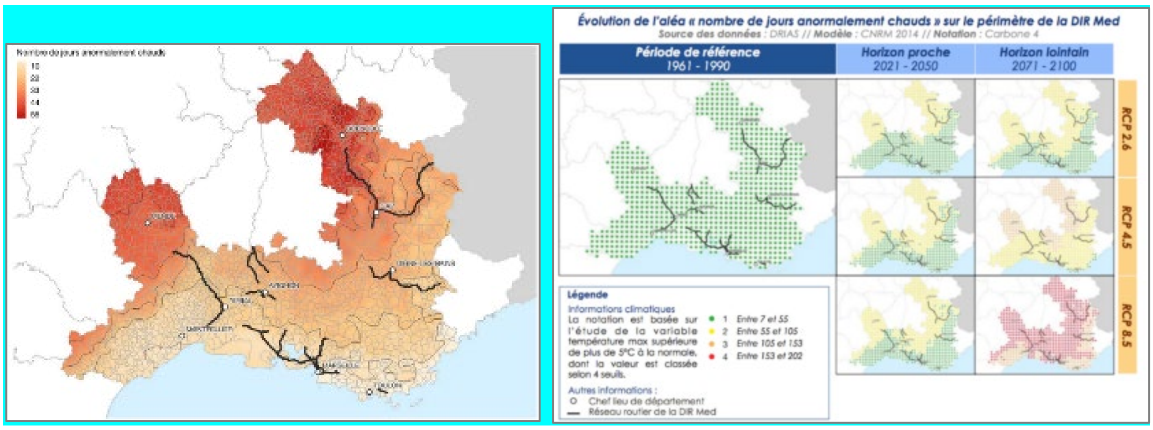
- its exposure to current and future climate events,
- the vulnerabilities of the various systems of the network: pavement, engineering structures, etc,
- and the vulnerability of the network's functionalities, particularly those related to everyday travel, for each of the analysed climatic events.

The analysis led to the production of risk maps that cross-reference different issues related to the infrastructure and functionalities of the DIR Méditerranée network, for several climatic events, concerning both current climate and future climate, with several scenarios.

The results are very useful for improving network management policies and strategies in an increasingly difficult budgetary context. Such an approach can be applied beyond the problems linked to climate change.

Scoring exposure

An example of exposure scoring is provided by the risk assessment on the DIR Méditerranée network. The first map shows an extract of climate data for a reference period of thirty years, and the second map shows the scoring of these data for three different periods: the period of reference, 2021-2050 and 2071-2100.



Scoring sensitivity

…was done by first recognising asset categories and sub-categories, such as:

- pavement – further divided into road surface and road structure;
- engineering works – further divided into bridges and retaining walls;
- small drainage systems – also divided into sub-categories;
- equipment; and
- other assets.

The main sensitivities of each asset category were assessed using a literature review and through communication with the transport authorities. General sensitivity indicators were identified, and a scoring scale developed.

More detailed exchanges with experts and with the road organisation helped define the aggravating and adaptive factors to differentiate the sensitivity of different assets within the same category. These include the traffic level (with a heavy traffic, the road may suffer from accelerated damage during heat waves), the porosity of the road (the more porous it is, the more it may be damaged by heavy rains), etc. Information from a national road database ("Isidor") was used for further detailing.

The scoring of the sensitivity of each asset is moderated by aggravating or adaptive factors from the overall scoring of the sensitivity of the asset category by hazard. This scoring has then been combined with the current and future exposure to assess the changing vulnerability, and a criticality assessment has then been conducted.

9.2.4. Spanish methodology for risk assessment

Back

In Spain, a methodology for climate change risk assessment is in the process of being finalised. Since each asset needs a different approach for sensitivity assessment, the following classification was proposed. Also, assets have been divided into those that will be studied with a higher priority than those are considered less prone to climate change impacts (and therefore will be studied in more detail in a second stage).

Higher priority assets or services	Lesser priority assets or services
Earthworks Bridges and structures Drainage (transversal) Bituminous pavements Tunnels	Drainage (longitudinal) Vertical signs Barriers

For each of these assets a detailed annex has been developed, including sensitivity matrices, with different factors. The factors are related to the impacts that have been pre-identified for each of the assets.

In Spain the main problem is related to landslides due to intense rainfall so the biggest efforts should be targeted to identify the sensitivity of the different assets against this hazard.

Risk assessment is performed considering previous episodes and experience of the maintenance staff, mainly. By applying this methodology, it is expected to improve the adaptation work of the road network to climate change and also to refine the methodology itself.

9.2.5. Assessment of trunk roads in relation to landslides, Germany

Back

As part of the climate impact assessment by the BMDV network of experts, the sensitivity analysis describes the investigation of the reaction of the transport infrastructure to climatic influences depending on the infrastructure properties.

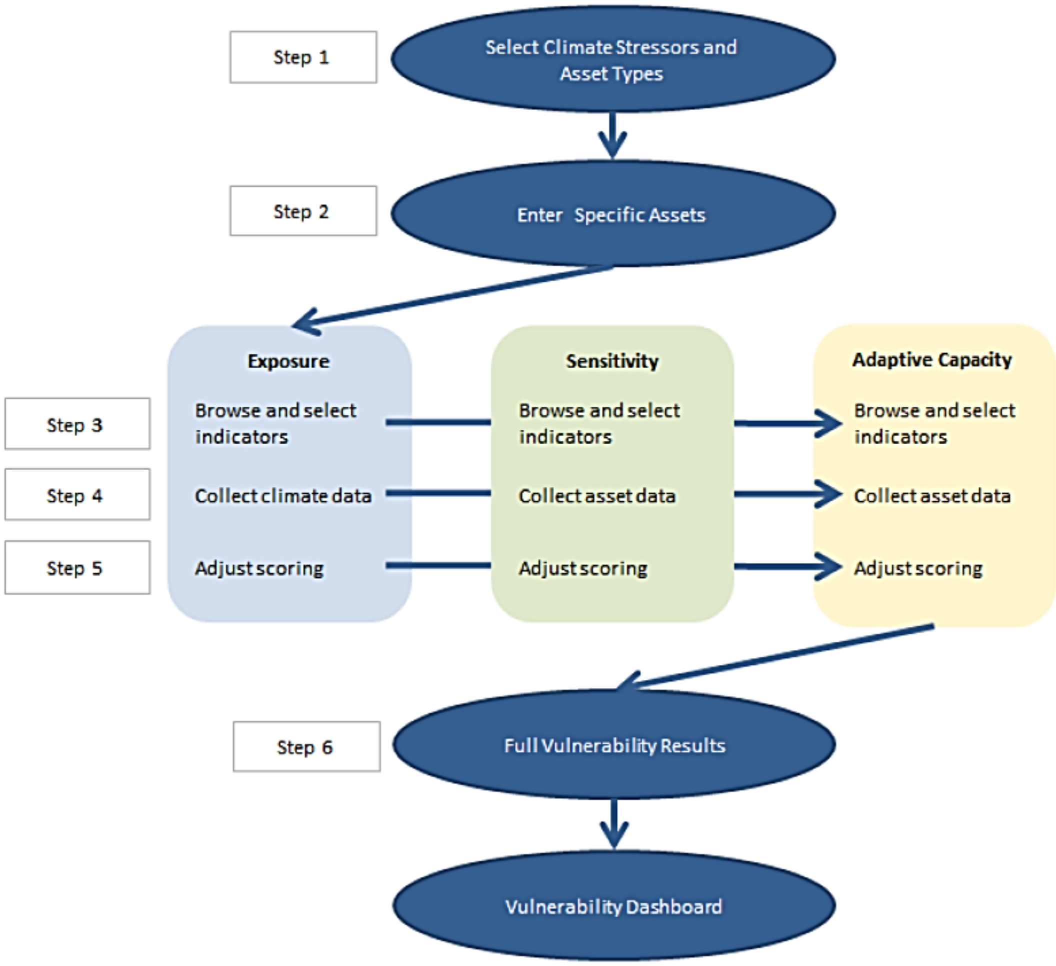
In the context of landslides, these infrastructure properties are evident in the form of different protection measures, e.g. rock anchors, fortification nets or earth walls. So far, the sensitivity of a road section has been investigated based on the binary understanding of sensitivity. While a road section, which is protected by a protection measure, is regarded as not sensitive, a road section, which is unprotected, is regarded as sensitive. This approach enables the analytical inclusion of the sensitivity analysis in the climate impact assessment. In a next step, further relevant infrastructure properties will be considered. These include, for example, the age and condition of the landslide protection measure as well as the case when the road section is already partially or completely protected by protection measures of other transport modes (e.g. rail).

9.2.6. U.S.DOT Vulnerability Scoring Tool (VAST)

Back

The U.S. Department of Transportation developed the Vulnerability Assessment Scoring Tool (VAST) to help state departments of transportation, metropolitan planning organisations and other organisations implement an indicator-based vulnerability screen assessment of their transportation assets.

Vulnerability is a function of exposure, sensitivity, and adaptive capacity. Certain characteristics of assets can serve as indicators of their exposure, sensitivity, or adaptive capacity.



Vulnerability Assessment Scoring Tool approach diagram

The approach used by this tool involves collecting information about indicators of each component of vulnerability and operationalizing that information into relative vulnerability scores. This can be done for any combination of stressors and asset types within this Microsoft Excel®-based tool (with macros).

Asset types covered in this tool are rail, ports and waterways, airports and heliports, oil and gas pipelines, bridges, and roads and highways.

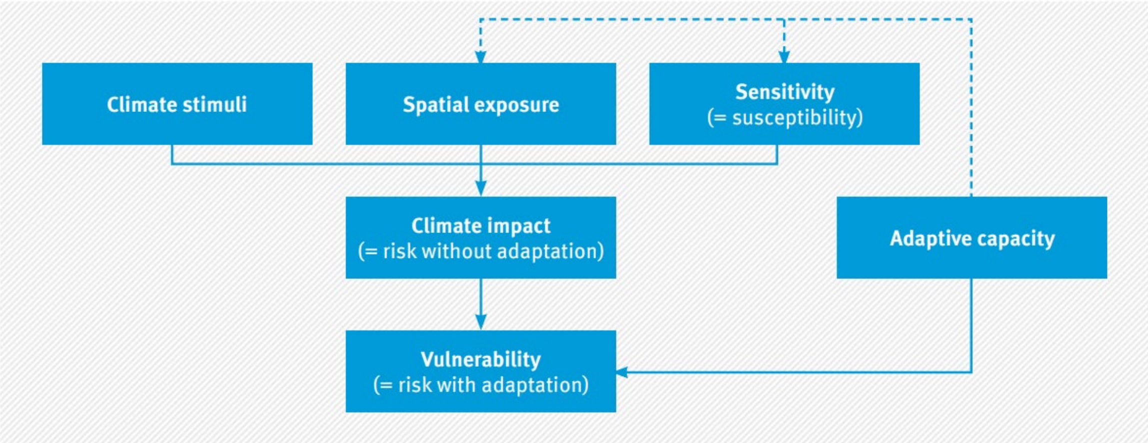
The tool is also available from FHWA’s Tools website.

9.2.7. Guidelines for Climate Impact and Vulnerability Assessment, Germany

Back

This case study illustrates an approach that combines IPCC AR4 definition of vulnerability (2007) and IPPC AR5 definition of risk (2014). The publication is by the German Ministry of the Environment [52]. The figure below illustrates the concept.

Combination of IPCC 2007 and IPCC 2014 definitions



Own source, German Environment Agency 2017

9.2.8. Qualitative vulnerability assessment, Spain

Back

In 2018, CEDEX, in collaboration with the Spanish Transport Ministry, AEMET, ADIF and ADIF High Speed and with the support of OECC, PIMA Adapta Plan and Fundación Biodiversidad, performed a study aimed at identifying the "Sections of the state-owned inland transport infrastructure network that merit priority attention because of climate variability and change" https://www.adaptecca.es/sites/default/files/documentos/accit_informe_final_cedex.pdf
Due to the difficulty to obtain all the needed data (assets' construction and maintenance details, sensitivity to the different hazards, previous events) it was decided to perform a qualitative assessment by interviewing experts and personnel. In the case of the road network, it was done with the help of technical staff from the Road General Directorate that manages and operates the network (Demarcaciones de Carreteras del Estado).
In the first place, the characterisation of the road network vulnerabilities was done based on a pre-established typology of impacts, as can be seen in the table below.

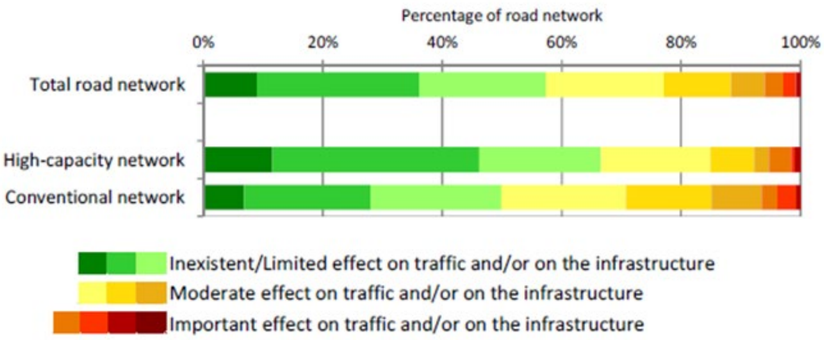
*Landslides and erosion and falling of materials of slopes as a consequence of **heavy rain***
*Erosion of slopes in **embankments** by the course of a river as a consequence of **extraordinary floods***
*Insufficient capacity of the **drainage works** due to **heavy rain***
*Erosion of abutments, undermining of foundations and impacts from debris materials on **bridges and viaducts** due to **extraordinary floods***
*Development of ruts on the **pavement** as a consequence of **high temperature***
*Insufficient **road surface drainage capacity** as a consequence of **heavy rain***
*Impact on the **road traffic conditions** due to **wildfires***
*Impact on the **road traffic conditions** due to **snow***

The next step was to characterise the level of the impact (limited/non-existent, moderate or important) of the current climate conditions on each of the sections defined, using a predefined scale. The level of the impact will usually be determined not only by the characteristics of the weather events, but also by the age of the infrastructure, the design criteria, the construction method and its maintenance.

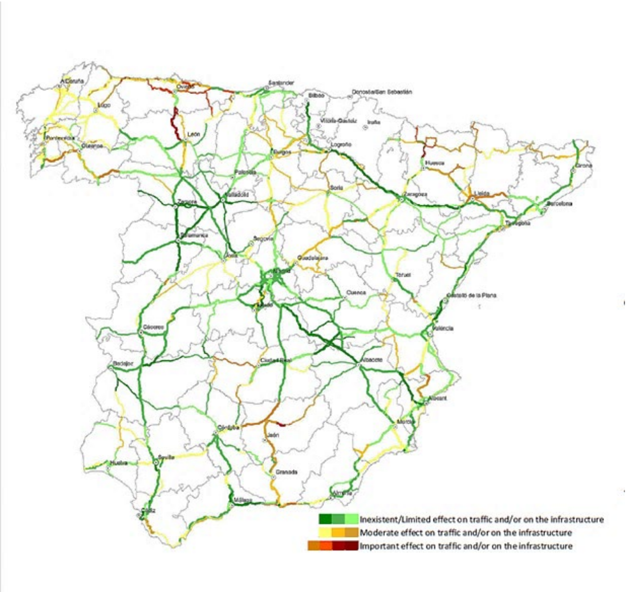
SCALE OF IMPACTS		
Inexistent/limited effect on traffic and/or on the infrastructure	**Moderate effect on traffic and/or on the infrastructure**	**Important effect on traffic and/or on the infrastructure**
1 2 3	4 5 6	7 8 9 10
The effect on the infrastructure and/or its functionality is non-existent or limited throughout the section. Repair is compatible with routine maintenance actions. Road/Rail traffic conditions may be affected by speed limits and/or traffic and/or access control measures during a short period of time (hours).	The effect on the infrastructure and/or its functionality is moderate at some point of the section, requiring modest repairs and/or replacements. Road/Rail traffic delays and/or traffic deviations may be required lasting hours or days.	The effect on the infrastructure and/or its functionality and/or its security is significant or complete at some point of the section. The repair requires the rehabilitation/ reconstruction of one or several infrastructure assets. Road/Rail traffic delays and/or traffic deviations may be required lasting weeks or months.

The level of the impact is graded with 1 when the effect is null, irrelevant or negligible. The numerical scale helps to qualify, within the same level of effect, the nearness to a contiguous level or the frequency of the impact.

Based on the information obtained, it was inferred that the road sections that are not affected by any weather event or affected in a limited way according to the definition established in the scale of impacts used, represented 57% of the length of the network. In the case of the high-capacity network this percentage rose to 66%. The road sections in which there was an important impact due to some weather event accounted for 6% of the length of the network.



This exercise was repeated considering climate change projections. To assist in the evaluation of the network future vulnerability (taking into consideration climate change), data provided by Spanish meteorological agency (AEMET) were used.



Maps on changes of exposure were prepared by CEDEX using those data. The significance of the change of vulnerability due to this change of exposures was estimated using the judgments of the same technical staff mentioned above, qualified in some cases with the judgement of experts regarding the behaviour of a specific infrastructure asset. This was considered a preliminary examination or screening allowing identification of network sections whose resilience should be analysed later in greater detail.

Figure. Estimate of the maximum effect of climate change on the sections of the road network in 30 years

According to the results obtained, it was concluded that the general perception was that the effect of climate change on the vulnerability of the road transport network was limited.

This methodology was adopted and completed by the Project CLARITY for road transport infrastructure assessments. At this moment, there is a group in ATC (PIARC national association) that is dealing with climate change impacts in the road network. The objective of the group is to move from this qualitative assessment to a quantitative assessment. To do this exposure GIS information (climate data from climate services, hazard maps) is being used. However, it remains difficult to obtain data. Also establishing thresholds can be difficult since they need to be regionalised and validated.

9.2.9. Analysis of the dynamics of erosion Quebec

Back

In the Côte-Nord region of Quebec, there is a problem with erosion that affects traffic along Route 138. Measurements along the coast of the Côte-Nord show that some coastal segments have a retreat rate significantly greater than adjacent segments. The erosion can progress rapidly and cause a retreat of 50 m of the coast in less than a decade. It is important to understand these erosional processes to be able to identify the most susceptible road segments and determine how to manage the coastal road. The reports from this work were published in 2008 and 2012[25].

Objectives

The main objective was to identify the vulnerability of road infrastructure along Route 138 and to identify appropriate adaptation measures. To analyse the vulnerability, the following three projects were identified:

- Map the erosion sites on the coast and establish a typology of erosion sites
- Develop a method that integrates the dynamics of erosion sites with the coastal change projections
- Evaluate the origin and dynamics of the erosion sites along the edges where Route 138 is threatened in the short (less than 5 years) and medium term (5 to 10 years).

Methodology

Mapping: To map the erosion sites on the north coast, analyses of displacement velocities (annual measurements) were carried out from the network of coastal monitoring stations (Laboratoire de dynamique et de gestion intégrée des zones côtières - Université du Québec à Rimouski).

Typology: A literature review was conducted to establish a typology of erosion sites.

Coastal evolution projections: The sites were analysed using a series of 3 to 9 aerial photographs (between 1930 and 2014) on which the shorelines were drawn. Transects were positioned perpendicularly every 50 m to carry out the analysis of their kinetics and the calculation of evolution rates and the historical mobility envelope (MobiTC software). These data, along with the literature review, constitute the basic foundations for coastal evolution projections (to horizon 2050).

Evaluate the origin and dynamics of erosion: The topography was surveyed at two sections where Route 138 is close to the coastline, west of Longue-Pointe-de-Mingan. Between May 2015 and December 2016, 15 topographic surveys of the foreshore and shallow pre-littoral zone were conducted approximately every 2 months. Geomatics then allowed visualisation of the areas of beach lowering and accreting between the survey dates. The analysis of the topographic profiles was used to establish the link between the dynamics of the sand bars and the evolution of the beach, including the recession of the coast. In addition, various instruments were installed on the beach and offshore to measure wave characteristics.

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[25] Bernatchez et al., 2008, Bernatchez and Fraser, 2012;

Results

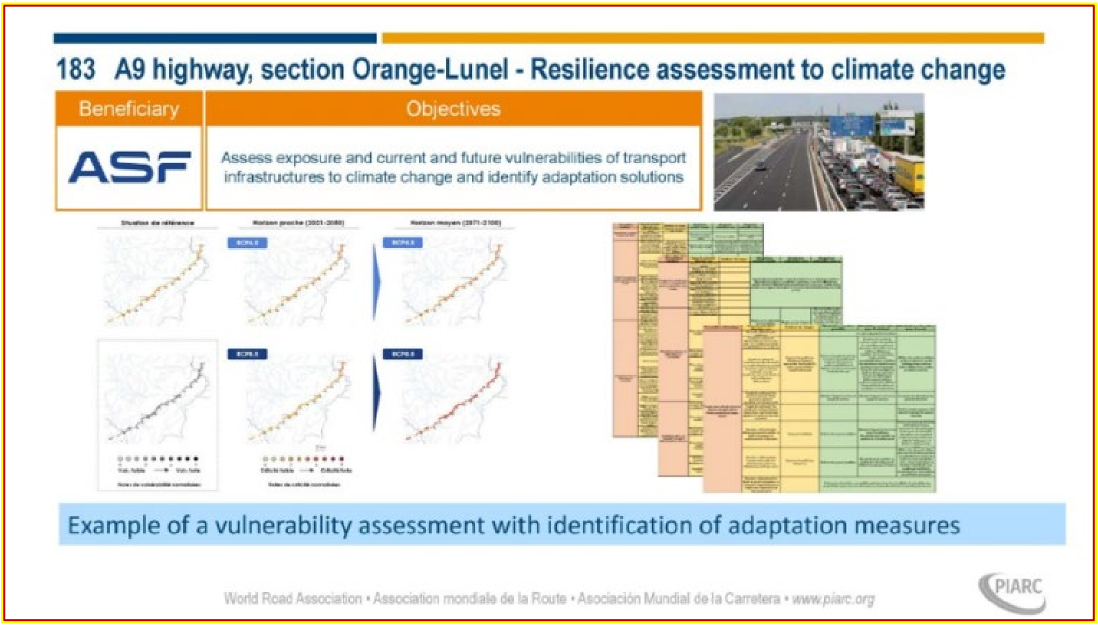
The analyses of several study sites showed how diversified the dynamics of the coastline and the erosion sites are, even for coastal segments belonging to the same hydrosedimentary cell. Results from the typology literature review suggested some possibilities for origins and causes of the erosion. However, it was the historical aerial photographic analyses that clarified the temporal component necessary to understand these erosion foci. This aerial analysis also became the basis for projections of coastal evolution. The projections required a method with site specific choices due to the observed diversity. For example, in the sectors with presence of pre-littoral sandbars, seasonal bathymetric surveys would be necessary to quantify the evolution of the beach and the coast. A better knowledge of the bathymetry would also be useful to specify the cause of erosion foci at specific locations. The effect of ice cover reduction on coastline evolution is still poorly documented. Winter topo-bathymetric surveys are necessary to quantify how ice cover reduction influences the shoreline evolution rate in the Estuary and Gulf of St. Lawrence.

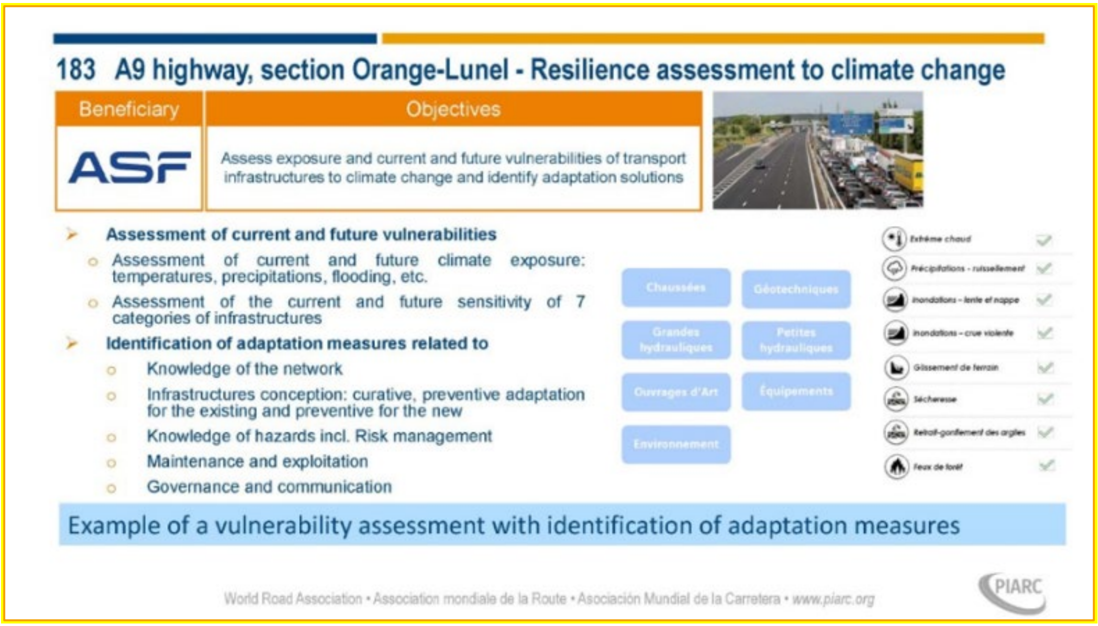
To view the final report: 1235270.pdf (gouv.qc.ca)

9.2.10. Vulnerability /resilience assessment Orange – Lunel, France

Back

The highway concession company ASF (operating 2737 km of network, a part of the Vinci group) requested Cerema's assistance in a risk assessment study. Cerema helped ASF define the objectives and scope of the study: climatic assumptions used, infrastructure taken into consideration, etc. It then assisted ASF in the application of the vulnerability assessment method and identified a range of adaptation solutions based on the results of the vulnerability assessment.





9.2.11. Vulnerability score – Western Australia

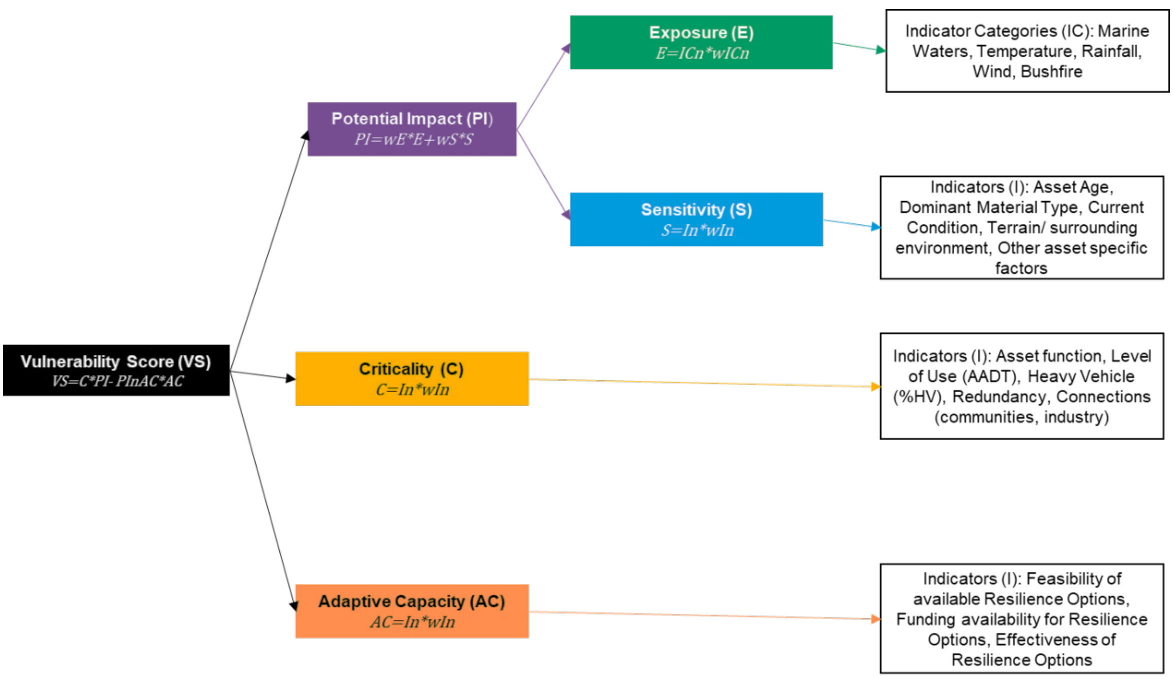
Back

To improve Main Roads Western Australia's capability to undertake vulnerability assessments at a network level a project was undertaken to identify best practice for assessing network and asset vulnerability. The project sought to increase Main Roads understanding of climate change, its effect on the performance of the transport network, including the various socioeconomic impacts that arise, and provide a methodology for finding component weakness in the road network that render the network vulnerable to the consequences of failure or degradation.

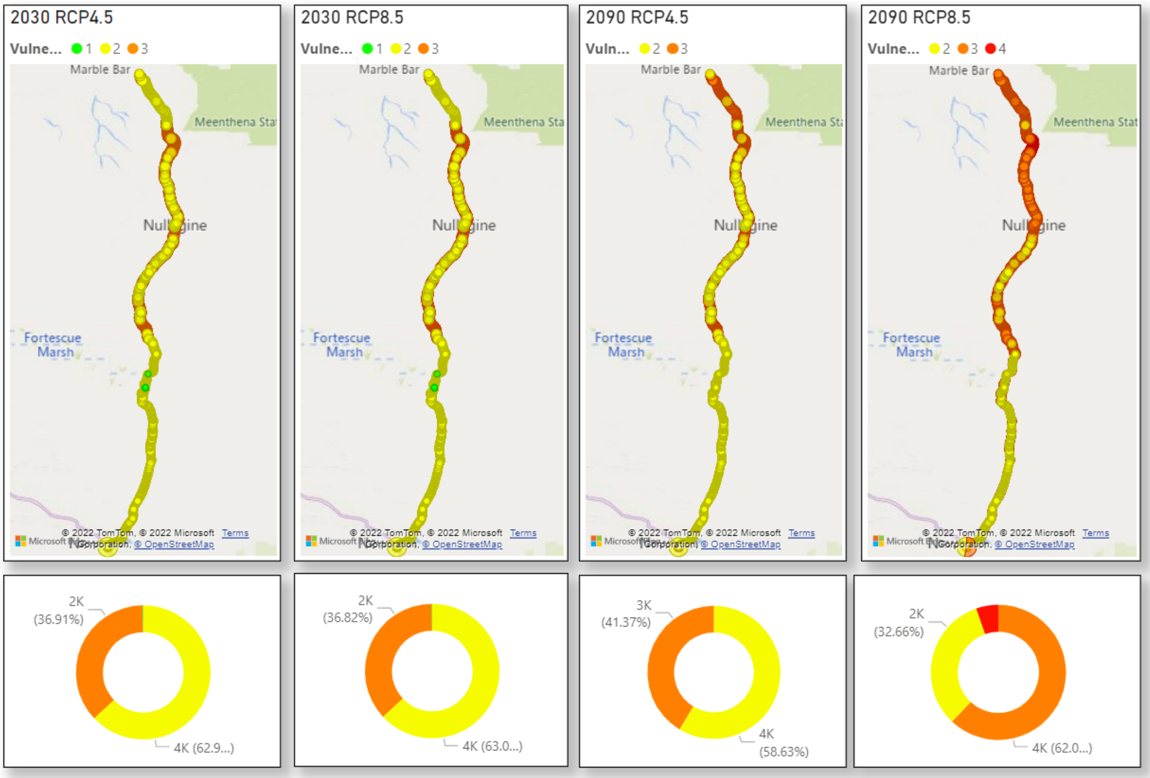
An output of the project was a Network Vulnerability Assessment Framework which was piloted on select areas of the Main Roads network. The framework relies heavily on asset and network data that Main Roads collects which is used to calculate a vulnerability score. The vulnerability score is calculated based on indicators for:

- the character, magnitude and rate of climate change and variation to which a road network is exposed.
- the degree to which the road network is affected, either adversely or beneficially, by climate related stimuli
- the importance of the asset or network link, or the level of contribution the infrastructure make towards the society in maintaining a minimum level of national and international law and order, public safety, economy, public health and environment.
- the road network's ability to cope with and adapt to existing climatic variability and future changes.

The image below represents the framework used for the calculation methodology for the network vulnerability assessment. This diagram details how indicators interact with vulnerability components to create the vulnerability score.



The vulnerability scores developed using the above framework are on a scale of 1 to 5, where 1 is negligible vulnerability, and 5 is extreme vulnerability. These results can also be represented visually to demonstrate vulnerability across different climate projection timescales (as shown).



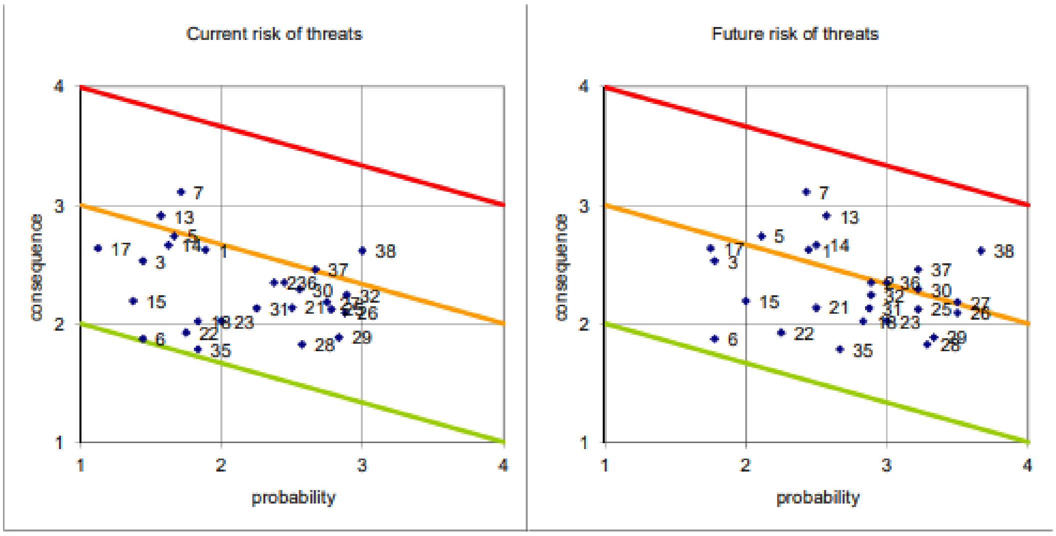
9.2.12. ROADAPT – assessing risk

Back

The ROADAPT Guidelines [31] provide a step-by-step approach for assessing and prioritising risk.

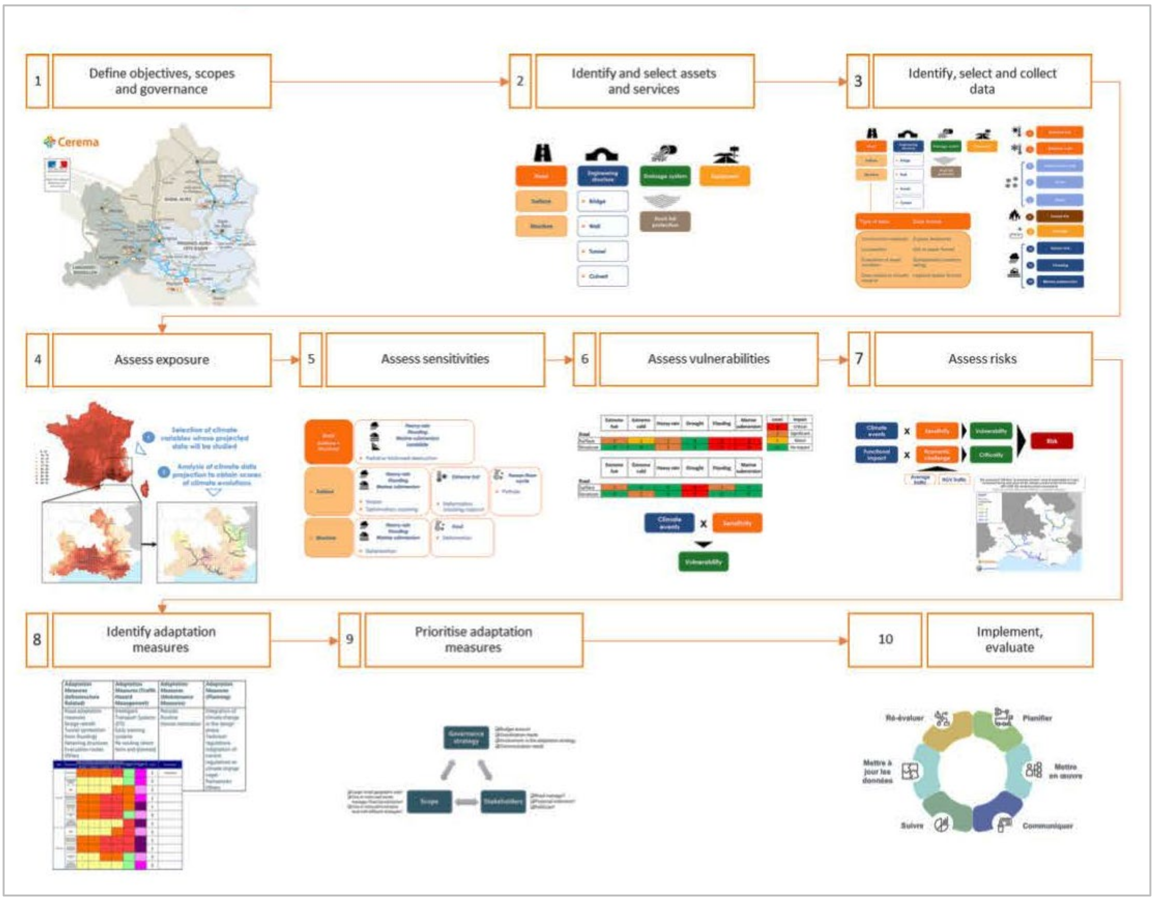
Part B is a guide through a QuickScan method for risk assessment. Risk is calculated from the scores of probability and consequences. The consequence scores are weighted to accommodate for the variations in importance of consequence types, in each case.

Risk matrices are developed for current situation and future climate, see Figure below.



9.2.13. Methodology for analysing risk – Cerema, France

Back



- 10 steps
  - Preparation of the risk assessment
  - Risk assessment
  - Strategy of resilience
- Useful for road networks, and also railways, ports, etc.
- Implemented many times in various contexts

This document proposes a method for analysing transport infrastructure risk in the face of current and future climate. This requires:

- defining and analysing the hazards that may impact the transport network. The hazards selected as potentially impacting are then noted based on their characteristics.
- breaking down the transport networks studied into smaller entities: systems (tunnels, bridges, etc.) and components (cables, etc.). The study of the physical vulnerability factors of the networks, systems and components then allows a vulnerability score to be assigned to them.
- defining and then rating the functional criticality of the network elements studied, which is obtained by cross-checking the network's challenges with its characteristics.

The cross-referencing of the hazard, physical vulnerability and functional criticality scores enables a risk level to be defined for each system or component. Such an analysis is the result of an iterative process: the number of iterations depends on the expected granularity of the results and therefore on the objectives of the analysis. At the end of the analysis, various strategies and measures for dealing with the risk can be identified and implemented.

The work resulted from implementation of Cerema's technical framework (2015) developed to help transport operators to identify vulnerable infrastructures and networks. Cerema facilitates a group of operators and experts who apply the framework and gather feedback on the implementation of this framework, in order to improve it.

Assessing the risks incurred by extreme climate events on transport infrastructure and networks, in a context of climate change | Cerema (Action 3)

9.2.14. Increasing resilience of earth structures on roads in Northern Spain

Back

Experience can be a major input when performing climate change assessments. This is the approach that has been followed in Cantabria, a region in northern Spain, providing very good results for the road owner.

Several roads in Cantabria had problems related to intense rain fall every year. Significant events took place on N-621 and A-67 between 2011 and 2018. The impacts motivated the implementation of several adaptation measures, which can be seen as examples of increasing the resilience of the network. The adaptation measures were the result of the evaluation of the impact, the exposure and the sensitivity of the assets, and not only addressed the consequences of the event but also sought to prevent the impacts. Had these measures not been implemented, recurrent impacts would continue to take place in the above-mentioned road sections.

This case study is an analysis of several experiences in slope and foundation drainage, and runoff water management to improve resilience of the road infrastructure. The actions were motivated by rain and adverse weather conditions between 2010 and 2018, which caused significant damage to several road slopes in Northern Spain. The objective of the works was to restore road safety and road stability. With regard to the drainage of earthworks, the action carried out on the slope of the A-8 highway included its stabilisation by Biological Engineering.

Some pictures of the problems that affected the road can be seen below.

More information can be found in the conference paper presented at the PIARC Winter Congress in Calgary, for PIARC members, available from here: Microsoft Word - IP0368-Collazos-E-Full.docx (piarc.org)

9.2.15. VegROS Norway

Back

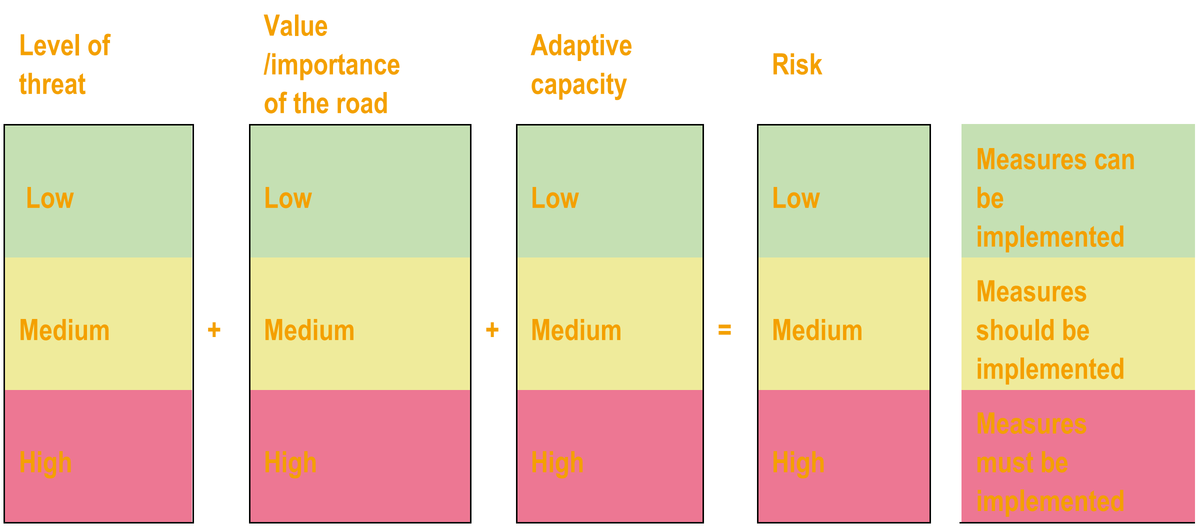
This is an example of a simple method for risk assessment of roads, which the Norwegian Public Roads Administration has used for scheduled assessment of national roads. The intention was to provide a basis for decisions concerning maintenance and operation. The scheduled assessment is being revised, but the scoring system may be useful for others.

The project team needs to cover all fields relevant for assessing the risk on the road stretch in the specific area, including traffic safety, security aspects and natural hazards. All available information is made use of: road data, geological and hazard maps for floods and landslides, weather and climate data etc.

A list of relevant risks for each road section is put together based on knowledge of previous events and experience from road operators, available hazard maps, information about the availability of critical services (traffic nodes, hospitals, fire stations) etc. For all relevant events, the probability and consequences are assessed, in addition to the capacity of the road organisation to manage the events.

- The **probability** is scored from 1-3 (low - medium - high) or 0-5 for an expected range of frequencies.
- The **consequences** are described through the extent and the duration of the disruption of traffic on the road. The score for ‘consequences’ and for ‘probability’ give a “level of threat” score.
- The **importance of the road** (or criticality) is scored depending on three factors: the total traffic load (ADT), the share of freight transport, the size of the area affected by the road being taken out of function.
- The **adaptive capacity** is estimated on the basis of two factors: readiness to handle and redundancy.

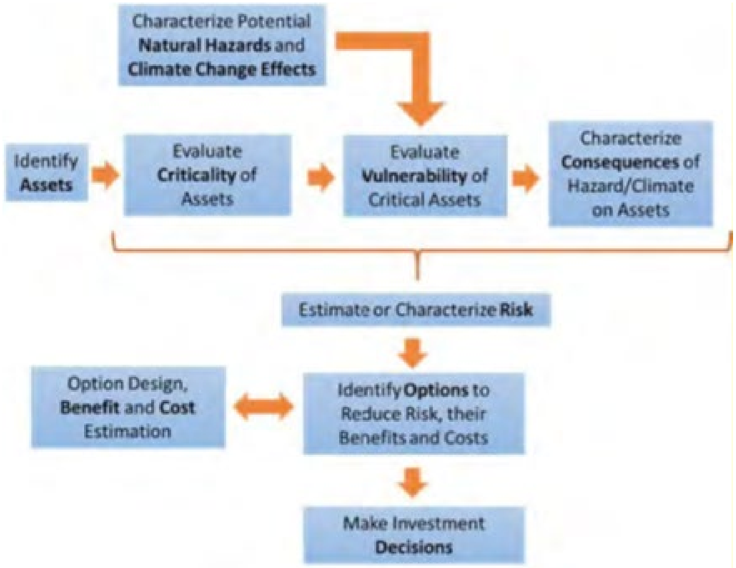
Although the assessment is done for the current climate, the team needs to be acquainted with the climate projections and take them into consideration when scoring. The figure illustrates the calculation of the risk score.



9.2.16. A Framework for Informed Choices – Transport Research Board

Back

"Investing in Transportation Resilience – A Framework for Informed Choices", published in 2021 [57], reviews practice and research in the field of resilience of transportation infrastructure. It suggests that more should be done to make resilience a more systematic and deliberate part of transportation asset management and investment decision making.



Components of the proposed decision support framework

For assessing the potential benefits of resilience investments, the authors suggest a multi-step, multi-hazard analytic (see figure above):

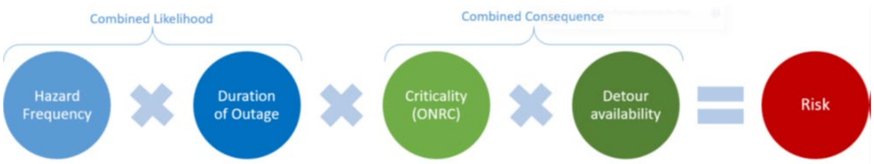
- inventories of existing and planned assets;
- evaluation of characteristics and likelihood of natural hazards occurring in the future;
- assessment of criticality of assets
- evaluations of vulnerability of critical assets to disruption, damage, and destruction from the hazards
- estimates of consequences of damage to the asset and its lost or degraded functionality.

Combining criticality and risk or vulnerability metrics will give a picture of overall resilience of the system. The societal benefit of effective resilience investments is the avoidance of future losses in functionality, from the aspect of infrastructure owners, users and the broader community.

The committee is of the opinion that a single resilience metric is unlikely to be found. Resilience to natural disasters is determined by complex interaction of a range of natural hazards, infrastructure characteristics, resources, demands for transportation services, demographic and environmental conditions, etc.

9.2.17. New Zealand - National Resilience Programme Business Case

Back



The purpose of this project (National Resilience Programme Business Case - NRPBC) conducted by Waka Kotahi New Zealand Transport Agency was to provide an evidence base of the nationally important risks posed to the New Zealand land transport system from natural hazards; and identify types of initiatives to address some identified systemic resilience risks, issues, deficiencies and opportunities.

This NRPBC tested the issues raised by a series of earlier studies and cases with a range of national-level stakeholders to validate the challenges and problems identified and identify potential system and strategic responses. High-level approaches were tested with stakeholders and a suite of system level responses was derived. These responses were then refined with Waka Kotahi staff in a workshop and finally examined in one-on-one meetings with national level stakeholders.

In parallel, a desktop evaluation of resilience related risks based on hazard and asset data was conducted to generate a preliminary view of priority risks for the land transport system. Testing of this preliminary analysis was undertaken with staff and stakeholders through a series of regional workshops throughout New Zealand and ground-truthed against existing climate change research. The prioritised geographic risks consider current and future hazards, the vulnerability of transport systems to these risks and the criticality of the system.

The main outputs from the work were the project report, and spreadsheets and geospatial files of the databases of risks and assessments. This project is an example of how to undertake a pragmatic risk assessment of a significant length of network, using the consistent data sets available at such a scale.

9.2.18. Coastal prioritisation index for erosion (IPIC-E) - Quebec

Back

One of the first structuring actions of the action plan on adaptation of infrastructure to climate change (PAGI3C) of the Ministère des Transports et de la Mobilité durable du Québec was the development of indices for prioritizing coastal interventions (IPIC-E).

Considering the number of road segments that are or will be affected by erosion in the coming years, and in a context of limited financial and human resources, indices are being developed to assess the risks at the site level and to prioritise the issues. These indices would allow the selection of short-, medium- and long-term interventions and could become important decision aids for the programming of major works in coastal areas.

Based on a quantitative risk assessment methodology, an initial coastal prioritisation index for erosion (IPIC-E) has been developed and will be operational in the Ministry's asset management system once it has been externally reviewed. Indices for marine flooding and for landslides are under development. The following figure shows the erosion risk assessment matrix for IPIC-E.

Exposition to Erosion				
	100 %	Moderate	Very High	Critical
	50 %	Low	Moderate	Very High
	0 %	Very Low	Low	Moderate
		0 %	50 %	100 %
		Consequences		

Each group of parameters evaluated was assigned a score between 0 and 3 according to its propensity to increase (3) or not (0) the risk of affecting the road network. The index is the product of the scores of the different parameters weighted according to their importance. This decision support tool had to contain enough criteria to reflect the complexity of the natural and human systems, but straightforward enough to be operational and automated to allow recurrent updating.

Exposure to the hazard (score out of 100) is composed of the exposure data (80 % of the score) and the coastal rating (20 % of the score).

- The exposure data is the number of years before the infrastructure is affected by erosion and is calculated using the following formula:

$$\frac{\textit{Distance between the road and the coast — recession of the regional highest historical event}^{26}}{\textit{Mean annual erosion rate}}$$

- The coastal rank represents the number of rows of infrastructure present between the road and the coast.

The parameters used to establish the level of consequence (score out of 100) are:

- presence of detour roads and their length (40%);
- characteristics of the road segment (strategic network, functional class, average daily flow) (20%);
- presence of utility infrastructure under the road (10%);
- the ability to restore the service:
  - type of coastline (low coast, cliff with beach or without beach, etc.) (15%);
  - availability of human and material resources (machinery, materials, etc.) (15%).

To facilitate intervention planning, IPIC-Erosion is integrated with the PlaniActifs geomatics platform, which brings together information from the various asset management systems and enables the implementation of intervention strategies from an integrated risk and asset management perspective.

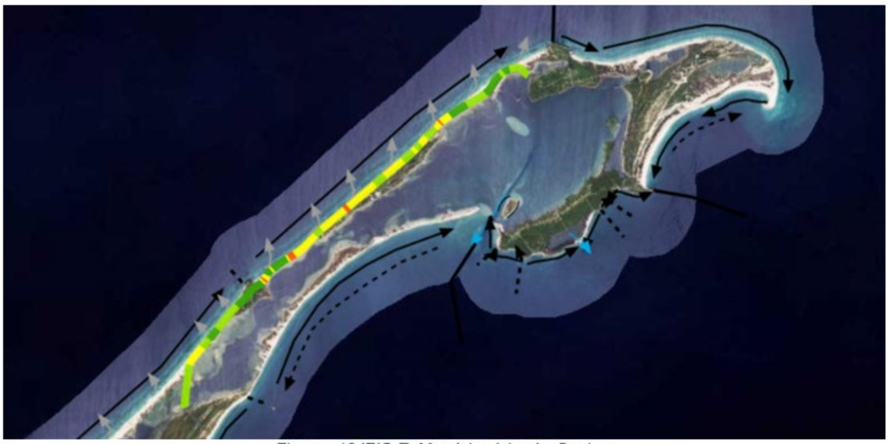


Figure - 10 IPIC-E, Magdalen Islands, Quebec

[26] Considering the multiplicity of phenomena at play in the coastal zone (storm regime, isostatic adjustment of the earth's crust, ice regime, sea level rise, etc.) the state of research does not allow us to measure future conditions with precision. Since the formula is based on historical data, the recession of the regional highest historical event is added as a safety margin to account for the uncertainty.

9.2.19. Mondego Mobility System Climate Assessment, Portugal

Back

This study, developed for Infraestruturas de Portugal[27], S.A., aims to identify and assess the vulnerabilities and risks induced by potential future changes in climate patterns on the Mondego Mobility System (MMS) or Mondego´s MetroBus[28], in its various components and services. This work also identifies the adaptation measures, proposed and already integrated into the system, to minimise the climate risks identified and maximise the respective resilience of the infrastructure and the service it provides.

The MetroBus system will be an integral and essential part of Coimbra Region's public transport system, responding to the travel demands already existing and structuring the urban network of the city. The planned MMS will serve part of the Coimbra region and will have two complementary functions:

- One, for commuting between the urban areas around Coimbra and
- The other, for intra-urban travel within the city of Coimbra.

The project of the Mondego Mobility System (SMM) or MetroBus do Mondego, in its urban and suburban mobility aspects, simultaneously represents a remarkable improvement in the quality of the mobility service available to the population and a driver of overall efficiency - social, economic and environmental in the local and regional public transport system.

An inventory of greenhouse gas emissions associated with the project and the related changes in regional mobility patterns resulting from the introduction of the MMS are also objectives of the work, having evaluated the respective absolute emissions, in scenarios with and without the implementation of the MMS. The induced savings in the global energy consumption of the regional mobility system was also evaluated.

[27] Infraestruturas de Portugal, SA (IP, SA), is the National Road Administration and provides the public service of managing the infrastructure of the National Railway Network (RFN), under a regime of delegation of powers by the Portuguese State, through the execution of a Program Contract for the railway sector - https://www.infraestruturasdeportugal.pt/pt-pt/sobre-nos/quem-somos

[28] https://www.infraestruturasdeportugal.pt/pt-pt/infraestruturas/investimentos/principais-investimentos-em-curso

The study assesses the climate vulnerabilities and risks induced by climate variability and potential future change in weather patterns, and identifies the adaptation measures adopted for the minimisation of these risks, which improve and optimise the resilience of the MMS to climate change and climate events and hazards.
The work carried out adopted the methodology proposed by JASPERS (JASPERS, 2017) which comprises a climate vulnerability assessment, an identification and evaluation of consequent climate risks, and the identification of adaptation measures to be adopted by the project in order to minimise the risk and increase its related resilience to climate change.
The analysis was based on best data and climate projections available which are considered reliable and adequate, with the best possible spatial resolution scale. It integrated the knowledge and technical competence of several experts from different areas, in particular on climate and mobility.
The analysis looked at the operation of the MMS in 2070 and assessed two contrasting climate scenarios and options considered to be the most adjusted to the particular characteristics of the MMS. The results obtained reveal that the project will only be exposed to a Moderate Risk level (intermediate level, on a scale of 5 levels) for the hazards of Maximum Extreme Temperatures, River and Pluvial Floods, Landslides of Excavation Slopes and Forest Fires.
No situations associated with High or Extreme risk climate events or hazards (higher levels) are expected to occur, and all other climate events or hazards identified are classified as Negligible or Low.
The systematic monitoring of the implementation progress and adequacy of the set of adaptation measures proposed and already integrated in the project throughout its lifetime are fundamental to ensure the resilience of the MMS to climate change.

"The adaptation measures include:

- *the construction of a pontoon crossing Ribeira do Gorgulão, drainage systems designed for flood flow rates with higher return periods (100 years), and enhanced reinforcement and tray enlargement,*
- *stabilisation and slope reprofiling,*
- *installing optical cables to monitor landslides,*
- *pavements resilient to high temperatures and*
- *regular cleaning and deforesting the infrastructure channel."*

With regard to climate change mitigation efforts, the implementation of the Mondego Mobility System will decisively contribute to the reduction of Greenhouse Gas emissions and to the process of global decarbonisation. It is estimated that the global relative emissions of Greenhouse Gases from the project, or in other words the net reduction in emissions, will be around 19,000 tonnes of CO2 equivalent in the year when the system starts up (2024). The energy saving, in this scenario, reaches around 2,750 tep.

This positive impact is due to the modal transfer movements triggered by the operation of the system, namely through the very important reduction in individual private travel.

9.2.20. Vulnerability and resilience assessment in the Philippines (Deltares, NL) … for mainstreaming Disaster Risk Management and adapting to climate change

Back

In the Philippines, transport infrastructure is regularly challenged by floods, landslides and earthquakes. There was a need to develop an adaptation strategy with a clear action perspective. The main objectives of the project were:

- To increase the capacity and knowledge of selected Local Government Units (LGUs) in dealing with climate/disaster risks faced by local transport infrastructure
- To pilot an institutionalised coordination process with the national agencies to better inform local roads planning, using a learning-by-doing approach.

The pilot location is Nueva Ecija, a landlocked province in the Philippines located on Central Luzon, the largest island in the country. Covering a total area of 5,751.33 square kilometres, it is the largest province in Central Luzon. Its terrain begins with the southwestern marshes near the Pampanga border. It levels off and then gradually increases in elevation to rolling hills. Then it approaches the mountains of Sierra Madre in the east, and the Caraballo and Cordillera Central ranges in the north.

The work consisted of two main steps:

- A resilience assessment was carried out to gain insight into the current and future resilience of the highway network.
- Development of an adaptation strategy, while providing a methodology to conduct a DMDU (Decision Making under Deep Uncertainty) approach on a basic level while acknowledging all uncertainties in climate change and socio-economic developments.

Vulnerability assessment was used for damage estimates. Criticality assessment was carried out for the estimates of losses. Vulnerability and resilience functions were lacking but were derived with local stakeholder input.

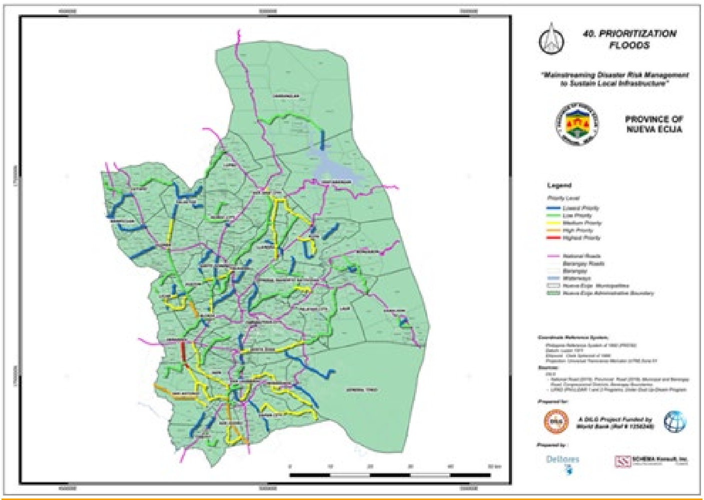
The adaptation strategy was developed based on the resilience assessment and use of decision making under deep uncertainty principles (DMDU). The developed DMDU approach considers all basic elements of DMDU and adaptation planning but has been adjusted to essential steps and the level of expertise at the road organisation. Capacity building and involvement of local stakeholders is the key for maintaining a strategy.

The project is reported in two reports:

- Risk assessment report
- Adaptive strategy building report

A summary report provides the methodology, main results and recommendations of both reports.

More information: Mainstreaming Disaster Risk Management to Sustain Local Roads Infrastructure : Main Report (worldbank.org)



		Damage Category				
		C1	C2	C3	C4	C5
Losses Category	C1	1	1	2	2	3
	C2	2	2	3	3	4
	C3	3	3	3	4	4
	C4	3	4	4	5	5
	C5	4	4	5	5	5

The sequence of steps used for the development of the adaptation strategy was as follows:

- After a data gathering process, a natural hazard risk assessment is carried out to identify hazard hotspots and prioritise road sections for upgrade.
- Subsequently, for each road section or hotspot, an appropriate response type(s) is selected and an initial DMDU analysis of potential measures undertaken. This helps identify promising and potentially adequate strategic measures and prioritise them into short-, medium- and long-term actions. Several criteria can be considered in this analysis, including effectiveness, costs, robustness for various possible future scenarios and benefits.
- With all information gathered, it becomes possible to perform fit-for-purpose, quantitative, strategic modelling to analyse current and future impacts of the prioritised measures.
- The initial measures prioritisation and adaptation pathways can then be further detailed into preferred measures and pathways, ensuring that the impacts of future uncertainties (e.g. climate change) are considered in the analysis.
- A stakeholder process is needed to assist implementation of these strategies and to provide a broad discussion of impacts. If necessary, the entire process or specific steps can be iteratively repeated (e.g. when new data or insights arise).
- When all plans are made final, the 'normal' steps of a project delivery need to commence, from design to construction and maintenance.

9.2.21. FORESEE: CEN workshop agreement – Assessing resilience

Back

The FORESEE-project (see 0.9) developed the CEN Workshop Agreement CWA 17819 "Guidelines for the assessment of resilience of transport infrastructure to potentially disruptive events". This document is focused on the resilience of transport systems to specified events. It can be used by any organisation that is interested in measuring resilience regardless of size or extent of infrastructure. As transport can occur on infrastructure of multiple types, the measures of service and resilience are also suitable for infrastructure enabling multi-modal transport.

Considering the context of potentially disruptive events, this document can help determine:

- how to measure the service provided by, and the resilience of, transport infrastructure;
- how to set service and resilience targets of transport infrastructure.

This document includes:

- the concepts of how service and resilience can be measured;
- the concepts of how service and resilience targets can be set;
- the steps to determine how to measure service and resilience;
- the steps to set service and resilience targets.

CWA 17819 is available from CWA 018 (cencenelec.eu).
See also Tool#0.1 – Learning Hub (foreseelearning.eu)

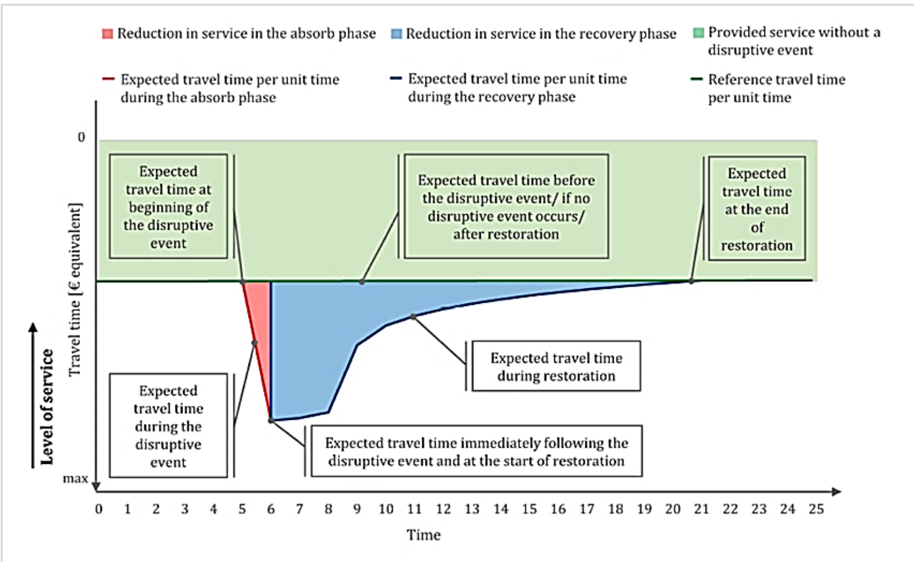


Illustration of transport infrastructure resilience using the "Travel time" measure of service

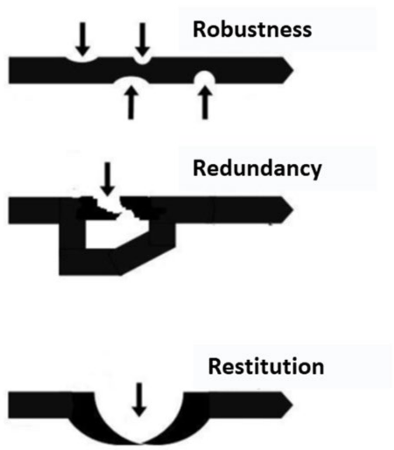
According to the guidelines (CWA), the measurement of the characteristics of the service are done by establishing and assessing journey times, safety, the cost of interventions and the impact on socio-economic activities. The differences in travel time and traffic volume are the keystone indicators for the indirect costs the hazards and their resilient strategies might have to the society. It has to be noted that calculating indicators as proposed in the guidelines requires a substantial amount of information, and not all the aspects that determine the resilience of the transport system are considered.

9.2.22. Norway: 3R method, simplified resilience approach

Back

The 3R-method is a simplified assessment of roads from the aspect of societal safety and security. Robustness of the road is only one aspect of ensuring a steady transportation service. The other two main factors are redundancy and possibilities for recovery. The method has been implemented on several road corridors to provide a better decision base in both design phase and renewal of existing roads.

For each of the three factors, one assesses the level of impact of an event. In addition, one scores the "importance of the road", a measure of how far-reaching the impact of a project is. The importance score amplifies the impact score. The combination of impact and importance will give an over-all consequence score.

Robustness is an expression of the ability of the road to withstand stress, including capacity for traffic loads, climate effects, etc. **Redundancy** – is a measure of flexibility, of the existence of good alternative solutions for the road with the disruption. The adequacy of alternative routes is also important, and it should be evaluated for the specific traffic needs, with respect to the geographical area. **Recovery** – is a measure of how quickly and efficiently the disruption can be overcome. There are two aspects here: the short-term repair for getting traffic in place, and the long-term recovery to previous conditions, or preferably even better resilience. Recovery, or robustness for that matter, is particularly important where there is little or no redundancy**.**	

More information: A Simplified Resilience Approach for Assessing Road Projects in Norway (piarc.org), PIARC Calgary. Available for PIARC members.

9.3. CASE STUDIES – STAGE 3 ADAPTATION MEASURES

9.3.1. ROADAPT – Database of adaptation techniques

Back

ROADAPT project developed a database of adaptation techniques. It lists over 500 possible measures, related to seven main threats and underlying specific threats, and provides information on their applicability and effectives.

The main threats are :

- Flooding of road surface (assuming no traffic is possible)
- Erosion of road embankments and foundations
- Landslips and avalanches
- Loss of road structure integrity
- Loss of pavement integrity
- Loss of driving ability due to extreme weather events
- Reduced ability for maintenance

For each adaptation technique, a quality score is given for availability, safety, impact on networks, direct costs and impact on reputation. The techniques are also assessed from the aspect of sustainability: energy need, effect on people and communities, ecology and biodiversity, physical resources, quality of life, safety, health and equity.

The database is available from the CEDR website Call 2012 Climate Change (cedr.eu) and can be downloaded here.

9.3.2. ROADAPT 10-step approach for selecting an adaptation strategy

Back

This 10-step-approach (ROADAPT, Guidelines Part E) gives an overview of decisions that should be taken in the process of selection of adaptation responses and combining then into strategies.

- Step 0: What are the road owner's needs?
  Relevance of the specific threat for the road owner, the specific needs of the road owner.
- Step 1: Definition of the relevant climate variable from design guidelines.
  Current design guidelines, corresponding climate variable, rate of change of impact.
- Step 2: Resilience of the asset in current situation.
  Current resilience of the asset, factors affecting resilience, hidden safety margins.
- Step 3: Resilience of the asset in possible future situations.
- Step 4 : Identification of applicable / appropriate adaptation measures.
- Step 5: Establishing a policy by the help of a *policy matrix* for the specific threat (provided by the project).
- Step 6: Assessment of consequence criteria for measures.
  Semiquantitative rating of the criteria: availability, safety of road users, implications for operation, direct cost and reputation of the road owner (according to the ROADAPT database)
- Step 7: Decision on the most appropriate strategy and shift from one strategy to another.
- Step 8: Stakeholders to be involved in the implementation of the strategies.
- Step 9: Existing knowledge gaps This step gives an overview of knowledge gaps in climate parameters, upcoming techniques / measures and data.
- Step 10: Time to market of upcoming techniques.

The programme further provides specific information on the contents of these steps for the main climate-related hazards.

9.3.3. Incorporating Bushfire Impacts into Road Design: Literature Review

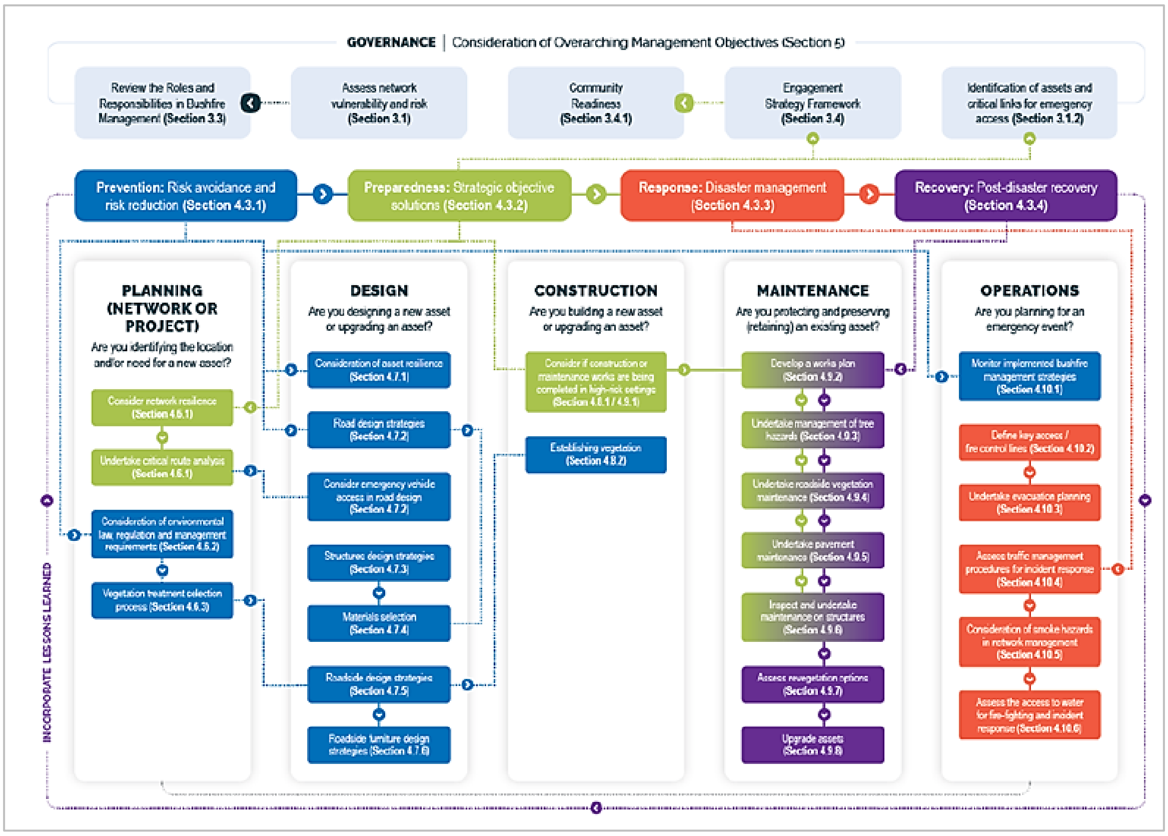
Back

In Australia, climate variability, due to climate change, is impacting the frequency and intensity of bushfire events. A number of unprecedented events in Australia in recent times and have highlighted the importance of roads, road organisations and associated infrastructure are critical enablers for bushfire management.

A joint initiative undertaken by the National Assets Centre of Excellence through Queensland Department of Transport and Main Roads (TMR), and the Western Australian Road Research and Innovation Program, through Main Roads Western Australia (MRWA), aimed to develop a framework which imbeds the consideration of bushfire prevention, preparedness, response and recovery into the planning, design, construction and maintenance of transport infrastructure in addition to recommending updates to TMR and MRWA practices and documentation to reflect best practice.

The literature review undertaken as the first phase of this project aimed to examine how to assess the risk and vulnerability of road and transport infrastructure when impacted by a bushfire event, and what best practice is for organisations undertaking bushfire management is within, and interfacing, the road corridor and across the project lifecycle.

As a result, the first recommendation is the adoption of the Prevention, Preparedness, Response, Recovery (PPRR) framework with organisation practice. The following is a strategy selection process which details the various recommended activities for the various phases of the PPRR framework which introduces governance measures including strategic planning and stakeholder engagement to the framework. The setting of strategic planning objectives should occur prior to commencing any works in relation to the prevention of, preparedness for, response to or recovery from bushfires.


GOVERNANCE | Consideration of Overarching Management Objectives (Section 5)
Review the Roles and Responsibilities in Bushfire Management (Section 3.3)
Assess network vulnerability and risk (Section 3.1)
Community Readiness (Section 3.4.1)
Engagement Strategy Framework (Section 3.4)
Identification of assets and critical links for emergency access (Section 3.1.2)
Prevention: Risk avoidance and risk reduction (Section 4.3.1)
Preparedness: Strategic objective solutions (Section 4.3.2)
Response: Disaster management (Section 4.3.3)
Recovery: Post-disaster recovery (Section 4.3.4)
PLANNING (NETWORK OR PROJECT)
Are you identifying the location and/or need for a new asset?
DESIGN
Are you designing a new asset or upgrading an asset?
CONSTRUCTION
Are you building a new asset or upgrading an asset?
MAINTENANCE
Are you protecting and preserving (retaining) an existing asset?
OPERATIONS
Are you planning for an emergency event?
INCORPORATE LESSONS LEARNED

9.3.4. RESOLUTE project – European Resilience Management Guidelines

Back

The European Resilience Management Guidelines support decision makers and critical infrastructure managers with a self-evaluated multilevel gap analysis for resilience improvement. The guidance identifies key recommendations for considering interdependencies and provides a framework for sustaining adaptive capacity of a system to continuously changing operating conditions. The guidance covers four resilience cornerstones: anticipate, monitor, respond and learn that are the foundation for sustained adaptability concept adopted in the RESOLUTE project. Under each cornerstone a number of managerial responses are outlined including:

- Anticipate
  - Strategic Plan
  - Resources
  - Assess risk
  - Training
  - Coordinate service delivery
  - Awareness and user behaviour
  - Maintenance
- Monitor
  - Safety and security
  - Operations
  - Resources
  - User generated feedback
- Respond
  - Emergency actions
  - Restoration and Repair
- Learn
  - Collect event information
  - Adaptation and improvement insights

The critical infrastructure the guidelines are designed for include agriculture and food systems, health care facilities, national monuments and commercial facilities, to energy and water systems, chemical facilities, road infrastructure, transportation systems, nuclear power plants, telecommunications and information technology systems and wide variety of other public facilities.

9.3.5. Submersible pavement design, Quebec

Back

This study explored the qualities and benefits of submersible pavements for use in flood-prone areas. One of the current predictions of climate change is an increase in the frequency and intensity of extreme precipitation events (Ouranos, 2010). Flooding often occurs in the spring, due to melting snow and ice, but also in the presence of heavy rainfall. A review of a flooding event that occurred in 2011 in the Lake Champlain and Richelieu River basin resulted in a recommendation to develop flood resistant pavements for strategic locations.

The aims of the study were:

- To describe methods for design and construction of submersible or flood-resistant pavements.
- Identify the most important design parameters
- Define parameters to identify the strategic locations at risk of flooding
- Propose a design method for the design of submersible or flood-resistant pavements. The method should include typical cross-section(s) adapted for Quebec.

Methodology

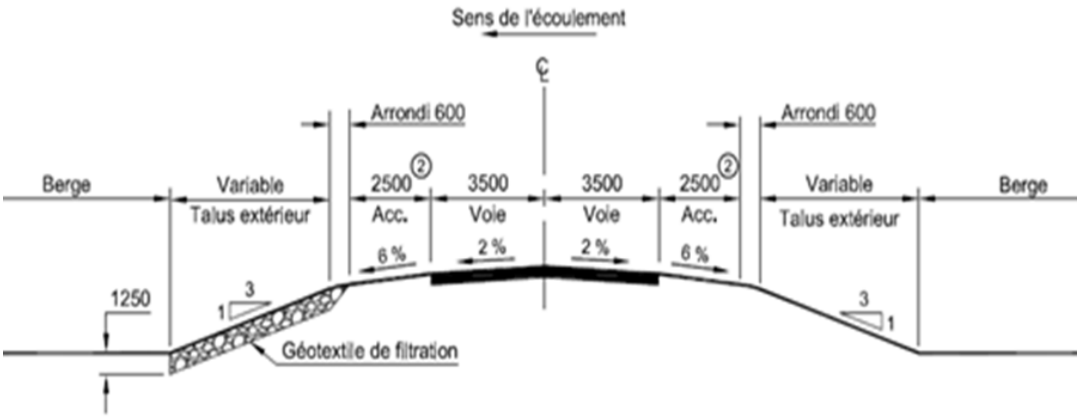
A literature review provided an overview of the situation regarding the problem of flooded roadways. The first step evaluated the flooding risks of the Quebec road network, based on temperature and precipitation projections. Then, various forms of flood damage that affected the pavement were listed. The project studied the impact of water and water flow both on pavements and within pavement structures. The mechanisms that caused the water to move and react with the various materials of the pavement structure were highlighted. The computational models applied to these flows, the design methods of submersible pavements as well as the solutions to improve the resistance of pavements to flooding, used elsewhere in the world, are studied and analysed. Based on the elements resulting from this review, a calculation approach adapted to the Quebec context is proposed.

Conclusion

This project concluded with a proposed solution adapted to the Quebec context, based on the criteria identified in the literature review. These design criteria are essentially divided into two aspects: the geotechnical aspect, which deals with the nature of the materials used and the subgrade soil, and the hydraulic aspect, which deals with the various flow characteristics. The literature review then introduced two design methods, the American method (Briaud and Maddah, 2016) and the Australian method (MRWA, 2006).

A proposed solution for Quebec, based on an example of a calculation performed in the context of this research, was provided. This example depends on the maximum flow velocity during a roadway flood and is used to size the protection to be adopted at the embankment level. This does not imply any change in the sizing of the layers of the pavement studied, a Type C pavement according to MTQ (2018). However, the proposed solution must be validated experimentally, notably through laboratory or full-scale tests. It is recommended that further research be conducted to improve the proposed solution and also to consider new solutions.

To view the final report: http://www.bv.transports.gouv.qc.ca/mono/1240598.pdf



9.3.6. Intensive Maintenance Work Closure of All Lanes - example from Japan

Back

Hanshin Expressway outlined options for conducting intensive maintenance works through the closure of traffic lanes. Lane closures provide a method for minimising impacts on traffic in a central city area. Hanshin Expressway's major work in this area focusses on the road pavement and flexible joints. It commenced in 1973 (including work with single-lane closure) and has been carried out approximately every year since 1985. Hanshin Expressway gain public cooperation through publicity campaigns informing the public about the work they are carrying out (Evans, 2018 REAAA Technical Report: Infrastructure Resilience Scanning Tour of South Korea and Japan, FEHRL).

There are several advantages to intensive maintenance works requiring all lanes to be closed as opposed to regular maintenance works with traffic control. These include: adequate work space, a shortened work period, and an improvement in the quality of work by securing a path for work vehicles in and out of the work space. The effects of closing all lanes for intensive maintenance works compared with regular maintenance works using traffic control is shown in the table below.

Table 7.4: Comparison of maintenance works with traffic control and all lanes closed

	(a) Regular maintenance with traffic control	(b) Intensive maintenance with all lanes closed	(b)/(a)
Necessary days	approx. 190 days	Approx. 8 days	–
Total traffic congestion factor *	approx. 5,400 km/h	Approx. 540 km/h	0.10
Monetary value of time loss**	approx. 12.8 billion yen	Approx. 2.2 billion Yen	0.17

* Only amount of congestion caused by the works.

** Including major surfaced roads.

Source: Kunihiro Hayashi, Deputy Manager Hanshin Expressway: Intensive maintenance work using all-lane closure.

9.3.7. Early Warning Against Floods - Japan

Back

Under the auspice of the Public Works Research Institute (PWRI) Japan is the International Centre for Water Hazard and Risk Management (ICHARM). Its objective is to serve as the Global Centre of Excellence to provide and assist in the implementation of best practice strategies to manage the risk of water-related hazards, including floods, droughts, landslides, debris flows and water contamination. It works towards reducing water-related risks and promotes research into flood risk assessment. ICHARM provides higher education training in disaster management and develops technologies to assess real time hazard mapping, flood forecasting, and the evaluation of the river basin (Evans, 2018 REAAA Technical Report: Infrastructure Resilience Scanning Tour of South Korea and Japan, FEHRL).

SOUSEI project

A key project being undertaken is the Program for generation of climate change risk information (SOUSEI Project). Collaborative organisations include Kyoto University, Yamanashi University and the Governments of Pakistan, Thailand, Cambodia, Indonesia and the Philippines. This project seeks to develop a methodology for the local application of the predicted values of flood/drought hazard. It provides:

- local customised hazard assessment
- uncertainty assessment
- socio-economic impact assessment (flood and drought)
- a vulnerability monitoring system.

The development of the basic technology for the socio-economic risk assessment is based on:

- the development of a response framework to assess hazard and socio-economic impact
- assessment of the socio-economic impact, including uncertainty
- the provision of necessary information for local adaptation (Evans, 2018 REAAA Technical Report: Infrastructure Resilience Scanning Tour of South Korea and Japan, FEHRL).

The flood risk assessment involves an assessment of various experimental scenarios and basin scale rainfall information; this is downscaled on a regional basis with a bias correction. Hydrological models (e.g. IFAS/BTOP/RRI) are also used to carry out flood evaluations and projections for present and future climates according to projections of variations in discharge, water level and water depth. Based on this uncertainty assessment, a socio-economic assessment is undertaken. This risk assessment simulation can also be used to estimate agricultural damage (Pampanga river basin), drought risk and water utilisation. It can also assist in the prediction of the impacts of salinity on pavements (Evans, 2018 REAAA Technical Report: Infrastructure Resilience Scanning Tour of South Korea and Japan, FEHRL).

9.3.8. RESPONS(e) portal for natural hazards

Back

RESPONS is a web-based mapping solution that combines static information from natural hazard mapping with dynamic data on weather, avalanche hazard and other events. RESPONS is designed both for professionals who work with natural hazards and for contractors responsible for road operation.

Hazard assessment:

Landslide personnel in the Norwegian Public Road Administration carry out daily assessments of landslide and flood hazards on roads. The results of the assessment are presented on a map and are also sent out by e-mail to professionals in the road organisation and partners. RESPONS is also used for local assessment of known landslide locations or road sections exposed to adverse weather.

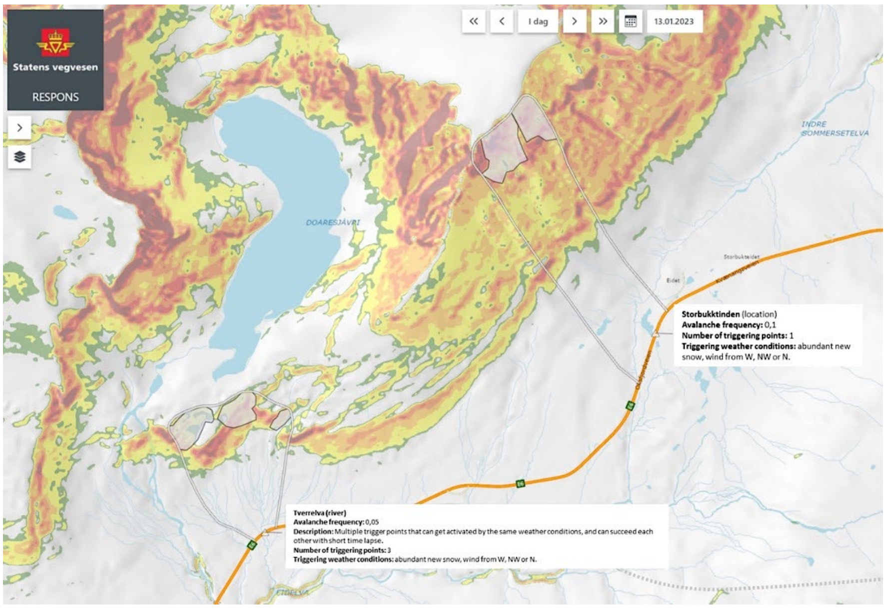
Emergency events on the road:

In the case of flood or landslide events on the road, RESPONS acts as a support tool, both table-top and in-field, for relating to previously documented relevant incidents, estimating hazard from neighbouring avalanches and assessment of possibilities for reopening the road.

Operation, maintenance and protection of the road network exposed to natural hazards:

RESPONS shows information about natural hazards, of various origin, relevant for roads. This includes hazard zone maps from other agencies, events registered by the operating contractor, and geotechnical reports and notes. The official database for storing road data is the National Road Data Bank (NVDB).

When all available information is gathered in one place, it will always be possible to produce an updated digital natural hazard map, which is useful both for the daily operation of the road network, and for work on protection against natural hazards.



Source: Norwegian Public Roads Administration, 2023

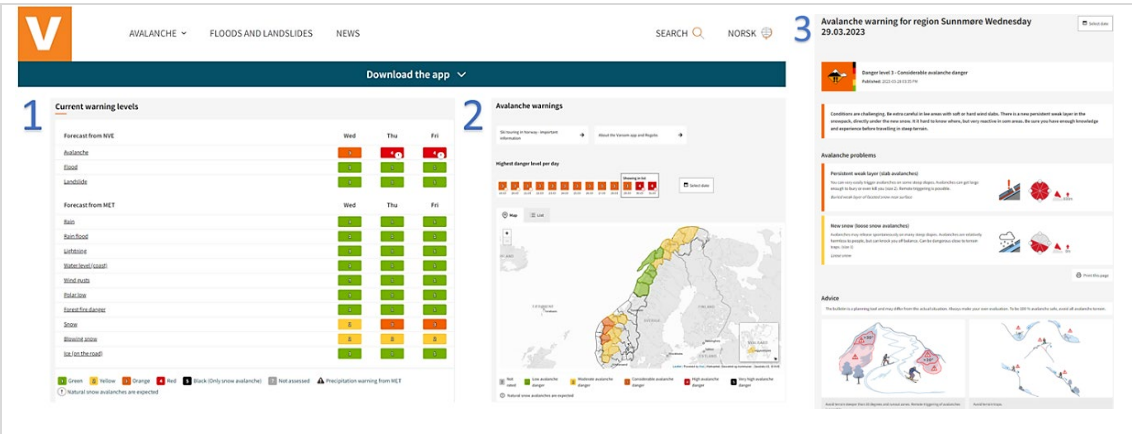
9.3.9. National warning system for landslides and avalanches

Back

The Norwegian Avalanche Warning Service, also known as “Varsom”, was launched in 2013. The platform provides information about natural hazards in Norway, with a particular focus on avalanches, but also flood and landslide hazards. The warning service is a collaboration between stakeholders, suppliers of data and expertise. It is delivered by The Norwegian Water Resources and Energy Directorate (NVE), in collaboration with Norwegian Meteorological Institute (MET) and The Norwegian Public Roads Administration (NPRA), and other organisations. NPRA contributes with field observers and experts issuing warnings.

The main goal of the warning service is to prevent accidents and minimise damage to roads, buildings, and infrastructure caused by avalanches. The warnings are delivered online through the website www.varsom.no and via the Varsom app, which is compatible with iOS and Android devices. Varsom provides daily avalanche forecasts, warnings, and weather updates for the entire country, which are disseminated through their website and mobile app. Users can also download offline maps for use in areas with limited network coverage.

The primary user groups include recreational winter sports enthusiasts, road and railroad authorities, preparedness authorities, and search and rescue teams. These groups use the service with continuous updates on the current situation to take appropriate measures to protect people and infrastructure from forecasted hazards. The bulletins and forecasts are published according to the European Avalanche Warning Services (EAWS). The bulletin and forecasts are important tools for evaluating the snow avalanche conditions, but do not provide the correct answer for every snow-covered slope. The bulletin and forecasts are therefore set up to be as educational as possible; with an informative and educational avalanche service, the avalanche awareness will increase, and enable the public to avoid accidents. For example, Avalanche problems are described through typical situations as they occur in avalanche terrain. The figure below shows three different levels of information provided by www.varsom.no, each offering progressively more detailed and specific information.



Source: Norwegian Public Roads Administration, 2023

9.3.10. NEXCO Urgent Repair Operation Standard

Back

Following the 2011 Great East Japan Earthquake, the Urgent Repair Operation Standard was implemented by NEXCO. Details of the urgent repair assessment are shown below. According to NEXCO standards, in the event of an earthquake, the road is closed if the magnitude of the earthquake is greater than 5. Urgent inspections are undertaken by NEXCO maintenance companies, followed by a detailed inspection by NEXCO engineering companies, and detailed design (if required) using consultants (Evans, 2018 REAAA Technical Report: Infrastructure Resilience Scanning Tour of South Korea and Japan, FEHRL).

The following three-staged repair restoration of roads and bridges was enacted:

1. Tentative repairs so that rescue vehicles can travel pass on Tohoku, Joban and other expressways (within 20 hours).
2. Urgent repairs – lifting almost all closures (in 13 days). This included urgent repairs of bearings using vertical supports sustained by saddles; side blocks by setting horizontal movable limits; and expansion joints by covering steel plates with asphalt.
3. Main repair – the network was back to normal in 21 months.

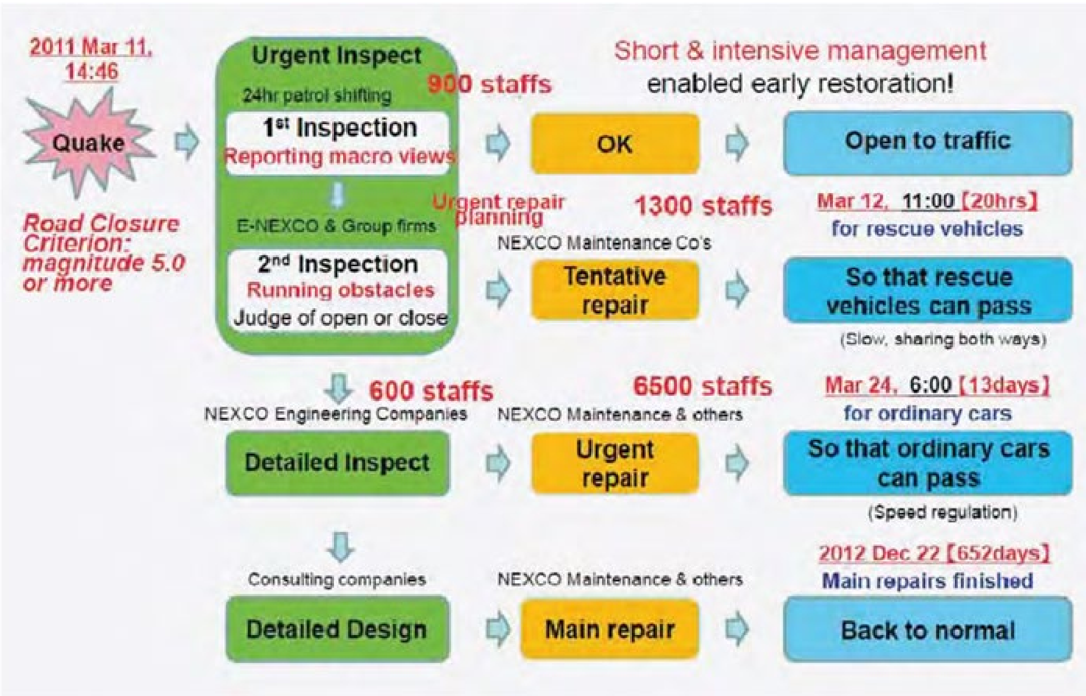


Figure 7.16: Details of urgent repair assessment

Source: Takeshi Hirose, Bridge Division Chief (NEXCO Research Institute).

9.3.11. Accounting for Life-Cycle Costing Implications and Network Performance Risks of Rain and Flood Events, Queensland, Australia

Back

Between 2009 and 2013, Queensland experienced road closures of 23-62% of their roads due to an increase in frequency and severity of storms. Approximately 26%, or 8,741 km of the state-controlled network required full or partial reconstruction.

The project aimed to provide clarity to Queensland Department of Transport and Main Roads (QTMR) and government funding bodies on the life-cycle cost implications of rain and flood and extreme weather events, and the funding levels required to enable the desired level of service to be achieved e.g. “What are the economic benefits of improving the ability of the road network to better withstand the effects of flooding events, and how might it be done?”. Seven case studies across four representative regions across Queensland were selected, according to traffic volume, function and flood event frequency, and to enable some conclusions to be drawn regarding the whole network. The risk factors chosen included the damage itself, its immediate recovery time and cost, its eventual reconstruction and the cost of repairs, community and industry delays and associated costs.

The model was run over a 30-year analysis period, so that a period of several years before the major event could be incorporated, as well as a significant length of time afterwards to allow for reasonable assumptions to be made regarding future event reoccurrence intervals. Additionally, the analysis considered the condition e.g. based on the measured pre-event level of rutting and roughness, and vulnerability based on a combination of seal width, seal age pavement age and soil properties for 1km sections of road.

The base case uses actual data from the road closure database, reconstruction completion reports, and QTMR-sourced data to quantify the life-cycle cost impact of rain and flood events on the network. Funding in this scenario is often limited, and major works occur after event-incurred damage. The Full resilience option represents a scenario where the road has been engineered to be sufficiently immune to events, and no reconstruction works would be required after a major event, and delays due to road closures would be reduced. The ‘stitch-in-time” option advocates periodic major work targeted at vulnerable sections with more aggressive trigger points for remedial works. The network is more immune to immediate effects and repair programs post-events are a fraction of the current magnitude. Delays may still occur here, however the damage will be greatly reduced and allow for more rapid emergent works to reopen sections.

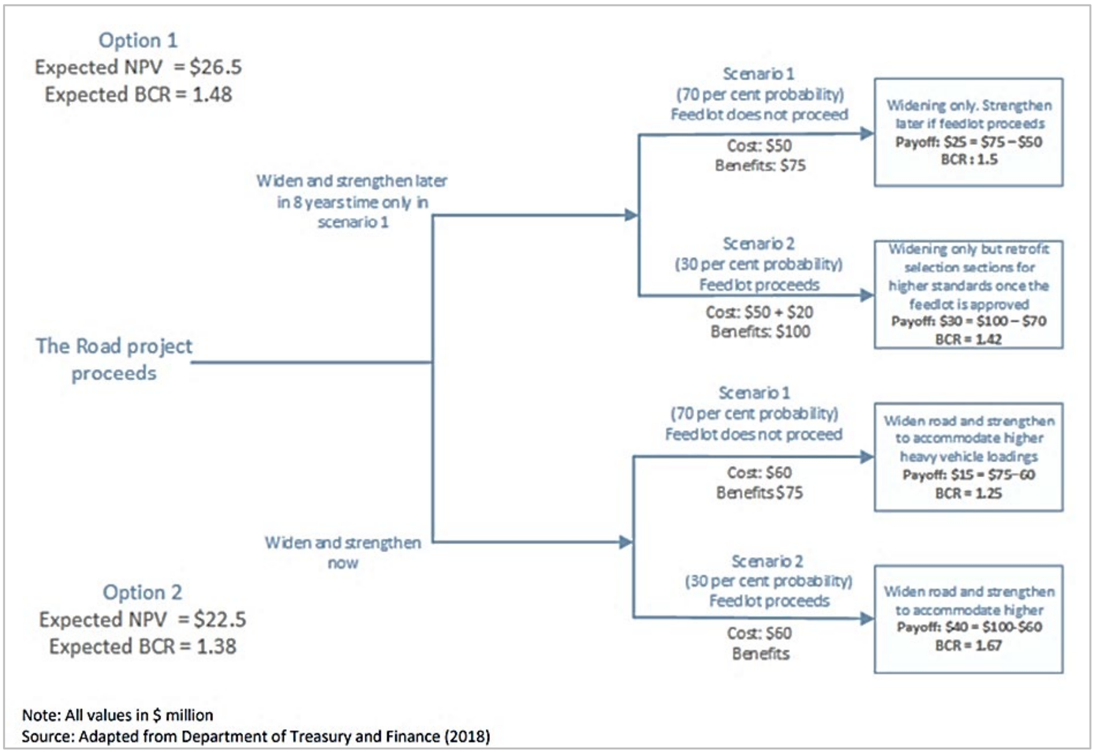
It was found that different combinations of options could be more suitable for particular roads and traffic in urban or outer areas.

Source: Beecroft et al. (2016) [112]; Beecroft et al. (2017) [113]

9.3.12. Example of real option analysis in a road renewal project

Back

A case study example of the widening and strengthening of a sealed road using a real options assessment is identified below (ATAP T8, 2020). This is based on a decision tree analysis.



Decision tree – Widening and strengthening a sealed road (Adapted from [84], cited in [114])

9.3.13. The “real option triage”

Back

The ‘real options triage’ enables organisations to identify the uncertainties that could impact their investment, the vulnerability of the investment to those uncertainties, and the level of flexibility within the investment to adapt its strategy to mitigate those impacts (Victorian Department of Treasury and Finance, 2018 [84]).

Identify the primary sources of uncertainty that could impact your investment	• What factors could impact the investment need or demand for a service, the preferred response, solution implementation or benefits realisation? • Could any of the uncertainties materially impact the business case assumptions and assumed future state?
Identify how these uncertainties are likely to impact the preferred investment strategy	• What would your ‘preferred investment strategy’ look like under different conditions and future states? • Under what circumstances would the preferred investment strategy: – no longer offer the best value for money; – no longer achieve the intended benefits; – be less effective than a different approach; and/or – be regretted?
Identify how you increase your investment strategy's flexibility to better deal with uncertainty	• If conditions or assumptions do not turn out as you expect, what actions would you take to adapt your project to suit prevailing conditions? Examples include: – delaying or staging investment until there is greater certainty; – expanding or reducing capacity to suit changes in demand; – switching inputs /outputs to suit changes in demand or supply; – abandoning the investment; and – increasing design flexibility to add greater resilience.
Identify trigger points that would prompt a decision to take a different course of action	**An event(s) or change of conditions (beyond expected).** Examples include: • population increase or decrease; • change to demographic makeup; • economic downturn/upturn; • failure of project interdependency; • globalisation/isolationism; • climate change; • switch in technology platform; and • new market participant.

Source: DTF (2018)

Outline of the Real Options Triage (DTF, Australia, 2018) ([84] cited in [114]).

9.4. Case studies – Stage 4 Implementation

9.4.1. New Zealand's National Infrastructure Plan

Back

New Zealand's 2010 National Infrastructure Plan (NIP) [102] 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 2011 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".

The latest 2022 NIP update recognises that New Zealand will need to rebuild, strengthen, or relocate infrastructure in response to the changing climate and to recover from natural disasters, like volcanic eruptions and earthquakes. Adapting New Zealand's infrastructure to climate change and repairing infrastructure after earthquakes will cost at least 0.2% of GDP every year over a 30-year period. At present, New Zealand spends around 5.5% of gross domestic product (GDP) on public infrastructure.

In parallel with the Infrastructure Plan, New Zealand has also created a whole of Government "National Climate Change Risk Assessment" (NCCRA, 2020, to be renewed every 6 years) and a National Adaptation Plan (NAP, 2022).

The NCCRA aims to help the Government identify where it needed to prioritise climate adaptation action, giving the first national picture of the risks New Zealand faces from climate change. It identified 43 priority strategic risks covering all aspects of national life, grouping the risks according to five value domains: natural environment, human, economy, built environment, and governance. It laid the foundation for the National Adaptation Plan which outlines the Government's response to these risks. The NAP considers the impacts of climate change now and into the future and it sets out how New Zealand as a whole will adapt to these challenges. The NAP has over 120 actions and responds to risks raised in the NCCRA.

These three documents provide a key strategic position outlining and guiding how Climate Change Adaptation will be managed and integral to Government direction and activities into the future. In addition, New Zealand's Government Policy Statement on Land Transport outlines the Governments funding policy aspirations, including objectives that relate to integrating climate change resilience into investment decision-making across the allocation of national funds to the transport system. This will be reflected in more detail and specificity with the next (2024-27) National Land Transport Plan (the funding plan for the government's national land transport fund).

9.4.2. Adaptation of Road Standards, Guidelines and Regulations to Climate Change, France

Back

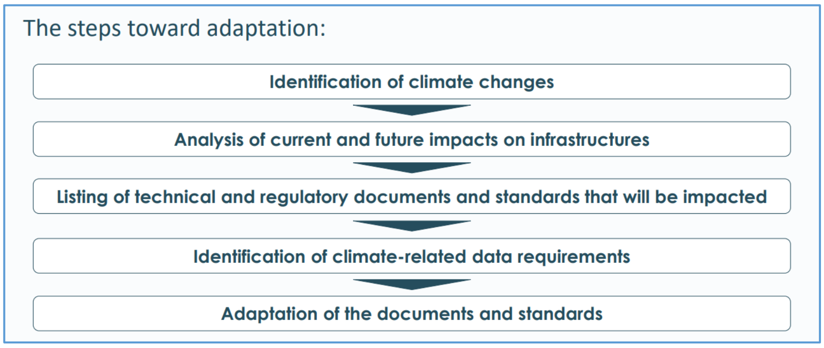
The design, maintenance and operation of roads is based on guidelines, standards and regulations that include climate parameters. However, our climate is changing and it is therefore necessary to update these documents by taking into account the evolution of the climate parameters.

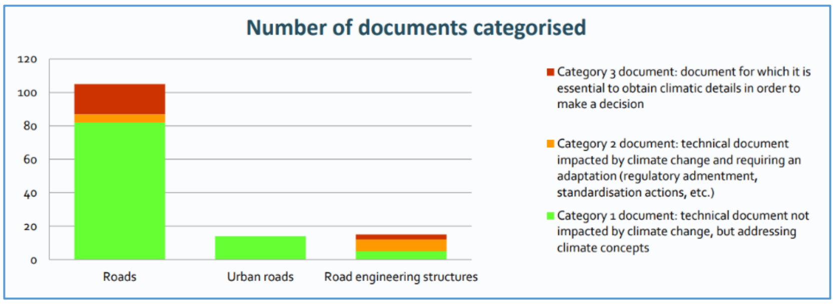
Cerema, France, published in 2015 a report focusing on the adaptation of technical documents and standards used for the design, maintenance and operation of transport infrastructures to climate change [103]. The report covers road infrastructures including earthworks and road constructions, maritime, river, port, airport and rail infrastructures, and cable transport systems.

The study first focuses on the main climate changes expected in France by 2100. The climate models that have been assessed by the IPCC notably predict an increase of mean temperatures, sea level and the frequency and intensity of extreme events, as well as an evolution of the precipitation and wind patterns. Then the report presents the current *impacts* of the climate and the potential impacts of the expected climate changes on: highway (including urban transport structures), earthworks, rail, river, maritime, port and airport infrastructure and mechanical drag lifts.

The main outcome of the study is a list of documents commonly used to design, maintain and operate roads that need to be updated. To establish the list, a group of experts has assessed over 130 documents with references to climate parameters and sorted them by priority of adaptation. The list of documents is accompanied by an explanation of the climate features that may be useful to adapt the documents: either climate data or climate parameters.

This comprehensive assessment provided a basis for effective adaptation to the future climate.





9.4.3. Business case approach – Waka Kotahi NZ

Back

The Waka Kotahi Business Case Approach (BCA) is a robust, principles-based approach for developing business cases for investment in the land transport system.

Its approach is outcomes focussed for investment decision-making and encourages early and meaningful engagement with stakeholders. The approach requires a structured evidence-based project or programme development, where key questions or issues are assessed at the appropriate stage of the case's development. This results in well-defined decision-making points to check and determine whether the case should continue or be re-directed/re-scoped.

An example outline guide for Waka Kotahi business case process as developed for a road organisation is: https://www.nzta.govt.nz/assets/Highways-Information-Portal/Processes/Business-case-phases/NZTA-BusinessCaseApproach-final.pdf.

The benefits of the Waka Kotahi Business Case Approach include:

- Increased effectiveness of investment resulting in an increase of outcomes and benefits – better value for money, and better connects strategy to shovel
- Increased efficiency of processes and reduction in churn – quicker for less cost
- Greater clarity of evidence-based decision making on investment – evidence to back up decisions
- Planning and investment optimised across the whole network – getting the most out of the whole network

These benefits arise through:

- More clarity – identifies desired outcomes; sets investment objectives; sets measures at outset to monitor benefits
- Greater efficiency – reduced churn throughout process; all stakeholders agree to scope at the outset; the right options are appraised
- Reduced risk – greater assurance at project stages
- Improved stakeholder engagement – provides a basis for meaningful, upfront conversations; early agreement on outcomes

The Waka Kotahi Business Case approach has been used and progressively developed and streamlined since 2014, with particular focus on use with projects and programmes seeking national funding support for the land transport system improvements, operations and maintenance.

More information: Processes | Waka Kotahi NZ Transport Agency (nzta.govt.nz)

9.4.4. Wellington Regional Land Transport Resilience

Back

The Wellington Region is vulnerable to a range of natural hazards, including earthquakes, tsunami, major storms, floods and landslips. If key sections of the Wellington land transport network become impassable, there are few viable alternatives. Currently, if a large natural disaster happens, communities will be isolated with land transport access not available for critical response needs and it will take a long time for socio economic functionality to recover.

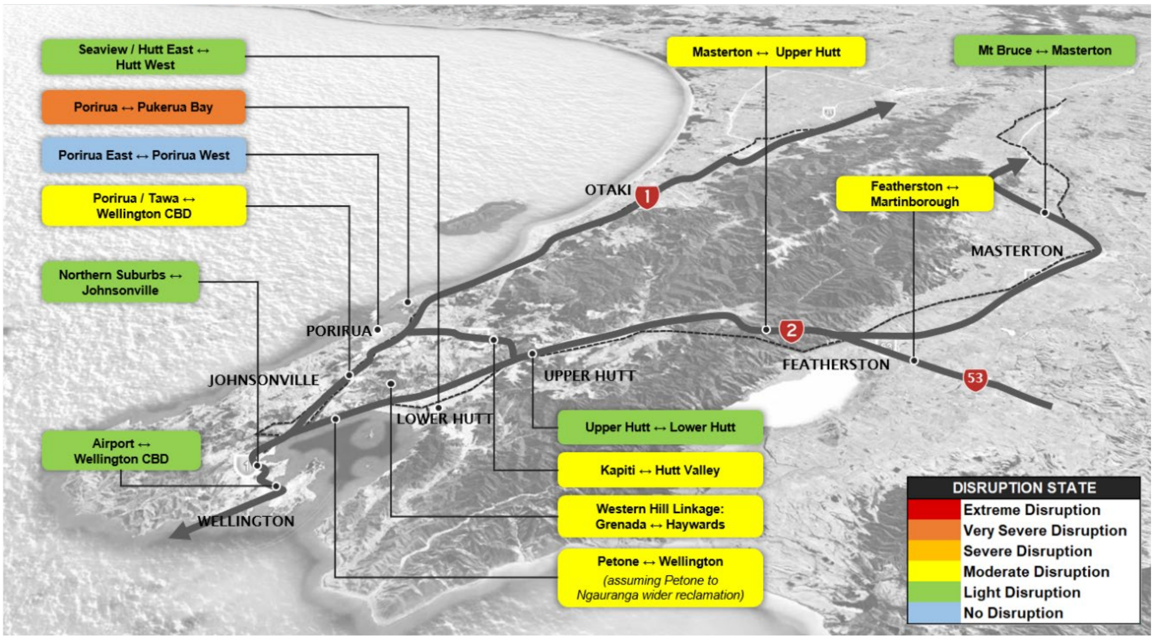
Waka Kotahi, in collaboration with local councils and KiwiRail, undertook a business case to establish appropriate programmes for future investment in land transport to achieve resilience in the Wellington Region's network for hazard events.

The 2014 Strategic Case concluded that the area is connected by seismically vulnerable road corridors at risk of High Impact, Low Probability (HILP) event(s) which if damaged would lead to significant logistic difficulties, fragmentation and isolation as well as impeding recovering efforts resulting in significant regional impact and national implications.

A location-based Regional Resilience Risk Register was developed based on "**Importance**" and "**Disruption State**" ratings which were then combined to provide a basic "**Criticality**" rating to natural hazard event types. This provided an indication of locations that are vulnerable to multiple hazards. The assessment was further modified to factor in additional key considerations, including multi modal impacts on the transport network (rail etc) and shared vulnerability with utilities (water, electricity, gas).

A series of alternative programmes of interventions were developed and assessed for level of effectiveness in improving resilience of the risk locations (in order of priority) to low frequency/high impact hazard events and high frequency/low impact events. The focus of the preferred programme to be implemented in the next 10 years is to enable response in HILP events, begin investigations for more complex improvements for HILP and LIHP events, and enable functionality along critical journeys in LIHP events.

BALANCED PROGRAMME OUTCOMES - HILP



The business case was used as an input to a wider integrated multi-sector/multi-utility plan for improving resilience of the Wellington region.

9.4.5. The UK Climate Impacts Programme

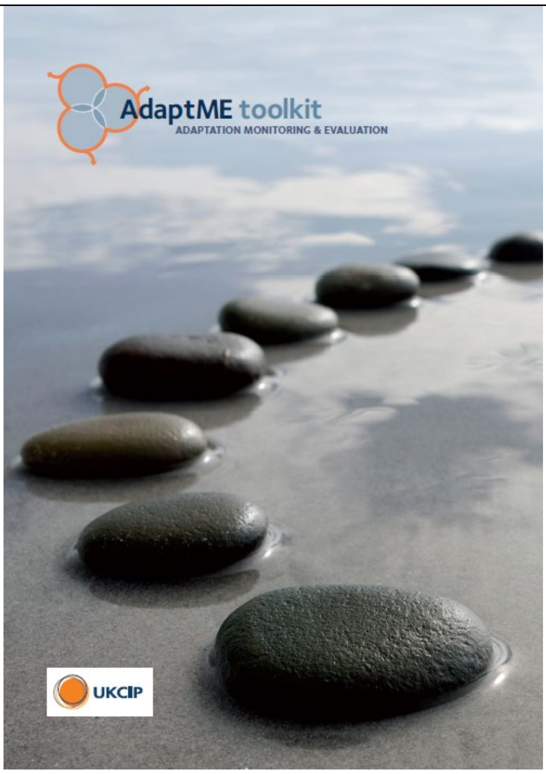
Back

UKCIP AdaptME Toolkit

The UK Climate Impacts Programme (UKCIP) developed in 2011 the ‘AdaptME Toolkit’ for practical support in evaluating adaptation progress and performance.
It may be useful for other organisations starting the work on adaptation.

The toolkit helps a user to:

- Refine the 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.



UKCIP-AdaptME.pdf

10

Appendices

This section provides supplements to the main sections. It is not meant to be read as a continuous text. The appendices vary in detail and purpose. Some contain information or discussion material that was taken out of the main text for better legibility or focus, and should be read in conjunction with the related main text section. Others are additional pieces of information or sources of content for the reader interested in exploring any issues in more detail.

10. APPENDICES

10.0. APPENDIX TO THE INTRODUCTION

10.0.1. Key recommendations from the 2019-report

Back

The 2019 review report “Refinement of PIARC’s International Climate Change Adaptation Framework for Road Infrastructure” [3] made a number of recommendations for improving the original 2015 Framework. They have been the basis of the work programme of TC 1.4 “Climate Change and Resilience of Road Networks”, Working Group 2 for the 2019-23 cycle. In summary these are:

Structural changes:

- enabling “short-cuts” in the process, in cases when the whole procedure is not required or not feasible due to lack of data or resources,
- putting more emphasis on the preparatory work, i.e. recognising a “Preparation stage”
- allowing for alternative methods for risk assessment, i.e. separating the structure of the Framework from the methodology.

Added steps and sub-steps

- establishing or reviewing (regional) projections of climate change and selecting appropriate climate scenarios needed to be placed earlier in the process, because it has influence on the choice of assessment, the methodology, etc.
- introducing criticality as a parameter.
- addressing adaptive capacity as an important factor of vulnerability.
- identifying some important decisions at the initiation of the work, such as defining criteria for risk tolerance, the limits of feasibility of adaptation measures, indicators for evaluating the results of adaptation, etc.

Added contents

- The Framework should highlight the importance of amending design standards and technical specifications to consider climate change and provide guidance.
- More emphasis should be put on the road organisations need to obtain data as the basis for assessments:
    - Road data, traffic data, redundancy, supply chains, traffic freight transport;
    - Information about existing assets and structures: design levels, condition;
    - Information about historic events, damage, costs, etc.
- Adaptation pathway methods should be included.
- Include Lifecycle costing analysis to assess and prioritise adaptation measures.
- Expanding methodology to include:
    - Tailoring to the scale of analysis, and the severity of impact.
    - emphasise local knowledge at all stages.

- advice concerning evaluating sensitivity: general sensitivity, aggravating factors, qualitative/quantitative assessment.
- social acceptance of the adaptation measures; and
- distinguishing between current and future climate threats when evaluating the vulnerability of the system or the road assets.

10.0.2. Key Changes in the 2023 version of the PIARC Framework

Back

The main amendments made in updating the original 2015 Framework include:

- Stage 1, the Preparation Stage, is developed, defining and describing the starting point, or baseline for adaptation. The baseline is a function of existing expertise, available data and resources.
- Establishing climate change scenarios is added to the Preparations Stage.
- Vulnerability assessment is moved to Stage 2.
- The Framework explains the purpose and content of each step of adaptation planning, with an overview of relevant methods, although it leaves the choice of the method to the road organisation.
- Criticality and adaptive capacity are included more explicitly in the assessment
- The idea that the assessment can be undertaken by taking “short-cuts” or combining the most relevant modules into an assessment that is feasible and adequate to the purpose.
- Some thoughts on compatibility with existing systems and routines in the road organisation, to ensure that climate adaptation measures can be mainstreamed.

10.1. Appendix to Stage 1

10.1.1. Assessing available resources

Back

The assessment of available resources can be conducted at a number of different levels as follows:

a) Resources required to

- acquire the necessary data to enable decision makers to make clear and well-informed choices on priorities;
- design the adaptation measures through engagement of outsourced experts;
- train inhouse personnel on climate change adaptation to enhance technical capacity to implement adaptation interventions effectively, and establishment of R&D capacity to support sustainable and cost-effective adaptation work.
- set up institutional structure within the road organisation for consistent, effective and sustainable implementation of the above. Installation of an appropriate and properly managed RAMS is an essential element of the institutional set-up.

Based on desired capacity and existing budgets, an equitable balance between inhouse staff and outsourced services/expertise can be made. See also 1.4.1 Composing an expert team.

b) Budgets for implementation and monitoring & evaluation of effectiveness of the priority adaptation interventions on and around critical infrastructure. Most new roads should incorporate the necessary adaptation measures to ensure resilient structures. Existing roads will either incorporate those that give the best value for money in a proactive regime (retrofitting) or those that can be afforded in a reactive mode. This policy should be established by each road organisation.

c) For the sake of completeness, it is important to add that resources must be immediately available for emergency assistance during adverse climatic events and for post-event recovery interventions. The safety of communities and protection of their lives and livelihoods should be paramount in the recovery efforts.

10.1.2. Checklists for assessing available data and information

Back

GOVERNANCE – national policies and systems

No.	Description of the requirement	Yes	No	Observations
1	National Climate Adaptation Plan			
2	National Disaster Risk Management Plan			
3	National Climate Change System			
4	National Determined Contribution (NDC) Document (compliance with the Paris Agreement)			
5	National Development Plan			
6	National Budget			

GOVERNANCE – Institutional policies and systems

No.	Description of the requirement	Yes	No	Observations
1	Institutional policies on adaptation to climate change of roads, main strategic documents			
2	Specific budget for road adaptation			
3	Road maintenance program			
4	Human resources trained on climate change adaptation / Technical capacity to implement adaptation actions			
5	Organisational structure for adaptation to climate change			
6	Internal (stakeholders) and external (network users) communication mechanisms			
7	Emergency procedures and strategies			
8	Risk management			
9	Management of road assets			
10	Database on implemented adaptation measures and their monitoring			
11	Standards for road design (include climate variables / include adaptation to climate change)			
12	Network performance indicators			
13	Ability to repair damage quickly			
14	Identification of alternative routes in the network			

INFRASTRUCTURE DATA

No.	Description of the requirement	Yes	No	Observations
	Information on the road network			
1	• Geometry data			
2	• Georeferenced road network			
3	• Inventory of the road network’s physical assets (signs, culverts and other drainage infrastructure, etc.).			
4	• Bridge Inventory			
5	• Critical network assets			
6	• Physical conditions of the road asset			

HAZARDS DATA

No.	Description of the requirement	Yes	No	Observations
1	Historical information on climate change impacts on roads (damage record)			
2	Future climate scenarios (temperature projections, precipitation, etc.)			
3	Pre-selection of climate variables for adaptation			
4	Knowledge of the risks associated with climate change on the road network			
5	Maps of exposure of the road network to climate change			
6	Weather information records			
7	Inventory of risks in the network (landslides, floods, etc.) / Risk maps / Risk register			
8	Statistics on partial or total network closures associated with climate change			

DEMOGRAPHIC AND SOCIO-ECONOMIC DATA

No.	Description of the requirement	Yes	No	Observations
1	Population data (i.e., users or beneficiaries)			
2	Economic statistics of influence area (income, inequality, etc.)			
3	Industries served by the road network			
4	Information on vulnerable communities			
5	Estimation on the socio-economic impact caused by network closures due to past events associated with climate change			

ENVIRONMENTAL DATA

No.	Description of the requirement	Yes	No	Observations
1	Environmental features close to the road network (e.g., rivers, lakes, forests, environmental protected areas, etc.)			
2	Air quality data			
3	Historical information on climate change impacts on roads (damage record)			
4	Future climate scenarios (temperature projections, precipitation, etc.)			
5	Weather information records			
6	Road-specific weather records and reports			

10.1.3. Barriers for adaptation

Back

Information quality and availability:

- lack of data regarding status of infrastructure assets,
- lack of information regarding climate conditions and projections (current scenarios and future projections), etc.
- lack of knowledge on the impacts of climate change, key vulnerabilities and /or lack of understanding of the concepts associated with adaptation.
- no clear indicators to measure the benefits of adaptation efforts
- organisational difficulties in involving all stakeholders in developing holistic knowledge.

Resources available – staff and financial

- lack of financial means, and funding for adaptation and for R&D work supporting it. by the lack of information on the costs and benefits of adaptation options.
- An established "routine" where investments are done following short-term criteria, and uncertainty is used as a possibility for saving money;
- lack of access to local personnel, expertise, and capability; dedicated human resources or teams or lack of technologies. Local knowledge, expertise, or technologies are crucial for LMIC.

Incentives on which decision-makers have to act:

- Legal constraints and /or lack of regulations, lack of national policy, unclear responsibility;
- Positive/negative externalities of actions, lack of co-benefits with other objectives of action;
- Organisational culture that does not support change, introduction of new strategies and processes, with the consequence that adaptation is dealt with as a stand-alone topic.
- Lack of corporate understanding of the necessity for adaptation work and agreement to pursue it, officially stated priority at a high level, buy-in from executive management
- Lack of awareness and engagement even among professionals (particularly engineers in charge of technical aspects of road management)
- Social, cultural or financial rigidities and conflicts and aversion to change (existing or perceived as such);
- Belief that there is plenty of time to start deciding on adaptation.

10.1.4. Critical climate parameters for climate change analysis in the transport sector.

Back

RIMAROCC Guidelines (2010) [30]

Table 1. Climate parameters or variables, imposing risk to the road infrastructure

Critical climate variables	Major risks to the road infrastructure
Extreme rainfall events (heavy showers and long periods of rain)	➢ Flooding of roadways ➢ Road erosion, landslides and mudslides that damage roads ➢ Overloading of drainage systems, causing erosion and flooding ➢ Traffic hindrance and safety
Seasonal and annual average rainfall	➢ Impact on soil moisture levels, affecting the structural integrity of roads, bridges and tunnels ➢ Adverse impact of standing water on the road base ➢ Risk of floods from runoff, landslides, slope failures and damage to roads if changes occur in the precipitation pattern (e.g. changes from snow to rain in winter and spring thaws)
Sea level rise	➢ Inundation of roads in coastal areas ➢ Erosion of the road base and bridge supports ➢ Bridge scour ➢ Reduced clearance under bridges ➢ Extra demands on the infrastructure when used as emergency/evacuation roads
Maximum temperature and number of consecutive hot days (heat waves)	➢ Concerns regarding pavement integrity, e.g. softening, traffic-related rutting, embrittlement (cracking), migration of liquid asphalt. ➢ Thermal expansion in bridge expansion joints and paved surfaces ➢ Impact on landscaping
Drought (consecutive dry days)	➢ Susceptibility to wildfires that threaten the transportation infrastructure directly ➢ Susceptibility to mudslides in areas deforested by wildfires ➢ Consolidation of the substructure with (unequal) settlement as a consequence ➢ More generation of smog ➢ Unavailability of water for compaction work
Snowfall	➢ Traffic hindrance and safety ➢ Snow removal costs ➢ Snow avalanches resulting in road closure or striking vehicles ➢ Flooding from snow melt
Frost (number of icy days)	➢ Traffic hindrance and safety ➢ Ice removal costs
Thaw (number of days with temperature zero-crossings)	➢ Thawing of permafrost, causing subsidence of roads and bridge supports (cave-in) ➢ Decreased utility of unimproved roads that rely on frozen ground for passage
Extreme wind speed (worst gales)	➢ Threat to stability of bridge decks ➢ Damage to signs, lighting fixtures and supports
Fog days	➢ Traffic hindrance and safety ➢ More generation of smog

RIMAROCC Guidelines (2010)

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Table 2. Summary of present knowledge regarding critical climate parameters for climate change analysis in the transport sector

Weight	Climate event affecting roads	Critical climate parameter	Amount of change compared to 1961-1990 period (++, +, +/-, -, --)	Availability of predictions: qualitative, quantitative or impossible	Certainty of predictions: Virtually certain > 99% probability of occurrence, Extremely likely > 95%, Very likely > 90%, Likely > 66%, More likely than not > 50%, Unlikely < 33%, Very unlikely < 10%, Extremely unlikely < 5% (IPCC legend)	Geographical resolution (grid size / resolution for which it can be used)	Time Horizon (when will it happen?)	Available data / models
4	Extreme rainfall events (heavy showers and long rain periods)	Max. intensity in [mm/h] and [mm/24h]	Intensity: + Frequency: North Eur. + South Eur. ?	Qualitative	Likely	Extremes are only visible on small grids. 50 km (difficult to use smaller grids).	Some statistical evidence of trends; happening today	Regional models + local expertise
4	Seasonal and annual average rainfall	Average amount [mm/ 3 months]	Sum. / Wint. North Eur.: +/- / ++ South Eur.: -- / -	Quantitative	Sum. / Wint. North Eur.: L / VL South Eur.: VL / L	Main signal perceptible for 250 km grid, but can be refined locally (50 km) to get more locally based averages	Already observed.	Global IPCC models + regional ENSEMBLES
4	Sea level rise (long-term effect) + waves and storm surges (short-term effect; see specific row in table)	Rise [m]	++ 21th Cent.: (0.2 to 0.6m) IPCC assumption: no accelerated ice cap melting	Quantitative Qualitative if accelerated ice cap melting is considered	> 0.2m is virtually certain in 2100	Global but not uniform (may vary according to sea basins)	Already observed (ice cap melting not within a century)	IPCC scenarios

3	Maximum temperature and number of consecutive hot days (heat waves)	Average max. [T°C on 24h] Maximum [T°C] Heat wave duration [number of consecutive days], [hw/year]	South: ++21th Cent. Global: 1.8 to 4.0°C (best estim. scen.) North/continent: + ++ Even more for extremes ++ 5 to 30 days	Quantitative Quantitative Quantitative	V. Certain in Eur. V. Certain Very likely	Main signal perceptible for 250 km grid. However to gain an insight into extremes and influence of sea, local refinement is necessary and possible (50 km). Specific case of cities (higher T°C) is not predictable	Already observed (figures available)	Global IPCC models + regional ENSEMBLES
2	Drought (consecutive dry days)	Drought duration [no. of consecutive days], [d/year]	++ in South, Centr. & West Eur.	Quantitative Qualitative	Very Likely More likely thannot	Well perceptible at 250 km grid. Regional refinements improve understanding	Has begun	
2	Snowfall	Max. snowfall in 24h [m/day] Snow duration at the ground [no. of days]	Int: + Far North Eur. ? Rest of Eur. Freq: - N/W/cent Eu Duration: -- whole Eu	Qualitative Qualitative Quantitative	Likely Likely V. Certain	Some understanding from 250 km grid. Slightly possible to get details from 50 km, but with big margin of error	Has begun	
2	Frost (number of icy days)	Minimum [T°C] Average [min. T°C on 24h]	+ (small possibility that minimum temp. increases more than average minimum) ++ 1,8 to 4,0 °C	Quantitative Quantitative	Likely V. Certain	Some understanding from 250 km grid. Slightly possible to get details from 50 km, but with big margin of error	Has begun Ditto	

		Frost duration [number of days/year] Frost index [frost penetration into the soil, Hellmann number]	-- -- Same changes over whole Eur.	Quantitative Quantitative	V. Certain V. Certain		Ditto Ditto	
2	Thaw (number of days with temperature zerocrossings)	Thaw days [number of days with 0°C crossings]	+ North. and Cent. Eur. - South Eur.(research going on)	Qualitative	V. Certain in North. Eur.	Some understanding from 250 km grid. Slightly possible from 50 km, but with big margin of error	Has begun	
2	Extreme wind speed (worst gales) : extra tropical or convective systems induced	Max. speed [km/h]	+ North-West Eur. ? elsewhere North shift of the storm tracks (500 – 1000 km)	Qualitative	Likely in North Eur. Poor (unknown) in South and West Eur.	250 km grid	Not yet recorded	Global IPCC models
1	Fog days	Fog days [number of days with fog]	?	Not yet possible Local effects (e.g. land use) – vertical res.	Unknown		Observed locally (less pollution)	

10.1.5. ROADAPT: Table of threats

available from ROADAPT_integrating_main_guidelines.pdf (cedr.eu)

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Threat description		Climate information			Vulnerability factors		Impact	
Threat main	Threat sub	Climate parameter (an increase of the mentioned variable will increase the possibility of the threat happening)	Unit	Time resolution for climate variable	Infrastructure intrinsic factors = road factors that contribute to vulnerability	Contextual site factors = surrounding factors that contribute to vulnerability	Duration of the threat when it has occurred until resume of normal operation	Time between realization that threat might happen and threat occuring (warning time horizon)
Flooding of road surface (assuming no traffic is possible)	flooding due to failure of flood defence system of rivers and canals, caused by snowmelt, rainfall in the catchment area, extreme wind	Temperature (in the catchment area)	number of days with average temperature above 0 °C	days	Road surface level (lower = higher vulnerability)	Rivers, canals, low lying areas	weeks - months	minutes - days
		Extreme rainfall events (long periods of rain in the catchment area)	mm/day	several days - week				
		Extreme wind speed, wind direction	m/second	hours-days				
	pluvial flooding (overland flow after precipitation, increase of groundwater levels, increase of aquifer hydraulic heads)	Extreme rainfall events (heavy showers)	mm/h	minutes - hours	Earthworks, bridges, culverts, drainage	Valley floors, low lying areas	days - weeks	hours - days
		Extreme rainfall events (long periods of rain)	mm/day	several days - week				
	Inundation of roads in coastal areas, combining the effects of sea level rise and storm surges	Sea level (rise)	cm	day	Road surface level (lower = higher vulnerability)	Coastal areas	days - weeks	days
		Extreme wind speed, wind direction (-> storm surge)	m/second	hours-days				
	Flooding from snow melt (overland flow after snow melt)	Temperature	number of days with average temperature above 0 °C	days-weeks	Culverts, ditches	Hilly and mountaineous areas, altitude, latitude	days - weeks	hours - days
Erosion of road embankments and foundations	Overloading of hydraulic systems crossing the road	Extreme rainfall events (long periods of rain)	mm/day	several days - week	Culverts	Valley floors, low lying areas	week - months	hours
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Thaw (for rapid ablation of snow)	°C	days				
	Erosion of road embankments	Sea level (rise)	cm	day(s)	Earthworks, culverts (higher vulnerability where culverts cross the road), road embankment materials	Valley floors, low lying areas	week - months	minutes - days
		Extreme wind speed, wind direction (-> storm surge)	m/second	hours-days				
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Extreme rainfall events (long periods of rain)	mm/day	several days - week				
	Bridge scour	Sea level (rise)	cm	day(s)	Bridges	Rivers, canals, low lying areas	months	hours - days
		Extreme wind speed, wind direction (-> storm surge)	m/second	hours-days				
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Extreme rainfall events (long periods of rain)	mm/day	several days - week				

Threat description		Climate information			Vulnerability factors		Impact	
Threat main	**Threat sub**	**Climate parameter (an increase of the mentioned variable will increase the possibility of the threat happening)**	**Unit**	**Time resolution for climate variable**	**Infrastructure intrinsic factors = road factors that contribute to vulnerability**	**Contextual site factors = surrounding factors that contribute to vulnerability**	**Duration of the threat when it has occurred until resume of normal operation**	**Time between realization that threat might happen and threat occuring (warning time horizon)**
Landslips and avalanches	External slides, ground subsidence or collapse, affecting the road (including eg. embankments aside the road)	Extreme rainfall events (long periods of rain)	mm/day	several days - week	Earthworks, pavements, drainage, foundation	Natural slopes, underground cavities, loss of vegetation	days - months	seconds - hours
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Drought (consecutive dry days)	(consecutive) days	multiple days-months				
	Slides of the road embankment	Extreme rainfall events (long periods of rain)	mm/days	several days - week	Earthworks, cut and fill slopes, retaining walls, embankment materials (clay/silt = higher vulnerability), slope angle (higher slope angle = higher vulnerability)	Hilly and mountaineous areas	weeks - months	seconds - minutes
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Drought (consecutive dry days)	(consecutive) days	multiple days-months				
	Debris flow	Extreme rainfall events (heavy showers)	mm/h	minutes - hours	Drainage, embankment vegetation, erosion protection works	Mountainous areas, loss of vegetation	days - months	seconds - minutes
	Rock fall	Extreme rainfall events (long periods of rain)	mm/day	several days - week	Manmade cracks: road cut/blasting, rock fall protection works	Mountainous areas	days	seconds - minutes
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Frost-thaw cycles (number of days with temperature zero-crossings)	number of days	days				
	Snow avalanches	Snowfall	mm/day	day-weeks	Distribution of avalanche protection works	Mountainous areas, avalanche tracks	days - weeks	seconds - days
		Frost-thaw cycles (number of days with temperature zero-crossings)	number of days	days				
		Temperature	mm/day	days-weeks				
Loss of road structure integrity	Impact on soil moisture levels (increase of watertable), affecting the structural integrity of roads, bridges and tunnels	Seasonal and annual average rainfall	mm/season mm/year	season-year	Pavements, bridges and tunnels	low lying areas, high watertable	days - weeks	days - months
		Sea level (rise)	cm	years				
		Extreme wind speed, wind direction (-> storm surge)	m/second	hours-days				
	Weakening of the road embankment and road foundation by standing water	Seasonal and annual average rainfall	mm/season mm/year	season-year	Earthworks, pavements	Rivers, canals, low lying areas	weeks	hours - weeks
	(Unequal) settlements of roads by consolidation	Drought (consecutive dry days)	consecutive days	multiple days-months	Pavements	soft ground layers	months	months
	Instability / subsidence of roads by thawing of permafrost	Thaw (number of days with temperature zero-crossings)	number of days	days	Pavements	frozen ground	days - weeks	days - months
	Uplift of tunnels or light weight construction materials by increasing watertable levels	Seasonal and annual average rainfall	mm/season mm/year	season-year	Tunnels, Deep lying sections, light weight materials	High watertable, soft soil	months	seconds - months
		Sea level (rise)	cm	day(s)?				
		Extreme wind speed, wind direction (-> storm surge)	m/second	hours-days				
		Extreme rainfall events (long periods of rain)	mm/day	several days - week				

Threat description		Climate information			Vulnerability factors		Impact	
Threat main	Threat sub	Climate parameter (an increase of the mentioned variable will increase the possibility of the threat happening)	Unit	Time resolution for climate variable	Infrastructure intrinsic factors = road factors that contribute to vulnerability	Contextual site factors = surrounding factors that contribute to vulnerability	Duration of the threat when it has occurred until resume of normal operation	Time between realization that threat might happen and threat occuring (warning time horizon)
Loss of pavement integrity	Cracking, rutting, embrittlement	Maximum and minimum diurnal temperature	˚C	days	Flexible pavements, type of surface and binder course, pavement age		days	days
		Temperature (heat waves)	number of consecutive hot days					
	Frost heave	Frost	˚C and number of days	days		Soft ground layers, high ground water table	weeks - months	days
	Aggregate loss and detachment of pavement layers	Frost	˚C and number of days	days	Flexible pavements, type of surface course, pavement age		days	days
	Cracking due to weakening of the road base by thaw	Frost-thaw cycles (number of days with temperature zero-crossings)	number of days	days	Pavements		weeks - months	days - weeks
	Thermal expansion of pavements	Maximum and minimum diurnal temperature and number of consecutive hot days (heat waves)	˚C and number of (consecutive) days	days	Concrete pavements		days	days
	Decreased utility of (unimproved) roads that rely on frozen ground	Frost-thaw cycles (number of days with temperature zero-crossings)	number of days	days	Unpaved roads		weeks - months	days - weeks
Loss of driving ability due to extreme weather events	Reduced visibility	Fog days	Number of days	day			hours - day	seconds - minutes
	Reduced visibility during snowfall, heavy rain including splash and spray	Snowfall or rainfall	mm/hour and mm/day	hour-day	Closed pavements (no porous pavements), presence of storm water runoff		minutes - day	seconds - minutes
	Reduced vehicle control	Extreme wind speed (worst gales and wind gusts)	m/second				hours - day	seconds
	Decrease in skid resistance on pavements from slight rain after a dry period	Drought (consecutive dry days)	consecutive days	multiple days-months	Pavements		minutes - hours	seconds - hours
	Flooding of road surface due to low capacity of storm water runoff	Extreme rainfall events (heavy showers)	mm/hour	minutes - hour	Closed pavements (no porous pavements), presence of storm water runoff		minutes - hours	minutes
	Aquaplaning in ruts due to precipitation on the road, splash and spray	Extreme rainfall events (heavy showers)	mm/hour	minutes - hour	Closed pavements (no porous pavements), presence of storm water runoff		minutes - hours	minutes
	Decrease in skid resistance on pavements from migration of liquid bitumen	Maximum and minimum diurnal temperature and number of consecutive hot days (heat waves)	˚C and number of (consecutive) days	days	bitumen		hours - days	minutes
	Icing and snow	Snowfall	mm/day	days			hours - days	seconds - hours
		Hail	mm/day	days				
		Frost and rainfall	˚C and mm/day	days				

Threat description		Climate information			Vulnerability factors		Impact	
Threat main	**Threat sub**	**Climate parameter (an increase of the mentioned variable will increase the possibility of the threat happening)**	**Unit**	**Time resolution for climate variable**	**Infrastructure intrinsic factors = road factors that contribute to vulnerability**	**Contextual site factors = surrounding factors that contribute to vulnerability**	**Duration of the threat when it has occurred until resume of normal operation**	**Time between realization that threat might happen and threat occuring (warning time horizon)**
Reduced ability for maintenance	Reduced snow removal planability	Snowfall	number of days	days-season			day - months	weeks - months
	Reduced ice removal planability	Frost	˚C and number of days	days			day - months	weeks - months
	Impact on shoulder maintenance: increased vegetative growth	Temperature	˚C	days	shoulder vegetation		days - weeks	days
	Impact on road works: decreased time window for paving	Maximum and minimum diurnal temperature and number of consecutive hot days (heat waves)	˚C and number of (consecutive) days	days	Pavements		days - weeks	days
Pollution aside the road after incapacity of storm water runoff system of the road		Extreme rainfall events (heavy showers)	mm/hour	minutes - hour	Closed pavements (no porous pavements), presence of storm water runoff, shoulder vegetation		minutes - hours	seconds - hours
Susceptibility to wildfires that threaten the transportation infrastructure directly		Drought (consecutive dry days)	consecutive days	multiple days-months		Forest cover	hours - days	hours - days
Damage to signs, lighting fixtures, pylones, canopies, noise barriers and supports		Extreme wind speed (worst gales and wind gusts)	m/second	seconds-hours	Signs, lighting fixtures, pylones, canopies, noise barriers, supports		hours - weeks	seconds - hours
Damage to energy supply, communication networks (eg. pylones) and/or matrix boards by wind, snow, heavy rainfall and/or lightning		Extreme wind speed (worst gales and wind gusts)	m/second	seconds-hours			days - weeks	seconds - hours
		Snowfall	mm/day	days				
		Extreme rainfall events (heavy showers or long periods of rain)	mm/day	hour to days				
		Lightning	number of discharges	hour to days				
Trees, wind mills, noise barriers, trucks falling on the road		Extreme wind speed (worst gales and wind gusts)	m/second	seconds-hours	Noise barriers	Trees, mills	hours - day	seconds - hours

10.1.6. Possible sources of meteorological and climatic information

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The Intergovernmental Panel on Climate Change (IPCC)

The IPCC is the United Nations body for assessing the science related to climate changes. Researchers from all over the world evaluate scientific literature and comprise new research into the main reports. This contributes to better knowledge on climate changes, both natural and anthropogenic, the impact and possibilities of adaptation and reduced emissions of greenhouse gasses. The latest main report is the IPCC sixth assessment report (AR6).

The IPCC climate projections are seen to be reliable and transparent. The IPCC provide a global overview of climate change projections that can be generated from a range of different emission scenarios. IPCC has identified some relevant scenarios that can be used in the projections. The IPCC have compared a large number of climate models and some of these provide national-scaled projections which can be used.

IPCC projections may however be of limited value for some 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.

In order to reduce the uncertainties of the climate projections, some use meta-models, model ensembles and/or a comparison of the output of climate models.

The FORESEE project: "The assessment of existing climatic databases"

In project document D 4.1 from the FORESEE project, an extensive review of climatic databases is presented. European databases that could be used to analyse the effects of extreme weather events on transport infrastructures were prioritised. They provide high frequency information as well as an adequate spatial resolution.

Three different types of databases were included in the analysis:

- Instrumental: Pluviometric and meteorological station information, which constitutes the best representation of perceived weather. This will be the primary source of information for any analysis.
- Satellite: Satellite information presents biases that need to be accounted for, but it provides areal coverage that serves to properly include the spatial structure of the hydrometeorological variables.
- Numerical models: Numerical models do not normally capture the small-scale dynamics of climate, but they constitute an essential tool to study climate variability in decennial time scales.

The report is available online:

https://foreseeproject.eu/wp-content/uploads/2020/03/D-4.1-Assesment-of-existing-climate-databases-_FINAL.pdf

Climate Projection Database for Roads (CliPDaR) [104]

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.

The scope of CliPDaR was to identify and describe climate change risks on the European road networks. It was essential to assess the uncertainty and reliability of given climate projections by using ensemble approaches and downscaling methods. CliPDaR reviewed and analysed existing approaches and methodologies in some European countries, discussed their differences and - in close cooperation with the road owners - developed a common line on future applications of climate projection data to road impact models.

CliPDaR established some guidelines that are used in the field of road maintenance to decide which methods and scenarios to apply for the adaptation measures. Based on regional scale climate change projections specific road-impact models are used to identify protection measures.

Source: CEDR, 2014.

Interactive Atlas: Regional information

As a contribution to the IPCC sixth assessment report, Working Group 1 developed an Interactive Atlas with spatial and temporal analyses of much of the observed and projected climate changes. The Interactive Atlas provides information from observations and model simulations for paleoclimate, recent-past and future periods. One can choose between a simple and an advanced interface. With this tool, the user can select to see results from various models and scenarios, at different time scales and in different regions. The results, such as precipitation and temperature changes, can be downloaded.

Source: https://interactive-atlas.ipcc.ch/

Coordinated Regional Climate Downscaling Experiment (CORDEX)

Global climate models can provide reliable predictions on spatial scales of about 1000 km, meaning that local effects are lost. Regional downscaling provides projections with greater detail and more accurate representation of local events. The downscaling techniques, application and the community using downscaling are broad and varied.

The CORDEX is a global partnership aiming to help bridge the gap between climate scientists and users of projection data, as well as advance and coordinate the science and application of regional downscaling. The project evaluates climate model performance and produce high resolution climate projections for use in impact and adaptation studies for the entire globe.

The goals of CORDEX are to

- better understand relevant regional/local climate phenomena, their variability and changes, through downscaling
- evaluate and improve regional climate downscaling models and techniques

- produce coordinated sets of regional downscaled projections worldwide
- foster communication and knowledge exchange with users of regional climate information

Source: CORDEX and EURO-CORDEX website - http://www.cordex.org/about/ and https://www.euro-cordex.net/index.php.en

[GFCS | Global Framework for Climate Services (wmo.int)]

GFCS's vision is "To enable better management of the risks of climate variability and change and adaptation to climate change, through the development and incorporation of science-based climate information and prediction into planning, policy and practice on the global, regional and national scale."

Climate Change Knowledge Portal (CCKP)

The climate change knowledge portal (CCKP) is a collection of climate data and information. The CCKP is a resource to explore and analyse global, national and regional climate data. The climate data (temperature and precipitation) are presented on map views and as graphs. The portal gives access to global, national and regional climate projections with various scenario and models. The data can be downloaded. The CCKP is a useful tool for decision-makers to evaluate and analyse climate variability for the region and time period of interest.

[Home | Climate Change Knowledge Portal (worldbank.org)]

10.1.7. Examples of internal documents or systems where the impact of climate change should be included

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- General transport strategy, defining the challenges, priorities etc,
- Urban planning strategies, where relevant,
- The organisation may have implemented a Corporate Risk Management or/and Project Risk Management,
- Collaboration networks that might have been developed for other purposes. Informal communities of interest across staff and organisational structure,
- Collective action plan to include all stakeholders (internal and external) with clear roles and responsibilities,
- the overall infrastructure lifecycle and project lifecycle system (assess, select, develop, deliver, operate) this can tell you where you can intervene,
- Design rules. Amendments of design rules are a way of ensuring resilience,
- Network surveillance, audits, and deficiency criteria = any existing periodical survey where the aspect of climate change could be added,
- Any existing routine or system for managing natural hazards (in today’s climate). Warning systems and Road Weather Information Systems (RWIS) for road users and operators are very useful for increasing the adaptability of the road network,
- Monitoring systems to record and track events and consequences.

10.1.8. FHWA – suggested list of key actors /stakeholders (2018)

Back

The Federal Highway Agency (FHWA, 2018) suggests a possible list of key actors that can participate in a climate change assessment, who can provide relevant guidance and expertise:

- Transportation planners are responsible for long-range planning of the transportation system and regularly use scenario planning and other tools for planning long-term investments and policies in the face of uncertain futures.
- Asset managers are familiar with the conditions of transportation infrastructure and may have relevant datasets.
- District-level staff and maintenance personnel have on-the-ground familiarity with and institutional knowledge of how current and past weather events affect transportation assets, and what is needed to maintain and operate the system.
- Emergency responders (e.g., fire and police departments and emergency response staff within DOTs) provide rapid response to natural disasters and are familiar with evacuation routes and other operational needs during severe weather events.
- Engineers (e.g., structural, hydraulic, coastal, or other relevant disciplines) can provide input into the sensitivity of infrastructure to climate impacts and propose ideas for and anticipated costs of adaptation solutions.
- Transportation systems management and operation staff have knowledge about how climate and extreme weather can impact traffic congestion and traveller safety, and what is needed to minimise service disruption, delay, and crashes in such situations.
- Geographic Information System (GIS) specialists can spatially analyse and display transportation assets and vulnerability information.
- State level environmental staff (e.g., DOT environmental staff and State environmental agency staff) can provide insight into how projected changes might impact ecosystems and the benefits ecosystems provide. Environmental or natural resource organisations may have access to local datasets or knowledge of climate change research conducted by other organisations that can be useful for the transportation study.
- Governmental and university climate science research centres can provide targeted, geographically focused climate projections.
- State climatologists can provide information and insight on historical climate data and trends and, in some cases, future projections.
- Municipal government staff can provide information on assets within their jurisdiction and have staff with expertise in a variety of areas relevant to the vulnerability assessment, such as emergency management and roadway maintenance.

10.1.9. 2015 PIARC Framework – Communication plan – Main points

Back

Aims and Objectives

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.

The objectives of this communications plan and likely objectives of a road organisation communication programme, campaign or initiative include:

- Raising awareness of current and projected climate change and extreme weather impacts on highways, based on scientific evidence;
- Raising awareness about the need for proactive action to minimise the risks from climate change and extreme weather impacts, and the benefits of early adaptation to these impacts;
- Highlighting the actions road authorities are currently undertaking/proposing/planning to address CC effects, while emphasizing stakeholder partnership and collaborative efforts;
- Encouraging behavioural changes among users that can reduce climate change-related risks;
- Communicating the opportunities posed by climate change upon highway networks to decision makers, managers etc.

Communication 'Must Haves'

Regardless of the intendent audience, a communication plan or strategy should include the following sections:

- Introduction: clearly state the purpose of the communication, such as raising awareness of climate change and impacts.
- Background information: set the context for the reader, outline the current risks of climate change and the potential consequences of not adapting.
- Current situation: provide an overview of the current situation and any progress made in climate change adaptation.
- Required actions: outline necessary actions to move forward with adaptation measures and building resilience.

Developing a Communications Action Plan

For a successful communications plan, various measures and actions are likely needed. As such, it is advised to develop an action plan as a dynamic document with regular reviews and updates. An Action Plan template might include the following elements:

Start Date	Progress	Last Progress Report	End Date	Projected Cost	Primary Contact	Priority	Campaign	Key Themes/ Messages	Target Audience
Provide starting date of programme, campaign, or initiative's inception	*Is the programme, campaign or initiative complete, ongoing, on hold or yet to begin?*	*When was the progress of the programme, campaign or initiative last reported to relevant stakeholders?*	*When is the programme, campaign or initiative expected to end?*	*What is the projected cost of the programme, campaign or initiative?*	*Who is the primary contact who is responsible for the delivery of the programme, campaign or initiative?*	*What level of priority has been assigned to this programme, campaign or initiative?*	*Please give details relating to the programme, campaign or initiative*	*What is the key theme and/or message which the programme, campaign or initiative is trying to convey? (In relation to identified motivators or barriers)*	*Who is the target audience for the programme, campaign or initiative?*

10.1.10. Definitions of criticality

Back

Criticality is defined by the All-Hazard Guide for Transport Infrastructure (2016) [105] as "*the relevance of an infrastructure element or section to the availability of a road infrastructure system"*. Additionally, a critical asset is defined in the NCHRP Project 20-05, Synthesis Topic 48-13: *Resilience in transport planning, engineering, management, policy and administration, as assets, that if lost or damaged, would severely degrade or curtail an owner's ability to perform core functions or its mission*.

Critical infrastructure is also defined by Commonwealth of Australia (2015) as, "those physical facilities, supply chains, information technologies and communication networks which, if destroyed, degraded or rendered unavailable for an extended period would significantly impact the social or economic wellbeing of the nation or affect Australia's ability to conduct national defence and ensure national security" [106].

10.1.11. Functional criticality

Back

Cerema report (2015) [28] lists the following functions of a network:

- Essential transport functions: this category includes movements that must be possible at all times and at all costs, especially if a hazard occurs. This includes access for rescue services, medical services, firefighters, the police, the evacuation of persons, military transport, etc. This is essentially an issue linked with connectivity. It must be possible to reach anywhere from anywhere, given that the solutions providing this connectivity may include barring access to the transport networks to other users, the design and use of special vehicles, the use of other modes of transport, etc.
- Service or accessibility functions: this category includes movements involving essential services, such as access to food, health services, etc. Substitutes are available for these movements. For example, if one food store becomes inaccessible for people living somewhere, but another food store is available, then there is no particular problem. On the other hand, if all the stores become inaccessible, then the consequences can quickly become very serious.
- Regular travel functions: this category includes all the movements of persons and goods that contribute to the workings of society and particularly the economy. The function of a transport network is to allow these movements to be made under good conditions and ensure safety. From the users' perspective (passengers and goods carriers), a loss of performance of the transport network results in travel time delays, the need to postpone or reorganise travel, or to defer activities and to transfer these activities to a site other than the preferred site, or even to cancel them. In a supply chain, this can result in breakdowns in supplies, with economic consequences that go as far as bankruptcy, and, therefore, job losses.

10.2. Appendix to Stage 2

10.2.1. Vulnerability – other definitions

Back

There are several definitions of vulnerability /ref. Briefing note:

The degree to which a system is susceptible to, or unable to cope with, adverse effects of hazards, including climate change, variability, and extremes (PIARC Framework, 2015).

The conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. (UNDRR)

The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. (Sendai Framework 2015).

ISO 14090 defines vulnerability as “propensity or predisposition to be adversely affected”, with added note: Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. (Adapted from IPCC, 2014)

The Fourth Assessment Report of the IPCC (AR4) refers to vulnerability as: ‘(…) the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity’ (Parry et al. 2007).

"Vulnerability to climate change describes the degree to which a system – an ecosystem, an economic system or a social system – is endangered by climate changes"
In Guidelines for Climate Impact and Vulnerability Assessments (Buth et al., 2017) [52]

10.2.2. Sensitivity – Asset categories, example

Back

Drainage systems are generally sensitive to precipitation patterns. But a drainage structure that is poorly maintained is probably more sensitive. In this case, the level of maintenance is an aggravating factor.

10.2.3. Adaptive capacity – definitions

Back

In the PIARC Framework (2015), adaptive capacity is defined as "the ability or potential of a system to respond successfully to impacts of environmental (often climate) variability and change, and includes adjustments in both behaviour and in resources and technologies".

This is very similar to the 2007 IPCC definition. Another perspective is provided with "*adaptive capacity is the ability of a system to adjust and moderate potential damages and cope with consequences*" (Hughes and Healey, 2014) [107]

« Adaptive capacity is the property of a system to adjust its characteristics or behaviour, in order to expand its coping range under existing climate variability, or future climate conditions. »

https://www4.unfccc.int/sites/NAPC/Country%20Documents/General/apf%20technical%20paper07.pdf

The IPCC's AR4 describes adaptive capacity as 'the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences' (Parry et al. 2007).

According to The European Climate Adaptation Platform Climate-ADAPT, adaptive capacity refers to « the ability of a (human) system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences ». Adaptive capacity is a function of available financial recourses, human resources and adaptation options, and will differ between risks and sectors.

10.2.4. Adaptive capacity

Back

FW2015:

When assessing adaptive capacity the following questions should be asked [96]:

- **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. It is useful to quantify or categorise the varying levels of adaptive capacity. An example of potential groupings is shown below [9]:

- **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 organisation'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 organisation'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 organisation'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.

10.2.5. "Unknown unknown" events and deep uncertainty

Back

Some may wonder about whether in identifying the most relevant and critical events thought should be given to preparing for unknown events or for decision making under deep uncertainty.

Unknown unknown events are also commonly known as Black Swan events. They are typically a surprise at least to an observer. Black Swan events occur despite any preparations or precautions and are often characterised as leading to catastrophic consequences although this is not necessarily so, given the Internet and cell phones can be considered Black Swan events. Notwithstanding, they are very rare events often with widespread impact and cannot be predicted beforehand to the observer although may seem obvious with the benefit of hindsight.

The best means to deal with Black Swan events may be to simply recognise them as unpredictable, inevitable outliers that can not be address in detail, and that the next Black Swan outlier will be very different from the last. Some thought and effort is still warranted in seeking to reduce the unknown-unknown space by improving knowledge, broadening experience, expanding perspectives and keeping vigilant to changes in circumstances, whilst still acknowledging that surprises will still occasionally occur – there is always risk and error in our systems and information.

Deep uncertainty occurs when it is not possible to assign probabilities to a risk or unknown space. It can be expanded to also capture the problem where it is practically impossible to determine the probability distribution in the time available before some action is needed. Additionally, it may not be possible to undertake research or study to determine the probabilities.

To deal with this situation, an approach can be to not try to assign the probabilities, and instead construct a series of scenarios (perhaps focused on points of interest in the probability field), and undertake as full analyses as possible within the scenarios. The results and discoveries from the analysis will assist the decision-makers to form a picture of the potential outcomes without needing the probability of each scenario. The process should consider multiple futures in which the unknown probabilities would be placed, and the best, most robust plans are the ones which result in acceptable risk profiles over multiple futures and scenarios. Typically plans which are flexible and adaptive deal best with the variety of risks potentially being assessed.

10.2.6. Unknown, uncertain, concurrent, and cascading events

Back

In risk management, there are two types of unknown factors for disruptive events: the unknown known and the unknown unknown. Both relate to the road organisation not being aware of the factors or event. The unknown known situation has knowable characteristics but the analyst, whilst potentially aware of the situation, simply is not aware of the features or characteristics or potential outcomes. Knowledge of and associated information for the range of hazard impacts of climate change are an example. This could theoretically be addressed with further work collecting more data, evidence and knowledge of the poorly understood system.

The unknown unknown is an area of complete ignorance for the analyst, who is not aware of the potential system, peril or outcome. These unknown unknowns are events which are unidentified, not recognised or obscure, and can be called Black Swan events. These are very important to recognise, as they result in surprises which can be very difficult to respond or adjust to in an emergency. One means of seeking to minimise the size of unknown unknowns in a system is to seek input from as many experts from as wide a range of specialities and sectors as possible, as well as ongoing scanning of the context and future.

When analysing the probabilities of events of interest, it is important to remain alert to the possibilities of unknown events and risks.

Uncertainties are those variables which are recognised but the exact detail is not known and often could be characterised by a range of potential outcomes (potentially with associated probabilities). They can relate to both probability and consequence, and the focus of the uncertainty can be either or both. For example, there may be uncertainty about the probability of a rainfall of 50mm in a 24-hour period; or there may be uncertainty about the 0.01 AEP for a 24-hour period. Irrespective of how much information and data is collected to refine the distributions of potential outcomes, which outcome occurs will almost never be known until it occurs – this could be related to the difference between predictions which state what will happen in the future and projections which provide a potential future result usually with a distribution of possibilities. Nevertheless, to best address uncertainties around probabilities, more data and information is needed to improve the confidence/reduce the uncertainty in the distributions used.

An important matter to recognise in developing information for use in the probability assessments for events of interest is the limitation of using projections for the future based on past records or events. Climate change is probably the strongest current example of this – the changes in climate over the past 20 or 50 years are not the same as best science is indicating as the likely changes over the next 20 or 50 years. In some situations, the difference is likely to be acceptable and within the bounds of variabilities, but in all situations, care should be taken.

This raises the issue of analysis needing to consider how to deal with moving probability and probability distributions. Recognition is needed of changing probabilities through time. In the climate change context, the need for a distribution or range of probabilities in the future can be seen in the range of RCP's (Representative Concentration Pathway, now being replaced by SSP's - Shared Socioeconomic Pathway) used in the IPCC projections and reporting. However, it should also be recognised that it may not be needed for variables where the changing context is same for counterfactual/base case and the options.

Once the direct impacts have been dealt with, additional consideration should be given to the potential impacts and consequences from compounding events and cascade failures. Without including these in the assessment, a significant proportion of the potential costs (and benefits from resolving them) may be overlooked in the analysis and related decision-making.

Compounding events essentially relate to the concurrent or closely following series of events which could occur in at least three situations:

- extreme events happening at the same time or within close time so that only limited response has been possible for the first event
- an extreme event which occurs in combination (concurrently) with a background event which exacerbates the extreme event impacts, such as a high tide occurring as a flood front arrives near the ocean
- the amplification of a number of "less than extreme" events which in combination cause extreme event level impacts.

Cascade failures could be described using the metaphor of falling dominoes – one action/failure causes a follow-on action/failure of another asset or system. It can also result in a branching tree structure of failures which diverge from one another, but all add to the total impact of an originating event. One of the opportunities that occurs with tracking a cascading failure tree is the increased range of potential responses which may also address multiple failure escalation pathways concurrently.

Once the direct effects of a hazard event have been considered, thought should be given to whether wider matters and effects should be or could be included in the assessments. To some degree how far these matters can be pursued will be driven by availability of reliable or suitable data and information to allow analysis of these potential effects on a wider basis; and whether they are matters of import to the Road Organisation.

These wider areas of potential assessment include the effects on other utility providers (water supply, gas supply, telecommunications, electricity lines, etc.) or sensitive environmental areas (e.g., sensitive to flooding, contamination, severance, etc.). Thought should be given to these secondary effects, such as who or what else one-step away from the transport system could be affected.

This area of assessment could also uncover additional impacts and consequences on the transport system due to interdependencies between the transport system and the other related systems and utilities under investigation.

It is worth engaging with these utility providers, as they may

- have already undertaken their climate change assessments which could be shared with the road organisation
- be keen in engaging and supporting the road organisation project for mutual benefit
- be willing to share the data and information to improve what is available for the severity/impact assessment

10.2.7. Interdependent impacts, compounding, and cascade failures

Back

Once the direct effects of a hazard event have been considered, thought should be given to whether wider matters and effects should be or could be included in the assessments, such as interdependencies with other utilities and services, compounding events or cascading failures. To some degree this will be driven by availability of reliable or suitable data and information to allow analysis of these potential effects on a wider basis. These wider areas of potential assessment include the effects on other utility providers (water supply, gas supply, telecommunications, electricity lines, etc.) or sensitive environmental areas (e.g., sensitive to flooding, contamination, severance, etc.). Thought should be given to these secondary effects, such as who or what else one-step away from the transport system could be affected.

This area of assessment could also uncover additional impacts and consequences on the transport system due to interdependencies between the transport system and the related system under investigation.

It is worth engaging with these utility providers, as they may

- have already undertaken their climate change assessments which could be shared with the road organisation
- be keen in engaging and supporting the road organisation project for mutual benefit
- be willing to share the data and information to improve what is available for the severity/impact assessment

Further key areas of consideration in the Severity Assessment once the direct impacts have been dealt with are the impacts and consequences from compounding events and cascade failures. Without including these in the assessment of the impacts from a natural hazard, a significant proportion of the potential costs (and benefits from resolving them) may be overlooked in the analysis and related decision-making.

Compounding events essentially related to the concurrent or closely following series of events which could occur in at least three situations:

- extreme events happening at the same time or within close time so that only limited response has been possible for the first event
- an extreme event which occurs in combination (concurrently) with a background event which exacerbates the extreme event impacts, such as a high tide occurring as a flood front arrives near the ocean
- the amplification of a number of “less than extreme” events which in combination cause extreme event level impacts.

Cascade failures have been thought about using the metaphor of falling dominoes – one action/failure causes a follow-on action/failure of another asset or system. It can also result in a branching tree structure of failures which diverge from one another, but all add to the total impact of an originating event. One of the opportunities that occurs with tracking a cascading failure tree is the increased range of potential responses which may also address multiple failure escalation pathways concurrently.

10.2.8. Consequence categories

Back

Example of template for quantitative assessment of direct transport system costs with possible indicators

Category	Insignificant (1)	Minor (2)	Moderate (3)	Severe (4)	Extreme (5)
Number of affected vehicles	$< X_1$	$< 5\ X_1$	$< 20\ X_1$	$< 75\ X_1$	$> 75\ X_1$
Number of vehicle – hours delayed	$< X_2$	$< 5\ X_2$	$< 20\ X_2$	$< 75\ X_2$	$> 75\ X_2$
Total duration of disruption	$< X_3$	$< 5\ X_3$	$< 20\ X_3$	$< 75\ X_3$	$> 75\ X_3$
Number of disrupted routes	$< X_4$	$< 5\ X_4$	$< 20\ X_4$	$< 75\ X_4$	$> 75\ X_4$
Repair cost ($)	$< X_5$	$< 5\ X_5$	$< 20\ X_5$	$< 75\ X_5$	$> 75\ X_5$
Lost depreciation cost of replaced assets	$< X_6$	$< 5\ X_6$	$< 20\ X_6$	$< 75\ X_6$	$> 75\ X_6$
Depreciated value of lost or irreplaceable assets	$< X_7$	$< 5\ X_7$	$< 20\ X_7$	$< 75\ X_7$	$> 75\ X_7$

Examples of standard consequence tables for semi-quantitative indirect transport system cost assessment levels are defined below.

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
Funding impact (repair cost)	Less than $1m	Less than $10m	Less than $100m	Less than $250m	More than $250m
People and employees	Employees within a local works/depot affected	Employees within a 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

The following table is an example of scales of consequences for damage categories.

Category	Measure	Insignificant	Minor	Moderate	Severe	Extreme
Management Effort	Required marginal time and effort to manage issue, event or crisis	No marginal effort, managed through BAU processes.	Minor marginal effort, managed through BAU processes.	Some marginal time and effort required to prevent or manage.	Extensive senior management attention to manage issues OR prevent or manage a crisis.	Management attention diverted entirely to crisis managem.
Reputation	Overall reputation impact (Transport Agency level)	No noticeable impact.	Limited impact.	Short-term, at regional level.	Short-to-medium term, at national level.	Long-term, at global, national or regional level.
	Media coverage	Local, max 1 day	Local, 1-5 days	Local / national, multiple days	Sustained coverage (weeks)	Sustained national and/or any international coverage
	Stakeholder relationships	Minor disagreement with stakeholder/customer/ community groups	Isolated relationship issues with stakeholder/customer/ community group	On-going relationship issues with stakeholder/customer/ community groups	Strained relationships with stakeholder/customer/ community groups requiring independent arbitration	Breakdown in relationships with external groups resulting in public impasse

Service Delivery (Processes / Outputs)	Impact on ability to provide or maintain infrastructure and/or services	Infrequent and inconsequential disruption.	Temporary disruption - localised level	Inability to provide core infrastructure - localised level	Inability to provide key infrastructure / services - widespread.	Inability to provide or key infrastructure and/or services for significant periods of time.
Financial Impact	Cost versus Business Unit / team budget OR revenue impact	< 5%	5 - 10%	10 - 20%	20 - 30%	> 30%
Health and Safety (Staff and Contractors)	As stated	Injury requiring short term first-aid care and no absence from the workplace	Injury requiring short term medical treatment and workplace absence less than one day	Injury requiring medical treatment or lost time of 1 day to three weeks	Serious injury (injuries) requiring specialist medical treatment or lost time greater than three weeks	Loss of life, permanent disability or injury, or multiple serious injuries
Environmental	As stated	Small scale pollution or other environmental damage is localised with no resultant effects. Contained locally.	Small amount of pollution or other environmental damage. Short term effects only.	Pollution or other environmental damage at a localised level, with medium term effects.	Significant and widespread pollution or other environmental damage, with long term effects.	Permanent pollution damage or other environmental damage.
Security	As stated within renewal lifecycle of operation	>0.2% likelihood of failure of cyber or physical security operations due to natural hazard event	>1% likelihood of failure of cyber or physical security operations due to natural hazard event	>5% likelihood of failure of cyber or physical security operations due to natural hazard event	>20% likelihood of failure of cyber or physical security operations due to natural hazard event	>50% likelihood of failure of cyber or physical security operations due to natural hazard event

10.2.9. Risk Analysis Discussion

Back

It is important to note that often the words ‘threat’ and ‘risk’ are often used interchangeably across literature. However, risk is not a synonym of threat. Although closely related, the two are significantly different. A threat (often external to an asset or system and is tangible) is something that can impact a vulnerability, intentionally or accidentally and cause damage or disruption. A natural hazard could be considered a threat. In many circumstances a ‘threat’, or threats will provide a source for one or more risks. A threat is what road organisations trying to protect against. It is the interaction between the threat and someone or something, at a particular instance or over a period of time that will create the risk. Threats may exist, but not pose a risk.

In a similar vein in defining Risk Analysis, the UN Development Programme comments that Risk Analysis is “an assessment of the nature and extent of such risk, by analysing hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend.”

The Briefing Note also recognises Risk Evaluation (also ISO 2009) as a “Process of comparing the results of risk analysis against risk criteria to determine whether the level of risk is acceptable or tolerable.”

Consultation on developing and application of the Risk Analysis is suggested amongst relevant and responsible groups and associate stakeholders, as it will provide agreement and perspectives on the results of the base case analysis from which everything else subsequently will hinge.

10.2.10. Community Resilience

Back

Recent work [63], supported by the findings of the EU-funded project Search and Rescue, has proposed a 4-step approach for narrowing down and harmonizing the 'community resilience' (www.search-and-rescue.eu), see figure below.

1. Clearly setting the scope and context of the project/system in order to establish a common and agreed understanding among involved partners and stakeholders (is this project just looking at the transport system operation and condition, or the impacts on the services provided to the community through it support of strategic social and economic infrastructure?). This step also aims at limiting the factors to be considered to those that are clearly linked with the project/study objectives.
2. Enhance the established collective knowledge by identifying the fundamental attributes that are most applicable to the project/system. A combination of top-down (e.g. literature search) with bottom-up (e.g. case studies) should maximise the benefits of comparing across different units of analysis with the local particularities, information and knowledge offered by the local 'community'.
3. An important step for the purposes of an efficient and clear project is to clearly link the identified 'community resilience' attributes with the 'community' needs.
4. The final step consists of identifying the gaps and user/'community' requirements so as to prioritise their needs and target 'resilience' enhancement actions by also having these recommendations validated by the concerned 'community'/stakeholders.

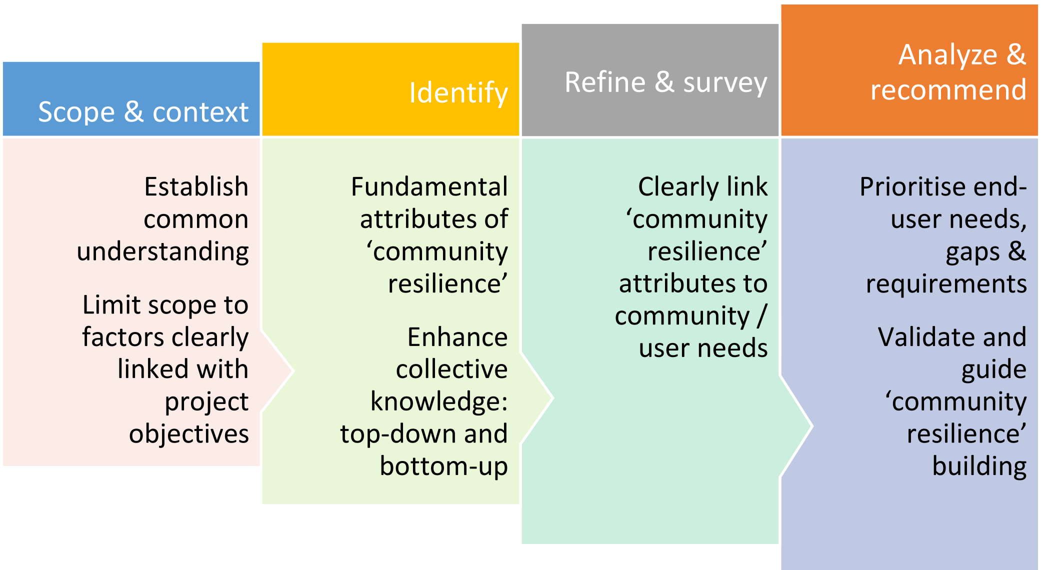


Figure. Proposed approach for establishing a commonly agreed 'community resilience [64]

It should be noted that the aforementioned proposed approach does not aim at quantitatively or qualitatively establishing or measuring some pre-defined 'resilience' metric. It rather proposes an approach for establishing a stakeholder understanding and agreement on basic principles and definitions and then provide the relevant targeted insights so as these can be duly considered in the adopted 'resilience' quantification approach or method [65], [66].

10.3. Appendix to Stage 3

There are no appendices to Section 3.

10.4. Appendix to Stage 4

10.4.1. Guidelines BAST Germany

Back

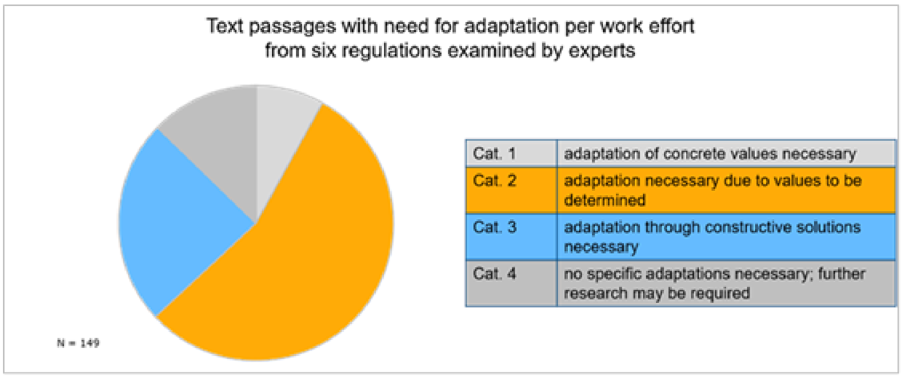
The Federal Highway Research Institute (BASt) in Germany conducted a review of standards and regulations in the road sector regarding their need for adaptation to climate change. This analysis was initiated by the former Federal Ministry of Transport and Digital Infrastructure (now: Federal Ministry for Digital and Transport) and aimed to comprehensively address climate changes in the regulatory revision.

In Germany, the majority of the investigated standards and regulations are from the FGSV (Road and Transportation Research Association). Other institutions drafting standards and regulations are e.g. the Federal Ministry for Digital and Transport (BMDV), the Federal Highway Research Institute (BASt), the German Association for Water, Wastewater and Waste (DWA), the European Committee for Standardisation (CEN) and the German Institute for Standardisation (DIN).

For the review two approaches were implemented. First, a syntax-based, partially automated keyword search. Second, an expert-based search. Overall, around 900 standards and regulations were identified. The syntax-based, partially automated keyword search was a purely quantitative search for keywords such as rain, precipitation, runoff, heat, wind and many more. Since a fully automated search was not feasible for the FGSV regulations, a search in three exemplary regulations was made. These regulations are the fact sheet for winter road maintenance, the so-called RAS-Ew (guidelines for road drainage) and the so-called RDO asphalt (guidelines for the superstructure of traffic areas with asphalt surface coating). The expert-based search comprised a quantitative and qualitative identification of climate-relevant text passages.

The qualitative identification was performed by dividing text passages into four categories depending on the information or data that needed adaptation. Text passages assigned to the first category required an adaptation of concrete values. The second category needed values to be determined. The third category referred to adaptations which are related to constructive solutions. Assigning passages to the fourth category meant that no specific adaptations are necessary or further research may be required. The four categories correspond with a different expected work effort. Adapting text passages of the first and fourth category is associated with a relatively low work effort while the adaptation of passages assigned to the third and in particular the second category is expected to be much more time- (and labour-) intensive.

It has been found that for 257 of the 900 investigated standards and regulations the need for adaptation is likely. From these 257 standards and regulations, exemplary text passages selected by experts have been further examined to estimate the work effort associated with their adaptation. The results show that only a relatively small share (21 % in total) of text passages can be assigned to the first and fourth category and therefore to a relatively low work effort. 24 % can be assigned to the third category and more than half (55 % in total) of the selected text passages can be assigned to the second category and therefore to a high work effort (see figure below).



Overall, the review of standards and regulations in the road sector shows that only 20 % do not need to be adapted. It also became clear that the precise determination of the workload related to the adaptation of text passages is complicated by the fact that there is a large share of standards and regulations for which the need for adaptation is unclear. To account for an efficient coordination process when adapting standards and regulations, it is recommended to interlink adaptations with regular revision processes of relevant reports, e.g. publications by the IPCC.

10.4.2. Guidelines Norway

Back

The Norwegian Public Roads Administration is responsible for developing and maintaining manuals for design and practice for all road owners. As a start of the adaptation work, the organisation carried out a qualitative impact assessment of climate (change) on the road network and identified the main hazards, vulnerabilities, and potential consequences.

Amending design rules to incorporate current knowledge on the impact of climate change was one of the main adaptation measures to be implemented. Keeping the manuals of design and practice updated is a continuous task.

The amendments of regulations for design and practice dealt with:

- ensuring flood-proof elevation of new roads
- ensuring sufficient drainage capacity
- including sea level rise in regulations, regarding elevation of coastal roads and erosion protection
- including natural hazards in risk analyses in the planning phase
- providing vulnerability maps for operation contracts
- adjusting courses for contractors, originally planned for avalanche risk management to incorporate other hazards
- adjust the risk assessment on existing roads to include considerations of future climate.

All regulations concerning water management and erosion were done in cross-sectorial collaboration (here, with the Energy and water resources Directorate).

10.4.3. Road User Perspective

Back

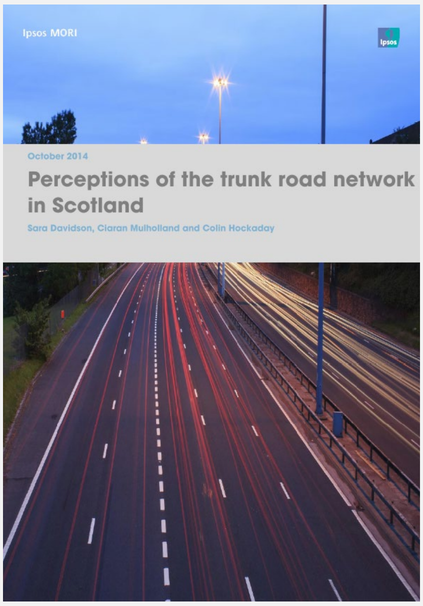
A research project carried out at Deltares and Eindhoven University [78] also mentioned in 3.3.6, bases its method to quantify the current level of resilience on analysing the users' perspective.

«Is this resilient enough? including users' acceptance levels into the critical infrastructure resilience assessment », Master thesis Anoek S.E. de Jonge, 2021.

Available from https://research.tue.nl/nl/studentTheses/is-this-resilient-enough

Transport Scotland [FW2015]

Transport Scotland undertakes an annual survey that looks at road user perceptions of their road network [108]. 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.



10.4.4. Examples from FW2015 - Business cases for adaptation to CC

Back

A. The Business Case for Action on Climate Change, Welsh Government 2019

The guidance "*The Business Case for Action on Climate Change*" [109], issued by the Welsh Government: Public Sector in 2019, suggests five considerations that authorities should bear in mind:

- **Be Selective:** Only look for the organisation or organisational partner's business case, and choose the benefits to build the business case around carefully; to build credibility for the case be sure to include known win-wins with quick returns alongside longer term priorities.
- **Challenge the Status Quo** Identify and interrogate the assumptions that make 'business as usual' in public sector planning and decision-making seem more attractive for the time being, and don't be put off by any previous weak business case.
- **Take Control of Risk:** Ensure the case takes into account risks that public sector organisations across Wales are already being exposed to from climate change, from local authorities through to the Welsh Government. This creates a benchmark for action that is difficult to dismiss.
- **Go Beyond the Case Itself:** A business case by itself is not always enough; consider whether there is also a need to actively influence decisionmakers involved, whether it's the person who looks after a specific issue related to the project, or another public sector organisation that may be affected.
- **Link Policy and Delivery:** Ensure that the case is aligned with public sector priorities and supports the organisation to deliver on what civil society and stakeholders expect in the short term.

B. IEMA, 2013

The Institute of Environmental Management and Assessment (IEMA, 2013) developed a guidance: *'Climate Change Adaptation: Building the Business Case'*. This guidance provides information for environment and sustainability practitioners and identifies a number of key principles in building a business case. More information online: www.iema.net

C. Innovate UK 2014

To strengthen a business case, Innovate UK [110] 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.

10.5. Appendix to Section 5 - Examples of assessments

10.5.1. Climate impact assessment of the German trunk road network

Back

In Germany, a climate impact analysis for the federal trunk road network is being performed by the Federal Highway Research Institute (BASt). The investigation is embedded in the climate impact analysis for the German transport system (federal trunk roads, federal railway infrastructure, federal waterways), which is conducted by the BMDV network of experts. (More on the BMDV in Section 4.3.)

The following table compares the steps of the assessment with the corresponding steps of the Framework.

Stage 1
Defining the baseline for adaptation
Drivers The motivation for looking at the climate impacts on federal roads is the potential impairment of the functionality of the transport system (e.g. damage of infrastructure elements, restriction of traffic flow) by changing climatic conditions and the increasing occurrence of extreme weather events. **Values** Apart from the integrity of the physical infrastructure itself, an important objective is maintaining the availability of roads for road users, i.e. ensuring their functionality under all conditions or recovering it as quickly as possible.
Establishing aims and scope
Aims The climate impact analysis forms an important basis for the identification and prioritisation of adaptation requirements and measures by the planners, operators and owners of the transport infrastructure. **Scope** The spatial scale was chosen depending on the responsible road organisation. Since federal highways and federal trunk roads fall under the level of national authority, they are part of the investigation (summarised as ‘federal trunk road network’). The type of assets included were federal highways and trunk roads. The temporal scope in consideration of climate change was twofold: 2031-2060 for the near future and 2071-2100 for the distant future. The key climate-related phenomena are flooding hazards, storm hazards and landslides. These have been found to potentially cause damage to infrastructure elements and therefore restrict the flow of traffic while often affecting more than one mode of transport at the same time.
Climate change impacts
For this investigation a separate climate analysis was performed by the German Meteorological Service. The DWD calculated and evaluated the climate change impacts on the basis of model simulations (climate and impact models) for various atmospheric, oceanographic and hydrological variables. The scenarios were developed for RCP 2.6, 4.5 and 8.5.

In the course of the investigation, it is planned to continuously adjust the analyses to new simulations, improved scenarios and the newly introduced shared socioeconomic pathways (as successor to the RCPs, IPPC VI AR).

Overall, more than 100 climate indices have been considered that concentrate on different aspects of climate change such as temperature, precipitation, humidity, barometric pressure and snow days. For each climate index, there is a defining equation that uses so-called ‘climate elements’. These are measurable parameters that influence the properties of the climate system. Due to the complexity and interdependence of climatic processes, there is not a definite list of key climatic variables, but rather a plethora of parameters that need to be taken into account.

As a climate impact we understand the effect of today’s climate on today’s system at time t_0 in relation to the effect of the future climate on a future system at time t_1 or t_2. The difference between the climate impacts t_0 and t_1 or t_2 indicates the potential impact of climate change (and other processes, which cannot be eliminated per se).

Establishing the context

The assessment is conducted to support the prioritisation of climate change adaptation measures. The first addressee is the Federal Ministry for Digital and Transport whereas further institutions such as the Autobahn GmbH might utilise the results for their operative management.

Stakeholders are well taken care of by involving the BMDV Network of Experts, which is the cross-modal format of departmental research and constitutes seven departmental Research Facilities that are subordinate to the Ministry for Digital and Transport.

Communication: The research process is accompanied by continuous interaction with users, e.g. with the state road construction authorities, Deutsche Bahn, and Federal Waterways and Shipping administration. This practical relevance enables the targeted development of application-oriented innovations.

Assessing criticality

Criticality is defined as the relative measure of the importance of an infrastructure in terms of the consequences that a disruption or loss of function has for the security of supply of important goods and services to society.

It can be operationalised by different indicator groups of criticality: traffic-related, economic, spatial planning-related and geographic. In the first stage, research efforts were concentrated on traffic-related indicators, such as the annual average daily weekday traffic. In the second stage, an extension to non-traffic-related indicators is sought.

Defining key tasks and delivery plan

The research process is divided into stages. The first stage took place from 2016-2019 and the second stage is taking place currently, from 2020 until 2025. A third stage, beginning in 2025, is envisioned. The delivery plan for different products contributed by the members of the network of experts is internally defined in detailed concepts and documented in status reports, which can be assigned to the different thematic focal points of the climate impact analysis.

Stage 2 Assessment pathways

Assessing vulnerability

Vulnerability of the roads was not directly assessed because it was not part of the concept. Instead, the sensitivity of the federal trunk road network with regard to the aforementioned natural hazards was assessed.

The climate impact assessment is conducted in a three-stage scheme:

1. Exposure analysis (Which road sections are potentially affected by climate change and extreme weather events?)
2. Sensitivity analysis (Which infrastructure properties are particularly sensitive?)
3. Criticality analysis (Which road sections are critical according to their importance for road traffic?)

It is performed for flooding hazards, storm hazards and landslides under consideration of a reference period (1971-2000), for the near future (2031-2060) and the distant future (2071-2100). Corresponding climate data is provided by the German Meteorological Service (DWD), itself being part of the BMDV network of experts.

Assessing sensitivity

The sensitivity analysis describes the investigation of the reaction of the transport infrastructure to the climatic impacts depending on the infrastructure properties. For landslides, an indicator of sensitivity is the presence (or absence) of landslide protection measures. We are looking at possibilities to further specify the description of sensitivity by e.g. looking at the quality/age/condition of landslide protection measures.

Adaptive capacity

Adaptive capacity was not assessed because it was not part of the conceptual framework.

Assessing and describing impact

For each investigated natural hazard, the assessed values/climate impacts resulted in statements about the extent of the affected trunk road network for a reference period as well as for the two scenarios for the near future and the distant future – under consideration of the different RCP scenarios. For the natural hazard of landslides for example, around 2,590 km of the federal trunk road network are exposed in the reference period. Assuming the business-as-usual scenario, the proportion of the network potentially affected will expand according to the model approach. In the near future an additional 390 km of the federal trunk road network could potentially be exposed. In the distant future the increase compared to the reference period is about 1,000 km. However, these figures only provide an overall network view and are no substitute for a detailed examination of roadway sections to determine the exact exposure toward landslides.

Stage 3 - Developing and selecting adaptation responses and strategies

Identification of adaptation responses and strategies

For resource reasons, it is not possible to analyse in detail the wide range of possible adaptation measures. Therefore, it its first phase, the BMDV network of experts concentrated on the consideration of selected exemplary measures, which were examined and described in terms of their effect and/or implementation. By involving users from the field in the project work, potential difficulties in the practical implementation of measures were revealed. Thus, initial approaches to overcoming them could be identified. With regard to these approaches, a distinction between the following types of adaptation measures was made:

- informational approaches through the development of central services for the provision of climate data,
- regulatory approaches through the adaptation of rules and regulations and design bases,
- engineering approaches resulting in structural adaptation measures
- operational management of transport infrastructure through adapted management and recommendations for action and operational management of transport operation by means of traffic shifts and adaptation measures on the part of the infrastructure user

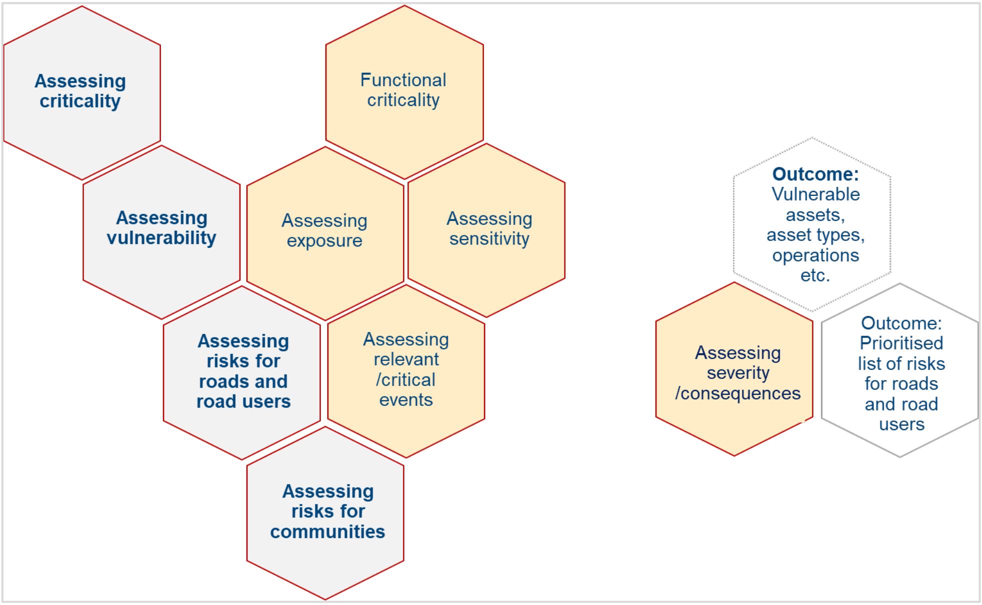
Combining adaptation responses into adaptation pathways

Out of scope

Development of an action plan or strategy
Out of scope

Stage 4 - Integrating findings into decision-making processes
Incorporating recommendations into decision-making
The methods and data products developed in the BMDV network of experts are of fundamental importance beyond the transport sector for climate impact analyses in Germany. They are used directly or indirectly by various actors in the BMDVs business area and beyond. Important users are e.g. the transport network operators. From the first stage (2016-2019), which was mainly the identification phase, in which the potential of research and technical data as well as new technical developments were identified and activated across all modes of transport, the network of experts is now moving forward and entering the integration phase. Here, the existing results will be further developed and additional scientific data and methods will be integrated, with the focus on holistic solutions to promote synergies between research, development and application.

This analysis can be graphically illustrated as in the figure below:



More information can be found on the following website: https://www.bmdv-expertennetzwerk.bund.de/EN/Home/home_node.html

10.5.2. Vulnerability and resilience assessment in the Philippines (Deltares, NL)

Back

KALSADA-Conditional Matching Grant to Provinces (CMGP) program was developed by the national government of the Philippines to help Local Government Units (LGUs) improve the quality of provincial roads, which is significantly below that of national and city roads.

This project aims to specifically increase the capacity of LGUs in dealing with climate and other risks affecting local roads, and enhance coordination with the national road organisation to better inform local roads planning, using a learning-by-doing approach and ultimately towards improving the resilience of local roads.

Stage 1 – the preparation stage
Identifying the baseline for adaptation
The main driver for improving the quality of provincial roads is reducing the economic consequences of disruptions and damages due to natural hazards, for road authorities and for the society. Policies strategies governance structures etc were not considered.
Establishing aims and scope and aims
<u>Scale & most relevant assets</u> The project is focused on the provincial roads and road assets (i.e. culverts, bridges, erosion protection, tunnels, under- and over-passes and the roads themselves) in the province of Nueva Ecija. The national roads are only considered in the traffic analyses. Municipal and Barangay roads were not considered. The project was conducted in approximately 1 year, from November 2018 to October 2019. <u>Main variables or climatic phenomena</u> Based on a first inventory and LGU’s experience, the most relevant natural hazards for this road network in Nueva Ecija were determined as: • Flooding • Landslides • Earthquakes <u>Temporal scope:</u> today /current situation
Climate change impacts
The scope of this project was limited to current climate risks. Climate change was not considered. Climate data were available from the Philippine Atmospheric, Geophysical and Astronomical Services Administration.
Establishing the context
The project beneficiaries are the LGUs (Local Government Units), which are responsible for the Provincial, City/Municipal, and Barangay roads. The DILG (Department of Interior and Local Government) can provide financial or technical support to the LGUs under specific programs.
Assessing criticality
The criticality of the road network under consideration was assessed by estimating the redundancy of the network through a single link redundancy analysis. A single-link disruption assessment was performed by, iteratively, removing each link of the network and calculating the best (shortest-path distance) alternative route to that network link.

The redundancy of the network is firstly assessed and subsequently combined with the traffic intensity to obtain criticality, expressed as the impact to road users per unit time. The actual estimated losses per hazard scenario are then calculated by combining the impacts per unit time with the actual expected interruption times for each hazard scenario.

Defining key tasks and delivery plan

The main tasks were:

- assess vulnerability of critical provincial roads to the three main hazards,
- evaluate risk, assess possible measures
- prioritise measures and propose an adaptation strategy

Based on the consultant's expertise and experience, the work was planned in the following steps:

- Collection of data to perform the assessment related to the hazards, the road itself and traffic
- Calculating exposure of the road network for the different hazards
- Calculating the consequences, expressed in
    - Damages to the road
    - Losses for the users of the road
- Evaluation of the risk
- Road prioritisation
- Determination of measure effectiveness
    - Future performance
    - Robustness of measures
- Prioritisation of measures
- Adaptation pathways

Stage 2 Assessment pathways

Assessing vulnerability

Data was sourced from the following organisations and programs

- Mines and geosciences bureau
- Philippine Institute of Volcanology and Seismology
- Philippine Atmospheric, Geophysical and Astronomical Services Administration
- Disaster Risk and Exposure Assessment for Mitigation Program

The determination of the exposure was done by means of a straightforward intersection of the assets and hazard GIS layers. This requires having both the hazard maps and the road network assets in a GIS format and accurately represented.

Assessing vulnerability

In this project, the vulnerability of the different assets was assessed from the estimated degree of damage inflicted to the infrastructure by the varying hazard levels. Vulnerability is herein expressed as a percentage of the construction costs.

The damage is expressed in terms of costs per hazard scenario (Expected Annual Damages, EAD). Repair cost estimations were done based on the collected data for the infrastructure assets including small and large culverts, small and large bridges, paved and unpaved roads subject to each hazard and discriminated by hazard level, such as floods (flood depth less than 0.5m, 0.5 to 1.5m, and above 1.5m of normal water level), landslides (low, medium, high hazard), and earthquakes (0.2g-0.3g, 0.3g to 0.4g, 0.4g to 0.5g, and 0.5g to 0.6g Peak Ground

Acceleration - PGA). The vulnerability was not determined for landslides, due to insufficient information.

To determine the socio-economic impact, criticality information is combined with the exposure of the network, and the associated expected disruption times. The Expected Annual Losses (EAL) for road users for flood and earthquake hazard scenarios were calculated. These losses are expressed in monetary terms, just as the EAD.

Assessing sensitivity

Not explicitly determined.

Adaptive capacity

Not explicitly determined.

Analysing risk

Both EAD and EAL consider different hazard scenarios, and thus also probabilities.

Based on the EAD and the EAL, the different RBIS roads are ranked for the prioritisation of future interventions. The prioritisation process is solely based on the calculated damages and losses. It is not dependent on the design criteria of the roads, but can provide input for the LGU to improve their requirements on road design.

The aim of the prioritisation is to rank the roads from an action perspective. The top priority corresponds to roads that are both expected to sustain the highest damage costs and where the disruption will lead to the largest losses. At the bottom of the prioritisation ranking are the roads with the smaller expected damages and disruption losses.

The contribution of damages and losses to prioritisation, however, is not necessarily linear. Because the EAD are significantly larger that the monetised quantification of EAL, a simple sum of the values would dilute the importance of minimizing the losses for the road users.

We propose the use of a prioritisation matrix.

		Damage Category				
		C1	C2	C3	C4	C5
Losses Category	C1	1	1	2	2	3
	C2	2	2	3	3	4
	C3	3	3	3	4	4
	C4	3	4	4	5	5
	C5	4	4	5	5	5

Stage 3 - Developing and selecting adaptation responses and strategies

Identification of adaptation responses and strategies

A long list of measures was determined based on the ROADAPT table of measures (see 3.1) and was completed with local input. The measures were divided into 5 categories:

- Pro-action
- Prevention
- Preparation
- Response

- Reconstruction

Prioritised locations were divided into 7 key archetypes relevant to the different hazards considered in this project. Archetypes describe typical situations or 'location characteristics' such as flow direction, existing infrastructure, or geological conditions. The intention was to define generic road archetypes that would encompass all road locations, but which would not be too many to become unwieldy or too few to lack specificity.

Depending on the archetype and hazard, measures from the long list were assigned.

Selection and prioritisation of adaptation responses and strategies

A semi-quantitative assessment was used, whereby available data and expert judgement is combined in a procedure intended to be appropriate for provincial roads planners to implement independently. Given the large number of provincial road sections in Nueva Ecija, our analysis is presented at the level of generic archetypes, with the current and future performance of measures relevant to each archetype assessed via expert judgement. The impact of both climatic and socioeconomic uncertainties is included in the analysis, through examination of existing trends and projected developments in expected peak discharges and traffic demand. Robustness of individual measures is assessed across several plausible future scenarios via minimax analysis, with the measures ultimately prioritised and assessed semi-quantitatively by applying a flexible, weighted multi-criteria analysis framework.

Criteria and relative weight [%] used in the multicriteria analysis are:

- Cost (40%)
- Effectiveness (of the measure) (30%)
- Robustness (5%)
- Flexibility (5%)
- Implementation (15%)
- Maintenance (5%)

Combining adaptation responses into adaptation pathways

Prioritised measures can then be used to assemble initial relative adaptation pathways through consideration of simple sequencing of options in the short-, medium- and long-terms.

Development of an action plan or strategy

This project did not make location-specific action plans and as such, monitoring/ tracing the plans was not possible.

Stage 4 - Integrating findings into decision-making processes

Incorporating recommendations into decision-making

Decision-makers today have to manage deep uncertainties about future conditions. They need to be confident that the decisions taken today will also be relevant in the future.

To meet this challenge, new methods and approaches have been developed to help decision-makers identify and evaluate robust and adaptive strategies, and thereby make sound decisions in the face of these challenges.

The proposed semi-quantitative approach builds upon the previously reported outputs from the risk assessment, and combines available data, expert judgement and simple analytical methodologies in a procedure that provincial roads planners should find appropriate to implement independently.

The generic assessment tables should be adapted and contextualised to the specific local conditions of each road section, as the presented assessments score measures according to their maximum theoretical applicaton. Therefore, we encourage roads planners to update these tables with scores (and/or additional measures) more appropriate to the conditions of the specific road section as and if required.

Education, awareness, training, effective communication

Trainings were provided to the LGU in the province, to gain input but also to present and share the results. Moreover, the approach was tailored in such a manner that the local authorities should be able to adapt the generic assessment themselves.

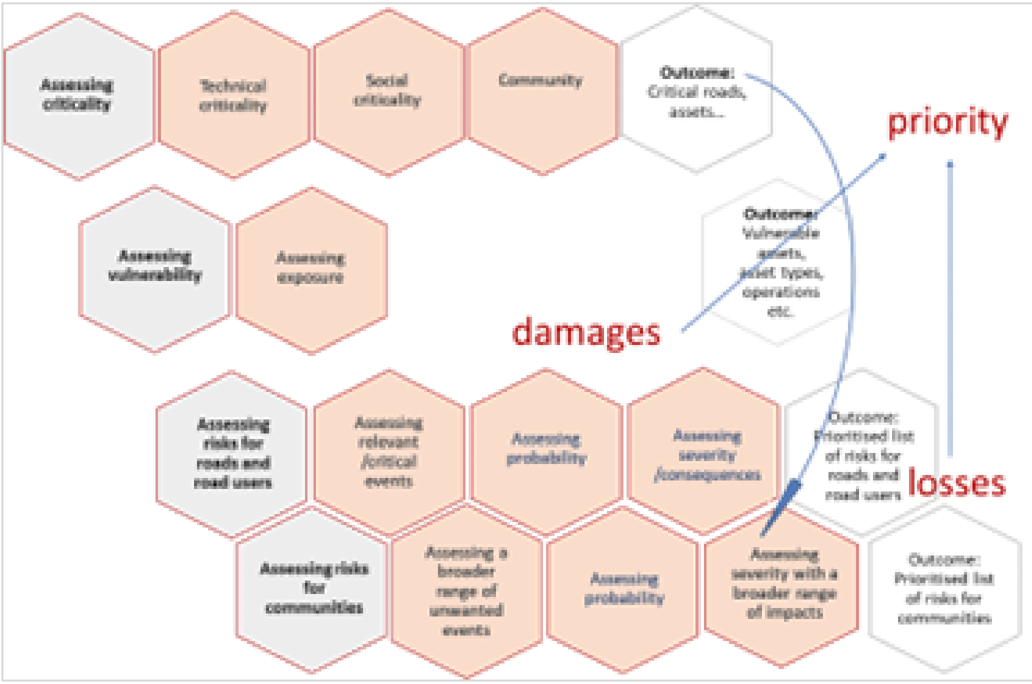
Developing a business case for adaptation

Not done

Monitoring, reporting, review

Not done

This analysis can be graphically illustrated as in the figure below:



10.5.3. U.A.E.: Potential Impact of Climate Change on Materials Selection and Asphalt Pavement Performance

Back

In the UAE, a study of potential impact of climate change on materials selection and asphalt pavement performance in the UAE was performed by the Ministry of Energy and Infrastructure (MoEI), in collaboration with University of Sharjah and The National Meteorology Center.

Climate criteria have a crucial impact on the pavement's condition. The investigation was aimed at adjusting the pavement design and requirements so as to limit the annual costs of repair

Stage 1 – the preparation stage
Defining the baseline for adaptation **The motivation for looking at the effect of climate change on asphalt material selection** is • Economic: to reduce the maintenance interventions and cost resulted from the deterioration of the roads due to climate change factors. • Social: to mitigate the climate change impact on the level of service of the roads, and improve the safety on the roads by improving the roads conditions. • Environmental: reduce the greenhouse gases (GHG) generated from the repeatable interventions. **Assessing data availability** The study requires collection of the historical data of hourly minimum and maximum air temperatures from the weather stations distributed across the UAE. Also, it is required to download future hourly temperature records from the CMIP5 platform considering the four RCPs. **Barriers** Historical data availability was not consistent.
Establishing aims and scope In this case, annual costs of repair were the main factor. The aim of the assessment is to find ways of reducing the annual costs of repair of rutting, fatigue cracking etc. High temperature was considered the main threat. Inadequate design the main sensitivity. Scope: national roads, owned by the MoEI, main hazards: temperature increase. Temporal scope: The study targets 2080, with main focus on air temperature as main climate change impacting factor for the pavement design.
Climate change impacts Rutting, fatigue cracking and thermal cracking are caused by climate conditions. These issues are expected to exacerbate with climate change, mainly increase in temperature. It was required to download future hourly temperature records from the CMIP5 platform considering the four RCPs.
Establishing the context Stakeholders & communication MoEI is communicating with all roads' operators in the UAE. All the roads' operators are following one design AASHTO 93 pavement design. The study indicates the importance to move towards Super Pave design to adapt to climate change along with traffic needs due to urban development.

Assessing criticality

Two indicators of criticality were applied: traffic volume and traffic speed.

Defining key tasks and delivery plan

Key tasks:

- Collection of historical climate database from local weather stations in UAE.
- Development of new Asphalt Binder specifications for the UAE according to local climate and traffic loading conditions
- Impact of the new asphalt binder specifications on the asphalt pavement performance in UAE
- Prediction of future climate change in UAE
- Impact of future climate change on asphalt binder specifications
- Impact of future climate change on asphalt pavement performance in UAE
- Life cycle assessment and Co2 emissions associated with all costing analysis scenarios

Two different models were used to predict the high and low pavement temperature based on the air temperature data. Using pavement temperature values, Pavement Grade (PG) maps were generated for near and far future periods referring to different scenarios at different reliability levels.

Stage 2 Assessment pathways

Assessing vulnerability

Exposure

Contouring maps were generated to indicate the projected air temperature for the UAE and the suitable pavement grade. The assessment was to be restricted to the highest temperature zone combined with the traffic volume and traffic speed.

Sensitivity

An indicator of sensitivity was the gap between the current climate criteria considered in the pavement design and the new pavement design based on the future prediction. Higher gaps illustrated higher sensitivity.

Assessing and describing impact

The projected air temperature following the RCPs trajectories, shows that the current pavement design would require continuous interventions to maintain the required service level.

The current design criteria require pavement grade of PG 64-10, while the study shows that with the climate change pavement grade would vary based on the geographical location. PG 64-10 is not any more efficient nor sustainable. The minimum required PG is 70-10, and majority of the roads require PG 76-10.

Stage 3 - Developing and selecting adaptation responses and strategies

Identifying response strategies was not part of the study. This would be done on operators' level in each Emirate.

Stage 4 Integrating findings into decision-making processes

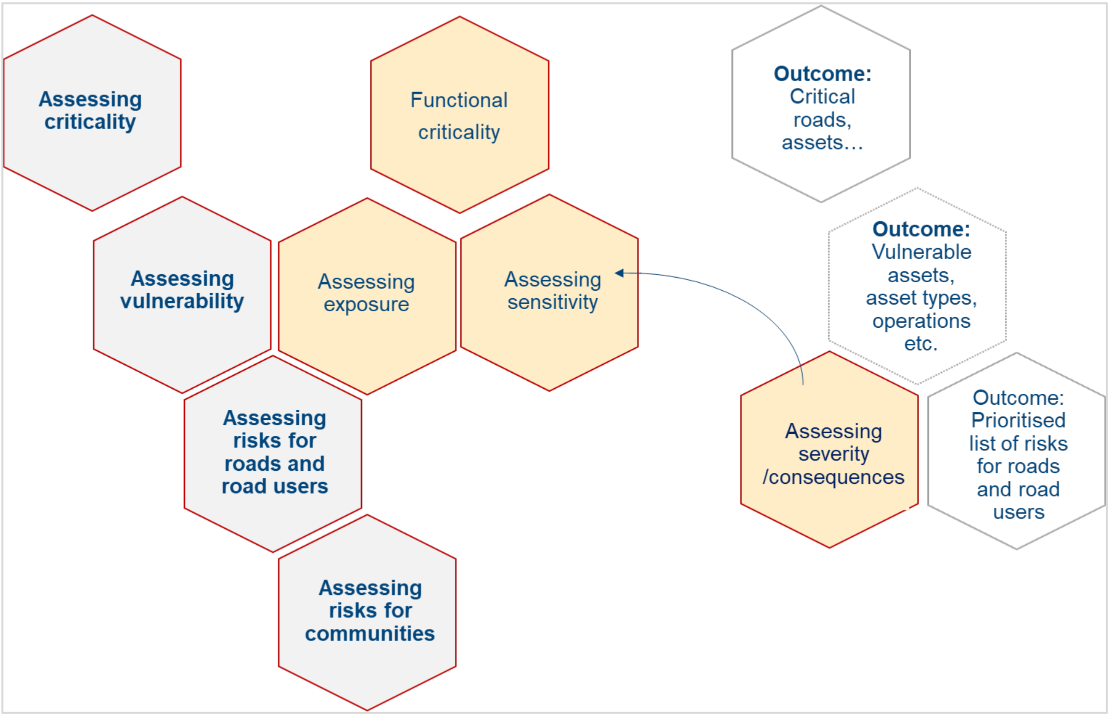
Updating the pavement design and shift from AASHTO to Super Pave to adapt with climate change.

Upgrading the pavement grade by the bitumen manufacturers and suppliers, to integrate the projected climate change criteria with the urban development impact on the traffic volume.

Technical workshops to communicate the findings with all roads' operators on the national level.

Parallel study to advance the pavement design with circular economy by using recycled plastic is ongoing.

This analysis can be graphically illustrated as in the figure below:



10.5.4. UAE: The effect of climate factors on traffic safety and transportation system performance

Back

The UAE aims to investigate the effect of different climate factors on traffic safety and transportation system performance to achieve adaptation to climate change

Stage 1 – the preparation stage
Identifying the baseline for adaptation
Climate events have crucial safety impacts on the roads, including traffic safety. The UAE aims to investigate the effect of different climate factors on traffic safety and transportation system performance to achieve adaptation to climate change. **Values:** In this case the focus is on traffic safety. **Availability of data and information** The study requires collection of the historical data of climate events (rain, dust and fog) and the crash accidents historical data caused by these climate events. Historical data availability varies on the local levels, between 20 years and 10 years of historical data. **Barriers:** Historical data of climate events availability was not consistent. Crash accidents data had many missing information.
Establishing the aims and scope
The aim of this is to establish a relation between future weather conditions and traffic safety, and to develop a safety statistical model to predict future accidents under different climate change projection scenarios, with focus on rain, dust and fog events. The project would assess the historical accidents data during fog, dust, and rain conditions, Assess historical accidents data during fog and dust conditions, and assess accidents data during the rain conditions. Conduct a temporal analysis of the number of accidents, and investigate the relationship between accidents and the climate conditions. Develop risk map for the areas that experience bad weather-related accidents. Development of GIS-based risk maps under different climate change scenarios **Scope** All national roads for Sharjah, Dubai and Abu Dhabi Emirates. Main climate hazards: fog, dust, and rain conditions. Temporal scope: The study targets 2080.
Climate change impacts
It was necessary to develop climate change projections in for heavy rainfall under different greenhouse gas emission scenarios. The project would specify the seasons with high risks per each event, the number of days a year and most critical times a day.
Establishing the context
Stakeholders' involvement MoEI is communicating with all roads' operators in the UAE. Besides the operators, the following stakeholders are included:

Police Departments
Crisis Management
Storm water development and flood management – Municipalities
Health sector

Target group
Local governments and national organisations.

Assessing criticality
Not done

Defining key tasks and delivery plan

Key tasks:

- Collection of historical climate database from local weather stations in UAE.
- Collection of the road network geometric, traffic and accidents data in UAE.
- Assessment of the historical accidents data during fog and dust conditions, temporal analysis of the number of accidents, and investigation of the relationship between accidents and the climate (fog and dust) conditions
- Assessment of the accidents data during the rain and sandstorms, temporal analysis of the number of accidents, and investigation of the relationship between accidents and the climate (rain and sandstorm) conditions

- Development of safety statistical model to predict future accidents under bad weather conditions
- Collection of historical climate database from local weather stations in UAE.
- Collection of the road network geometric, traffic and accidents data in UAE.
- Assessment of the historical accidents data during fog and dust conditions, temporal analysis of the number of accidents, and investigation of the relationship between accidents and the climate (fog and dust) conditions
- Assessment of the accidents data during the rain and sandstorms, temporal analysis of the number of accidents, and investigation of the relationship between accidents and the climate (rain and sandstorm) conditions

- Development of risk map for the areas that experience bad weather-related accidents
- Development of climate change projections for heavy rainfall under different greenhouse gas emission scenarios
- Development of GIS-based risk maps under different climate change scenarios.
- Conduct Geographical Information System (GIS)-based evaluation of transportation infrastructure vulnerability.

Stage 2 - Assessment pathways

Assessing vulnerability

Exposure analysis
GIS maps are generated to indicate high risk areas per each climate event. All road stretches in areas recognised as high-risk areas were identified.

Assessing sensitivity
Not performed. An indicator of sensitivity was the frequency of earlier accidents on the road stretches.

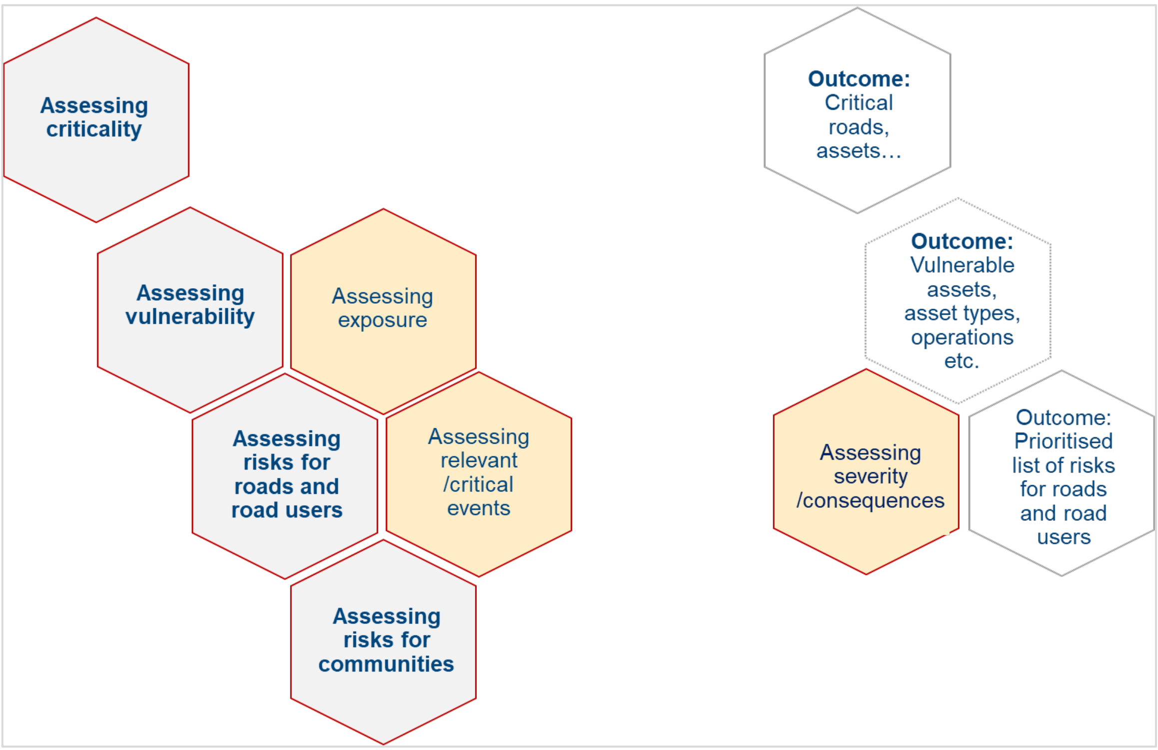
Adaptive capacity
Not considered.

Assessing and describing impact
In winter, the rate of accidents per day is increasing and is the highest of out the other weather conditions. Accidents severity's categories are: Minimal, Minor, Major, and Fatal. The results show that the traffic accidents were significantly affected by the adverse weather conditions. Fog and dust are responsible for most accidents that involve a serious/fatal injury. Most of the bad weather conditions show a significant increase on the number of accidents.

Stage 3 - Developing and selecting adaptation responses and strategies
Response strategies were not a part of the study report. This would be done on a regional level in each Emirate.

Stage 4 - Integrating findings into decision-making processes
Incorporating recommendations into decision-making
Updating the national master urban plan.
Education, awareness, training, effective communication
Technical workshops to communicate the findings with all local governments and stakeholders the national level.

This analysis can be graphically illustrated as in the figure below:



10.5.5. Western Australia: Assessing network vulnerability to future climate risks and natural hazards: An applied approach

Back

Stage 1 – The preparation stage

Identifying the baseline for adaptation

Drivers for adaptation:
Recent extreme climatic events and natural hazards across Australia have caused major damage to critical road and transport infrastructure, disrupting access and operations, and leading to unacceptable associated social, environmental and economic consequences. Transport organisations have a responsibility to protect their significant assets and maintain service levels in a cost-effective manner. In the face of increasingly frequent and severe climatic threats and natural hazards, asset managers need to strategically prioritise limited resources and funding, the most vulnerable assets is a consideration for prioritisation.

The Western Australian state-controlled road network comprises more than 18,500 km of major roads and highways, as well as bridges, culverts, drainage and other related road assets and furniture. Many of these assets and linkages are, or may become, increasingly vulnerable to future climate hazards or events.

In Western Australia is expected that there will be 1.1-2.7°C increase in temperatures by the end of the century. The overall climate risks can be summarised as

- generally higher temperatures and increased frequency of bushfires
- increases in the frequency, duration and magnitude of extreme heatwaves
- more rainfall in the north and less rainfall in the south
- increased intensity of storms and flood events
- sea level rise, including increases in the level of estuarine and river systems which are influenced by tide.

When considering the risks to the road network, there are two main aspects:

- road infrastructure – for example, pavements and structures impacted by flooding or cyclones, leading to possible severe damage, loss of function, or accelerated deterioration
- road use – for example, temporary loss or reduced quality of access, with increased journey times on preferred routes or from diversions, where diversions are not available (i.e. in remote locations) access is cut-off and journeys are not possible. Operating conditions are also likely to be less safe with reduced vehicle control during adverse weather conditions and where overtopping occurs.

An understanding of the expected impacts of future climate change by road planners, designers and asset and network managers can help prioritise intervention investments and may result in better outcomes for the road organisation itself but also for the broader community.

To improve Main Roads capability to undertake vulnerability assessments at a network level a project was undertaken to identify best practice for assessing network and asset vulnerability, and to identify gaps in Main Roads' practices, tools and guidance.

Establishing aims and scope

The project intends to enable assessment of vulnerability on the network scale for Main Roads controlled roads and includes:

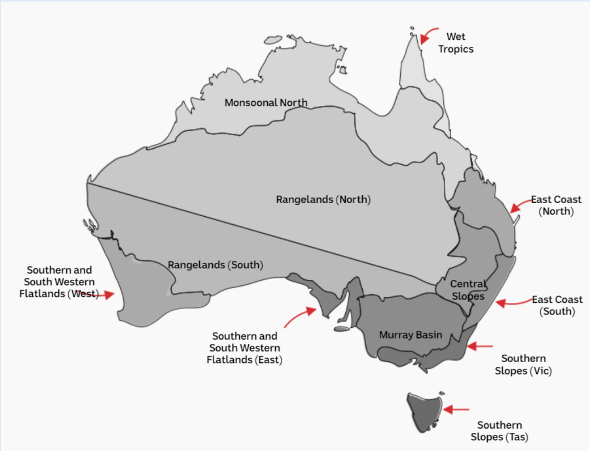
- understanding and dealing with the socioeconomic impacts and performance of degraded transport networks.

- provides a methodology for finding component weakness in the transportation network that render the network vulnerable to the consequences of failure or degradation.

Climate change impacts

Climate change projections are required to predict the severity of future climate threats for each assessable asset. Projected climate parameters provided by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) published on the Climate Change in Australia website is the most widely accepted source of data on climate change projections.
The climate change projection data is provided by Climate Change in Australia website is disaggregated at a high level known as at subclusters. There are four projection subclusters that overlaps the boundary of Western Australia:

- Monsoonal North
- Rangelands (North)
- Rangelands (South)
- Southern & South Western Flatlands (West)



Establishing the context

To demonstrate the Network Assessment Framework developed, two pilot vulnerability assessments were undertaken. The pilot tested the framework’s ability to assess vulnerability in a repeatable manner using a data sourced from the asset management system.

Assessing criticality

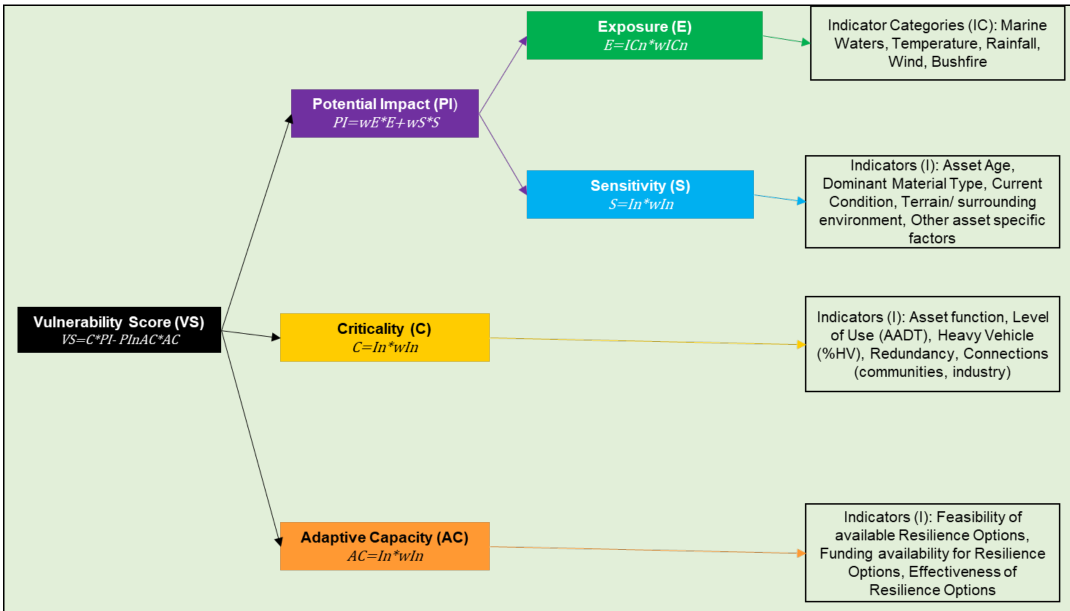
This was a part of the vulnerability assessment, according to the applied “Network Vulnerability Assessment Framework”

Defining key tasks and delivery plan

Stage 2 Assessment pathways

Network Vulnerability Assessment Framework

The image represents the framework used for calculation methodology for the network vulnerability assessment. This diagram details how indicators interact with vulnerability components to create the vulnerability score.



Assessing criticality

Criticality is the importance of the asset or network link, or the level of contribution infrastructure make towards the society in maintaining a minimum level of national and international law and order, public safety, economy, public health and environment.

Criticality has been assessed using five indicators, including: Asset function, Level of Use (AADT), Heavy Vehicle (%HV), Redundancy, Connections (communities, industry)

Assessing vulnerability

Assessment is based on indicators for each factor: exposure, sensitivity and adaptive capacity.

A weighting index is attached to each indicator.

Exposure

Exposure is a function of the character, magnitude and rate of climate change and variation to which a system is exposed. **Assessment is based on indicators and weighting factors** Indicator Categories (indicators within each) (IC): (proximity to?) marine waters, temperature, rainfall, wind, bushfire was used to assess exposure.

Sensitivity

Sensitivity is the degree to which something is affected, either adversely or beneficially, by climate related stimuli.

To assess sensitivity, five indicators were used, including: asset age, dominant material type, current condition, terrain/ surrounding environment, other asset-specific factors

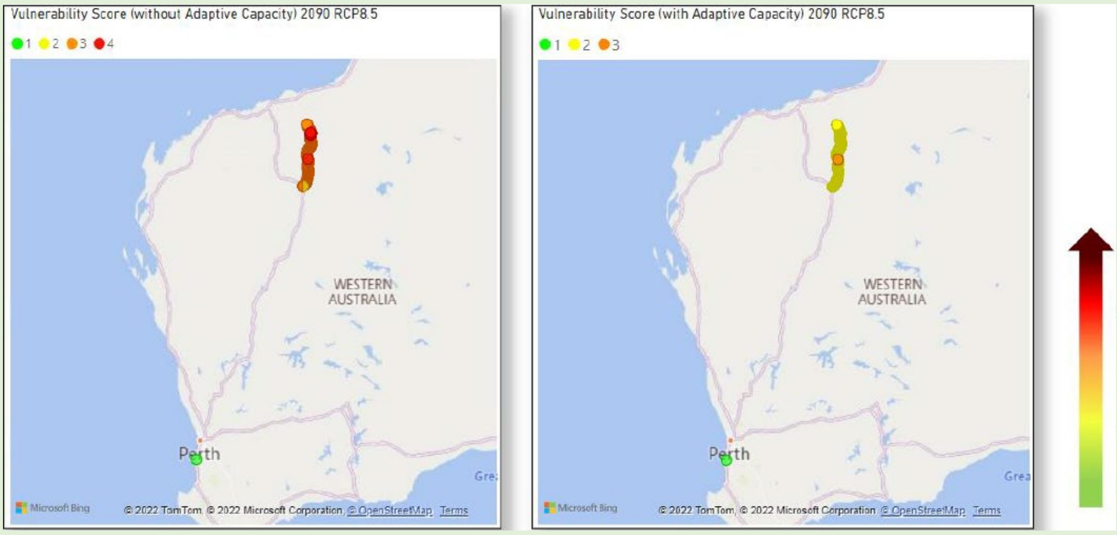
Adaptive capacity

Adaptive capacity refers to the system's ability to cope with and adapt to existing climatic variability and future changes.
Adaptive capacity has been assessed using three indicators, including: feasibility of available resilience options, funding availability for resilience options, effectiveness of resilience options.
Adaptive capacity is subtracted in the network vulnerability equation.

Assessing /calculating vulnerability

Vulnerability scored calculated based on scores of factors and weighting indices. Five categories of vulnerability recognised: from negligible to extreme.

The pilot analysis calculated vulnerability scores for the selected network links across multiple scenarios including time horizons, emission intensity scenarios (i.e. representative concentration pathways), and with and without adaptive capacity. As adaptive capacity is subtracted from the vulnerability score (i.e. improves the network vulnerability score) it may mask the high risk scoring aspects of the network.



Stage 3 - Developing and selecting adaptation responses and strategies

The adaptive capacity indicator considers the availability of resilience options or responses in its calculation. Given the stage of this project it has not been used as part of a process to develop, select and prioritise adaptation responses and strategies.

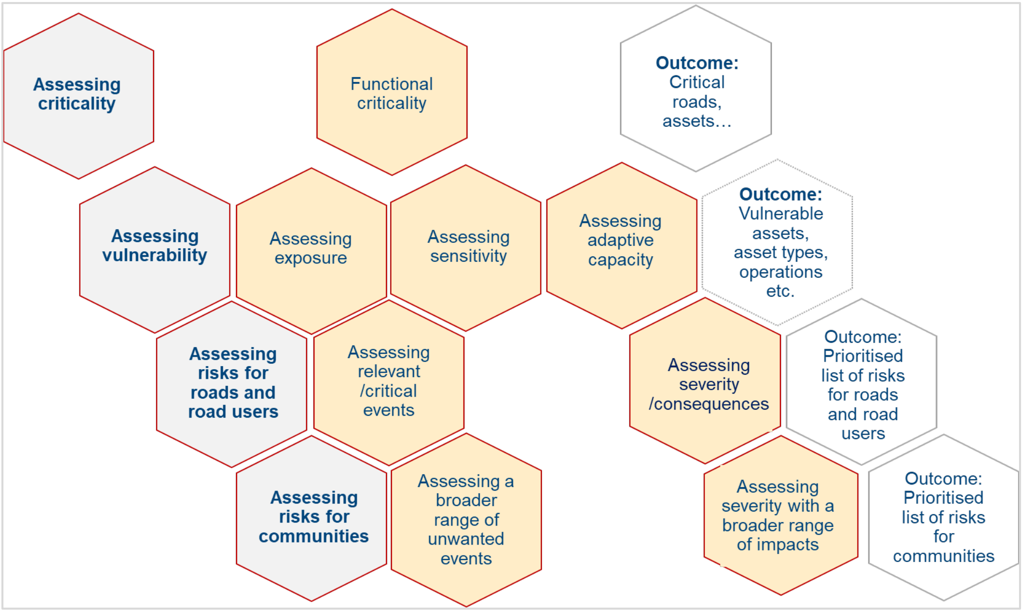
Stage 4 - Integrating findings into decision-making processes

Incorporating recommendations into decision-making

An intended project outcome is to integrate this methodology into processes to prioritise road asset investment.

Education, awareness, training, effective communication

This analysis can be graphically illustrated as in the figure below:



10.5.6. Assessment of A2 Motorway Guadalajara – Alcolea del Pinar

Back

CLARITY project (https://clarity-h2020.eu) was a H2020 project that pursued the development of operational eco-system of cloud-based climate services to calculate and present the expected effects of cc-induced and -amplified climate change hazards at the level of risk, vulnerability and impact functions. The project received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No730355. All the information was uploaded in the CLARITY platform (D3.1 Science Support Plan and Concept (clarity-h2020.eu).

The **motivation** behind the CLARITY project was to demonstrate the benefit of climate services for climate proofing of vulnerable large-scale investments, such as urban infrastructures (including roads).

CLARITY project builds upon existing functionalities, such as services for access to climate change information, downscaling services and long-term predictions. In particular, the democase takes into account results from two documents prepared by Spanish managers:

- Climate change adaptation needs of the core network of transport infrastructure in Spain — English (europa.eu), and
- Sections of the state-owned inland transport infrastructure network that merit priority attention because of climate variability and change (in Spanish).

Four studies show-cased CLARITY climate services in different climatic, regional, infrastructure. One of these demonstration case studies was located in A2 Motorway in Spain, from Guadalajara to Alcolea del Pinar. The climate services were designed following the EU guidelines:

Guidelines for Project Managers: Making vulnerable investments climate resilient — English (europa.eu)

Stage 1 – the preparation stage
Identifying the baseline for adaptation
Drivers According to the document Climate Change Adaptation needs of the Transport Infrastructure main Network in Spain climate change would entail important negative effects in highways. Therefore there is a need to perform more detailed studies of some relevant roads. The A2 connecting Madrid and Barcelona cities is one of the most important axis in Spain, so a section from this road, running from Guadalajara to Alcolea was selected as a case study for the Clarity project. **Data availability** One of the points of the whole project was to use existing public climate services. The main source of climate data was therefore Adaptecca (Visor de Escenarios de Cambio Climático (adaptecca.es)). Data was also obtained from the Clarity project.
Establishing aims and scope
The aims of this investigation are to provide a good basis for climate information based on available information. It is also important to identify climate variables that can be relevant for road maintenance and operation in order to have more precise and useful hazard information. The road section assessed was located in A2 Motorway in Spain, from Guadalajara to Alcolea del Pinar. It is a four-lane highway section 73 km long.

The climate threats are based on data from the Spanish Meteorological Agency (AEMet). The road section is in a region with Continental-Mediterranean climate with long dry and very hot summers and equally long and severe winters. Therefore, the main threats considered are maximum and minimum temperatures as well as daily oscillations.

Temporal scope was in three stages: 2011-2040, 2041-2070, 2071-2100

Climate change impacts

The potential impacts considered were those identified in a previous study performed at network level and provided in the document "Sections of the state-owned inland transport infrastructure network that merit priority attention because of climate variability and change":

*Landslides and erosion and falling of materials of **slopes** as a consequence of **heavy rain***
*Erosion of slopes in **embankments** by the course of a river as a consequence of **extraordinary floods***
*Insufficient capacity of the **drainage works** due to **heavy rain***
*Erosion of abutments, undermining of foundations and impacts from debris materials on **bridges and viaducts** due to **extraordinary floods***
*Development of ruts on the **pavement** as a consequence of **high temperature***
*Insufficient **road surface drainage** capacity as a consequence of **heavy rain***
*Impact on the **road traffic** conditions due to **wildfires***
*Impact on the **road traffic** conditions due to **snow***

The climatic variables that were assessed were:

- Maximum temperatures
- Minimum temperatures
- Number of days T<0ºC
- Intense rainfall
- Fire index

Data were obtained from Adaptecca , a publicly available database, and also from the CLARITY project (predictions for the whole Europe).

Establishing the context

The study was performed with the cooperation of the road concession, in charge of the road maintenance and operation. Communication was a key element of the project. Therefore, several workshops with the participation of climate and road experts were held during the duration of the project.

Assessing criticality

The criticality was assessed dependent on: average daily traffic, TEN-T and accessibility to populated area. The criticality was used as input for defining the risk thresholds, after the risk assessment was performed.

Defining key tasks and delivery plan

The climate services were designed following the EU guidelines: https://climate-adapt.eea.europa.eu/en/metadata/guidances/non-paper-guidelines-for-project-managers-making-vulnerable-investments-climate-resilient/guidelines-for-project-managers.pdf

Stage 2 - Assessment pathways

Assessing vulnerability

Exposure Analysis

Road elements that might be impacted by climate events were identified with the collaboration of several experts and technicians in charge of the road maintenances and operation; then the elements were created and edited in the CLARITY platform. User modifiable attributes were defined (slope, height, etc.)

Sensitivity was also assessed by the help of input from interviews with maintenance staff.

Adaptive capacity

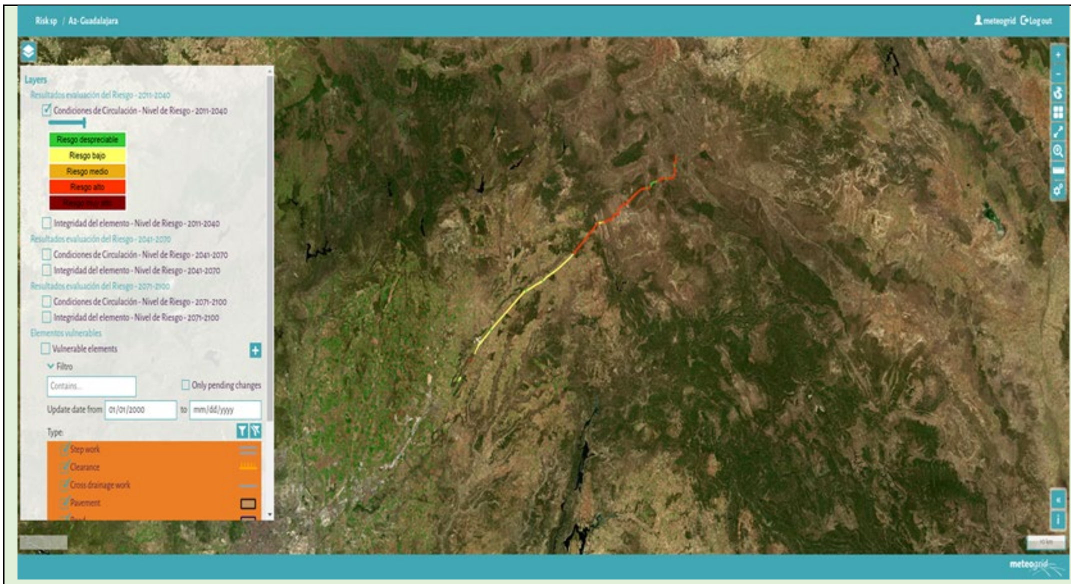
Not explicitly assessed, but implicitly included in the expert judgement.

The **vulnerability assessment** consisted of taking into account exposure and sensitivity, by means of expert criteria.

Analysing risk

An automatic **risk evaluation** was done, based on the probability of impact and the severity, both for traffic conditions and for the integrity of the element in the short, medium and long term.
The probability and severity of the impact was again assessed with the help of the maintenance staff, taking into account their experience and also the climatic information.
Their expert judgement was also very important for the validation of the results obtained.
Although the methodology followed was mainly qualitative, the results obtained were coherent with the situation of the road section.

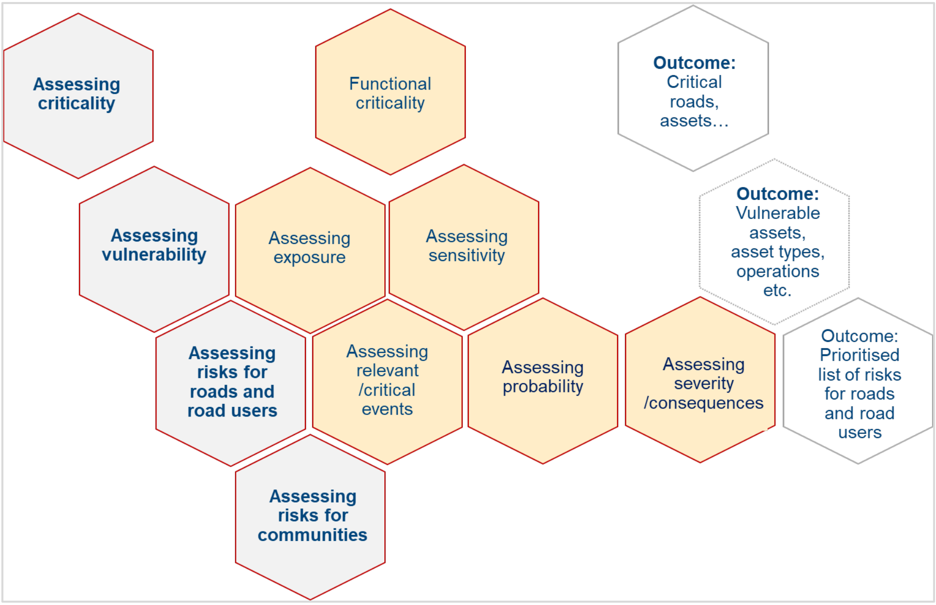
Element type	Element	Element integrity			Circulation conditions		
		2011-2040	2041-2070	2071-2100	2011-2040	2041-2070	2071-2100
	Km 84	-	-	-	-	-	-
	prueba 1	Despreciable	Alto	Desconocido - 0	Medio	-	-
	Desmonte 1	Alto	Despreciable	Alto	Medio	Medio	Alto
	Talud 1	Bajo	Bajo	Bajo	Despreciable	Alto	Despreciable



Stage 3 - Developing and selecting adaptation responses and strategies
Adaptation responses
In the case the risk obtained for a road element or road section was medium-high, the assessment concluded the need to implement some adaptation measures. A table with an overview of adaptation measures was prepared, addressing each hazard and element at risk identified in the case study. For each adaptation measure, the expected average cost was estimated and expected efficiency.
Prioritising adaptation responses
Guidance was provided on how to perform a simplified cost-benefit assessment. The following was considered: • The repair costs; • The cost of traffic disruptions, taking into account alternative routes.

Stage 4 - Integrating findings into decision-making processes
Several webinars were show-cased and papers published, as part of the dissemination of the results of the CLARITY Project. Learnings from the Clarity project provide input to the development of a methodology for risk assessment in Spain.

This analysis can be graphically illustrated as in the figure below:



10.5.7. Mexico – Implementing the International Climate Change Adaptation Framework for Road Infrastructure

Back

Stage 1 – the preparation stage
Identifying the baseline for adaptation
Drivers for adaptation: Roads: Number of events that have affected the road infrastructure, reducing its level of service. Damages and losses: socioeconomic impact of climatic phenomena in the transport sector (using ECLAC methodology) **Data availability** All available public information was used, such as: geo-referenced road network, traffic and infrastructure condition data (bridges and pavements), climate maps (current and future hazards), etc.
Establishing aims and scope
Aims • Adapt the framework proposed by the AMC to assess the vulnerability of the road network at the federal level to extreme natural phenomena caused by climate change. • Develop a process for the identification of vulnerable sites of the federal road network exposed to hydro meteorological phenomena. • Determine the type of actions that could be implemented to reduce the damage that would impact the disruption of road services. **Scope** To analyse the effects of climate change on the federal road network and its application to the federal free network in five States (Jurisdictional Scope).
Climate change impacts
The case study used climate information developed by other government organisations, such as: • records of past and present climate, including extreme weather events, • records of past and present impact, • projections of future climate changes and expected impacts.
Establishing the context
For the development of the project, coordination with the federal highway network operators in each state, under the supervision of Transport Ministry.
Assessing criticality
A criticality assessment was not performed, however, indicators such as: Level of Use (AADT), Heavy Vehicle (%HV), Connections (communities, industry), etc., to assess the severity of the impact on risk assessment.
Defining key tasks and delivery plan
The objective is to link the tasks to be performed with the objectives and scope of the evaluation to be carried out through the Framework. The deliverables of the projects: • Guide for the implementation of the Framework at the state level. • International Framework for Adaptation to Climate Change for Roads Modified for Mexico.

- Training workshop
- Vulnerability reports on the federal highway network in the states of Colima and Nayarit.
- Georeferenced database with the identification of the exposed sites of the road network.

Stage 2 - Assessment pathways

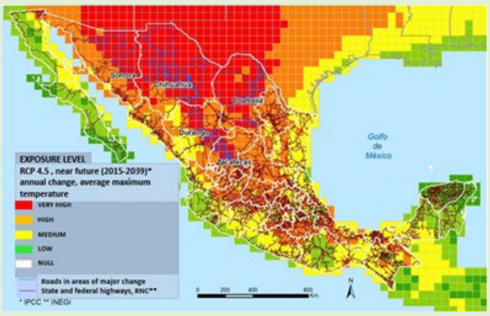
Assessing vulnerability

Assessment is based on indicators for each factor: exposure, sensitivity and adaptive capacity.

The analysis procedure was based on the PIARC Framework with an adapted scale to set the level for each parameter.

Exposure

Exposure levels were based on historical and recent events, observations, local and technical knowledge, on existing research in the country, particularly on hydro meteorological phenomena. The Environment Ministry has built maps to assess the degree of exposure, which can be identified by overlapping with the road network.



Assessing sensitivity

In order to evaluate the sensitivity of each infrastructure element, matrices were constructed to quickly assess the condition of the road asset.

Table 2. Sensitivity assessment for a road cutting section

Sensitivity Factor	Sensitivity Level					Rating
	Very Low (1)	Low (2)	Medium (3)	High (4)	Very High(5)	
Soil Type	Material with low sensitivity to erosion (rigid rocks)	Material with low sensitivity to erosion (soft rocks)	Material moderately prone to erosion sensitivity (compacted soils)	Material with high sensitivity to erosion (loose soils)	Material with very high sensitivity to erosion (very loose soils)	
Angle of inclination	-	The inclination of the cut is less than 30°.	The inclination of the cut is greater than 30° and up to 40°.	The inclination of the cut is greater than 40° and up to 60°.	The inclination of the cut is greater than 60°.	
Vegetable cover	The cut is covered with shrubby vegetation	The cut is covered with shrub vegetation	The cut is covered with herbaceous vegetation	The cut is covered with herbaceous vegetation	The cut is uncovered, has very little presence of vegetation	
Degree of erosion	No erosion observed	Initial erosion is observed	Erosion is observed in at least 20% of the cut area.	Erosion is observed in more than 20% and less than 50% of the cut area.	Erosion is observed in more than 50% of the cut area.	
Mechanical resistance	Its composition and structure have very high resistance to stress.	Its composition and structure have a high resistance to stress.	Its composition and structure have a medium resistance to stress.	Its composition and structure have a low resistance to stress.	Its composition and structure have very low resistance to stress.	

Adaptive capacity

Adaptive capacity is the capacity or potential that a system has to be able to respond successfully to the impacts of climate variability, climate change, and extreme weather. The assessment of adaptive capacity can be done geospatially, supported by the map in Figure, which establishes a value at the municipal level based on the capacities and resources of the area.

Assessing /calculating vulnerability

Through the combination of exposure and sensitivity ratings, it is possible to identify if the asset is vulnerable to climate variables, and to what extent. Assets with high exposure and sensitivity will be more vulnerable to climate variables than those with low exposure and low sensitivity.

		Sensitivity				
		Very Low	Low	Medium	High	Very High
Exposure	Very High	6 (Medium)	7 (High)	8 (Very High)	9 (Very High)	10 (Very High)
	High	5 (Medium)	6 (Medium)	7 (High)	8 (Very High)	9 (Very High)
	Medium	4 (Low)	5 (Medium)	6 (Medium)	7 (High)	8 (Very High)
	Low	3 (Low)	4 (Low)	5 (Medium)	6 (Medium)	7 (High)
	Very Low	2 (Very Low)	3 (Low)	4 (Low)	5 (Medium)	6 (Medium)

At the end of this step, a list of assets with high or very high levels of vulnerability is obtained.

Analysing risk

This stage involves assessing the risk based on its probability of occurrence and the severity of the impact.

Evaluation of the probability of impact

In order to determine these probabilities, information on the occurrence of extreme hydro meteorological phenomena was required: Atlas of national, state or municipal risks, as well as the climate maps of the National Centre for Disaster Prevention (CENAPRED) on the probability of the impact of different climatic phenomena.

Assessment of impact severity

Severity refers to a judgment about the severity of an impact (such as: flooding of a road, etc.) if it were to materialise. Severity is assessed by the user based on their knowledge, as well as by making estimates and evidence of similar events in the past, and can also be assessed using a severity scale.

The assessment of associated parameters for severity according to the Framework was adapted to the case of Mexico, whose parameters and thresholds for assessing severity are shown in table.

Criteria	Consequence		
	Low = 1	Medium = 2	High = 3
Local population directly affected	Less than 2,500	Between 2,500 & 15,000	More than 15,000
Transit affected	< 3,000 v/d	3,001 - 6,000 v/d	> 6,000 v/d
Heavy traffic affected	< 10% del AADT	11-20% del AADT	> 20% del AADT
Adaptive capacity	High	Medium	Low
Level of social impact	Local	Regional	National

Risk assessment and records

Impacts can be classified and prioritised to address their "risk" according to their overall score and will be used to develop a risk register.

From the results of these phases, they allowed to obtain only the risks that will require an early attention because they are at the highest level.

Stage 3 - Developing and selecting adaptation responses and strategies

Adequate adaptation actions need to be developed in response to the identified risks to provide an effective response to the impacts of climate change on a road network.

Identification of responses and adaptation opportunities

In the international literature, there is a wide range of adaptation responses for the road infrastructure, these serve as a guide to determine optimal adaptation measures in order to increase the resilience of the network or road assets. In order to determine the responses, the experience of the field engineers and the contributions of the groups involved in the project allowed to determine feasible, realistic actions with a high potential to be effective.

For each site, an adaptation measure was proposed and costs were estimated.

Selection and prioritisation of responses and adaptation opportunities

For the application of the Framework in Mexico, multi-criteria Analysis was used to prioritise adaptation responses.

Multicriteria Analysis is based on different variables that may include costs, but also other variables such as indirect damages (loss of production of suppliers, costs of traffic interruption or costs of emergency services), environmental impact, social acceptance, etc.

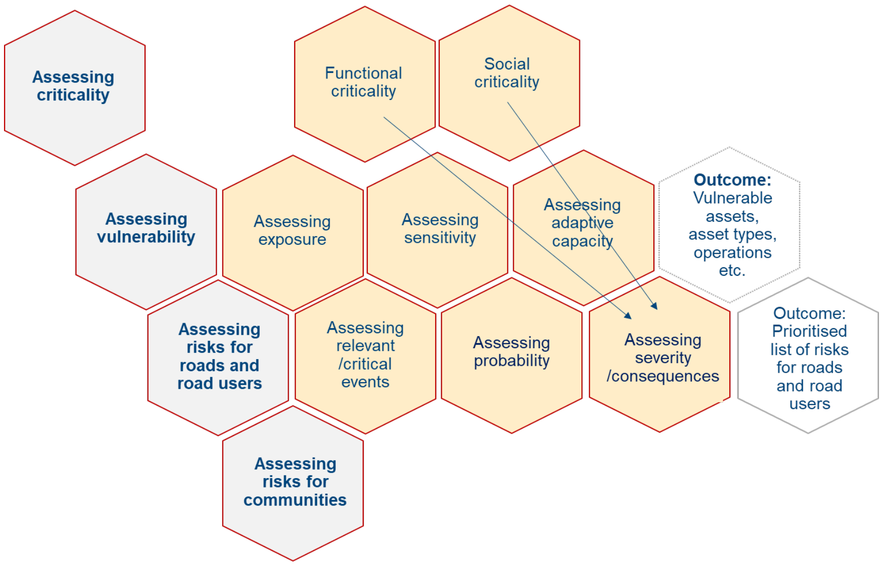
In the case of the Framework, it is suggested that the following variables be used for a Multicriteria Analysis:

Initial Investment	Technical feasibility	Applicability	Social acceptability	Flexibility	Environmental impact	Inaction risk	Available means	Capacity Adaptation

Stage 4 Integrating findings into decision-making processes
Incorporating recommendations into decision-making
The Framework suggests that adaptation measures be implemented within road maintenance plans. The application of the Framework is a tool with which budgetary resources can be managed to carry out actions that reduce the exposure of the road network to the risk of climatic events.
Monitoring
Monitoring and review of climate change risks, vulnerability and effectiveness of adaptation responses is essential. Road organisations are encouraged to continually review their results, strategies and plans as more information becomes available and as new risks become apparent.

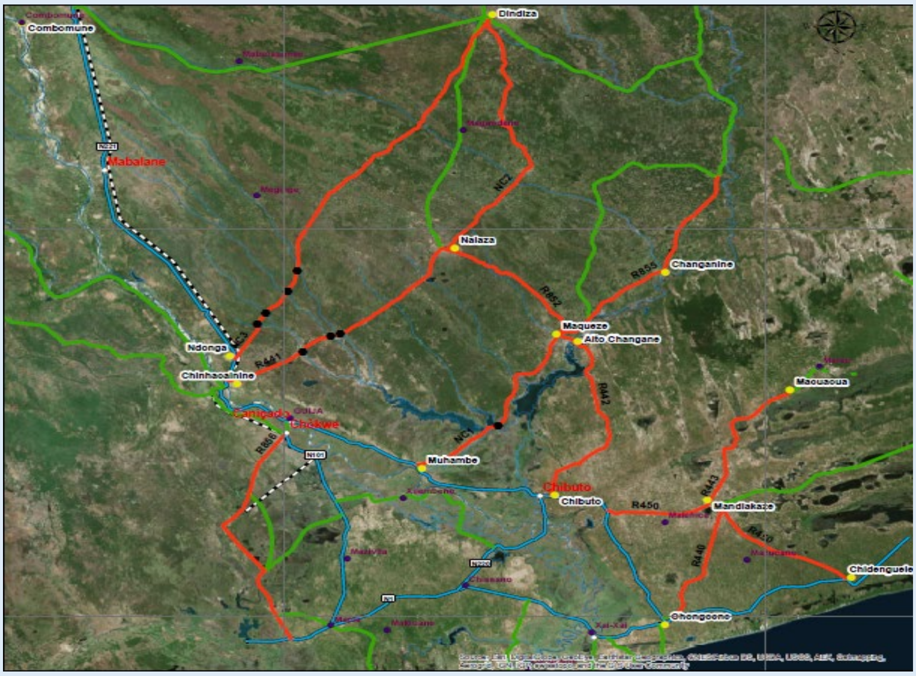
The results made it possible to adapt the PIARC Framework and build a customised version of the PIARC Framework.

This analysis can be graphically illustrated as in the figure below:

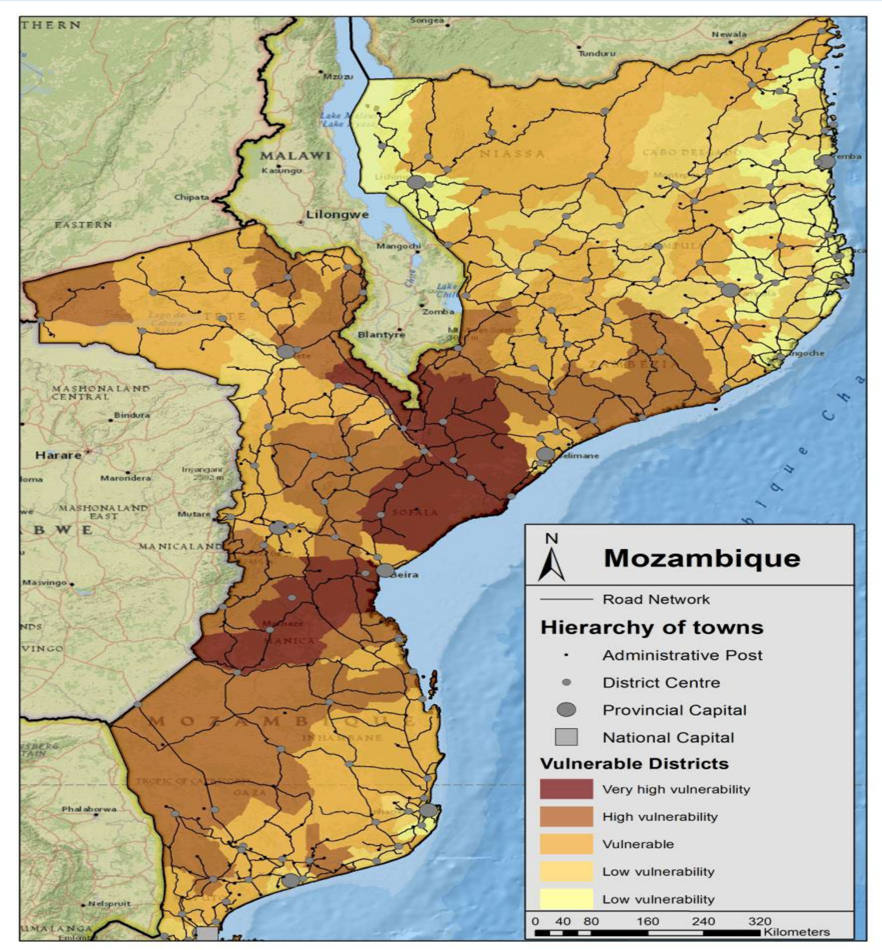


10.5.8. ReCAP Methodology - Mozambique

Back

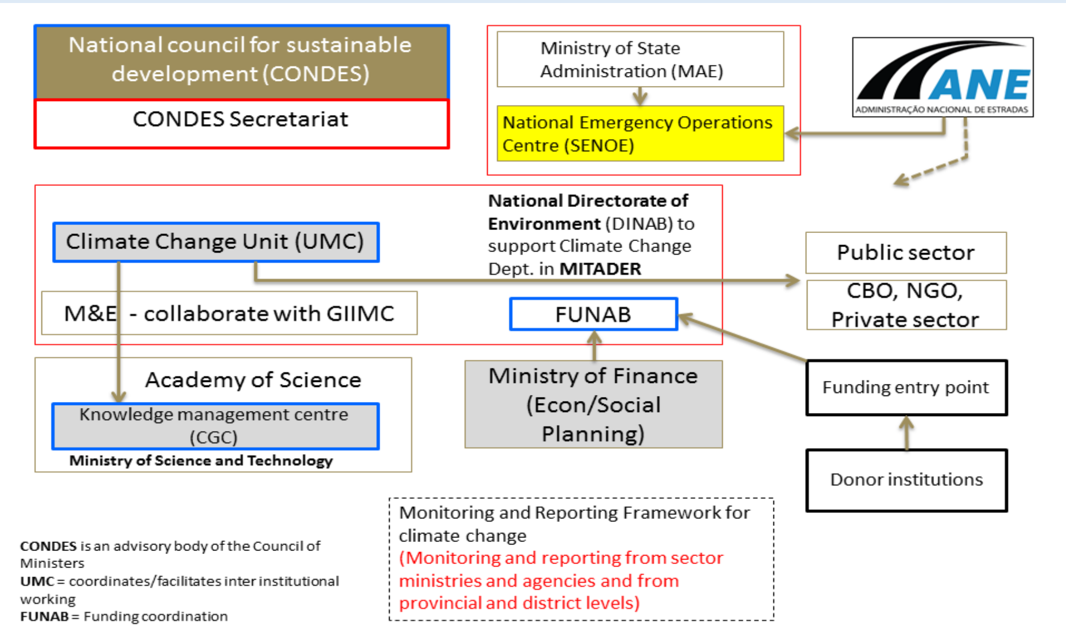
Stage 1 – the preparation stage
Identifying the baseline for adaptation
Drivers Open roads are a precondition for the safety and economic development of rural communities. Availability of open and accessible roads is one of the main motivations for the adaptation work. Initial road assessment process was carried out due to damages caused by heavy flooding along the Mohambe – Maqueze road in 2018. Access was curtailed for communities living in the hinterland. Stakeholder engagement was initiated which then motivated for a continuation of the work. Pilot Project Site Location Map  **Data availability** Mozambique has available good maps of prevalent hazards – floods, droughts, landslides, and a good overview of historical storm events. As a country with a 2000km coastline, it has suffered from these events for more than 2 decades hence has relatively highly developed systems compared to most SSA countries.
Establishing aims and scope
Aim of project was to apply procedures outlined in the ReCAP Guidelines on a rural road that has consistently been subjected to flooding for 3 consecutive years. Key objective was to deliver processes to identify, characterise and demonstrate appropriate engineering and non-engineering adaptation procedures on: • Climate threats and impacts • Vulnerability to impact (risk) • Non-engineering and engineering adaptations • Priorities and interventions **Scope**:

Scale –Road NC Mohambe -Maqueze (rural road) was selected based on damages caused by repeated adverse climatic events (flooding, erosion) over 3 consecutive years. All assets on the road stretch were considered. Time scope: 2050. Main observed climate threats: heavy rain from catchment areas causing flooding
1.3 Climate change impact
Mozambique experiences the highest frequency of land-falling tropical cyclones and pressure-lows of any African country, often in association with widespread and catastrophic floods. Contributing to flooding is the fact that Mozambique shares nine river basins with neighbouring countries, with streamflow originating from these countries contributing to 50% of the country's total volume of runoff. Rainfall occurs mostly during the warmer months from October to April and is influenced by the warm Mozambique current, meridional displacements in the Inter-Tropical Convergence Zone (ITCZ), easterly waves (including tropical cyclones) and tropical-temperate troughs. Well-defined sea-breeze circulations also frequently develop on the coast during days when the synoptic-scale forcing is weak (le Roux *et al.*, 2018b). Information is sourced from national scale GIS datasets from national departmental authorities as a first priority. Road data was obtained from the Mozambican roads authority (Administração Nacional de Estradas, ANE). In the absence of such data, open-source data repositories were used as a second choice. As a starting point, country specific custodian data can be sourced from the following places: National departmental authorities (e.g. the National Disaster Management Institute (Instituto Nacional de Gestão de Calamidades, INGC) , the Mozambique National Meteorology Institute (INAM), the roads authority (Administração Nacional de Estradas, ANE); Road asset management systems (coordinated and maintained by ANE); The information was developed over time with maps prepared on vulnerable areas across the entire country and showing nature of hazards (see added text and typical maps extracted from the Guidelines and included in the text) Vulnerable districts under current climate and socio-economic conditions



Establishing the context

Key government structures involved Climate Change Adaptation/ Data Sharing



ANE is represented at the important National Emergency Operations Centre (SENOE) and is part of the secretariat. This therefore provides them access to other stakeholders involved in CCA, as well as external expertise to complement their own internal department responsible for emergencies on the national road network.

As part of the collaboration with development partners, this project was selected to be a pilot and was incorporated into an ongoing World Bank funded project that was addressing effects of an adverse climate change event in a peri-urban area a few kilometres away.

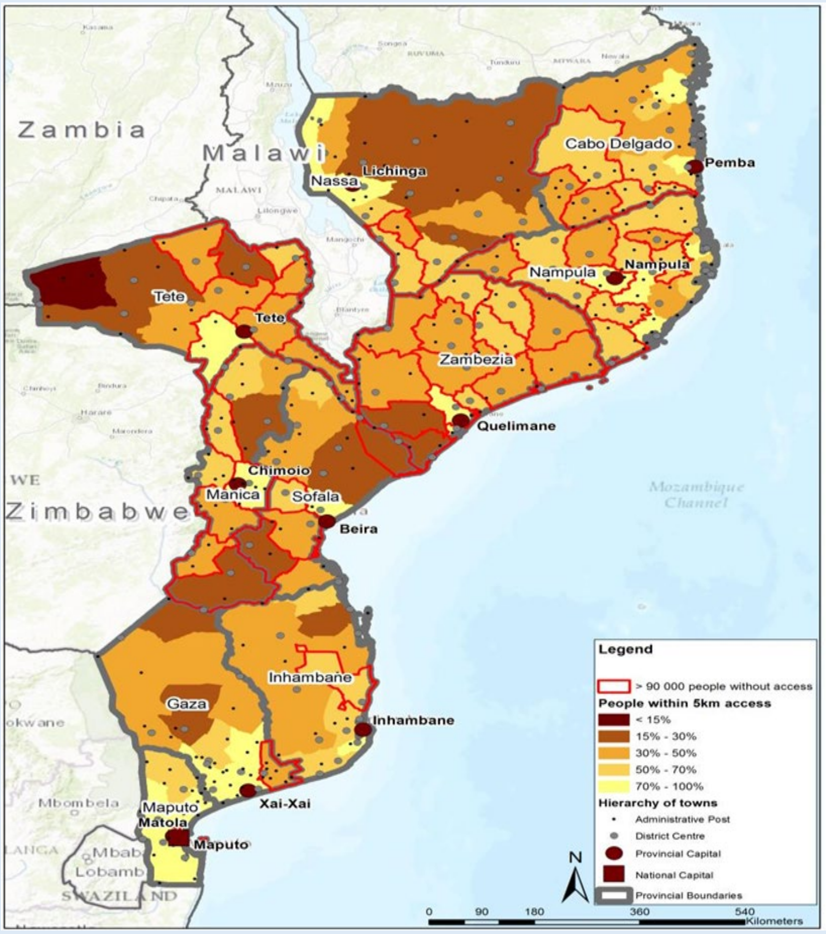
Assessing criticality

Road asset criticality was based on modified rural access index i.e. people living within 5km of an all-season road.

An assessment of criticality uses the serviceability- and accessibility-based methods particularly for regional and rural road networks. Design and maintenance quality are also important aspects considered when assessing vulnerability (Risk & Vulnerability Guideline).

The following aspects are considered in the calculation of the Road Criticality (Cr) score:

- Number of alternative routes available
- Predominant vehicle types on this road
- Public facilities reached by this road
- Road asset crticality



1.5 Defining key tasks and delivery plan

The assessment procedure for determining the key tasks in line with observations on site is described fully in Chapter 4 of the Visual Assessment Manual.

Based on these observations, various adaptation measures were discussed in the field and decisions taken to implement the following key tasks:

- Slope Restructuring and Reconstruction to reduce side slopes to a maximum slope of 1:4, planting deep-rooted local grass varieties on slopes and extending existing aqueducts to suit the wider embankment;
- A 150 mm wearing layer of limestone gravel was built over the road surface where the road is embanked and low-lying;
- A 100mm thick trapezoidal concrete slab was constructed, placed on the slopes at each entrance and exit of the culverts;
- The aqueducts' headwalls and drift on both the upstream and downstream were modified using gabions.
- Instal culverts of bigger diameter and increase the number of lines at identified locations.

Stage 2 – Assessment pathways

Assessing vulnerability

Assessing exposure
Most vulnerable districts are identified by aggregating the road exposure and road criticality analysis results.

Almost 70% of districts in Mozambique are classified as vulnerable due to their high exposure to frequent and severe flooding as well as their low rural accessibility and high isolation rates.

Overview of the ReCAP risk and vulnerability assessment methodology is detailed in the Risk & Vulnerability Guideline, Section 3.2.

As a solution to the challenge of spatial data availability and quality as well as the multi-faceted nature of the risk and vulnerability analysis, a semi-quantitative indicator-based risk assessment method was adopted.

An indicator-based risk method entails reducing a complex problem into key factors (or dimensions), identifying variables that characterise those factors and using mathematical and decision-theoretic techniques to quantify and aggregate the variables into measurements that are intuitive and accessible to practitioners and decision-makers.

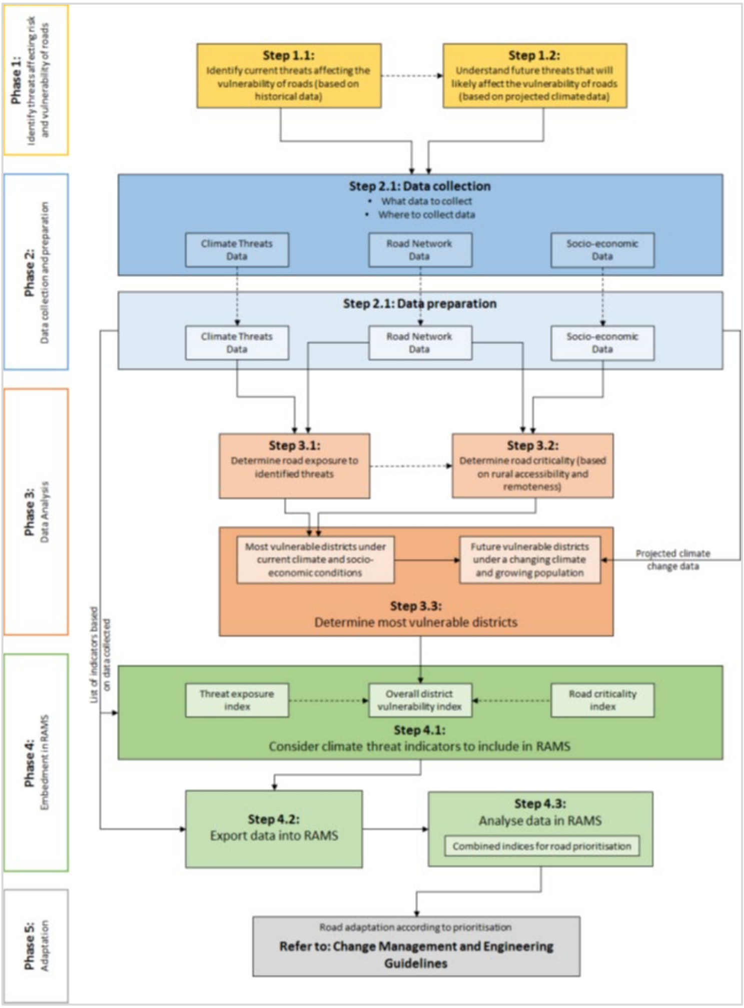
Assessing sensitivity
For rural roads, sensitivity is assessed through various road elements that make the road highly susceptible to adverse climatic events e.g. whether road is built using expansive soils; dispersive soils; saline clays; collapsible soils; high water tables, or low-lying, among others. Respective methods of recognising these characteristics are provided in Appendix B of the Engineering Adaptation Guidelines

Adaptive capacity
In Mozambique, systems and institutions are in place to enhance the existing adaptive capacity. More should be done to build capacity of the personnel in road organisations to increase effectiveness of the systems in a sustainable manner. (Education, awareness, training, effective communication). The adaptive capacity is demonstrated throughout the planning and implementation process (All Guidelines).

The ReCAP methodology provides a starting point for other LMIC to define their baseline and proceed with the setting up of policies, systems (RAMS) and other required institutional arrangements. The risk and vulnerability assessment process linked with road asset management and RAMS. The RAMS should be the source of information on the road network that is required for

the risk and vulnerability assessment process. Outputs from the risk and vulnerability assessment process must feed back into the RAMS to be used as additional indices.
Analysing risk
Recognising events of concern Maps have been developed and were used to rank vulnerable districts under current climate and socio-economic conditions. **Probability** Events such as flooding, storms, droughts have been observed over time and are now recognised as recurrent. **Severity** Also assessed and compared with previous occurrences. Now with greater intensity and of longer duration.

The figure below shows the entire process that needs to be followed in the assessment through to prioritisation of adaptation measures. This also serves to encourage roads authorities appreciate the data requirements and the importance of RAMS in the whole process.

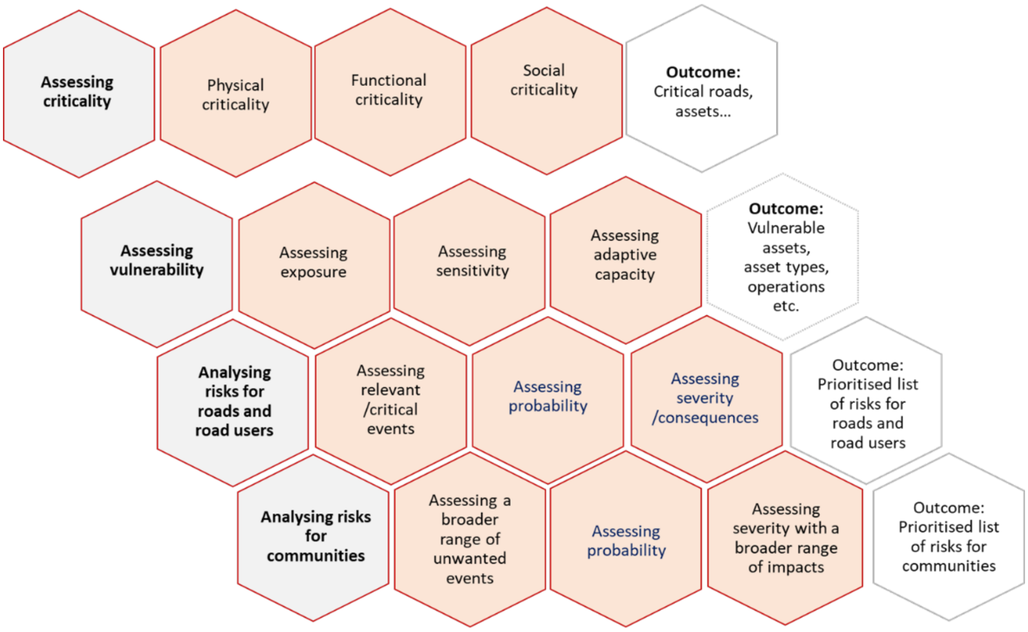


Stage 3 - Developing and selecting adaptation responses and strategies
Identification of adaptation responses and strategies
Covered fully in the Engineering Adaptation Guidelines (Chapters 4 & 5). Most new roads should incorporate the necessary adaptation measures to ensure resilient structures. Existing roads will either incorporate those that give the best value for money in a proactive regime (retrofitting) or those that can be afforded in a reactive mode. All of these decisions must be based on the road category (Level of Serviceability), the specific vulnerabilities and the prioritisation process carried out as described in the Change Management Guidelines.
Selection and prioritisation of adaptation responses and strategies
Selection and prioritisation were mainly based on assessed damage from previous climate events (reactive) with some retrofitting where breaches on the road were likely to occur in the event of greater intensity in future.
Development of an action plan or strategy
Action plan was developed on the basis of assessed and quantified & costed damages. The strategy included low-cost, do-nothing and managed retreat options.

Stage 4 - Integrating findings into decision-making processes
Incorporating recommendations into decision-making
Data collected through the risk and vulnerability assessment is prepared, analysed and recommendations for decision-making provided. Risk & Vulnerability Guideline, Section 3.2. The installation of adaptation measures initially required prioritisation of the needs, as per item 3.2 above. The process of prioritisation requires significant input from both road authorities and affected communities. Their differing needs and priorities needed to be balanced and typically required decisions of a strategic nature.
Communicating the findings
Internally within the Roads Administration, externally to affected communities and through the steering committee for other stakeholders.
Establishing stakeholder networks
Already in place, include national state authorities, community based organisations, Local Government authorities (districts, municipalities), sector representatives, among others.
Education, awareness, training, effective communication
Needs to be properly structured and carried out consistently. It is currently done in an ad hoc manner. Workshops were conducted in the project area with ANE head office technical personnel, local authority technicians and community representatives as participants. Objective was to explain nature of project, data collection process (pre-field work) and discuss action plan (post-field work). Simplified forms were used to collect data on site with a view to have the local technicians do this work themselves in future. These forms are available in the Visual Assessment Manual.

Developing a business case for adaptation
A simple cost/benefit analysis (CBA) was developed but the decision to do adaptation work on this particular road was influenced by existing funding from the World Bank that was applied on the ongoing peri-urban component of this road. According to the Engineering Adaptation Guidelines (chapters 4 & 5), factors to be considered include: • Potential loss of life (safety) • Availability of alternative routes • Cost and consequences of closure • Environmental/sustainability issues • Cost of repair • Available funds • Accessibility requirements. In the CBA, the cost of repairs, consequences of closure of various adaptation options will be compared against related accessibility requirements e.g. availability of alternative routes.
Monitoring, reporting, review
This was not carried out during the course of the ReCAP project but efforts are underway to collect performance data on the applied adaptation measures after recent flooding. However, there is apparently little or no consistent monitoring to learn lessons and adjust measures progressively based on analysis of performance data.

This analysis can be graphically illustrated with all the elements included, as in the figure below.



The ReCAP methodology was trialled on a road project in Mozambique and as part of the exercise, all the assessments (risk, vulnerability, exposure, and others) were carried out. This was to demonstrate the likely constraints such as paucity of quality data, limited technical capacity and

resources, and their impact on quantitative assessment processes for all elements of the risk and resilience assessment.
Stakeholder and community involvement was also key for informed understanding of the implications of disruptions of roads for the community's economy and security, from their perspective.

Availability of quality data was a challenge, but awareness was created on what the data requirements are for future assessments. The monitoring and review process, if instituted, should then address these data gaps.

10.5.9. Mn DOT: Assessing Resilience and Criticality in a Changing Climate

Back to 2.1.4 Vulnerability assessment

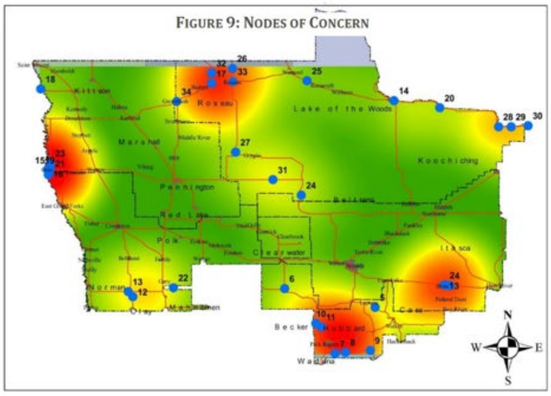
Back to Section 5

Stage 1 – the preparation stage
Identifying the baseline for adaptation
Climate change is already driving major weather changes in Minnesota. Local weather patterns are becoming much warmer and wetter. By 2020 winters had already warmed 13 times faster than summers and in the previous 20 summers there were two times as many mega-rains, with 6 inches of rain covering 1,000 sq. miles, as there were between 1973 and 1999.
Establishing aims and scope
After scanning Federal Highway Administration studies and the programs implemented by other state DOTs, Mn DOT identified two key actions: 1) analyse infrastructure vulnerability and 2) develop policies that incorporate changing weather patterns into infrastructure design.
Climate change impact
Minnesota's projected climate change impacts demonstrated a medium to very high likelihood that flooding, warmer winters, increased invasive species populations, droughts, and extreme heat would impact the state's transportation infrastructure.
Establishing the context
Multiple Mn DOT units already focus on different ways to maintain the operational resilience of Minnesota's transportation network. Resilience to climate change is a part of this work, touching each of the units, and Mn DOT's Statewide Multimodal Transportation Plan is clear that, *"System resiliency refers to reducing vulnerability and ensuring redundancy and reliability to meet essential travel needs. The transportation system is vulnerable to many types of threats and risks, such as severe weather, acts of terrorism and cyber-attacks. Advanced preparation as well as mitigation and adaptation to threats and risks helps to ensure the people and goods are able to continue to travel during emergencies."*
Assessing criticality
Recognizing the criticality in responding to changing weather patterns, Mn DOT completed a gaps analysis of the interconnected organisation plans and efforts to reduce weather-driven system vulnerabilities. Two key points highlights in the analysis make it clear that: Plans for adapting to climate change should fit into MnDOT's existing processes; and Climate adaptation is not a separate part of the organisation work, but rather another way of thinking about existing work and plans.
Defining key tasks and delivery plan
Identifying how climate risks and vulnerabilities could impact specific facilities needed to include qualitative and quantitative assessments and analyses of future vulnerabilities. An important acknowledgement has been that climate change has been happening and is exacerbating stressors that already exist which increases the vulnerability of people and assets.

Stage 2
Assessing vulnerability
After several mega storms damaged infrastructure across Minnesota, staff identified extreme flooding as a crucial vulnerability to assess. Using the combination of Federal Highway Administration

pilot projects to analyse flooding, a qualitative approach used in Washington State, and interview with MnDOT maintenance staff about issues that “kept them up at night,” a list of measures and locations were developed to assess.

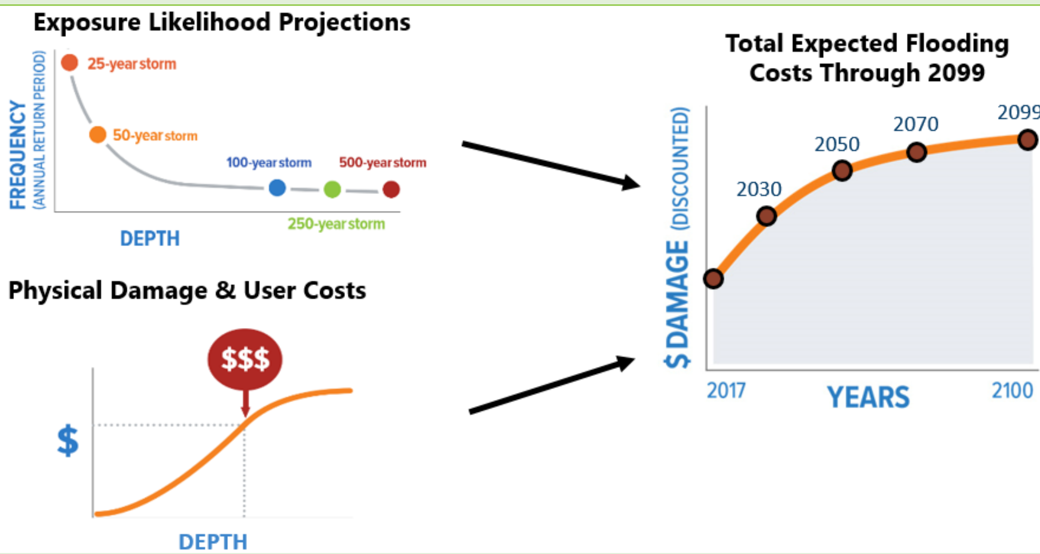
Extreme Flood Vulnerability Analysis



District 2 Resilience Pilot Project

Assessing sensitivity
With assets identified by MnDOT staff, precipitation projections were selected to compare the outcome for moderate and high climate change scenarios. Projections were developed for the 2, 5, 10, 25, 50, 100, 200, and 500-year peak flows at each asset for each scenario through the end of the century. The USGS StreamStats flow estimates were scaled up or down based on the projected precipitation change.

Adaptive capacity
Costs for asset failures or repairs were calculated by determining the costs to surrounding communities for diminished transportation network connectivity and for the potential costs to repair or reconstruct impacted assets.



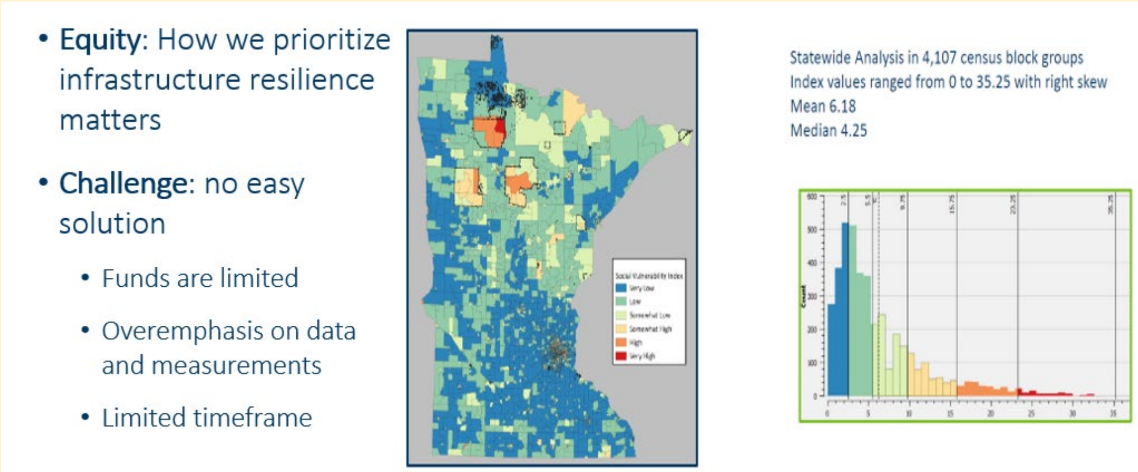
Calculating vulnerability

MnDOT conducted a qualitative assessment of climate vulnerability in the very rural upper northwest corner of the state to help identify areas of concern that might not be identified by climate data alone.
Analysing risk
Recognising events of concern Using the qualitative assessment was especially useful for identifying areas where overtopping or slope failures might occur but are easily repaired by maintenance staff. Understanding where low-cost work might regularly happen, helped staff understand where small issues might become bigger issues in the future. It had a secondary benefit of helping a broader group of staff start to think about both climate change and linked system impacts.

Stage 3 Developing and selecting adaptation responses and strategies
Identification of adaptation responses and strategies
MnDOT has identified four strategic approaches for adapting to climate change. Project-level context but the adaptive choices are simple: protect assets, accommodate increased exposure to water, retreat, or change a policy or practice to adapt to the impacts from precipitation changes.

Approach	Adaptation Options
Protect/Defend	Provide major structural protection
	Provide protection at existing elevation/locations
Accommodate	Elevate the infrastructure above the impact zone
	Enhance drainage to minimize closure time and/or deterioration levels
Retreat	Abandon infrastructure
	Relocate infrastructure (horizontally)
	Temporarily restricts use of infrastructure
Change policy or practice	Increase the infrastructure’s maintenance and inspection interval and continue to monitor/evaluate
	Modify land use and development policies to account for future impacts

Selection and prioritisation of adaptation responses and strategies
MnDOT maintenance staff track location and frequency of flooding, damage, closures, pavement condition and temperature, vegetation, weather data, winter metrics, pavement performance. As we determine what infrastructure is the most vulnerable to climate change, we also are starting to consider potential inequities that might results from our prioritisation processes.



Development of an action plan or strategy

This process described above has resulted in an understanding of how climate change will likely manifest itself across the state, how that will impact the transportation network, and the capacity to implement the most appropriate responses, given existing policies, practices, and funds to respond to climate threats and vulnerabilities. As a results, an interdepartmental Resilience Advisory Team was created to develop a wholistic strategy for MnDOT.

Stage 4 - Integrating findings into decision-making processes

Incorporating recommendations into decision-making

In addition to creating a Resilience Advisory Team to coordinate research and policy across MnDOT's divisions, MnDOT's leadership created a Climate Resilience Workgroup. This workgroup was charged with informing and recommending projects and strategies to an internal Transportation Programming and Investment Committee, a group that reports to the Transportation Commissioner.

Communicating the findings

The planners and leaders within MnDOT's eight districts are very attuned to the most cost-effective way to use their funds. Sharing this project's lessons has helped transform the way they consider adaptive responses to the "weird weather" they have already been responding to over the last couple decades.

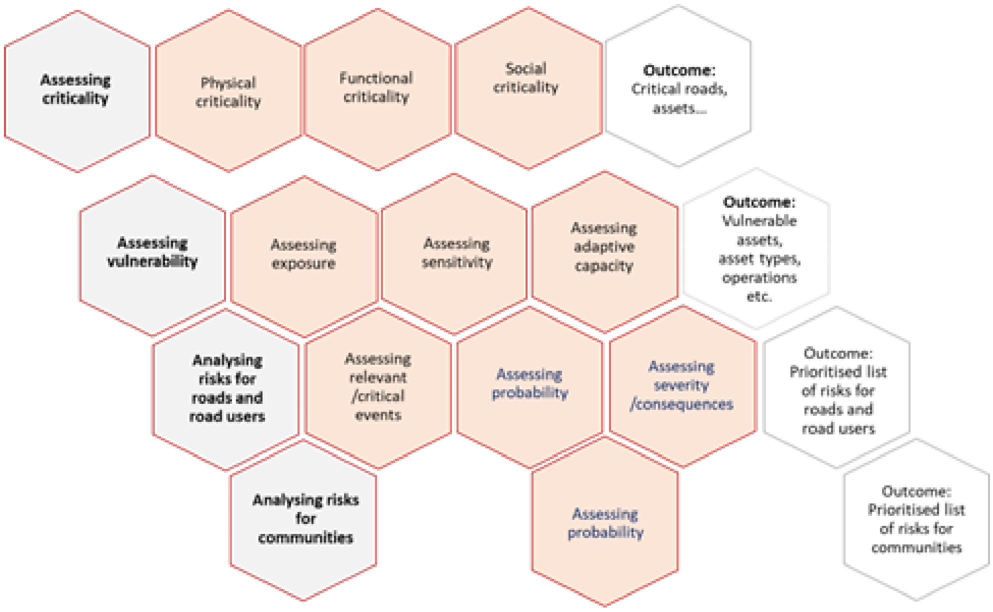
Establishing stakeholder networks

Creating the Resilient Advisory Team and the Climate Resilience Workgroup has expanding the internal stakeholders who consider climate change in their day to day work. Each of MnDOT's eight district manage an Area Transportation Partnership that coordinates projects with local units of government that help prioritise a set of projects within their district. Each of these partnerships has begun to incorporate climate resilience into their decision framework.

Education, awareness, training, effective communication

This has been a work in progress and yet engagement across MnDOT divisions, within the Districts, and the Area Transportation Partnerships has broadened awareness of the fundamental climate impacts to Minnesota's transportation system.
Developing a business case for adaptation
The business case for adapting to climate change often comes down to simple math. Calculating the adaptive capacity for cost effective responses to localised flood threats has proven to be crucial for who calculate asset lifecycle costs and incorporate the latest precipitation data into their formulas.
Monitoring, reporting, review
MnDOT's Resilience Advisory Team is developing strategies for adjusting current policies and practices so that staff can continuously monitor, report, and review the resilience of Minnesota's transportation network in the face of climate change.

This analysis can be graphically illustrated as in the figure below:



World Road Association (PIARC)

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