RISK MANAGEMENT FOR ROADS IN A CHANGING CLIMATE

A Guidebook to the RIMAROCC Method

Final version

This project was initiated by ERA-NET ROAD.

Project Co-ordinator:

SGI, Sweden

Project Partners:

EGIS, France

Deltares, The Netherlands

NGI, Norway

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Project No. TR80A 2008:72148
Project acronym: RIMAROCC
Project title:

Risk Management for Roads in a Changing Climate

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Due date of deliverable: 30.09.2010
Actual submission date: 30.09.2010

Project start date: 01.10.2008 Project end date: 30.09.2010

Authors of this deliverable:
Bles Thomas, Deltares
Ennesser Yves, Egis
Fadeuilhe Jean-Jacques, Egis
Falemo Stefan, SGI
Lind Bo, SGI
Mens Marjolein, Deltares
Ray Michel, Egis
Sandersen Frode, NGI

This guidebook is supplemented by a technical report and cases studies, presented in separate volumes.

Version: Final

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Preface

This project was initiated within the ERA-NET ROAD Coordination Action, “ENR SRO3 - Road Owners Getting to Grips with Climate Change”. The partners in ERA-NET ROAD (ENR) were Austria, Denmark, Finland, Germany, Ireland, The Netherlands, Norway, Poland, Spain, Sweden and the United Kingdom.

The Guidebook is part of the RIMAROCC project with the objective to develop a common ERA-NET ROAD method for risk analysis and risk management, with regard to climate change, for Europe. The project is led by a Project Management Group with representatives from all the partners: Swedish Geotechnical Institute (SGI), Bo Lind (co-ordinator); EGIS, Michel Ray; Deltares, Thomas Bles; Norwegian Geotechnical Institute (NGI) Frode Sandersen. The project working group also includes Yves Ennesser and Jean-Jacques Fadeuilhe, Egis; Stefan Falemo and Hjördis Löfroth, SGI; Marjolein Mens, Deltares. Additional funding to the Rimarocc project has been provided by all participating partners. We would like to thank KNMI (Netherlands), Météo France and SMHI (Sweden), for their input on climate change and critical climate factors.

The Project Steering Group from the ERA-NET Board, Åsa Lindgren (Project Manager), Swedish Road Administration; Alberto Compte and Eva Ruiz-Ayucar, CEDEX Spain and Geoff Richards, Highways Agency UK, have in a constructive way contributed to the project together with other persons from the ERA-NET ROAD organisations - they are all gratefully acknowledged.

Our sincere thanks also to all the other people who have made important contributions to the project. We would like to mention in particular:

Beatrice Quiquampoix, Egis
Estelle Morcello, Egis, Transport economist
Stephane Hallegatte, CIRED / Météo France, Climate change specialist
Eric Brun, Météo-France / CNRSI, Climate change specialist
Edouard Fischer, SANEF, Operating Division, Chief Technical Officer
Werenfried Spit, RWS, Environmental advisor
Paul Fortuin, RWS, Climate change specialist
Jaap Kwadijk, Deltares, Climate adaptation methods specialist
Unni Eidsvig NGI, Risk assessment
Lars Bärring, SMHI, Climate scientist
Håkan Nordlander, Swedish Road Administration
Albert Klein Tank, KNMI, Climate scientist

Glossary of key terms

This glossary has been built up with definitions from various sources in relation to climate change, natural hazards, and risk management: IPCC, ISSMGE TC32 (ISSMGE)[1], FLOODsite 2005 (FLOODsite), PIARC C18 (PIARC) and ISO/ 31000. Where several definitions are available for the same term we have proposed the one which appears to be most appropriate in the RIMAROCC framework.

Adaptation: Initiatives and measures to reduce the vulnerability and/or consequences of natural and human systems to actual or expected *climate change* effects. Various types of adaptation exist, e.g. *anticipatory* and *reactive; private* and *public; autonomous* and *planned*. Examples include raising river or coastal dikes, the substitution of more temperature-shock resistant plants with sensitive ones etc.

Climate change: Climate change refers to changes in the state of the *climate* that can be identified (e.g., using statistical tests) through changes in the mean and/or the variability of its properties, and which persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or *external forces*, or to persistent anthropogenic changes in the composition of the *atmosphere* or in *land use*.

Climate risk manager (or risk manager): The authority responsible for the climate risk management studies within the road authority.

Consequence: The negative effect, or effects, that can be expected if an asset or system is damaged, destroyed, or disrupted.

Exposure: Relates to the influences or stimuli that impact on a system. In a climate change context it captures the important weather events and patterns that affect the system, but can also represent broader influences, such as changes in related systems brought about by climate effects. Exposure represents the background climate conditions against which a system operates and any changes in those conditions.

Hazard: A potential source of harm; something with the potential to cause risk events and therefore adverse consequences.

Level of risk: Magnitude of a risk, expressed in terms of the combination of consequences and their likelihood.

Likelihood: Used to refer to the chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically (such as a probability or a frequency over a given time period).

Mitigation: Activities designed to reduce or eliminate risks to persons or property or to

[1] ISSMGE, International Society for Soil Mechanics and Geotechnical Engineering

lessen the actual or potential effects or consequences of an incident.

Organisation (or Road Organisation): Decision and operational structure of (road) management.

Risk: A measure of potential harm that encompasses threat, vulnerability and consequence. Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence.

Risk analysis: the use of available information to estimate the risk to individuals, populations, property or the environment, from hazards.

Risk evaluation: A process of comparing the estimated risk against given risk criteria to determine the significance of the risk.

Risk assessment: The overall process of risk identification, risk analysis and risk evaluation.

Risk management: the systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, mitigating and monitoring risk.

Risk scenario: In the present context a scenario is a description of a future situation based on the present situation and knowledge, on the hypothesis of presumed evolution of some parameters from the present to the future, in order to evaluate consequences of unwanted events created by climate change. Each set of climate risk source, road vulnerabilities and consequences constitutes one scenario.

Residual risk: The risk remaining after risk treatment (mitigation or adaptation). Residual risk may include unidentified risk.

Road authority: The executive agency responsible for operating, maintaining and improving the road network. Administrative and operational functions may be delegated to other entities (contractors).

Threat: In the present context, an extreme climate event that could be detrimental to the infrastructure and/or its operation.

Uncertainty: The state, even partial, of deficiency of information related to understanding or knowledge of an event, its consequence, or likelihood.

Vulnerability: The extent to which a natural or social system is susceptible to sustaining damage [from climate change]. It is a function of the sensitivity of a system [to change in climate], adaptive capacity and the degree of exposure of the system to [climatic] hazards.

Vulnerabilities: In the present context, elements of the road system (infrastructure, traffic, environment, etc.) vulnerable to climate change.

PART 1 – Basis for climate and risk management

1 Introduction: the purpose and contents of the Guidebook

1.1 *The purpose of the Guidebook*

This Guidebook is intended to be a concise methodological guide to risk management for roads with regard to climate change. The proposed method should enable the user to identify the climatic risks and to implement optimal action plans that maximise the economic return to the road owner taking into account construction cost, maintenance and environment.

The RIMAROCC method is designed to be general and to meet the common needs of road owners and road administrators in Europe. The method seeks to present a framework and an overall approach to adaptation to climate change. The method is based on existing risk analysis and risk management tools for roads within the ERA-NET Road member states and others. Work dealing with risk analysis and climate change is taking place in many countries. The proposed method is designed to be compatible and function in parallel with existing methods, allowing specific and functional methods for data collection, calculations and co-operation within each organisation to be maintained. The method is also in line with the ISO 31 000 standard on risk management.

It must be borne in mind that the definition and analysis of road system vulnerabilities to climate change do not fall within the scope of the RIMAROCC project.

The Guidebook is designed to be straightforward and easy to use. Further information and background details can be found in the “Technical report” from the RIMAROCC project, where the research and considerations behind the proposed method are presented.

1.2 *Structure and contents of the Guidebook*

The Guidebook consists of three parts;

Part 1 – Basis for climate and risk management.

Provides the reader with useful background information for understanding the following parts of the guidebook. Chapter 1 presents the purpose, structure and intended use of the guidebook. Chapter 2 describes the challenge of climate change adaptation and presents critical climate parameters to be considered. Risk management-related terms and methods are introduced in Chapter 3. In Chapter 4 the structure of the RIMAROCC framework is presented along with some reflections and recommendations.

Part 2 – Method and Guidance.

The RIMAROCC framework is presented step by step. The framework consists of seven steps, each with a number of sub-steps. All steps are presented in the same way, starting with a summary of the step and a list of the sub-steps. The sub-steps are structured as follows:

a) Objectives – describes the objectives of the sub-step

b) Output – describes the outcome of the sub-step

c) Method – presents the recommended methods or procedures

d) Data collection – describes what data is needed to perform the sub-step and how to obtain it.

e) Examples – each sub-step is provided with an example to improve readability. More examples can be found in the case studies.

Part 3 – Case studies.

Presents examples from case studies. Four case studies are presented, ranging from road structure scale (e.g. bridge) to road network or territory scale, and with a geographical context ranging from plain to mountain. These case studies show in concrete terms how the method can be implemented, what the possible adaptations of the overall methodological framework could be as well as the method, scope and limitations.

1.3 *How to use the Guidebook*

The Guidebook is intended to be used as support throughout the whole risk management process, from planning to real case practice. The RIMAROCC method is a framework that includes suggestions and recommendations for each step. However, risk management is a dynamic process and there must always be adjustments according to the specific situation and working organisation.

The guidebook provides a step-by-step procedure that can be followed through all phases of the risk management process. The road administrator’s existing procedures and methods can be adapted to the framework, or vice versa. The framework can also be adapted to existing procedures and methods. By following the steps, the risk of overlooking vulnerabilities and threats is reduced.

Some of the steps need to be executed only once for the organisation, while others are conducted in every new risk management project. The framework facilitates a structured way of viewing risk and the suggestions provided on procedures and methods should be seen as a starting point for the road administrator’s customisation of them to his/her own organisation and needs. Lists of climatic events and vulnerability factors should be used as a base to be supplemented according to the needs of the country of implementation. Suggestions on how to assess and prioritise risks are also provided. Understanding the framework is facilitated by the examples accompanying each step.

1.4 *Policies and definition of responsibilities*

Risk management aimed at identifying preferred options of adaption to climate change is a comprehensive and important task that should be acknowledged within the road organisation. This work should be a cyclical process to continuously improve the performance and capitalise on the experiences. The responsibility for risk assessments should be pointed out in the organisation. The work could be led by an appointed Risk Manager and sufficient resources should be allocated. In such a case the risk management process should be a success that minimises risk and saves money and resources both in the short term and the long term.

It is important that the risk management work is implemented in the organisation in a distinct way. Key responsibilities for different parts of the process should be clear as well as for data collection and other work. However, it is our experience that the RIMAROCC method can be adapted to many different types of organisation. We believe that the risk management process can be flexible and adjustable and use the strategic structures and policies of most road owners and administrations.

2 Climate Change Adaptation

2.1 *Adapting needs to start now*

There is a constant need for decisions and development of the road transport system and it is understood that a change in climatic conditions will have significant effects.

Indeed, there is a global scientific consensus that the world's climate is changing and the need for action is widely acknowledged. Despite existing uncertainties regarding the future climate, the EU white paper "**Adapting to climate change: Towards a European framework for action**" states that "*The challenge for policy-makers is to understand these climate change impacts and to develop and implement policies to ensure an optimal level of adaptation"* (Brussels, 1.4.2009, COM, 2009, 147 final). There is no time to wait; adaptation needs to start now to ensure protection against future climatic risks.

Risk management for roads with regard to climate change is work subject to genuine and long-lasting uncertainty. Uncertainty stems from a number of sources, such as the emission scenarios and the climate models. There is also uncertainty in the way the climate will affect the road system, e.g. the physical structures, maintenance and public relations. Some of the uncertainties will diminish over time while others will remain for many years. However, this should not inhibit decision-making but should be understood and taken into consideration. Existing climate models are improved and new, more accurate predictions are expected over time.

It should be noted that climate adaptation within the road sector cannot be an isolated process; adaptation is a dynamic and reflexive process that interacts with many other policies and measures. There is a need for a broad competence and co-operation between road experts, climate experts, stakeholders etc.

2.2 *What is Climate Change?*

Climate change is a continuous process and the magnitude of change depends on the planning horizon. The longer the time span, at least within a 100-year period, the greater the changes that can be expected. The RIMAROCC method is based on a time perspective from today up to about 80 years, i.e. the climate of today as defined by the period 1961-1990 compared to future climate scenarios for 2071-2100.

Basic worldwide climate scenarios for 2071-2100 are published by the IPCC and scaled down to the regional and local scale by national climate organisations. Various scenarios for the emission of greenhouse gases and different computer models produce varying climate scenarios. Figure 1 is an example of precipitation from SMHI (Swedish Meteorological and Hydrological Institute), showing the change, in per cent, of annual precipitation across Europe as calculated by the RCAO model system, based on emission scenarios A2 (right) and B2 (left) and the global model ECHAM4/OPYC3.

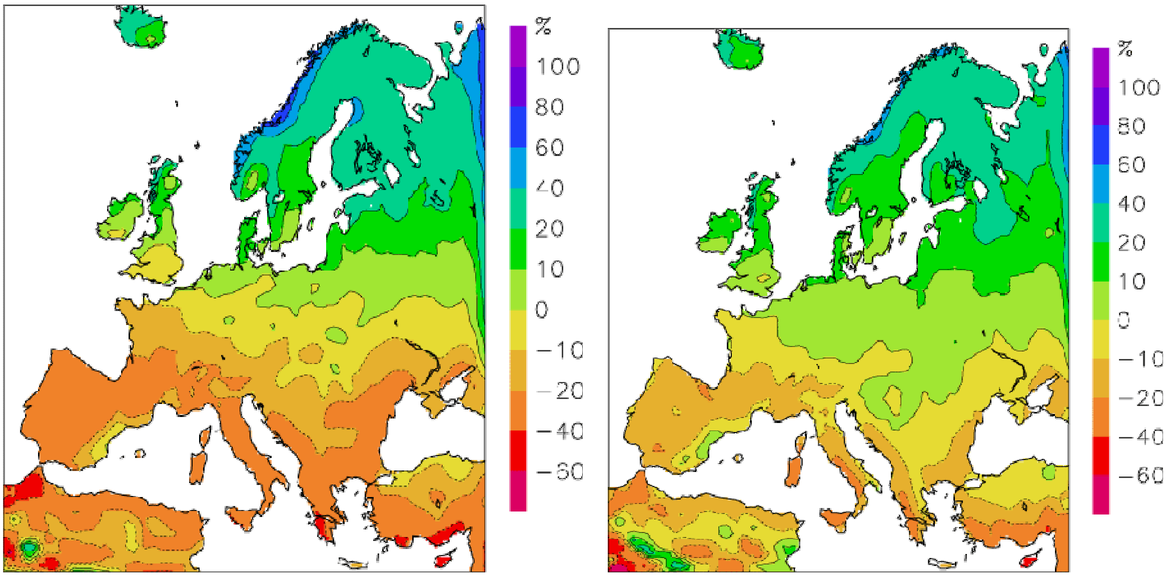


Figure 1: *The figures show the change in precipitation across Europe between the future scenario for the period 2071-2100 and the reference period 1961-1990. The climate scenarios are based on emission scenarios IPCC-SRES A2 (left) and B2 (right). The regional climate simulations are made using the RCAO modelling system and are based on the German model ECHAM4/OPYC3. (From the Swedish Meteorological and Hydrological Institute, http://www.smhi.se/klimatdata/klimatscenarier/scenariokartor).*

An important step in the development of climate scenarios is to adopt a probabilistic approach and present maps showing the probability of different scenarios. In Figure 2 we show examples from the UKCP09 project (http://ukcp09.defra.gov.uk/) with a variable – temperature. The maps show changes suggested by climate models at the 10, 50 and 90% probability levels. The example considers the impact of continued global greenhouse gas emissions on a pathway that is described in UKCP09 as the medium emissions scenario.

Note:

- Until 2030 (important for maintenance) economic scenarios in general do not produce differences in CO_2 levels and consequently only uncertainties in climate models are important,
- After 2030 (important for new infrastructure), economic scenarios are relevant in assessing the robustness of infrastructure policies.

Change in the summer mean temperature for the 2080s under a medium emissions scenario

10% probability level: very unlikely to be less than	50% probability level: central estimate	90% probability level: very unlikely to be greater than

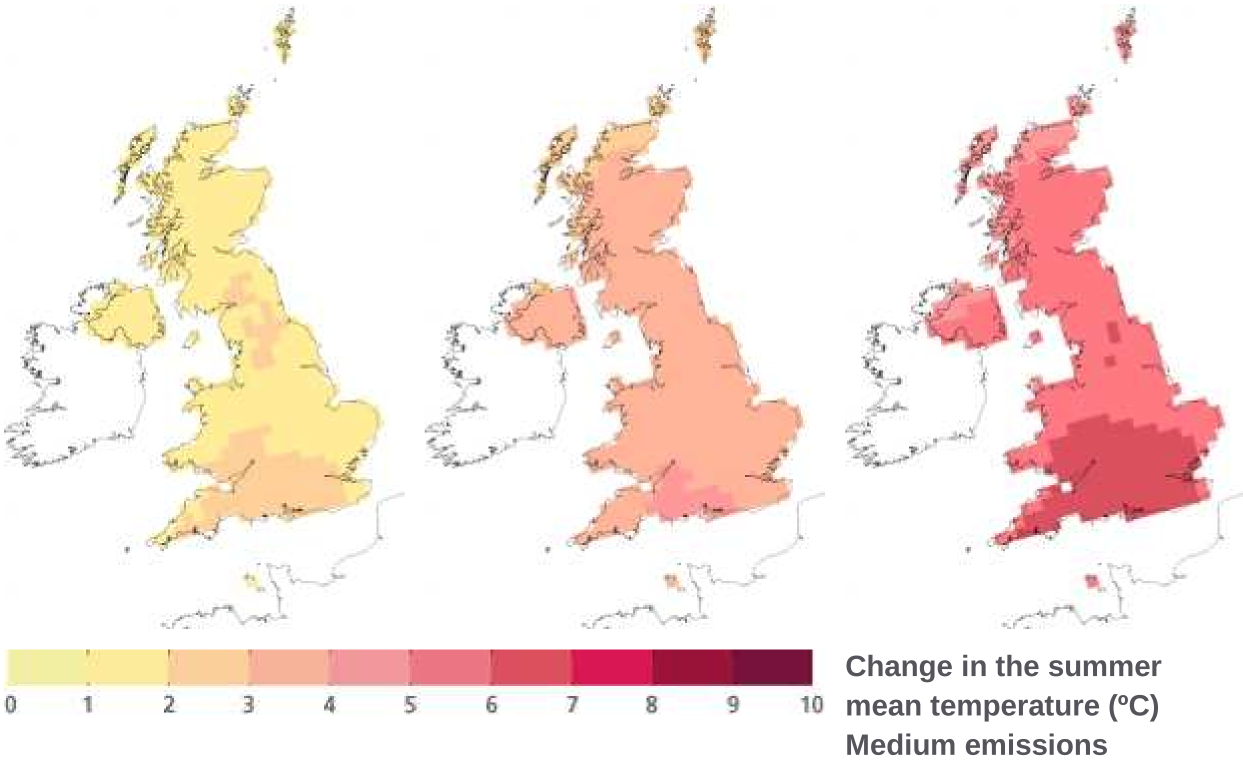


Figure 2: *Change in the summer mean temperature in the UK, (ºC). Medium emissions. From, UKCP09 project (http://ukcp09.defra.gov.uk/).*

The 10% probability level maps tell us that the probability that the change will be less than that shown is 10% – the term is very unlikely to be less than shown.

The 90% probability level maps tell us that the probability that the change will be less than that shown is 90%. In other words, the change is very unlikely to be greater than shown.

The 50% probability level maps tell us that the strength of evidence for the projected change is just as likely to be greater than the values shown as it is to be less than the values shown – this is called a central estimate. It is not necessarily the most likely projection.

2.3 *Critical climate parameters*

Through a bibliographical review of major references and a series of workshops with climate experts held within the framework of the present project, a list of the main climate parameters impacting on roads have been identified[2]. These are presented in

Table ***1***. Combinations of critical climate variables can cause other or increased risks. E.g. intense rainfall after a drought period caused more slippery roads than intense rainfall after a

[2] See RIMAROCC Technical report (2010) for more information.

wet period.

Table 1: Climate parameters, or variables, imposing risks 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

Present knowledge regarding critical climate parameters for climate change analysis in the transport sector is summarised in Table 2. The climate events are weighted according to their importance to the road sector, from 0 – irrelevant to 4 – of primary importance, and the amount of climate change is marked by a relative scale according to IPCC:

++ significant increase
+ moderate increase
+/- no significant change
- moderate decrease
-- significant decrease

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. [°C on 24h] ➢ Maximum [°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 than not	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] ➢ Frost duration [number of days/year] ➢ Frost index [frost penetration into the soil, Hellmann number]	+ (small possibility that minimum temp. increases more than average minimum) ++ 1,8 to 4,0 °C -- -- Same changes over whole Eur.	Quantitative Quantitative Quantitative Quantitative	Likely V. Certain V. Certain 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 Ditto Ditto	
2	Thaw (number of days with temperature zero-crossings)	➢ 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)	

3 Risk Management for Roads

3.1 *What is a risk?*

There are different ways of looking at, and defining, risk and the RIMAROCC method is robust enough to be used regardless of the specific definition of risk. When one asks: “What is the risk?” one is really asking three questions: What can happen? How likely is it to happen? If it does happen, what are the consequences? (Kaplan & Garrick, 1981)[3].

A common way of defining risk is the function of likelihood (H) and consequence (C), often presented as the product R = H x C. To make the risk more transparent it is fruitful to look at all the factors contributing to risk and divide them into categories.

That is why, in the RIMAROCC method, risk is defined as the combination of threat, vulnerabilities and consequences. *Threat* comprises hazard and environmental factors. The hazard is described by climate factors, and the environment (the surroundings) is described by contextual site factors, e.g. land use. *Vulnerabilities* describe the properties of the assets or functions that may be harmed; these are factors that affect the vulnerability. *Vulnerabilities* include factors such as infrastructure-intrinsic factors, traffic and environment. Consequences describe the outcome of the realised threat and include human life and injuries, economic losses, reconstruction cost etc.

As seen in Figure 3, the risk may then be defined as:

Risk = a function of [Threat, Vulnerabilities, Consequences]

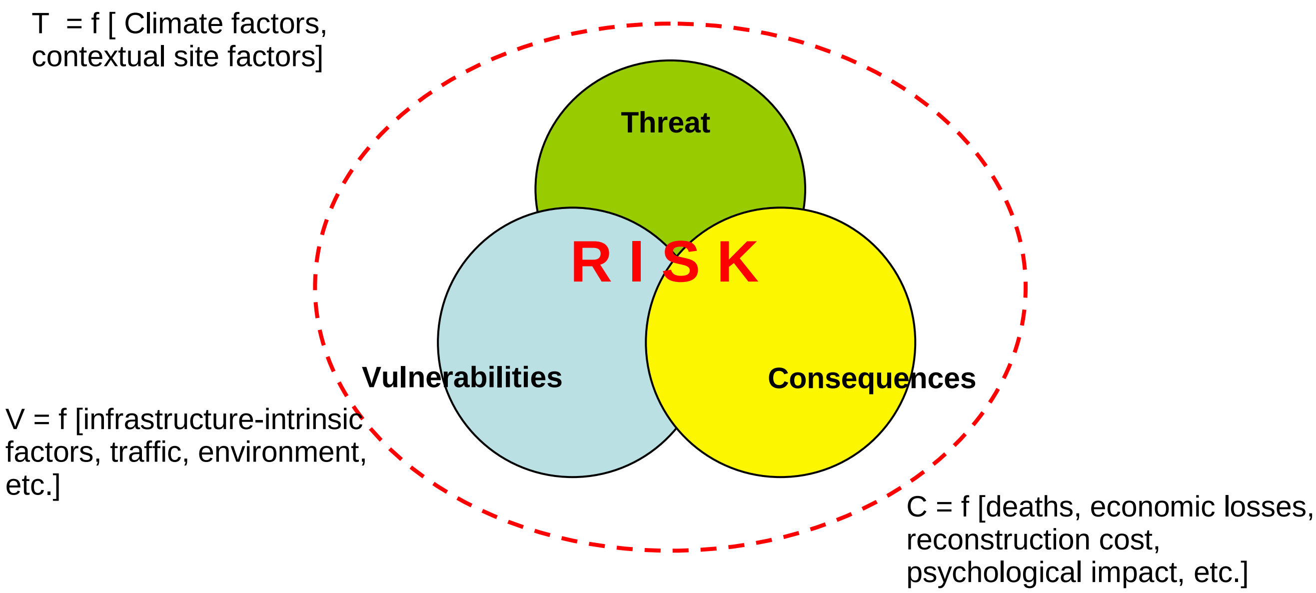


Figure 3: *Risk is defined as a function of threat, vulnerabilities and consequences.*

[3] Kaplan, S. and Garrick, B. J. 1981: On the Quantitative Definition of Risk. PLG-P0196, Risk Analysis Vol 1, no 1, pp 11-27.

Likelihood and Probability

The term likelihood is used in a broad sense to refer to the chance of something happening, whether described mathematically or in words. Probability is narrowly interpreted as a mathematical term. The likelihood of an unwanted event to be realised is based on a series of events, each with their own likelihood; the likelihood of a climate event and the likelihood of evolving steps to make the unwanted event happen, e.g. heavy rain – flooding - erosion – landslide – road damage.

There are several tools and specific methods to assess the likelihood or calculate the probability of different scenarios, from simple “likely or not” estimations to calculations based on statistics, such as failure frequency e.g. by using decision trees.

Threat

The RIMAROCC approach focuses on climate risks. Hence, climate factors (hazards) deserve specific attention. However, the method should be capable of dealing with all risk factors likely to worsen climate-related risks (contextual site factors).

Climate factors

The climate factors likely to affect road infrastructures are: rain, wind, cold/frost, snow, fog, heat, and drought.

Contextual site factors

Contextual site factors include physical, biological and human factors of the environmental context of the infrastructure. They can be intrinsic risk sources (e.g. unstable ground conditions, trees likely to fall down on the road, etc.), but may also be induced by artificial changes (e.g. soil sealing due to urban development or deforestation of upstream river basins).

The present list is of course not comprehensive and the user should adapt and supplement it according to the infrastructure context and scale (structure, section, network, territory).

Vulnerabilities

Vulnerabilities are assets or functions of the road system vulnerable to climate factors. In this respect, a road infrastructure can be defined by its technical characteristics (construction standards and designs), its use (traffic), and the environment (e.g. tree alignments). Here Environment is understood to be the environmental assets pertaining to the road system. For example; tree alignments may be considered vulnerabilities, however it must be remembered that trees standing near the road, but outside the direct control and responsibility of the road authority, and which are likely to fall down on the road are contextual site factors (threat).

The infrastructure age, design characteristics, used standards, type of maintenance (of the infrastructure and/or its environment), traffic type, traffic intensity, etc. can be considered vulnerabilities. E.g., an old construction with design mistakes, inappropriate standards, lack of maintenance, unexpected heavy traffic, etc. can be considered more vulnerable than a new construction with appropriate design and recent standards.

Consequences

Consequences of an unwanted event may be put into five categories:

- Loss of safety on the road (injuries or deaths)
- Direct costs; costs for reconstruction
- Financial costs (indirect costs for unavailability of the road)
- Loss of confidence / image / prestige / political consequences
- Impact on the environment

Consequences can be immediate or progressive. They can also be aggravated by factors such as season, time, holidays, etc. (e.g. a storm occurring at 3 am when the road is empty will not have the same consequences compared with if the same storm were to occur at rush hour).

3.2 *Risk assessment methods*

Risk management is used to address a wide range of different risks. A broad set of methods for risk assessment with differing scope and detail are available to assess these risks. Some are more suitable for global risk analysis of a whole system, and others for detailed studies of a limited system. The risk assessment methods can be divided into families based on data type, ranging from qualitative to quantitative analysis (van Staveren, 2006)[4].

Quantitative methods focus on numbers and frequencies rather than on meaning and experience. The calculations include statistics to address inevitable uncertainties in models and raw data and the results are presented in probability functions or risk curves. Examples of quantitative methods are *Quantitative Risk Assessment (QRA)* and *Probabilistic Risk Assessment (PRA)*.

Qualitative methods are ways of collecting data which are concerned with describing risks in words, rather than with drawing conclusions from statistics. Qualitative methods are primarily used to identify risks and can be used to rank the risks on an ordinal scale, e.g. from “low” to “high”. Examples of qualitative methods are *HazOp*, *“What if?”- analysis* and *checklists.*

Semi-quantitative methods lead to some kind of quantification of risks without using, for example, probability distributions or data analysis as described for the quantitative method. The quantification is reached by using meaning and experience for scoring the likelihood and consequences. Semi-quantitative methods are useful when not much data are available although a detailed and carefully considered classification is necessary for a somewhat quantitative content.

3.3 *Reference situation: point zero*

In risk management approaches, it is important to have appropriate knowledge of the “situation of reference”, also called “point zero”, for the following reasons:

1. As shown in practical case studies, starting the whole approach with a “point zero” helps to identify and quantify very significant evolutions of risk levels between now and when the motorway or road has been designed/constructed.
2. It is necessary to update existing data in order to have a pertinent risk analysis; data concerning infrastructure need to be data related to the current situation.
3. All elements of the risk management approach need to be studied by referring to the

[4] Staveren, M. Th. Van, 2006: Uncertainty and Ground Conditions: A Risk Management Approach, Elsevier Ltd

same time; this is a condition for comparing and ranking impacts and consequences appropriately,

4. In addition, developing a "reference situation" is an interesting and pedagogical way to use the methodology professionally for the first time.

Knowing this, we recommend defining point zero to bring the road network up to date with today's climate. Exploring the present risk situation is a good starting point for adapting to climate change.

4 The RIMAROCC Framework

The RIMAROCC Framework is designed for road risk management on all decision levels and on all geographical scales of pertinence. RIMAROCC is a method where the objective is to facilitate the production of a **Risk Management Study** by or for a road authority. The method can be used to mitigate threats, reduce vulnerabilities and minimise the consequences of an event.

4.1 *Possible Working methods*

When using the RIMAROCC method, the appropriate working methods depend on the scale of the analysis to be executed as well as available resources. More information on working methods is available in ISO 31010.

Possible working methods are for example:

- Individual:
  - Desk studies
    Studying satellite imagery and relevant thematic maps provides insight into the contextual factors. Literature studies can bring together knowledge of climatic risk factors in cases where co-operation with a national meteorological service is not possible.
  - Interviews
    E.g. with road maintenance contractors to identify infrastructure-intrinsic factors and contextual site factors from people with experience and in-depth knowledge
  - Questionnaires, Inquiries
    Can be used to gather stakeholder opinion on a proposed adaption action plan.
  - Expert judgement
    E.g. to assess the likelihood of identified risk scenarios.

- Group sessions:
  - Brainstorm sessions (group sessions)
    Can be used to identify critical climate factors or to identify risk scenarios using What-if-analysis.
  - Electronic board room session (acceleration room)
    A computer aided brainstorming session where all comments are logged and can be structured and evaluated during (and after) the session. E.g. useful for scoring identified risk mitigation options for a number of criteria, scoring of risk scenarios on vulnerability and consequence scores, or to create a list of contextual site factors relevant to the road system.

- Field visits

  On the network and territory scale, driving along the roads may help to identify contextual site factors and infrastructure-intrinsic factors. On the section and structure scale, the road components and the surroundings can be studied in detail.

4.2 *Scales of analysis*

Implementing a comprehensive risk management process in a road authority organisation is a complex procedure extending over a long period of time. Managers must choose between short-term decisions on critical points exposed to the forefront of climate evolution, and a global and consistent analysis in a long-term perspective in order to elaborate an investment programme on the scale of a whole network or territory.

Consequently, the choice of the scale of analysis and the most pertinent level of accuracy is important:

- **Territorial scale** orientation (territories serviced by the road network) is the stage on which the climate event could affect most or all of the territory. It is also the only scale of analysis where all the territorial stakes related to the road network can be addressed. Authorities responsible for various sectors co-operate to adapt the territory to climate change. For the territorial scale, the National Road Authority could be one such authority.

- **Network scale** orientation is necessary to identify the main vulnerabilities of a road network before focusing on critical sections, nodes or structures. Both territory and network scales correspond to strategic approaches, based on climate scenarios and qualitative analysis (expertise) of vulnerability and consequences. The network approach can also be implemented on a more detailed and technical level through a consolidated approach (aggregation) of the road section scale analysis.

- **Section scale** orientation is either conducted prior to the network scale consolidated approach when critical sections are already known (high levels of traffic, no alternative route, sensitive environment …), or after having identified the vulnerable sections through the network approach in order to refine the analysis. From a methodological standpoint, the section scale is more thorough and technical than the network scale. The approach will be of a qualitative or quantitative nature according to the availability of data and models required for a comprehensive analysis.

- **Structure scale** orientation is devoted to analysing critical points of a section, such as a viaduct, a tunnel, a node (interchange), etc. These critical points can be identified through the network and/or section approach. As the analysis focuses on a single object, it is easier to implement a comprehensive and technical (quantitative) approach.

The risk management process, or study, can be based on two main approaches, as illustrated in Figure 4. The left-hand side of the figure illustrates a qualitative approach, where expert judgements and strategic analysis gradually add more and more information, from an overview on a network scale to a detailed analysis of a specific structure. The right-hand side illustrates an approach which starts with gathering data on specific structures, which gradually adds up to comprehensive descriptions of sections and then on to the network scale. The left-hand approach, from an overview scale to a detailed scale, is more cost-effective and as such is recommended.

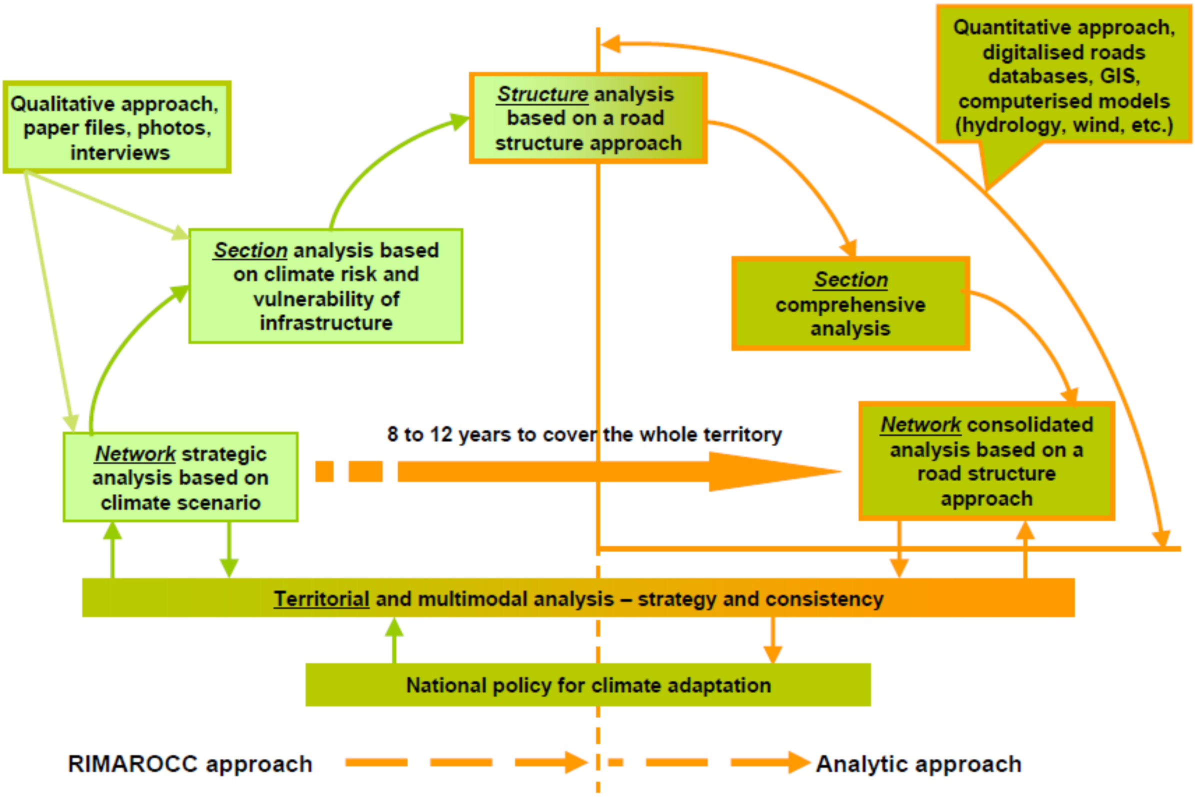


Figure 4: *Two main approaches in the risk management process.*

Objectives of the four scales of analysis selected for the RIMAROCC method:

- Territory scale analysis objectives:
  - Identify climatic evolution for the territory on various horizons,
  - Identify the most vulnerable territorial assets and functions regarding climate factors,
  - Identify network(s) or parts of network which are vulnerable with regard to climate factors,
  - Estimate risks and the order of magnitude of the economic consequences of traffic interruption on the regional or national level, for both the operator and the territorial stakeholders,
  - Examine alternative solutions with other modes of transport,
  - Define an adapted strategy for the long term, including the definition of network(s) or parts of networks to be analysed thoroughly, and the complementarities to develop with other modes of transport if necessary.
- Network scale analysis objectives:
  - Identify the most vulnerable sections and structures with regard to climate factors,
  - Estimate risks and the order of magnitude of the financial consequences of traffic interruption on the regional or national level, for the road operator,
  - Elaborate action plans, organise and schedule the next steps in order to preserve the network during the 21st century.
- Section scale analysis objectives:
  - Identify elements of the section which are vulnerable with regard to climate factors,
  - Evaluate risks and consequences for the road operator and the surrounding

environment (local stakeholders),
    - Elaborate action plans and set priorities for the coming years.
- Structure scale analysis objectives:
    - Identify vulnerabilities of the structure with regard to climate factors,
    - Evaluate risks and consequences for the road operator and the surrounding environment (local stakeholders),
    - Define mitigation or adaptation measures and the appropriate schedule

4.3 *Choosing an adapted approach in relation to the scale of analysis*

Risk identification is a key step in the framework. A non-identified risk can make the whole analysis worthless, whatever effort is put into the other risks. Risk identification, however, is a creative process. Only when using different approaches can one get a grip on the risks. This paragraph shows different options for carrying out risk identification.

The aim is to select which method to use in the Risk Management Study. It is not necessary to choose one option. Using both a road structure approach and a climate scenario approach will bring more certainty into the identification of all large risks.

Road structure approach; what can affect the road system?

Risk identification is performed by looking for hazards that have effects on the system (i.e. structure, section, network or territory). This approach means looking at the road system (including the surroundings) and asking – what can happen? By breaking the system down into components, one can get a grip on the risks. One way to do this is by using key domains of expertise (structured with families, sub-families and objects):

- pavements
- bridges
- equipment (e.g. road signs, lighting, safety barriers)
- small hydraulics (drums) and drainage
- geotechnics
- environment
- large hydraulics (culverts)
- sea level

Example: A tree is standing near the road. One asks the question: what can affect the tree with consequences for the road? The wind hazard will be identified and the risk formulated as follows: A hard wind can cause the tree along the road to fall down onto the road.

Climate scenario approach; the climate is changing and what are the effects on the road system?

Risk identification is done by looking for consequences for the system that are affected by hazards. This approach involves "moving" a climate event along the road structure and asking – what can happen? By bearing in mind different relevant hazards one can get a grip on the risks. The climate change table is useful in identifying the effects.

Example: More heavy storms are expected for a certain area. One asks the question: What could be the possible effect of a heavy storm? The tree along the road will then be identified and the risk is formulated: A hard wind can cause the tree along the road to fall down onto the road.

4.4 *Quality plan*

At the early stages of a Risk Management Study the sponsor of the study needs to establish terms of reference, including at least scope, schedule, budget and communication rules. This is presented in a quality plan. The quality plan should be developed in accordance with the national risk management policy in the field of climate change (this connection would be established with reference to ISO 31000 point 5.3.2). The objectives of the study should be defined and the decision-making process clearly indicated. The level of detail of the quality plan should be adjusted to the scale of the study.

This quality plan should include:

- The objectives of the study
- The perimeter and the scale of analysis (territory, network, section, structure)
- A description of risk management methodology to be used along with the RIMAROCC method
- A description of the management organisation
- A time schedule
- A budget
- Communication rules
- Other points as necessary.

4.5 *The conceptual framework*

The RIMAROCC method is a matter of Organising (e.g. who is responsible for what?) – Analysing (e.g. risks and vulnerability) – and Prioritising (e.g. non-acceptable risks). The method can be used to mitigate threats, reduce vulnerabilities and minimise the consequences of an event, as outlined in the figure below:

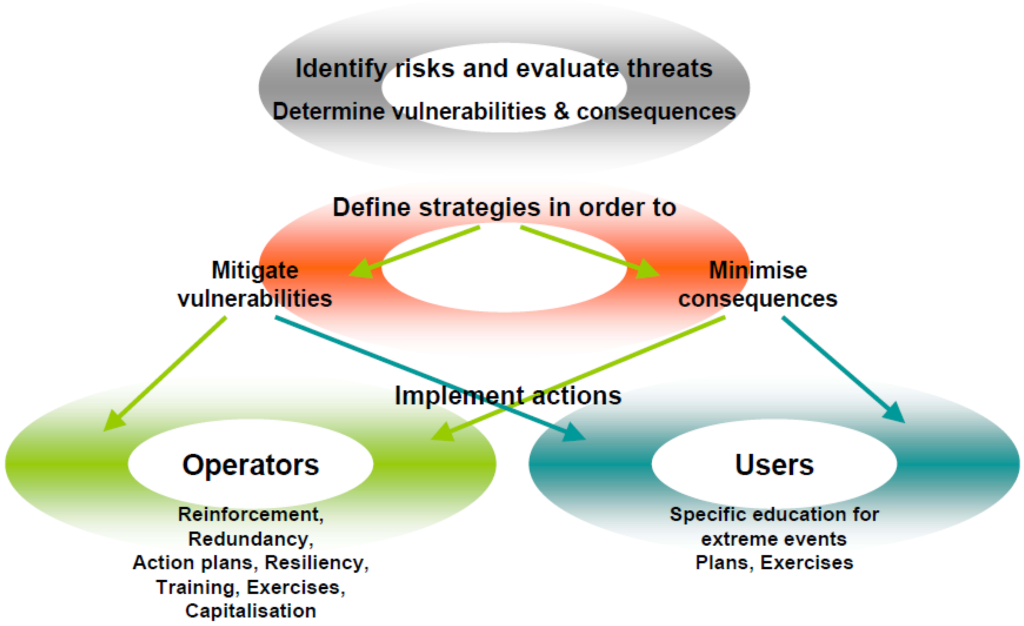


Figure 5: *The RIMAROCC method can be used to mitigate threats, reduce vulnerabilities and minimise the consequences of an event.*

The relationships with external sources of knowledge and national policies and existing methods are shown in Figure 6. The main input and output of the method are illustrated.

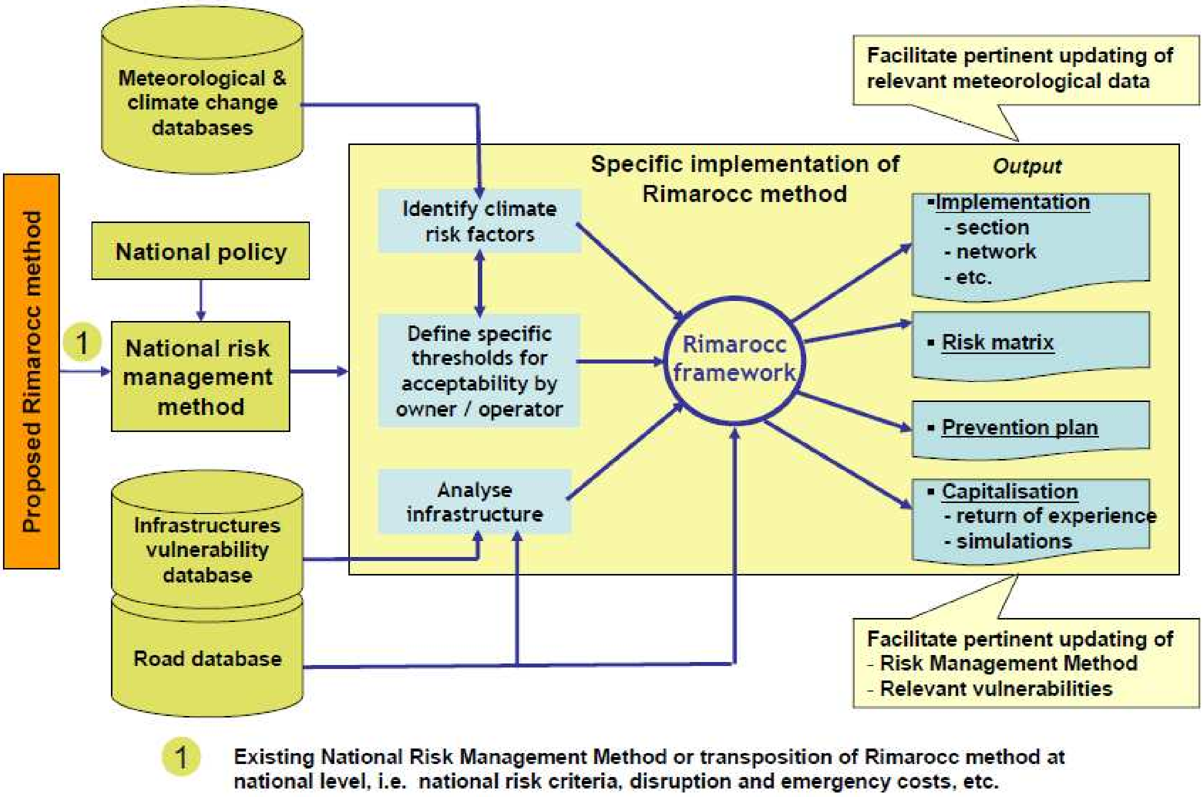


Figure 6: *RIMAROCC relationships with existing methods, policies and sources of knowledge (green fields). The RIMAROCC framework connects the risk management phases within the yellow box, where input are the databases and the risk management actions to the left, and output from the analysis is positioned to the right.*

❶ Existing National Risk Management Method or transposition of the RIMAROCC method on the national level, i.e. national risk criteria, disruption and emergency costs, etc.

A specificity of climate risk management is the fact that the road operator has no possibility of taking action against a climate source of risk in the short term. Besides the strategic work of mitigating climate change by reducing greenhouse gases, road authorities have two means of managing the risks: mitigate vulnerabilities and/or minimise consequences. This is illustrated in

Figure 7.

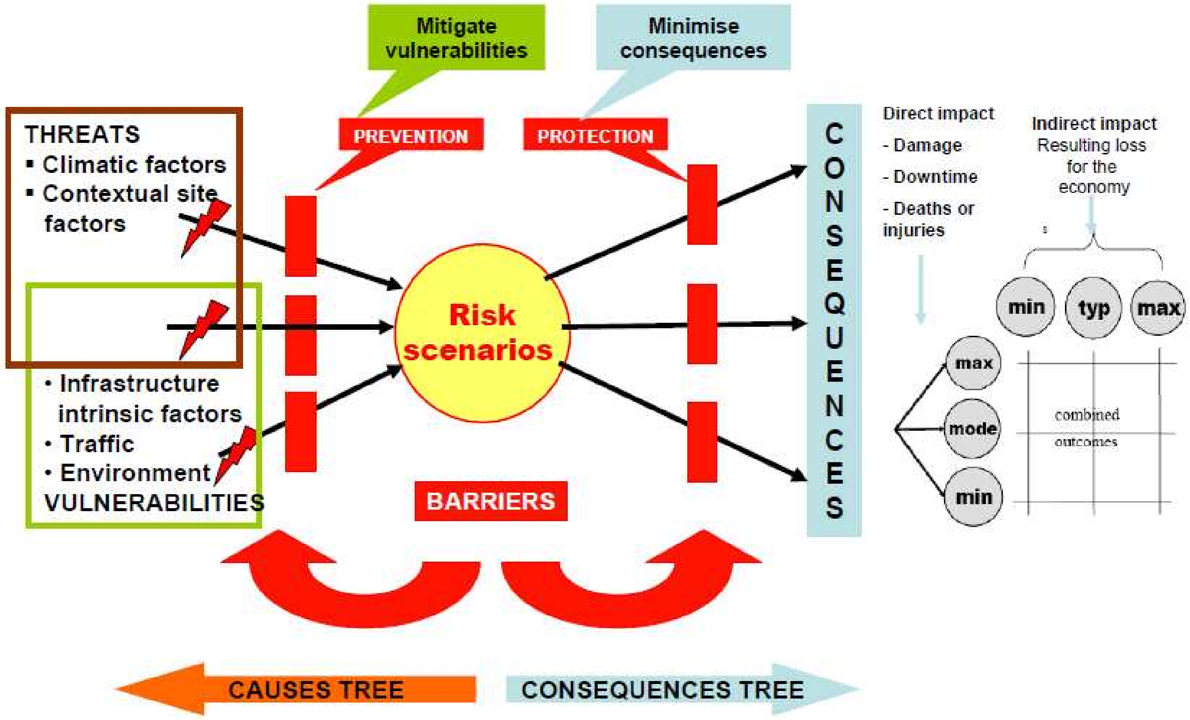
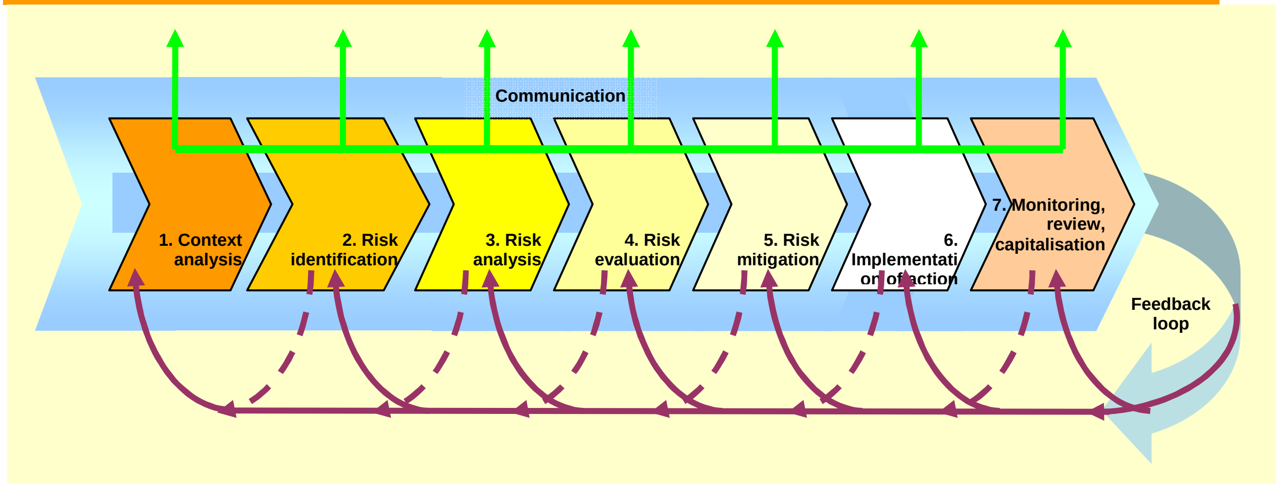


Figure 7: *To reduce climate-related risks, road authorities have two main means at their disposal: mitigate vulnerabilities and minimise consequences.*

4.6 *The technical framework: 7 key steps*

The proposed method is a cyclical process to continuously improve the performance and capitalise on the experiences. It starts with an analysis of the general context where risk criteria are established and ends with a reflective step where the experiences and results are documented and made available to the organisation. In practice, the steps are not always totally separate. There can be work going on in several steps at the same time but it is very important that the logical structure is maintained. There are feedback loops from each step to the previous ones and also a marked loop from the last step as a reflection and as part of the cyclical process.

The continuous communication with stakeholders, external experts and others is very important and marked as (green) arrows throughout the whole process.



Scope of steps and sub-steps

Key steps	Sub-steps
1. Context analysis	1.1 Establish a general context 1.2 Establish a specific context for a particular scale of analysis 1.3 Establish risk criteria and indicators adapted to each particular scale of analysis
2. Risk identification	2.1 Identify risk sources 2.2 Identify vulnerabilities 2.3 Identify possible consequences
3. Risk analysis	3.1 Establish risk chronology and scenarios 3.2 Determine the impact of risk 3.3 Evaluate occurrences 3.4 Provide a risk overview
4. Risk evaluation	4.1 Evaluate quantitative aspects with appropriate analysis (CBA or others) 4.2 Compare climate risk to other kinds of risk 4.3 Determine which risks are acceptable
5. Risk mitigation	5.1 Identify options 5.2 Appraise options 5.3 Negotiation with funding agencies 5.4 Formulate an action plan
6. Implementation of action plans	6.1 Develop an action plan on each level of responsibility 6.2 Implement adaptation action plans
7. Monitor, re-plan and capitalise	7.1 Regular monitoring and review 7.2 Re-plan in the event of new data or a delay in implementation 7.3 Capitalisation on return of experience of both climatic events and progress of implementation
Communication and gathering of information	

Comments on the steps:

1. By establishing the context, the authority responsible for the climate risk management study (subsequently referred to as the risk manager) articulates its objectives, defines the

external and internal parameters to be taken into account when managing risk, and sets the scope and risk criteria for the remaining process. Not all road organisations have risk managers. In that case, e.g. the Environmental Department of the organisation could be entrusted with this responsibility.

2. The road authority should identify sources of risk, areas of impact, unwanted events (including changes in circumstances) and their causes and potential consequences. The aim of this step is to generate a comprehensive list of risks based on events that might stop, degrade or delay the normal operation of the road system, or create trouble or damages in the exposed area.
3. Risk analysis involves developing an understanding of the risks. The risk analysis provides input to risk evaluation and serves as a decision basis for determining whether risks need to be treated, and for selecting the most appropriate risk treatment strategies and methods.
4. The purpose of risk evaluation is to assist the road authority in making decisions, based on the outcome of risk analysis, about which risks need treatment and the priorities for treatment implementation. Risk evaluation involves comparing the level of risk found during the analysis process with risk criteria established when the context was considered. Based on this comparison, the need for treatment can be considered.
5. Risk mitigation involves identifying, appraising and selecting one or more options for modifying the non-acceptable risks. A combination of the identified measures can be transformed into a strategy for the coming years in order to cope with climate change and keep risks acceptable. This step also includes securing financing as well as documenting in an action plan how the chosen adaptation measures will be implemented. Risk mitigation is a strategic step which may involve players from several departments: roads, civil security, finance and others.
6. In this step the action plan is developed in detail; responsibilities for implementation are addressed, resources are allocated and performance measures are selected. When all the details are in place, the action plan is implemented. This is a strategic step which involves players from several departments: roads, civil security, finance, etc. Network and territorial scale analyses require information on what geographical units of the organisation should be involved. This also applies to stakeholder contacts.
7. Since risk management is a learning process this step aims to monitor and review the implemented actions and to capitalise on the knowledge gained within climatic events and implementation of action plans. If conditions change, re-planning starts within this step.

4.7 *Field of validity and Limitations*

Climate change research and risk management are both fields undergoing rapid development. Consequently, this project focuses on finding a robust framework rather than the perfect solution for a fixed moment in time. The framework is developed in order to be valid in EU countries for the next five to ten years. Knowledge within climate change and risk management will be enriched continuously. Some ideas from this framework will remain strong and others will need improvement.

The method is valid for climate-induced risks. However, it also considers other risks and the same framework may be used for structuring risk analysis and management in general for the road system.

The following points of attention should be borne in mind:

- The application of the RIMAROCC method should be done by the road authority or the authority responsible for climate risk management studies within the road authority. The person in charge could be named the “climate risk manager”. In Part 2 of the guidebook, we simply refer to him/her as the “risk manager”.

- It is recommended to co-operate with national meteorological services from the early stages of the study through to the final step of capitalisation, with a focus on the 2nd step “identification of risks”. If no such link can be established, it is also possible to identify risks with the help of the risk tables provided in the framework (see Table 2).

- At the beginning of the risk management study, it is necessary to define the road characteristics; this is essential input for RIMAROCC.

- The legal system depends on the owner, operator and the national or regional administrative/political authorities. Specific systems are emerging in the field of adaptation to climate change on the European and national levels. Insurance companies are also a partner with private rules. The *risk manager* must identify these various systems as particular attention to legal possibilities is necessary, especially when elaborating on risk mitigation possibilities.

- One important point is the definition of the authorities in charge: who will be responsible for what in each step. Which authority, for example, has the power to validate risk criteria and indicators? Is it the risk manager, an authority within the road authority or a commission, including other administrations?

- Whatever the mitigation and adaptation measures implemented, it should be borne in mind that residual risks or unidentified risks will remain. Assessing these risks will be the purpose of a further cycle in the risk management process.

- Acceptability of risk is another point of attention. The viewpoint of the organisation is important when deciding on risk acceptability; risk could be evaluated from an economic, social, cultural, ethical, political or religious point of view. Acceptability of risk differs from one country to another. Consequently, RIMAROCC cannot propose an acceptable level of risk.

- Stakeholders should be involved during the whole process. In order to make the analysis, as performed with the RIMAROCC framework, used one should not only provide the outcome of the analysis at step 5 in the action plan, but one should keep them informed during all steps. This can also improve the analysis itself by using the stakeholders as experts in the field.

PART 2 - Method and Guidance

Part 2 presents the RIMAROCC framework step by step. The framework consists of seven steps, each with a number of sub-steps. All steps are presented in the same way, starting with a summary of the step and a list of the sub-steps. The sub-steps are structured as follows:

a) Objectives – describing the objectives of the sub-step

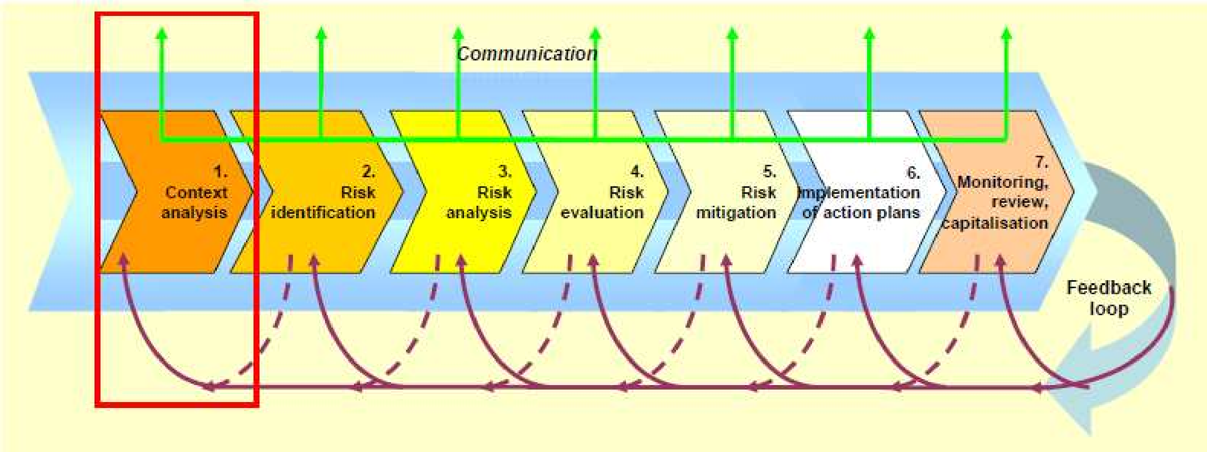
b) Output – describing the outcome of the sub-step

c) Method – presenting the recommended methods or procedures

d) Data collection – describing what data is needed to perform the sub-step and how to obtain it.

e) Examples – each sub-step is provided with an example to improve the readability. More examples can be found in the case studies.

Step 1 – CONTEXT ANALYSIS



1. Objectives of the step

By establishing the context, the authority responsible for the climate risk management study (subsequently referred to as the *risk manager*) articulates its objectives, defines the external and internal parameters to be taken into account when managing risk, and sets the scope and risk criteria for the remaining process.

2. Proposed sub-steps

The context analysis is structured into three successive sub-steps:

1 Establish a general context

2 Establish a specific context for a particular scale of analysis

3 Establish risk criteria and indicators adapted to each particular scale of analysis

The general context is the same whatever the scale of analysis (structure, section, network, area). It differs when addressing particular scales.

3. General recommendations for this step

When establishing the context for the risk management process, the external and internal parameters need to be considered in detail, and especially how they relate to the scope of the particular risk management process.

Sub-step 1.1 - Establish a general context

a. Objectives The purpose is to define general objectives and "decision-making criteria" as a first approximation, knowing that a concrete situation identified later in the process will help to refine these criteria. The general context aims to define the "rules of the game". The overall objective of the RIMAROCC approach can be defined as follows: to enable the road authority to systematically develop and implement their responses to the challenges of climate change in support of the delivery of their corporate objectives (cf. HAASM, 2008).

The general context also aims to define specific outcomes, conditions, end-points, or performance targets that constitute an effective risk management posture (cf. US NIPP).

b. Output

Description of the external context, the internal context, and the context of the risk management process. As a minimum, this sub-step requires cartography of the whole framework under study for it to be put in perspective with regard to its operational context. Each sub-part of the overall framework must be described and, for each element in the scope of work, specific files or forms could be prepared. These files or forms could be completed and fulfilled at subsequent steps of the RIMAROCC method.

c. Method

The method is based on the ISO 31000 2009 standard. It includes the following tasks:

Establishing the external context

The external context is the external environment in which the road authorities seek to achieve their objectives. Understanding the external context is important in order to ensure that the objectives and concerns of external stakeholders are considered when developing risk criteria. It is based on the road organisation-wide context, but with specific details of legal and regulatory requirements, stakeholder perceptions and other aspects of risks specific to the scope of the risk management process. As such, specific attention will be paid to the national and international context regarding climate change adaptation policies.

Establishing the internal context

The internal context is the internal environment in which the road authorities seek to achieve their objectives. The risk management process should be aligned with their culture, processes, structure, policy and strategy. Internal context is anything within the organisation that can influence the way in which the will manage risk.

At this stage, it is necessary to present the reference framework, especially the road reference (i.e. frame of reference) on vulnerabilities.

Establishing the context of the risk management process

The objectives, strategies, scope and parameters of the activities of the road authorities, or those parts of the organisation where the risk management process is being applied, should be established. The specific organisation for risk management should be clarified. The required resources, responsibility, authority and the records to be kept should be specified.

It is assumed that the context of the risk management process is based on the existing National Risk Management Method (i.e. national risk criteria, disruption and emergency costs, etc.), or the transposition of the RIMAROCC method at national level.

To be borne in mind:

- The "general context" file can be used whatever the scale of analysis (structure, section, network, area). It needs to be updated regularly, at least after significant changes in knowledge of meteorological phenomena or in the national policy regarding natural disaster preparedness.
- To ensure that all the steps are carried out, a table showing the individuals and organisations responsible for each step in the process described above could be established.

- Although time-consuming, road authorities would benefit from defining the general context whatever their needs regarding climate risk management. An alternative is to carry out a simplified context description focusing only on the main issues.

d. Data collection

Data collection should be adapted to the scale and objectives of each specific study. Below is an indicative list of important data that might be included in the analysis.

The external context includes, but is not limited to:

- The social and cultural, political, legal, regulatory, financial, technological, economic context, as well as the natural and competitive environment context, at international and national level;
- Key drivers and trends that have an impact on the objectives of the Road Authorities; and
- Relationships with and perceptions and values of external stakeholders.

The internal context includes, but is not limited to:

- governance, organisational structure, roles and accountabilities;
- policies, objectives and the strategies that are in place to achieve them;
- capabilities, understood in terms of resources and knowledge (e.g. capital, time, people, processes, systems and technologies);
- the relationships with and perceptions and values of internal stakeholders and the organisation's culture;
- information systems, information flows and decision-making processes (both formal and informal);
- standards, guidelines and models adopted by the road authority; and
- the form and extent of contractual relationships.

The context of the risk management process involves, but is not limited to:

- goals and objectives of the risk management activities;
- responsibilities for and within the risk management process;
- scope, defining the depth and breadth of the risk management activities to be carried out;
- description of activities, processes, functions, projects, products, services or assets included in the risk management process in terms of time and location;
- relationships between a particular project, process or activity and other projects, processes or activities of the organisation;
- the way performance and effectiveness are evaluated in the management of risk.

e. Example

Network scale case study, Northern motorway network, France

SANEF is the concessionary company for most of the French northern motorway network. The national authority in charge of concession contract control is “Direction des Infrastructures de Transport” within the French administration.

SANEF has an efficient organisation with competent employees, proofed procedures, operational equipment and adequate databases.

The internal organisation for risk management within the SANEF organisation takes place in the overall operation and maintenance organisation for road operation.

Organisation level	Tasks	Comments
Holding Company	General framework for risk management	Defines the main guidelines for risk management within the ABERTIS group
General Directorate	General management policy	Defines SANEF objectives, together with tasks and responsibilities of Directorates. Applies the risk management policy for infrastructures
Technical and Operational Directorate	Operational policy	Defines operational procedures and the technical framework of the network management
Construction Directorate	Construction policy	Defines and supervises investments required to meet SANEF objectives
Directorate for Risks and Audits	SANEF Risk management policy	Animation of the risk identification and mitigation process; co-ordination with the operational and construction directorates
Northern Network Directorate	Northern network management	Applies the risk management policy for operations
Local Technical Centres	Local operation and maintenance	Implement safety procedures; carry out maintenance and repair work

There is no specific frame of reference for network vulnerabilities within SANEF.

Sub-step 1.2 – Establish a specific context for a particular scale of analysis

a. Objectives

It is recommended that the "local" context be defined when it is different or complementary to the national context.

The purpose is to refine and clarify the context according to the specific scale of analysis for which the RIMAROCC method is applied: structure, section, network, territory. Each scale corresponds to specific decision levels and organisation structures, in compliance with the role and nature of the elements analysed.

b. Output

Description of the external context, the internal context, and the context of the risk management process. To avoid redundancy with Step 1.1, only elements pertaining to particular scales of analysis will be presented in this sub-step.

c. Method

The method is the same as for the General Context. The difference lies in the scale of the analysis: in Step 1.1 the analysis remains on the national level, while in Step 1.2 it is refined and adapted to the scale of the analysis.

Depending on the geographical scale (local or regional) and/or the geographical area (location within the country) involved, the external context will differ significantly and it is therefore necessary to adapt it.

However, it is assumed that the internal context and the context of the risk management process will remain approximately the same regardless of the scale of analysis. It will only be necessary to adapt it according to possible geographical specificities of the organisation and to refine it to ensure optimal consistency with the decision-making level (i.e. local, regional or national).

d. Data

Same list of data as for Step 1.1, but with an emphasis on the following information:

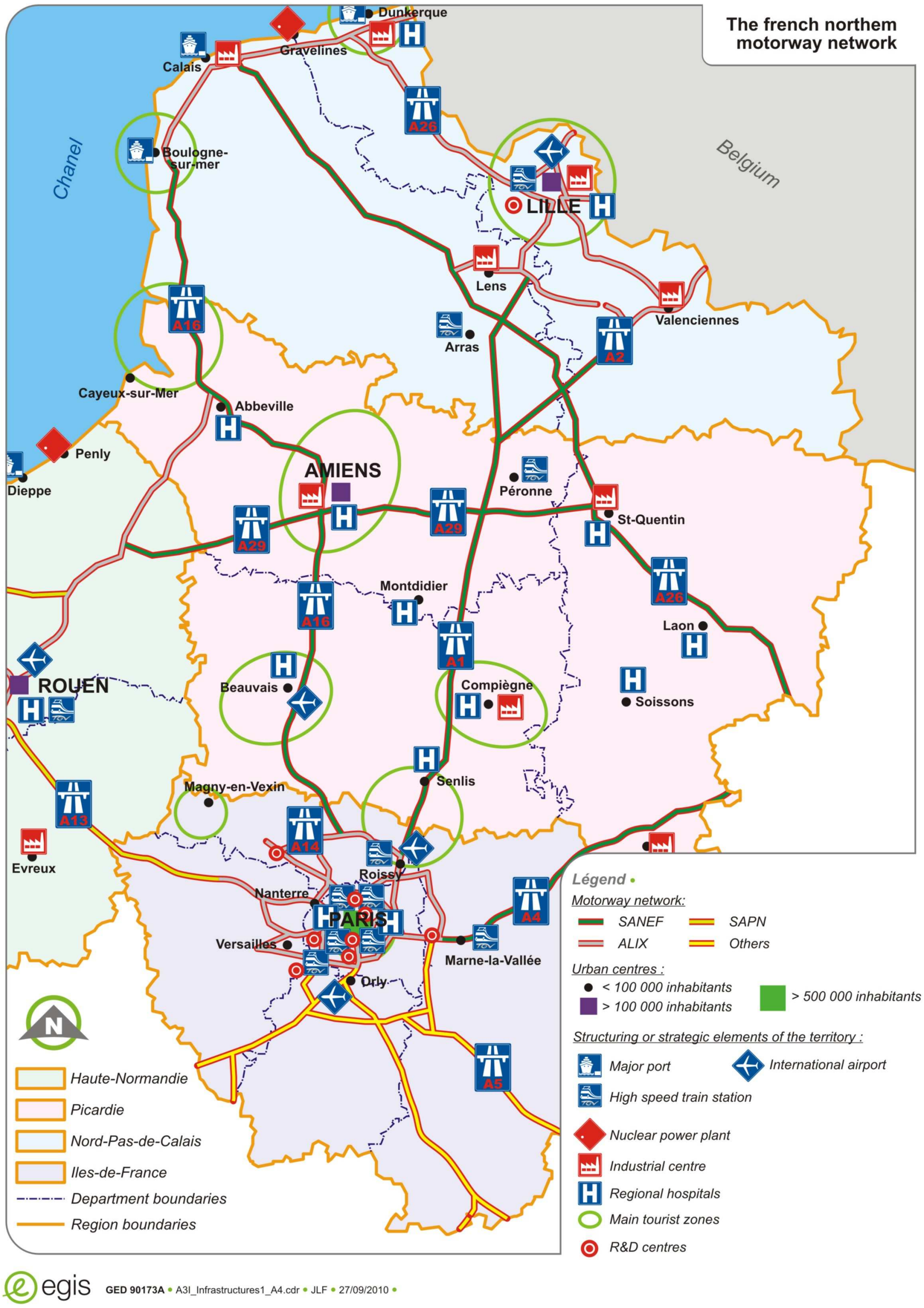
collection

- Climatic context
- Administrative (institutional) and legal context
- Social and political context
- Economical context
- Technical context (traffic, construction standards, etc.)

e. Example

Network scale case study, Northern motorway network, France

The perimeter of the northern network is shown on the following map, together with the main strategic components of the study area.



Sub-step 1.3 - Establish risk criteria and indicators adapted to each particular scale of analysis

a. Objectives

The purpose of this step is to identify the criteria, indicators and risk evaluation categories that will be used in the following steps 3, 4 and 5. The criteria provide a way to analyse the risks using an explicit and structured approach.

The risk manager should define the criteria to be used to evaluate the significance of risk. The criteria should reflect the organisation's values, objectives and resources. Some criteria can be imposed by, or derived from, legal and regulatory requirements and other requirements to which the organisation subscribes. Risk criteria should be consistent with the climate risk management policy, be defined at the beginning of any risk management process and be reviewed continuously.

When defining risk criteria, the factors to be considered should include the following:

- The nature and type of causes and consequences that can occur and how they will be measured
- How likelihood will be defined
- The timeframe(s) of the likelihood and/or consequence(s)
- How the level of risk is to be determined
- The views of stakeholders
- The level at which risk becomes acceptable or tolerable
- Whether combinations of multiple risks should be taken into account and, if so, how and which combinations should be considered.

b. Output

The output of this step is a list of criteria for exposure, vulnerabilities and consequences, with indicators and evaluation categories.

The criteria and indicators will be used in all subsequent steps. They will be transformed into a risk matrix and used in a multi-criteria analysis. The criteria should correspond to the scope and scale of the system under investigation.

c. Method

The definition of risk criteria is an important step. This may be seen as a “one-off” job, since the criteria may be used in many different studies on the same scale of analysis. It must be noted that defining risk criteria is an iterative process, requiring feedback from steps 2 and 3. It is indeed difficult, if not impossible, to set risk criteria without verifying that the required data are relevant and available on the appropriate scale.

Criteria and indicators for exposure, vulnerabilities (sensitivities) and consequences recommended by RIMAROCC are listed and commented hereafter. Careful determination of the suitability of each criterion is necessary. These criteria are not the only possible criteria; one can identify other relevant criteria as shown in d) data collection.

RIMAROCC recommends using four classes to score the level of the risk. Stakeholders should discuss the number of classes used and the details of the scale, i.e. how the table is filled out. The disadvantage of three or five categories is that people tend to choose the middle.

Criteria and evaluation classes for exposure, vulnerability, likelihood and consequences are provided below. It must be borne in mind, however, that these are only recommendations, and the risk manager of the study must decide on the criteria and the set of values that will be used during the risk evaluation. Hence, the example given in point e) shows some differences compared to the “standard” grid of analysis provided below.

Exposure indicators

With regard to climate risk factors, the main exposure indicators are duration, intensity, extent and likelihood.

Climate indicator	Indicator unit			
	Low (1)	Medium (2)	High (3)	Critical (4)
E1 - Duration of event	Hours	Days	Weeks	Months
E2 - Intensity	See Step 2.1.			
E3 - Scale of event	Very local (e.g. 100 km²)	Local (e.g. 1,000 km²)	Regional (> 10,000 km²)	National (> 100,000 km²)

Likelihood	Indicators	
Event may occur once in 10 years or more	4	Very likely
Event may occur once in 20 years	3	Likely
Event may occur once in 50 years	2	Unlikely
Event may occur once in 100 years or less	1	Very unlikely

Comments:

- Specific intensity thresholds (E2) must be defined for each climate factor, taking climate change into consideration.
- It is better if the likelihood scale fits in with design standards already in use in the country of the road operator.
- The likelihood may differ significantly with climate change (e.g. a climate event occurring at present only once every 20 years may occur every 10 years in 2050)

Threat and vulnerability indicators

These indicators refer to both aggravating factors related to climate risks (no warning procedures, contextual site factors likely to worsen floods, etc.) and vulnerable (sensitive) components of the infrastructure (undersized drainage system, cracks in the pavement surface layer, clogged up culverts, etc.).

	Low (1)	Medium (2)	High (3)	Critical (4)
V1 - Speed of occurrence / forecast time to event	> 3 days accurate predictions possible	½ to 3 days accurate predictions possible	< 12 hours accurate predictions possible	< 5 hours accurate predictions possible
V2 - Level of knowledge of the hazard and its related consequences	Detailed forecasts of occurrence and consequence of hazard	Rough forecasts of occurrence and consequence of hazard	Only qualitative insight (trends)	No idea
V3 - Amount and type of information to road users	Matrix boards available	Good radio coverage	Partial radio coverage	No road information
V4 - Age of the infrastructure	< 10 years	10 – 30 years	30 – 100 years	> 100 years
V5 - Design standards	Recent design standards (< 5 years)	5 – 25 years	25 – 50 years	> 50 years or unknown standards
V6 - Control and maintenance procedures	Systematic inspection after each unusual climate event + high maintenance means	Periodical inspection (at least 1/year) + average maintenance means	Occasional inspection (only after occurrence of damage) + low maintenance means	Almost no inspection or maintenance means
V7 - Traffic level	< 2,000 veh./ day	2,000 – 10,000 veh./ day	10,000 – 50,000 veh./ day	> 50,000 veh./ day
V8 - Site factors likely to worsen climate risks	Optimal situation regarding land cover, topography, erosion and flood control	Acceptable situation regarding land cover, topography, erosion and flood control	Degraded situation regarding at least one site factor	Degraded situation regarding all site factors, or situation highly degraded for one site factor

Comments: On the network scale, indicators V4 to V7 are considered more important and reliable than the other indicators, which are less discriminating (same situation for most of the road sections) and/or more difficult to assess on a large geographical scale (e.g. contextual site factors).

Consequence indicators

The main consequence indicators of climate risk refer to traffic accidents (deaths), traffic interruption or disturbance directy related to climate events or to damage caused by climate events. These indicators need to be selected for each scale of analysis, and for each country, by the relevant authorities.

Criteria for assessing the consequences	Indicator unit
C1 Loss of safety on the road	Number of persons killed/injured/rescued
C2 Costs for repair and reconstruction	Euros
C3 Unavailability of the road	% of normal capacity % more travelling time number of days
C4 Other indirect costs	Euros
C5 Loss of confidence / image / prestige / political consequences	?
C6 Impact on the environment	?

Comments:

- o Traffic interruption (downtime) is the most usual consequence of climate events.
- o Degraded operational conditions may occur after traffic interruption.
- o It must be pointed out that, given the cumulative effect of assumptions regarding exposure and vulnerability factors (leading to a high degree of uncertainty), consequences are not easily predictable. The consequence assessment can therefore be performed through “scenarios” based on previous events for which the consequences are already known.

d. Data collection

Within RIMAROCC, some common and general criteria are proposed. This list can be extended by making use of the following sources:

- It is recommended that objectives of the road authority related to the structure/section/network/area are translated into criteria.
- National Guidelines, laws and other directives.

For each criterion it should be identified which indicators can be used in order to assess the risks. The indicators should be measurable and should provide proper understanding of the magnitude of risk for the specific scale of analysis (structure/section/network/territory). The expected costs, for instance, should be related to the size of the project. Costs of €100 k can be negligible for a large road system but can be significant for a small system. Costs may be expressed as total investment in the physical structure or as cost/usage, e.g. average daily traffic.

e. Example

Section scale case study, Strynefjellet, Norway.

Risk criteria and indicators on the section scale are presented in three tables. The first table shows criteria for categorising exposure, the second table shows criteria for assessing vulnerability and the third table shows criteria for assessing consequences.

Criteria for assessing exposure

Criteria for assessing exposure	Low	Medium	High	Very high
E1:Frequency of key climate conditions/past extreme events	<0.001/yr	0.001/yr-0.01/yr	0.01/yr-0.1/yr	> 0.1/yr
E2: Exposure duration	Hours	Days	Weeks	Months
E3: Exposed area	Small area			Large area
E4: Exposed objects/people	Small number			Large number

Criteria for assessing vulnerability

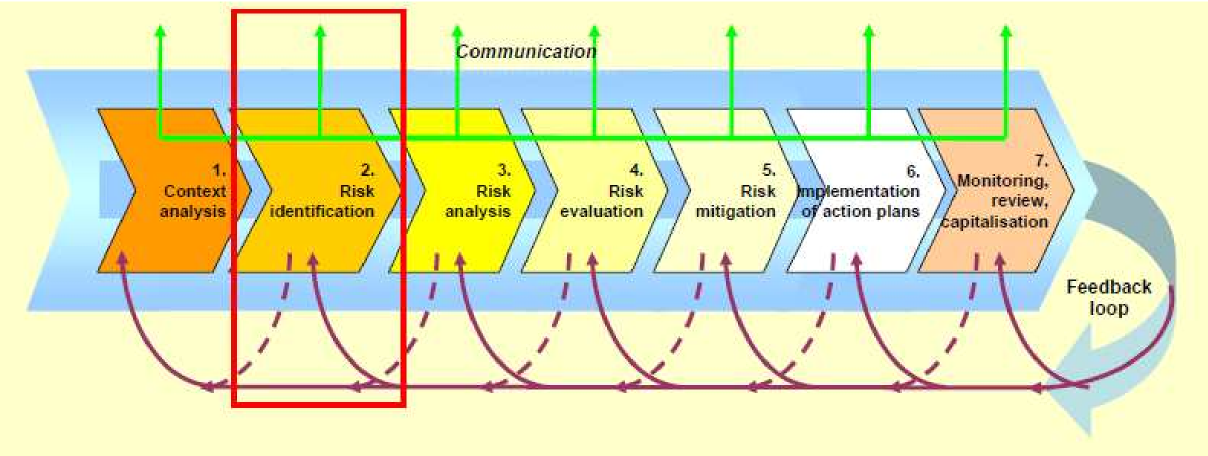
Criteria for assessing vulnerability	Low	Medium	High	Very high
Forecast time	>3 days	12 hours – 3 days	5-12 hours	Less than 5 hours
Amount and type of information to road users	Matrix board available	Good radio coverage	Little road information	No road information
Amount of knowledge of a hazard with related consequences	Detailed insight into occurrence of hazard	Insight into trends of hazard	Some knowledge of hazard	No knowledge of hazard

Design standards used and type of maintenance	Design standards used have an age of less than 5 years	Design standards 5 – 25 years.	Design standards older than 25 years, OK maintenance	Design standards older than 25 years, poor maintenance

Criteria for assessing consequences

Criteria for assessing consequences	**Low**	**Medium**	**High**	**Very high**
C1 Loss of safety of the road	Only light injuries	Heavy injuries	Death	Several deaths
C2 Direct cost, costs for reconstruction	<€5,000	€5,000 - 50,000	€50,000 – 2 million	>€2 million
C3 Unavailability of the road. Duration	<6 hours	6-24 hours	1-3 days	>3 days
C4 Indirect costs	<€50,000	€50,000 – €200,000	€200,000 – €1 million	>€1 million
C5 Loss of confidence	No image consequence	Local image consequence	Regional political consequence	National political consequence
C6 Impact on the environment	Temporary minor	Temporary serious	Permanent minor	Permanent serious

Step 2 – RISK IDENTIFICATION



1. Objectives of the step

The risk manager should identify sources of risk, areas of impact, unwanted events (including changes in circumstances) and their causes and potential consequences. The aim of this step is to generate a comprehensive list of risks based on events that might stop, degrade or delay the normal operation of the road system, or create trouble or damage in the exposed area.

2. Proposed sub-steps

Sub-steps are proposed in relation to the risk definition in section 3.1: risk is an unwanted event which is characterised as:

Risk = function of [Threat, Vulnerabilities, Consequences]

This step is therefore structured into three sub-steps:

1. Identify risk sources or factors (threats)
2. Identify vulnerabilities
3. Identify possible consequences

3. General recommendations for this step

See Part 1, section 4.3.

Identification should include risks, regardless of whether their source is under the control of the Road Authorities or not, even though the risk source or cause may not be evident. Risk identification should include examination of the knock-on effects of particular consequences, including cascade and cumulative effects. It should also consider a wide range of consequences even if the risk source or cause may not be evident. As well as identifying what might happen, it is necessary to consider possible causes and scenarios that show what consequences can occur. All significant causes and consequences should be considered.

Relevant and up-to-date information is important in identifying risks. This should include appropriate background information where possible. People with appropriate knowledge should be involved in identifying risks.

Sub-step 2.1 - Identify risk sources

a. Objectives

The purpose is to identify elements which, alone or in combination, have the potential to give rise to risk. Risk factors = risk sources = potential hazards.

Events involving risk factors (e.g. stormy weather) are likely to generate detrimental consequences for the road system.

b. Output

The main output will be a comprehensive list of risk factors.

c. Method

Climate is the source of risks considered within the RIMAROCC method and they are thus considered to be the primary risk factors. Since contextual site factors (environmental context of the infrastructure) are likely to moderate or worsen climate factors to some extent (e.g. a heavy shower will turn into a flood only in the case of specific topographic and land cover configurations), they can be defined as secondary risk factors. The current condition of the road infrastructure (pavement wear, embankment erosion, clogged up culverts, etc.) can also affect the infrastructure resistance capacity regarding climate factors and, as such, be considered a secondary risk factor. In the RIMAROCC method, however, it is considered more of a vulnerability factor and is analysed in Sub-step 2.2.

Climate factors

The climate factors likely to affect road infrastructure are rain, wind, cold/frost, snow, fog, heat, and drought.

Contextual site factors

Contextual site factors include the physical, biological and human factors of the environmental context of the infrastructure. They can be intrinsic risk sources (e.g. unstable ground conditions, trees likely to fall down onto the road, etc.), but may also be induced by artificial changes (e.g. soil waterproofing due to urban development or deforestation of upstream river basins).

It is pointed out that on broad geographical scales (network or territory), contextual site factors may be very difficult to survey. Hence, a comprehensive analysis of contextual site factors along a whole network is expensive and time consuming.

d. Data collection

Climate factors should be identified by/or in relation to National Meteorological Services. They are able to provide appropriate data, detailing strength and frequency of a selection of extreme weather phenomena:

- Maximum temperature and the number of consecutive hot days (heat waves)
- Extreme rainfall events (heavy showers and long rain periods)
- Seasonal and annual average rainfall
- Drought (consecutive dry days)
- Snowfall
- Fog days

- Frost (number of icy days)
- Thaw (number of days with temperature zero-crossings)
- Extreme wind speed (worst gales)
- Rise in the sea level

Contextual site factors depend on the geographical context and its evolution:

- Physical: hydrology, soil, slopes, etc.
- Artificial: land use, urban development, changes in river basins, etc.

According to the scale of analysis, contextual site factors will be surveyed through field investigations, aerial views or satellite imagery to determine evolution inside and outside the carriageway.

The lists of climate and contextual site factors presented in this guidebook are naturally not comprehensive and the user should adapt and supplement them according to the infrastructure context and scale (structure, section, network, territory).

e. Example

Structure scale case study, Väja, Sweden.

Climate factors and contextual site factors are presented in the tables below.

Climate factors threatening the road structure are presented along with the expected amount of change and the likelihood of the prediction. Change is predicted for the period 2071-2100.

Climate factor	Change	Likelihood
Winter rainfall amount)	++	Very likely
Intensity of extreme rainfall	+	Likely
Snowfall	-	Virtually certain

Contextual site factors surrounding the road structure.

Contextual site factors	Comments
Deforestation within catchment area	Unknown
Small dam upstream of road	Dam is in poor condition. Can be flooded or collapse.
Creek upstream of road	Undersized
Pipe under private road upstream from road	Undersized

Sub-step 2.2 - Identify vulnerabilities

a. Objectives

The purpose is to identify and characterise activities of the Road Authorities or infrastructure components likely to be affected by climate change, allowing in further sub-steps a prioritisation of these elements.

According to the HAASM, the way the Road Authorities' assets are designed, maintained and operated is defined as vulnerability. In the RIMAROCC approach, these elements are considered to be infrastructure-intrinsic risk factors but are related to vulnerabilities.

Identification of vulnerabilities is looking for the vulnerable elements of the road system in the event of occurrence of an unwanted (detrimental) event. Vulnerabilities are physical features or activities/functions of the road network that can be affected.

b. Output

The main output will be a comprehensive list or cartography of vulnerabilities on the appropriate scale of analysis.

c. Method

According to the scale of analysis, vulnerabilities cannot be estimated on the same basis. In the case of flood on the territorial or network scale for example, traffic would be impossible on a given road section; this section is considered vulnerable to a varying degree to floods. On the section or structure scale, however, vulnerabilities refer more to elements or objects, e.g. in the case of a strong wind, a signal gantry would fall down. This signal gantry is a vulnerable element in the road system.

It is possible to classify the vulnerabilities according to their degree of exposure, sensitivity and adaptive capacity to a given risk factor.

Study of vulnerabilities include at least:

a. Sensitivity and exposure of an asset (road, right-of-way, equipment, maintenance vehicles, etc.) to risk factors and/or to unwanted event
b. Traffic
c. Age
d. Design standards
e. Maintenance practice (routine and heavy repairs)
f. Adaptability of an asset, i.e. possibility of upgrading without a complete reconstruction of the asset.

In concrete terms, for each element of the road system this sub-step will consist of collecting information on the vulnerability of the sub-elements (embankment, pavement, hydraulics, etc.) for each possible risk identified in Sub-step 2.1. Each sub-element/vulnerability should be defined in a “National Vulnerability Reference Manual” or equivalent (a database, for example). If such a frame of reference does not exist, the analysis of the road system vulnerability should start at an early stage in the risk management process review, in step 1.1.

This survey can be carried out through surveys by the technical and operational staff of the Road Authorities.

d. Data collection

All Road Authorities' assets should be analysed according to their exposure, sensitivity and adaptive capacity to climate change. This covers all activities and infrastructure components.

Data to be collected include the following:

- Infrastructure-intrinsic factors: construction date, standards used, materials, equipment, etc. with a level of precision depending of the scale of analysis.
- Data covering actual traffic and a comparison with expected traffic: number of vehicles, type, origin destination analysis, etc.
- Data regarding maintenance (routine and heavy repairs).
- Structural defects or existing damages likely to be worsened by climate factors.
- Etc.

The main infrastructure components to be investigated are: major hydraulics, minor hydraulics and drainage, engineering structures, equipment, geotechnics, environment and pavement.

The UK Highways Agency HAASM includes over eighty vulnerability components.

The RIMAROCC method user should adapt and supplement these lists according to the infrastructure context and scale (structure, section, network, territory).

e. Example

Network scale case study, Northern motorway network, France.

Based on interviews with a pool of technical experts at the company SANEF, and according to risk criteria defined in Step 1.3., the following vulnerability factors have been identified:

- The infrastructure age (some of the northern network sections are the oldest motorway sections in France);
- The high traffic level of some sections, considered as critical in terms of traffic safety as well as economical activity;
- Design standards (e.g. when some parts of the network were upgraded from 2x2 to 2x3 lanes, the drainage network was not resized);
- Specific issues (sensitive elements) related to design, operation or maintenance. In some sections, for example, concrete security barriers prevent fast drainage in the event of heavy rainfall and this device could be the cause of flooding (e.g. Roye incident in 2003).

This information is summarised in the tables below. The first one shows, for each section, the link between climate risk factors and sensitive elements in the infrastructure. The second one presents the main vulnerability factors and the related climate risks.

Section	**Climate factors**					**Sensitive elements of the infrastructure (potential impact in the infrastructure/operation)** N.B.: all structural damage can lead to traffic interruption
	Extreme rainfall	**Seasonal and annual rainfall**	**Extreme winds**	**Frost**	**Snowfall**	
AX-1	X					Undersized drainage system (traffic interruption)
AX-2	X	X				Undersized bridge (bridge structure damage)
AX-3	X					Undersized culverts (road structure damage)
AX-4	X		X			Bridge showing structural defects (bridge structure damage)
…						
AY-1		X				Hydromorphic grounds (road structure damage)
AY-2		X		X		Pavement cracks (road structure damage)
…						
AZ-1				X	X	Steep roadway slope (traffic interruption)
AZ-2			X			Viaducts (traffic interruption)
…						
Node A	X					Poor underpass drainage (traffic interruption)
…						

Section	Length in km	Age / design standards	Traffic (veh./ day)	Exposure to climate events		Sensitive elements in the infrastructure
				Current situation	With CC (estimates) *	
AX-1	10-15	< 1960	60,000 – 70,000	Overflow for Q10	+ 10 % additional flow	Undersized drainage system
AX-2	25-30	< 1960	60,000 – 70,000	Overflow for Q100	+ 5 %	Undersized bridge
AX-3	45-50	1960-1970	40,000 – 50,000	Overflow for Q100	No change	Undersized culverts
AX-4	25-30	1960-1970	40,000 – 50,000	Extreme wind speed > 120 km/h	+ 5 %	Bridge showing structural defects
…						
AY-1	20-25	1980-1990	20,000 - 30,000	Average seasonal rainfall: 500 mm	+ 5 %	Hydromorphic grounds
AY-2	20-25	1980-1990	20,000 – 30,000	Average number of frost days: 20	- 5 %	Pavement cracks
…						
AZ-1	30-35	1990-2000	10,000 – 20,000	Average number of snow days: 15	- 20 %	Steep roadway slope
AZ-2	15-20	1990-2000	10,000 – 20,000	Extreme wind speed > 140 km/h	+ 10 %	Viaducts
…						
Node A		1960-1970	40,000 – 50,000	Flood for Q10	No change	Poor underpass drainage
…						

* A2 IPCC scenario for 2050

Sub-step 2.3 - Identify possible consequences

a. Objectives

The purpose is to identify and assess the consequences of events involving risk factors (detrimental climatic events) for vulnerable components of the road system.

b. Output

The main output will be a comprehensive list of the potential consequences of climate-related events, with clear indications regarding extent, severity and cost of these consequences.

At this stage in the RIMAROCC method, preliminary cost estimates based on lump sums are deemed sufficient.

c. Method

The consequences can be classified as **direct and indirect impact**.

- Direct impact = disruption in the road systems (activities and/or infrastructure)

- Indirect impact = human and socioeconomic impact

With reference to the HAASM, **road system disruptions** can be assessed according to their extent and severity:

Extent of disruption – number and/or extent of locations where the asset/activity and/or the number of users are affected. For example, the disruption could be important if it affects a high proportion of the network, or a small number of highly strategic points on the network.

Severity of disruption – recovery time in the event of a climate-related event e.g. a flood or a landslide. This is different from “how bad” the actual event is when it occurs, e.g. how many lanes are lost; it focuses on how easy/difficult it is to recover from the event, i.e. how long it takes to get those lanes back into use.

Human and socioeconomic impact relates to the consequences of the climatic event on the well-being of the users (psychological impact, stress, tiredness…), on safety (casualties), on the local or regional economy (economic losses), etc. It also includes direct costs for the Road Authorities (infrastructure damage).

The scope of the analysis may vary according to the scale. For example, on the structure or section scale only direct costs may be addressed. On the network or territorial scale, the analysis can be supplemented with the socioeconomic consequences of the traffic interruption or disturbance i.e. for the regional perimeter directly serviced by the network. Finally, the analysis may also encompass the consequences on the economic system level, i.e. from the regional to the European scale, and would involve analysing the impact of major or recurrent traffic interruptions on the organisational and operational aspects of the economic system. However, it is emphasised that such investigations require data not available within the road authority, and should therefore involve other stakeholders, such as regional or local councils.

Finally, **it is important to remember that it is always difficult to forecast the consequences of climate events for the road system**. For example, the number of deaths caused by a climatic event is highly unpredictable.

d. Data collection

The method should be adapted according to the infrastructure context and scale (structure, section, network, area), but also according to the Road Authorities' existing methods. The assessment of indirect costs may be a difficult and time-consuming exercise, but it is a very important element for decision-makers on the network and territory scales.

Some parameters seem to be of particular importance and should be addressed in all cases:

- Number of deaths or casualties (loss of safety of the road)
- Duration of the traffic interruption (unavailability of the road)
- Duration of traffic disruptions (during the event or the repair work)
- Reconstruction delays and costs

Specific studies that should be realised if necessary:

- Social and economic costs to society
- Loss of confidence / image / prestige / political consequences

Impact on the environment

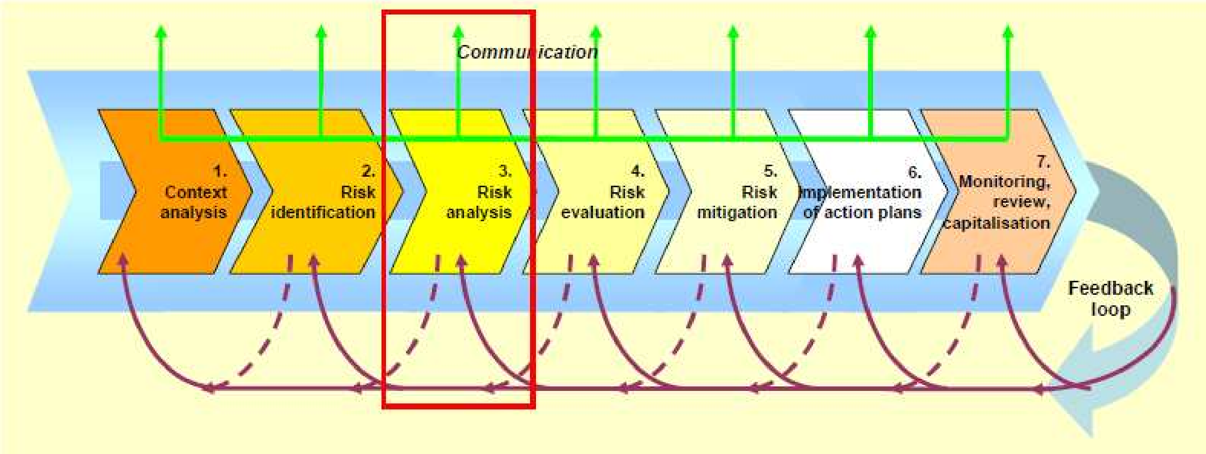
e. Example

Section scale case study, Strynefjellet, Norway.

With avalanches, snow and wind, identified as the critical climate factors, threatening a small but regionally important road, the following possible consequences were identified:

- Human injuries and fatalities
- Material damage to vehicles and the road infrastructure.
- Economic consequences caused by reduced traffic capacity and closures.
- Loss of road user confidence

Step 3 - RISK ANALYSIS



1. Objectives of the step

Risk analysis involves developing an understanding of the risks. The risk analysis provides input to risk evaluation and serves as a decision basis for whether risks need to be treated, and for selecting the most appropriate risk treatment strategies and methods.

2. Proposed sub-steps

3.1 Establish risk chronology and scenarios

3.2 Determine the impact of risk

3.3 Evaluate occurrences

3.4 Provide a risk overview

The number of sub-steps may vary according to the scale of analysis.

3. General recommendations for this step

This step consists of analysing the risks identified in Step 2. This analysis is based on the use of criteria and indicators defined in Step 1.

Sub-step 3.1 - Establish risk chronology and scenarios

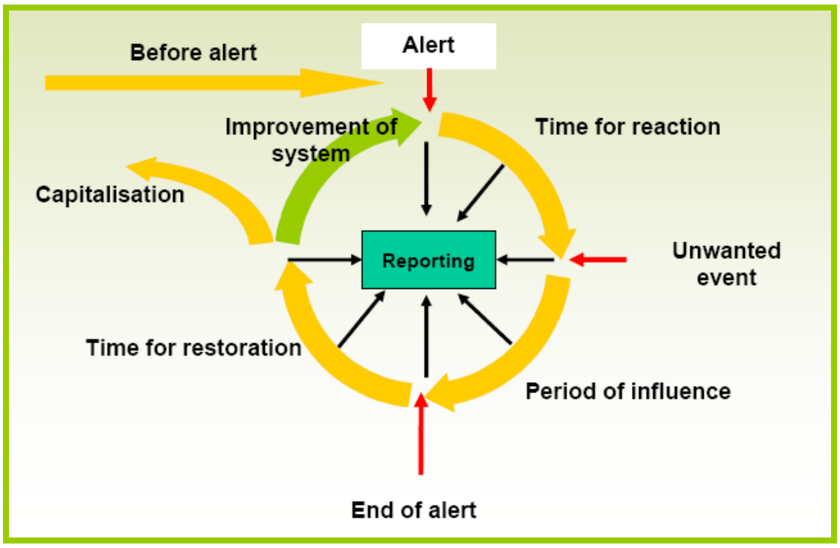
a. Objective The objective is to acquire good comprehension of the risk process, from the event source to the recovery of the ex-ante situation, in order to develop a system of defence based on prevention barriers (reducing vulnerabilities) and protection barriers (minimising consequences). The threats, vulnerabilities and consequences identified in step 2 are used to construct risk scenarios in this step.

b. Output

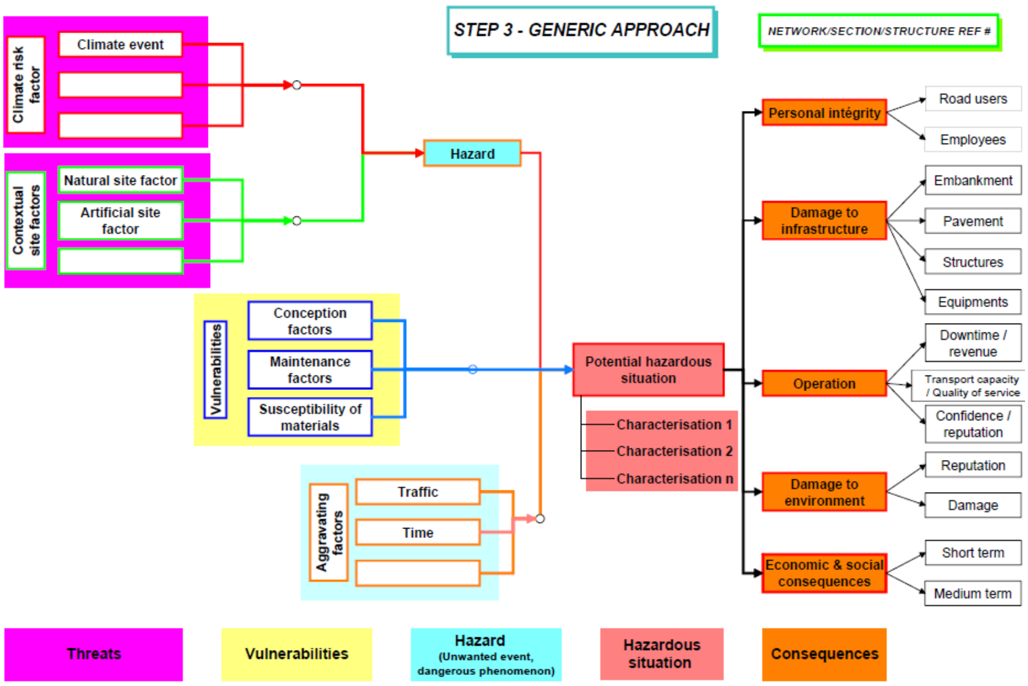
For each risk/road element, a table or diagram is prepared indicating the structuring and duration of each phase of the unwanted event. A list of the identified risk scenarios is also an output from this step.

c. Method

The diagram below shows the chronology of a climate risk scenario



Other kinds of presentations, more analytical, can be proposed, such as in the following diagram:



These diagrams allow all elements of the risk analysis to be broken down and facilitate understanding and dialogue with stakeholders. Various scenarios, based on several sets of risks factors, can be tested using this structured approach.

For each type of risk factor, an analysis can be carried out by the road operator's specialists and meteorological services to determine possible risk scenarios. Each risk scenario will be made up of a description of a specific climate event, the road system vulnerabilities to that climate event, and the related consequences. The level of detail of risk scenarios will increase from territory to structure scale analysis.

Knowing which climatic factors will emerge as more critical in the future, good help in formulating risk scenarios can be obtained from studying places with corresponding present climate conditions (climate homologues).

d. Data collection

The production of risk scenarios requires characterisation of all risk factors (climate and contextual site factors), vulnerabilities, and possible consequences.

For each configuration of risk identify possible first alert signs, time between first signs and alert, time for reaction, first consequences, period of influence, possible end of alert, time to recovery.

e. Example

Section scale case study, Strynefjellet, Norway.

The "weather-triggered" risk scenarios contributing most to the risk in terms of loss of human lives and economic losses are for the current climate situation:

- Risk scenario 1: Medium-sized snow avalanche crossing the road with a width of up to 100 m
- Risk scenario 2: Large snow avalanche crossing the road with a width of 100 to 450 m
- Risk scenario 3: Snowdrift and bad weather makes road use and maintenance impossible. Trapping of road users in tunnels or stranded vehicles.

These scenarios were also analysed under an assumed future climate scenario with more snow and more wind; risk scenarios 4, 5, and 6.

Identification of timeline representation of events for snow avalanche risk scenarios.

Risk chronology	
Time between first signs and alert	Weather forecast for 72 hours
Time for reaction:	Maximum 24 hours
Period of influence	3 – 12 hours
Consequences	Closing of the road
Time for restoration	5 – 12 hours (depending on the scenario; highest restoration time for scenario 2 and 5)
Cost of restoration	No extra cost. Restoration falls within the contract of the company "Mesta".
Palliative solutions	

Sub-step 3.2 - Determine impact of risk

a. Objectives

The possible consequences of climate risks and their related indicators are determined in sub-steps 1.3 and 2.3. The objective of the present sub-step is to score the consequence indicators for each risk scenario, or to value them, so as to make possible economic evaluation of risk scenarios and choice of strategy for mitigation. The purpose is to obtain a general indication of the level of risk and to reveal the major risks.

b. Output

A list or matrix of the estimated impact (consequences) of each risk scenario, together with their estimated economic values or, if the analysis is qualitative, a scoring for each consequence indicator.

c. Method

As explained in sub-step 1.3, the impact of risk would be determined in relation to the following categories:

- Integrity of people (users and employees) in terms of persons killed or injured
- Damage to the infrastructure in terms of cost of restoration
- Operating losses for road managers (revenue, quality of service, image) and for users (loss of time, additional cost of using vehicles)
- Damage to the environment (image and degradation)
- Economic and social consequences for the nation/region/area of influence (impact on modal choices, impact on accessibility of local territories, role of transportation in the global economic system)

The cost of palliative solutions should also be determined.

The risk manager will choose the most appropriate methodological approach for the economic valuation of the impact of risk. The evaluation should at least be based on a scoring system, using four risk classes (from low to critical) as proposed in sub-step 1.3.

d. Data collection

Several sources of information can be used:

- Specific enquiries and studies, produced on the national level, may help in estimating the cost of deaths or injuries (specific cost ratios according to the casualty category),
- Internal expertise of the road authority for direct damage and operational losses,
- Specific socioeconomic studies, on the appropriate scale of analysis, to value users' losses, environmental damage, and socioeconomic impact. Each case being particular, these studies need to be performed on a case-by-case basis.

e. Example

Structure scale case study, Väja, Sweden.

The identified risk scenarios are presented along with their respective consequence indicator values (black) and estimated costs (blue).

Risk scenario	Description	Consequences: Indicator value 1 - 4 (low – high) Estimated cost (MSEK)				
		Persons	Property	Environ.	Financial	Intangible
		C1	C2	C3	C4	C5
R1	Extreme rainfall event causes flooding of dam; high flows in the stream and flooding of the road.	2	3	1	1	1
		1	1.5	0	0.1	0
R2	Extreme rainfall event causes neighbouring dam to collapse; rapid and high flows in the stream, flooding and severe erosion of the road.	3	3	1	2	1
		2	2	0	0.5	0
R3	Spring flood causes flooding of dam; high flows in the stream and flooding of the road.	2	3	1	1	1
		1	1.5	0	0.1	0
R4	Spring flood causes neighbouring dam to collapse; rapid and high flows in the stream, flooding and severe erosion of the road.	3	3	1	2	1
		2	2	0	0.5	0

Sub-step 3.3 - Evaluate occurrences

a. Objective

Determine the occurrences of climate events to be incorporated into the calculation of the probable cost of consequences of risk scenarios in Step 4 – Risk Evaluation

b. Output

Future probability (if quantified) or likelihood (estimate) of risk scenarios

c. Method

Determination of occurrence is basic in economic risk evaluation but in the field of climate change probabilities are not available and uncertainty is the rule. Today there is only a small amount of information to determine the actual probability of extreme climate events, together with their future evolution. It is thus necessary to use approximations. It is only possible to indicate the likelihood that such an event will appear in the next five, ten or twenty-five years, based on expert judgement. It must also be borne in mind that risk analysis scenarios could be independent of probability, and describe a situation "in case of…" (e.g. worst case analysis).

In practical terms, based on available statistics, climate experts today are able to define the occurrence (probability) of each climate risk factor for a specific area. Evolution trends taking climate change into account can be provided from IPCC output, and more precisely from downscaling models. The likelihood of each climate risk factor in the medium or long run can thus be estimated.

Extreme climate events that are likely to have an impact on the road system are – by definition – exceptional. As a result, climate events to be considered in the present analysis are those exceeding the design standards of the road system. In the case of drainage and hydraulic issues for example, the main occurrences to be taken into account will be 10 or 20 years for the drainage system and 100 years for culverts and bridges.

Theoretically, the same assessment scale as the one proposed in step 1.3 should be used. However, the likelihood depends mainly on the intensity of the climate event under consideration. The intensity values depend on local available meteorological data. In addition, the climate event likelihood appears relevant only if a comparison with the infrastructure design standards is possible. For example, extreme rainfall exceeding the 10-year return period design standard for the drainage system may be known but no such return period can be considered for high seasonal rainfall or snowfall (there is no related design standard).

If no objective criteria of likelihood can be used (i.e. if there is no information on the climate event threatening to impact on the road system), it is recommended that the evaluation is based on climate change trends. As climate change may induce beneficial effects (e.g. a drop in seasonal rainfall and snowfall), likelihood may be scored + or -. However, to simplify the scoring, it is recommended to give a "0" value for climate factors showing improvements in the future situation.

The evaluation scale could be as follows:

- Evolution showing improvement for the climate factor (+ or ++): 0
- Evolution showing deterioration for the climate factor (- or --): from 1 (low) to 4 (critical).

It must be emphasised that climate change trends and intensity will depend strongly on the emission scenarios (A1, A1B, A2, etc.) and on the time horizon (2030, 2050, 2080, etc.) under consideration. This aspect will need to be discussed thoroughly by climate specialists and the road authorities. In addition, the probability of road damage might be conditional, depending on the occurrence of a series of events. We can assume that we have a known probability for a climatic event, which alone cannot damage the road system. To pose a threat, the climatic event must be coupled with a contextual site factor, e.g. the breaking of a water barrier. This contextual site factor is not always present. We can describe it by using a conditional probability: Provided the climatic event has occurred, how likely is it that the contextual site factor will occur? By multiplying the probability of the climatic event and the contextual site factor, we obtain the probability of the risk scenario, which is the output of this step.

d. Data collection

Climate change projections will be provided by the national meteorological authorities, based on IPCC results or, preferably, local downscaling.

In addition to climate change projections, detailed data on the current situation regarding extreme climate events can be used to refine the analysis. Mapping climate factors allows the situation of the whole area under the influence of the climate event to be analysed and thus enables correlations between possible impact on the road system and possible impact on adjacent transport infrastructure or territories to be established.

e. Example

Structure scale case study, Väja, Sweden.

A short explanation of the procedure for calculating the likelihood of risk scenarios is given below. For further information see the full case study.

The frequency of an extreme rainfall event powerful enough to flood the dam is estimated at once every 10 years. Given this event occurrence, the conditional probability of flooding of the road with moderate damage is estimated at p = 0.8. By multiplying the frequency of the climate event by the conditional probability, the probability for scenario R1 (0.08) is obtained.

The complementary event for the extreme rainfall event is that the dam collapses; the conditional probability of a dam collapsing and severe erosion is estimated at p

= 0.2. Multiplying the frequency of the climate event by the conditional probability results in the probability for scenario R2 (0.02).

The conditional probabilities for the scenarios following an extreme rainfall event is summarised as one.

Risk scenarios, likelihood of climatic events, probability of a dam collapsing given a climatic event, probability of a risk scenario and expected risk change with time.

Risk Scenario	Description	p(climatic event)	p(risk scenario given that the climatic event occurs)	p(risk scenario)	Future probability for scenario
		$year^{-1}$		$year^{-1}$	
R1	Extreme rainfall event causes flooding of dam; high flows in the stream and flooding of the road	0.1	0.8	0.08	Increasing
R2	Extreme rainfall event causes neighbouring dam to collapse; rapid and high flows in the stream, flooding and severe erosion of the road.	0.1	0.2	0.02	Increasing
R3	Spring flood causes flooding of dam; high flows in the stream and flooding of the road	0.1	0.8	0.08	Decreasing
R4	Spring flood causes neighbouring dam to collapse; rapid and high flows in the stream, flooding and severe erosion of the road.	0.1	0.2	0.02	No change

Sub-step 3.4 – Provide a risk overview

a. Objective

The present sub-step aims to provide a quantified evaluation (rating or score) of the risks and related vulnerable elements of the road system. It is the synthesis of all the previous steps, from sub-step 1.3 to sub-step 3.3.

b. Output

The output of this step is a risk table, giving the magnitude of all identified risks in terms of probability (likelihood) and consequences. The risk table is the input for the risk matrix that will be produced in Step 4.

c. Method

Implementing a semi-quantitative approach allowing a “risk table” to be prepared for each element of the road system.

Such a risk table describes the corresponding intensity, probability (likelihood), exposure, vulnerabilities, and related consequences for each climate risk factor. This information has been scored in the previous steps (e.g. 1 for low exposure, 4 for high exposure). The purpose here is to gather the information, allowing road elements to be compared with each other and aggregating the scores for all risk criteria in a single figure. After completion of all the risk tables, the road elements can be ranked according to their overall score, from the lowest to the highest risk level regarding climate factors.

d. Data collection

The information required for this step is the output from the previous steps.

For each infrastructure or asset element and for each climate factor, it is necessary to:

- Describe the risk factors (climate, intrinsic and site)
- Examine conditions for appearance of the risk (combined risk factors)
- Describe the risk and its expression (example for extreme rainfall: intensity,

probability in the present situation, future likelihood with climate change)

- Indicate the vulnerability of the specific element or asset to the specific risk
- Examine the possible consequences and the conditions of aggravation of these consequences (traffic, time, etc.)

Risk description, likelihood and exposure are given by climate experts. Vulnerable elements are defined through interviews with the road operator experts. Possible consequences are determined through similar events already experienced within the road system (expert interview + incident database).

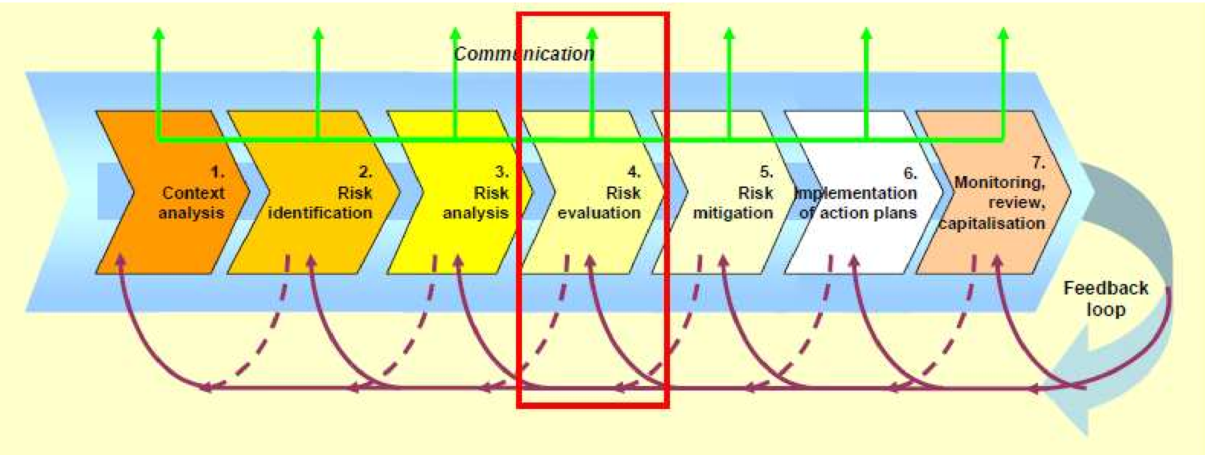
e. Example

Structure scale case study, Väja, Sweden.

All risks need to be scored using the criteria in order to gain an insight into the magnitude of the risk. The risk table below summarises the probability, exposure, sensitivity and consequence indicator scores for each risk scenario.

Risk scenario	Probability for risk scenario (year-1)	Exposure			Sensitivity				Consequences				
		Duration E1	Area E2	People/Object E3	Speed S1	Information S2	Knowledge S3	Standard S4	Persons C1	Property C2	Environ. C3	Financial C4	Intangible C5
R1: Extreme rain + flooding	0,08	2	2	2	4	2	1	1	2	3	1	1	1
R2: Extreme rain + collapse	0,02	2	2	2	4	2	1	1	3	3	1	2	1
R3: Spring flood + flooding	0,08	2	2	2	2	2	1	1	2	3	1	1	1
R4: Spring flood + collapse	0,02	2	2	2	2	2	1	1	3	3	1	2	1

Step 4 - RISK EVALUATION



1. Objectives of the step

The purpose of risk evaluation is to assist the risk manager in making decisions, based on the outcome of the risk analysis, about which risks need treatment and the priorities for treatment implementation. Risk evaluation involves comparing the level of risk found during the analysis process with risk criteria established when the context was considered. Based on this comparison, the need for treatment can be considered.

2. Proposed sub-steps

4.1 Risk prioritisation

4.2 Compare climate risk to other kinds of risk

4.3 Determine which risks are acceptable

Sub-step 4.1 – Risk prioritisation

a. Objective

This step aims to evaluate the risks and prioritise which risks need proper attention. Steps 2 and 3 show which risks are present and the magnitude of the risks. In this step the indicators defined in sub-step 1.3 are weighted and the resulting risk scores are visualised, e.g. in a risk matrix.

b. Output

Output is a risk matrix that results in a list of risks that need proper attention in the subsequent steps of the RIMAROCC framework.

c. Data collection

The risk table from step 3.4 is the input for this step.

d. Method

Weighing of indicators

The consequences were scored for different criteria defined in sub-step 1.3 (reputation, people, economic consequences and environmental impact). Each criterion can be measured using certain indicators. Weighting can help the road owner to decide which risk needs the most attention. A decision-maker might, for example, be more interested in economic consequences than in damage to prestige or reputation. In that case, the economic indicators receive a higher weighting than the reputation indicators.

One way to arrive at indicator weightings is to point out how the different indicators are related to each other. This results in a graded list of the criteria.

The following steps are recommended to obtain a graded list of criteria.

1. Prepare an indicator matrix (see the example section below)
2. Score all indicators relative to each other

    0 = Not important in relation to the other criteria

    1 = Of minor importance but still contributes

    2 = Of major importance

    3 = Absolutely of major importance in relation to the other criteria

3. Make a summary
4. Standardise the weightings to obtain a sum of weightings of 1
5. Prepare the graded list of indicators

Calculating risk scores

Next, the weightings and the risk table from step 3.4 are used to calculate the total consequence score:

$$totscore = \sum_{n=1}^{n} indicatorvalue_n \cdot indicatorweight_n$$

where n refers to the number of the indicator.

In order to prioritise the risks, the total scores of probability and consequence can be put on a graph, normally referred to as a risk matrix. An example is shown in the example section below. Colours indicate which risk requires most attention, i.e. a risk with a high probability score *and* a high consequence score.

A risk matrix gives a total overview of the risks. However, when a lot of risks are identified a risk matrix quickly becomes too “crowded”. Alternatively, the risk table from step 3.4 can be used to evaluate the risks. The following equation is used to calculate the total risk score:

$$TotalRiskScore = H \cdot C_{average}$$ (in which H = probability, C = consequence)

A colour scheme also needs to be added to the table. The table has the advantage over the matrix in that individual criterion scores can also be shown. This gives an insight into which indicator contributes most to the total risk. See also the example below.

Risk evaluation

Recommendations for risk evaluation:

- Prioritisation of risks as follows:
    1. High probability – High consequence → High priority
    2. Low probability – High consequence → Medium priority

3. High probability – Low consequence → Medium priority
4. Low probability – Low consequence → Low priority

- Risk criteria can be totalled to obtain a total overview of the risk although it must be borne in mind that one bad score for one criterion can also represent a major risk, especially for the criteria that are rated high in step 3.1 (criteria matrix)
- Do not rely purely on the numbers in the risk table but also make use of common sense

e. Examples

Structure scale case study, Väja, Sweden.

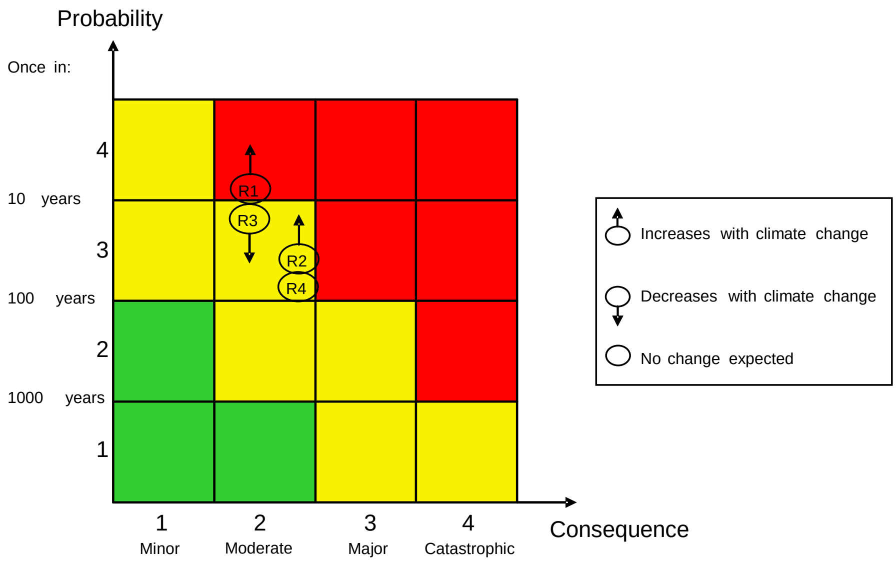
The first table illustrates the weighting of consequences described above. These weightings were discussed in a small group for use in the case study and consequently the results should be regarded purely as an example. In the second table, the consequence scores are weighted and summarised. The results are displayed in a risk matrix.

Indicator matrix for consequences. For each consequence criterion, the weightings are totalled from left to right. The standardised indicator weighting is obtained by dividing the sum of each consequence criterion by the total sum (30).

Fel! Objekt kan inte skapas genom redigering av fältkoder.

The consequence indicators are weighted by multiplying the consequence scores by the indicator weights from the above table. The total consequence score C_{Tot} is calculated as the sum of the weighted scores.

Risk	Probability for risk scenario (year^{-1})	Weighted consequences (indicator value*indicator weight)					
		Persons	Property	Environ.	Financial	Intangible	C_{Tot}
		C1	C2	C3	C4	C5	
R1: Extreme rain + flooding	0.08	0.8	0.6	0.17	0.13	0.1	1.8
R2: Extreme rain + collapse	0.02	1.2	0.6	0.17	0.26	0.1	2.3
R3: Spring flood + flooding	0.08	0.8	0.6	0.17	0.13	0.1	1.8
R4: Spring flood + collapse	0.02	1.2	0.6	0.17	0.26	0.1	2.3



Risk matrix with probability and weighted consequences indicated for all four risk scenarios.

Section/Network scale case study, A2/A58 Hertogenbosch - Eindhoven - Tilburg, The Netherlands.

Risk table for evaluation of risks.

Risk description	Threat		Consequence							Risk	
	current	future	C1	C2	C3	C4	C5	C6	weighted average	current	future
1a	2	2	1	2	4	3	2	2	2,4	4,7	4,7
1b	2	2	1	2	3	2	2	2	1,9	3,8	3,8
2a	2	2	3	2	4	2	2	1	2,7	5,3	5,3
2b	2	3	3	2	4	2	2	1	2,7	5,3	8,0
2c	2	3	3	1	3	1	1	1	2,0	4,0	5,9
2d	2	2	3	1	3	1	1	1	2,0	4,0	4,0
2e	2	3	3	1	3	1	1	1	2,0	4,0	5,9
2f	2	2	3	1	3	1	1	1	2,0	4,0	4,0
3a	2	2	4	2	4	2	2	1	3,0	5,9	5,9
3b	2	2	4	2	4	2	2	1	3,0	5,9	5,9
3c	2	2	4	1	3	1	1	1	2,3	4,5	4,5
3d	2	2	4	1	3	1	1	1	2,3	4,5	4,5
3e	2	2	4	1	3	1	1	1	2,3	4,5	4,5
3f	2	2	4	1	3	1	1	1	2,3	4,5	4,5
4a	2	2	1	2	1	1	1	3	1,1	2,3	2,3
4b	2	2	1	2	1	1	1	3	1,1	2,3	2,3
5	1	1	2	1	2	1	1	1	1,5	1,5	1,5

Sub-step 4.2 - Compare climate risk to other kinds of risk

a. Objective

Unwanted events from a climate change point of view are only a selection of all possible unwanted events that can affect a road. Consequently, a climate change related risk is not by definition the most important risk. With a comparison with other risks it is possible to gain an insight into the most important risks for the scale of interest.

b. Output

Evaluation of different kinds of risk which provides insight into the magnitude of the climate change risks compared with other risks.

c. Data collection

Other administration services in relation to risk management should be contacted. Asset management is probably the central point at which the information can be gathered and compared.

d. Method

It could be important to compare the climate change risks (as identified, analysed and evaluated in the previous steps) with other risks.

Risks related to climate change represent a newly recognised field and comparing them to risks that have been known for many years requires proper attention. Climate-related risks may be small or great in comparison to other risks.

Possible risk sources are:

- technical
- organisational
- spatial planning
- political/governmental
- legal
- financial
- social

These other risks can be assessed using an approach similar to the RIMAROCC framework. Other frameworks or standards are probably already being used within the responsible authorities.

By comparing climate-related risks with these other risks a final prioritisation can be made. For instance, a comparison can be made of financial consequences.

Points to be noted include:

- It is thought that normally the comparison mentioned in this sub-step is more important on smaller scales than on larger scales (e.g. the network/territory scale).
- One should always be aware that climate change risks are risks with a special character compared with other risks, since it is expected that climate change risks change over time to a greater extent than other risks. This is also combined with a much higher uncertainty as to the magnitude of this change.

e. Examples

Section scale case study, Strynefjellet, Norway.

The climate-related risk scenarios were compared to traffic accidents and to tunnel fire.

Hazard score ↑				
	R3, R6	R4		
		R1	R2, R5, Traffic accidents	
				Tunnel fire
Consequence score →				

Risk matrix, summary of all scenarios for consequence C1: Safety, and comparison with the risk of traffic accidents and tunnel fires.

Sub-step 4.3 - Determining which risks are acceptable

a. Objectives

In this sub-step the acceptability of the prioritised risks is discussed.

b. Output

A list of non-acceptable risks is the output of this sub-step. For those risks, measures should be identified and presented in step 5.

c. Data collection

Available is a list of risks that require proper attention, based on their relatively high combined probability and consequences. Input for this step comprises the identified risks that have been given priority in step 4.1.

d. Method

The acceptability can be based on:

- Risk standards
- Tipping points
- Uncertainty
- Vulnerability criteria (from step 1.3)

Analysing these aspects provides an insight into the acceptability of the risk. However, in the end it is the user of the RIMAROCC method who needs to decide whether the risk is acceptable or not. This is a result of previous discussions (see Part 1, Chapter 4.7).

Risk standards

With use of the risk standards for roads that are available in guidelines and standards an insight can be gained into the acceptability of climate-related risks. For instance, a possible amount of standardised rainfall and frequency give an idea of the vulnerability of a road. When the amount and/or frequency increase due to climate change, the road potential no longer meets the requirements. As a consequence, the risk can be marked as unacceptable. It should be mentioned that climate change itself has already been incorporated into certain new guidelines which can also provide insight.

Tipping points

Adaptation Tipping Points[5] (ATPs) are boundary conditions where technical, financial, spatial or societally acceptable limits are exceeded. Analysing ATPs helps to identify when alternative adaptation measures are needed, without having to choose one of the climate change scenarios. The question to be answered is: “How much climate change can the current strategy cope with?” This provides an indication of whether the risk is acceptable or not. In step 5 it will be analysed whether measures should be taken.

Uncertainty

Climate change risks deal with a high degree of uncertainty, since it is very difficult to predict how the climate will change and how other factors will change in the coming tens or hundreds of years. A large degree of uncertainty increases the need to be given more attention and will increasingly give an unacceptable risk. This links to the precautionary principle. This implies that a lack of certainty should not be used as an argument to not take measures. It is the responsibility of the authority whether or not to take measures, knowing that with some amount of (un)certainty an identified risk can occur. The need for control measures increases with both the level of possible harm and the degree of uncertainty.

Vulnerability criteria

The vulnerability criteria from step 1.3 can also be used to gain more insight into the acceptability of a risk. Especially the first three proposed criteria (speed of occurrence, knowledge and road user information) can be used for this purpose. If a certain unwanted event is predictable early warning is possible and road users can be informed efficiently in case of the event happening, The risk can be more acceptable than if these criteria were not fulfilled. However, if these vulnerability criteria were used to assess the magnitude of the risk, this method of investigating acceptability is not appropriate, since it would be double-counting these criteria.

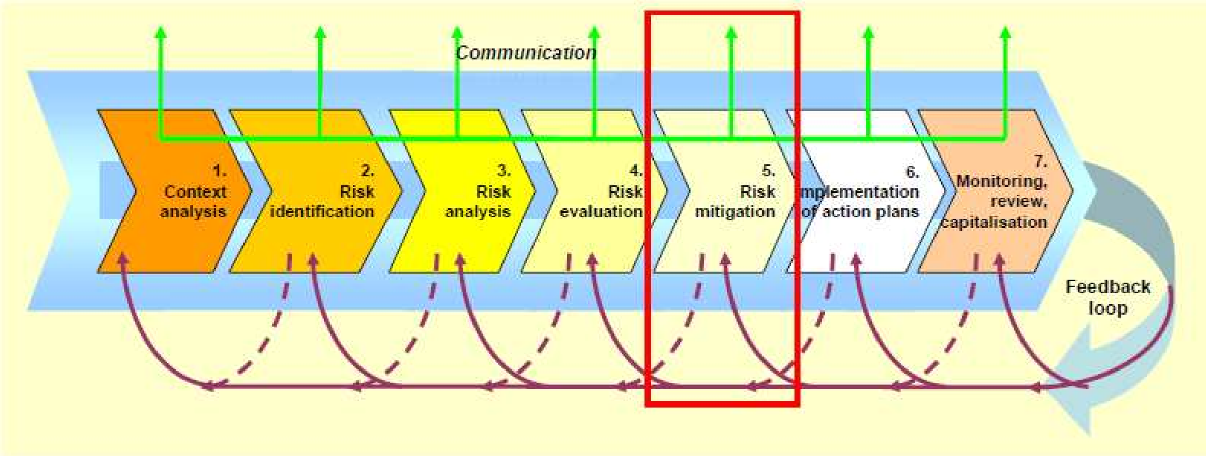
e. Examples

Example using the Tipping points approach:

The maximum acceptable closing frequency of a storm surge barrier in the Netherlands is once a year, as shipping companies will not accept a higher frequency. In the current situation, the barrier needs to close once every 10 years. The acceptable limit is expected to be exceeded at a sea level rise of 85 cm. In the most pessimistic climate change scenario, this level will be reached around 2050. This gives an indication of when the current strategy should be reconsidered.

[5] Kwadijk, J. C. J., Haasnoot, M., Mulder, J. P. M., Hoogvliet, M. M. C., Jeuken, A. B. M., van der Krogt, R. A. A., van Oostrom, N. G. C., Schelfhout, H. A., van Velzen, E. H., van Waveren, H. and de Wit, M. J. M. , Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. Wiley Interdisciplinary Reviews: Climate Change, n/a. doi: 10.1002/wcc.64

Step 5 - RISK MITIGATION



1. Objectives of the step

Risk mitigation involves identifying, appraising and selecting one or more options for modifying the non-acceptable risks. A combination of the identified measures can be transformed into a strategy for the coming years in order to cope with climate change and keep risks acceptable. This step also includes securing financing as well as documenting in an action plan how the chosen adaptation measures will be implemented. Risk mitigation is a strategic step which may involve players from several departments: roads, civil security, finance and others.

2. Sub-steps

5.1 Identify options
5.2 Appraise options
5.3 Negotiation with funding agencies
5.4 Present an action plan

Sub-step 5.1 - Identify options

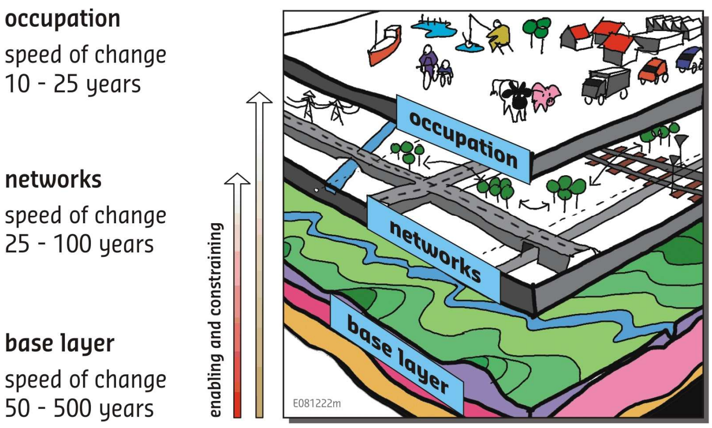
a. **Objectives**	The purpose of this step is to identify possible adaptation measures for the non-acceptable risks.
b. **Output**	For a non-acceptable risk several optional measures are identified and combined into a strategy. In subsequent steps these options will be analysed in order to determine the applicability**.**
c. **Data collection**	The RIMAROCC framework does not provide a complete list of possible measures. Only categories are presented, as well as different approaches to identify measures. The user should not hesitate to use other ways than presented in this step to identify the options. The identification of options is, however, a creative

process. It is used to guide the user of the RIMAROCC framework in the identification of possible measures.

d. Method

Risk remediation measures can be identified by making use of three different physical layers as shown in the figure below. These layers are:

- occupation layer
- network layer
- base layer



Layering model

For each layer risk-reducing options can be identified. Risks are reduced by either reducing the probability or by reducing the vulnerability and consequences. Because the probability of climate events cannot be influenced, reducing the vulnerability and consequences is the only way. One can choose from the following types of measures:

A. *Resistance*: Increasing the threshold before damage will occur, e.g. prevention by increasing the drainage capacity or by changing the pavement type.

B. *Consequence reduction*: If an unwanted event occurs, measures can be taken in order to minimise the consequences. Examples are limitation of the spread of the disturbance to other areas, being prepared to take emergency measures (divert traffic), making assets less sensitive (promotion of winter tyres).

C. *Recovery capacity*: enhancing a quick return to the pre-disturbed situation, e.g. having pumps available to pump out water after flooding, insurance, well-trained people to help clean up and repair.

D. *Adaptive capacity*: be prepared to take measures for the future. This means that there is some form of flexibility to change functions or assets over time, e.g. plan for the possibility to be able to change the drainage capacity in coming maintenance cycles.

Within these four categories one can think of several approaches to strengthen the capacity. These are presented in the table below. It can be advantageous to try to identify measures that are flexible and which can be characterised as “no-regret” options. Flexibility refers to the possibility of a measure to be changed in time. Since climate change is accompanied by a large degree of uncertainty, a flexible approach is favourable over a non-flexible approach. A no-regret measure is a measure that is already beneficial, without any climate change occurring.

Seven different approaches to strengthen the capacity (mainly based on Highways Agency Climate Change Adaptation Strategy, 2009). The letters refer to the types of measures described above.

Do minimum (A, B, C, D)	Minimum actions necessary to maintain a safe and serviceable network. May include: developing contingency plans, monitoring changes and, for assets, doing patch-and-mend repairs/like-for-like replacements, as required. This approach could also be called “wait and see, repair little by little”.
Future-proof designs (A, C, D)	Updating design requirements, including technical standards and specifications, to provide additional capacity/functionality. These updated requirements could apply to all ‘designs’ e.g. designs for new structures or new roads, as well as to designs for maintenance, renewal and improvement work when these are implemented within the normal cycle for such activities. Typically, it will be appropriate to adopt a precautionary approach in future-proofing designs, so that the asset/activity will perform satisfactorily throughout its life in the event of climatic changes towards the extreme predictions.
Retro-fit solutions (A)	Proactively applying modifications to existing assets/activities outside the ‘normal’ cycle for renewal/replacement. For example, proactively replacing/fitting additional equipment or components or providing additional provision/capacity to existing assets. This option could be applied everywhere in the network, or just at high risk sites. Work could start now, or only once climate change effects meet certain threshold criteria. There are several possible options to implement retro-fit solutions, such as increasing the preventive maintenance and reinforcement and the focus on specific roads instead of focusing on an entire network.
Develop contingency plans (B, C)	Development of a pre-planned response for when/if climate change risks are realised so that their immediate effects can be managed. This option could apply where nothing can reasonably be done to mitigate an identified risk during the period until other measures are put in place, or where there is a residual risk, despite adaptation action being taken. It should be included as standard within the ‘do minimum’ option.
Update operating procedures (B, C)	Updating operating procedures to take account of the impact of climate change, e.g. updating the procedure for working in high temperatures.
Research	The main purpose of research is to reduce uncertainty, where this presents a barrier to determining preferred adaptation options with a reasonable level of confidence. It could be done to provide better understanding of the likelihood and consequences of a risk to the network. Alternatively, it could be done to help determine or refine appropriate adaptation options. With monitoring it should be possible to make a careful selection for programming new investments and the creation of alert and response thresholds designed to anticipate a critical situation.
Monitor	Monitoring of the rate of climate change and/or the subsequent effects on a particular asset/activity to increase confidence in the appropriate adaptation option, or to determine the appropriate point at which to implement some pre-determined action. An important part of this option would be to identify indicators of change and threshold ‘triggers’ for action.

e. Examples

Structure scale case study, Väja, Sweden

Four risk scenarios resulting in flooding and erosion problems have been identified in earlier steps. In a seminar the risk scenarios were mapped on a white board and the possible mitigation options were discussed. The following options were identified;

- protecting against erosion
- securing drainage by cleaning up and checking the dimensions of ditches and piping
- removing the dam
- protecting against mudflows

Options, including discussions and co-operation with other stakeholders, were discussed.

Sub-step 5.2 - Appraise options

a. Objectives

Different adaptation options are identified in the previous step 5.1. This step will classify these options and assist in choosing the measures to be presented in an action plan (steps 5.3 and 5.4) and implemented (step 6).

b. Output

A list of adaptation measures that require implementation is combined into a strategy for the coming years in order to cope with climate change and keep the level of risk acceptable.

c. Data collection

Necessary input for this step comprises:

- the list of risk criteria from step 1.3
- the list of non-acceptable risks from step 4.3
- the list of identified adaptation measures from step 5.1

Stakeholders should be invited to a dialogue regarding the proposed adaptation measures and the action plan (step 5.4) where appropriate.

d. Method

In general, it is recommended that adaptation measures are planned when:

- acceptable risk levels will be exceeded in the short term,
- future measures will take a long time to implement or will be increasingly expensive,
- no-regret measures are possible.

In order to determine which measures should be presented, based on the previous three remarks, for each non-acceptable risk an analysis should be made. In this analysis all identified adaptation measures for each risk will be classified and compared with the current situation (do nothing). The proposed method for analysing the possible adaptation measures consists of two parts.

1. At first the effectiveness related to the amount of climate change is estimated. The question is: “how much climate change is necessary for the adaptation measure to become insignificant?” Some adaptation measures will only become effective after climate change has already developed. This should also be analysed.
   Answering these questions is independent of time. The time scale can later be

added in the strategy analysis by using different climate scenarios. This provides information on when in time a certain adaptation measure is not effective anymore or will become effective. With arrows from one option to another option one can show the possibility of changing from one conceivable measure to another measure when the first one is not effective anymore. This shows the flexibility of the different options.

2. Secondly, each option is analysed using a multi-criteria analysis making use of the consequence criteria from step 1.3. One can compare qualitatively the alternatives for effectiveness related to the objectives of the road owner. With the qualitative cost estimation one can also obtain an idea of the feasibility of the option.

Both parts can be integrated into a strategy analysis sheet as shown in the table below. At the end of this sub-step an example is provided of a strategy analysis sheet.

With examination of the strategy analysis sheet one can choose promising options, keeping in mind necessary flexibility for climate change. Implementation costs and benefits of the options are examined qualitatively. However, it is sometimes necessary to make an in-depth cost-benefit analysis (depending on the scope and type of project) for the most promising options. Each road authority and country has different and standardised ways of performing a cost-benefit analysis. This is the sub-step in which they should be performed when assumed necessary.

Finally, a check should be made whether the risks are acceptable after taking the identified best measures. If not, one should identify other options in step 5.1 and execute a new option appraisal or adjust the level of acceptable risk. The residual risk should be documented and will be monitored and reviewed in step 7.

A strategy analysis sheet for a certain risk.

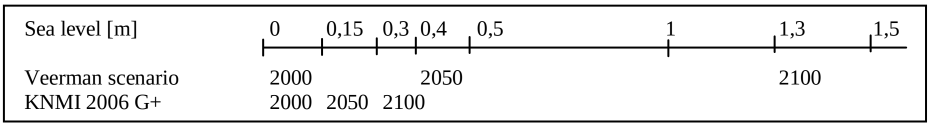
<table>
<tr><td colspan="10">Risk description</td></tr>
<tr><td rowspan="4">Options</td><td colspan="2">Hazard (climate change)</td><td colspan="6" rowspan="2">Consequences (estimation after taking measures)</td><td rowspan="4">Implementation cost</td></tr>
<tr><td>Change of parameter</td><td>List a range of change of the climate parameter</td></tr>
<tr><td>Timescale (scenario 1)</td><td>Using the scenario information: link expected years to the change of the climate parameter</td><td>People conse-quences</td><td colspan="3">Economic consequences</td><td>Repu tation</td><td>Impact on environment</td></tr>
<tr><td>Timescale (scenario 2)</td><td>Using the scenario information: link expected years to the change of the climate parameter</td><td>C1</td><td>C2</td><td>C3</td><td>C4</td><td>C5</td><td>C6</td></tr>
<tr><td colspan="2">Current</td><td>→</td><td>--</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Measure A</td><td>→</td><td>+</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Measure B</td><td>→</td><td>++</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">…</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

For each risk a separate strategy analysis sheet must be made.

The measures from step 5.1 for the risk in question are written down, including the current status.

For the climate parameter in question a rate of change is provided. Time scales are added to this rate of change (in this case two, but can be more). This provides insight into the uncertainty of the rate of change according to different climate scenarios.

For instance the change of parameter could be a rise in sea level in metres, or the frequency of a certain amount of rainfall, which increases in time. The time scales are derived from a certain climate scenario with the purpose of adding a date to the change in parameter. An example using Dutch climate scenarios is provided below:



Using arrows it is possible to show to and from which amount of change in the climate parameter a certain measure is effective. Using blue arrows one can also show the possibility of changing to another measure, following implementation.

Some points of attention:

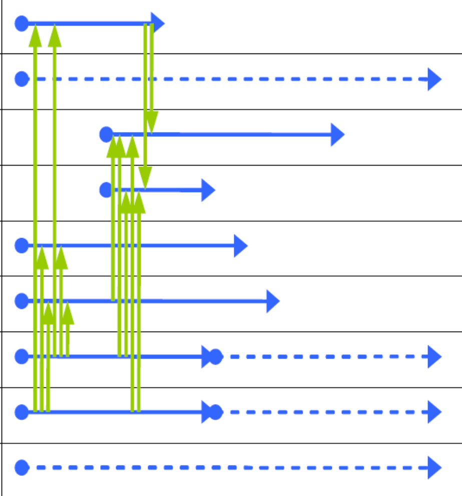
- the more to the left (earlier) the arrow with the current situation stops, the more urgent the early measures
- the further to the right (later) the arrow of a possible measure starts the greater the possibility that the measure, if taken, was not necessary
- the longer the arrow of a possible measure (valid for a longer period of time) and the further to the right (later) the arrow stops, the more robust the measure is.
- the more a blue dotted arrow points from one measure to another measure, the more flexible a measure is.

In this part of the strategy analysis sheet the consequence criteria from step 1.3 are listed. If deemed necessary other criteria can be added. The implementation costs are also put on this side of the sheet. Using a legend such as (++, +, 0, -, --) and a corresponding colour scheme provides an insight into the effectiveness of each measure.

e. Examples

Section/Network scale case study, A2/A58 Hertogenbosch - Eindhoven - Tilburg, The Netherlands.

The strategy sheet example below is based on assumptions but gives a good insight into how the adaptation tipping point in a strategy analysis sheet can be used to choose a strategy, as a combination of several related measures. The x-axis is the time scale, and the blue arrows show the timeframe for which each measure is effective. The measure's tipping point is where the blue arrow ends. At present, measures I, V, VI, VII and VIII are applicable. Measures III and IV will only become effective after climate change has already developed. The green arrows show the possibilities of changing from the current measure to another measure. The effects of each measure on the consequence criteria are scored as described above, as are the implementation costs.



Measure	The increase of heavy precipitation with a timescale according to climate scenarios	Consequence criteria						Estimated costs
		C1	C2	C3	C4	C5	C6	
I		--	-	--	--	--	0	++
II		-	-	--	-	0	0	+
III		++	-	++	++	0	0	--
IV		+	-	+	+	0	0	-
V		0	-	0	+	0	0	+
VI		+	-	++	+	0	0	0
VII		+	-	-	-	++	0	+
VIII		+	-	-	+	+	0	-
IX		-	-	--	-	+	0	+

Sub-step 5.3 - Negotiation with funding agencies

a. Objectives Making sure that the chosen strategies from step 5.2 can be implemented.

b. Output Commitment of funding agencies.

c. Data collection The following information is necessary to show the relevance of actions:

- The effects of climate change on the level of scale and the estimation of the risk. The risk matrix or risk table from step 4.3 can be used,
- The chosen strategy and comparison of costs and benefits from step 5.2, which shows the expected reduction in the risk,
- The comparison with other kinds of risk in step 4.2.

d. Method The execution of this sub-step depends very much on the organisation of the authority in question. It is therefore not possible to provide a general method for obtaining funding from relevant agencies.

It is important to note that in reality one should not wait until this moment to contact funding agencies. In order to gain the confidence and support of the funding agencies they should be informed continuously on the progress of the risk analysis. If possible, they can even be invited to attend meetings for steps 1.3, 4.3, 5.2 and 5.4.

Step 5.4 – Present action plans

a. Objective The purpose of the action plan is to document what adaptation measures will be implemented. The focus in step 5.4 is on the actual measures that will be taken. Step 6.1 deals with how these measures should be organised in order to be sure that they are executed.

b. Output

Output of this sub-step is an action plan which shows how the measures will be implemented, as well as monitoring indicators in order to have continuous insight into the progress that will be made.

c. Data collection

The most important input is the outcome of step 5.2. This provides the chosen strategy that needs to be transformed into an action plan. However, a continuous comparison should be made with all information in previous steps on the basis of the action plan.

d. Method

At first a global plan should be defined with the aim of minimising global costs/benefits under constraints. This is strongly related to the strategy that is chosen in step 5.2. Since the RIMAROCC framework only deals with climate change the action plan in this sub-step only deals with climate change adaptation measures. In reality, the measures will (and should) be integrated into other existing plans (see also step 4.2). This can be done in this global plan.

Afterwards, the specific action plan should identify the priority order in which individual adaptation measures need to be implemented. Based on these choices residual risks will be examined and mitigated with appropriate planned measures.

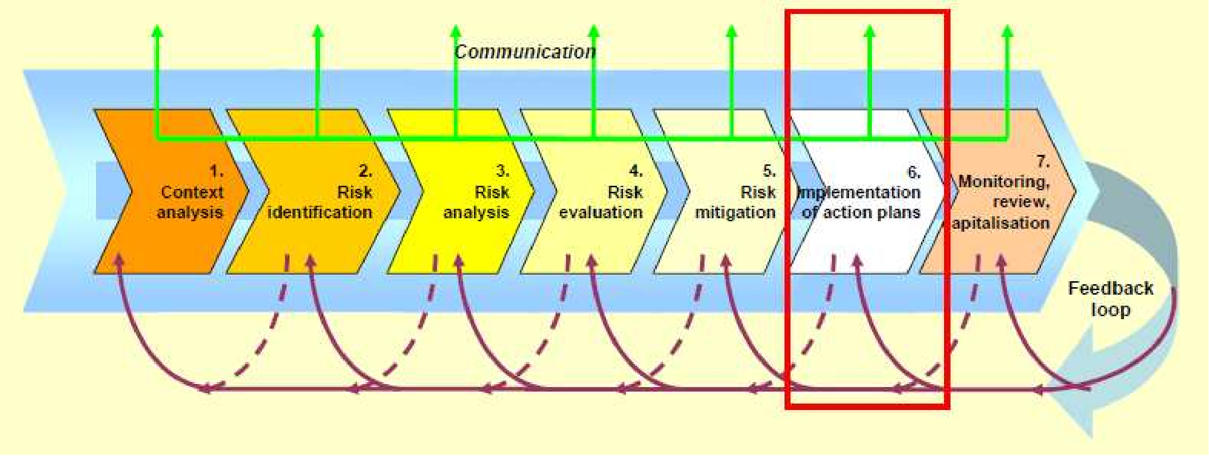
The action plan should provide information on (following ISO 31000);

- The selected adaptation measure and reasons for selecting this measure (output step 5.2). The measures should be presented and designed.
- Responsibility for approving and implementing the plan (output step 6.1)
- Resource demands in terms of staff, funds etc. (output step 6.1)
- How it is possible to keep up with the performance of the measures. Reporting requirements should therefore be part of the action plan as well as monitoring requirements.
    - Monitoring of climate change evolution
      This provides an insight into the relevance of the planned measures. New insight into climate change evolution can affect the measures to be taken. They may have to be changed, are no longer useful or can be left.
    - Monitoring of climate change impact
      This provides an insight into the effects of climate change on the road. Uncertainties about such impact can decrease with the same consequences for the measures that are implemented in this action plan as stated at the previous bullet.
    - Monitoring of the effect of implemented actions
      This provides an insight into the effectiveness of the applied measures and this knowledge can be used to make adjustments to subsequent measures.

  Monitoring activities can be applied on a higher level and integrated with other monitoring programmes. The action plan should be evaluated and updated continuously based on monitoring results. See RIMAROCC step 7 for recommendations on this point.
- Time plan (output step 6.1)

It is recommended, as also stated in step 5.3, that stakeholders should be invited to take part in a dialogue regarding the proposed adaptation measures and the action plan.

Step 6 - IMPLEMENTATION OF ACTION PLAN



In this step the action plan is presented in detail; responsibilities for implementation are addressed; resources are allocated; performance measures are selected. When all the details are in place, the action plan is implemented. This is a strategic step which involves players from several departments: roads, civil security, finance, etc. Network and territorial scale analyses require information on which geographical units of the organisation should be involved. This also applies to stakeholder contacts.

Sub-step 6.1 - Develop an action plan on each level of responsibility

Sub-step 6.2 - Implement an adaptation action plan

Sub-step 6.1 - Develop an action plan on each level of responsibility

a. Objective	The objective is to detail the action plan(s) presented in step 5.4, focusing on how to implement the action plan, allocating responsibility and detailing human resources demands.
b. Output	Time schedule and a clear division of responsibility for implementing the action plan.
c. Data collection	Step 1 provides information on context and responsibilities. The list of selected adaptation measures from step 5.2, and their action plans from step 5.4.
d. Method	▪ Identify an appropriate level of detail; large-scale analysis requires more in-depth description. Adopting a time schedule according to a specific study. ▪ Divide responsibility for approving and implementing the adaption action plan: responsibility for each activity is divided, including control activities. This can be based on the responsibilities identified in step 1 but may also include new structural or organisational suggestions. ▪ Action plans should be integrated into the management processes of the road

administrator and discussed with appropriate stakeholders. Decision-makers and other stakeholders should be aware of the nature and extent of the residual risk following risk mitigation.

- It is important to incorporate the time schedule and budget into the road administrator's investment programme to ensure resources are available.
- Clarify the responsibilities and links between the various organisations participating in the road management.
- Detail resource demands in terms of staff, funds etc.
  - Per activity: how many working hours per staff grade, costs apart from staff etc.
  - Other demands, such as expertise from an external organisation, special equipment etc.

Sub-step 6.2 - Implement adaptation action plan

a. Objective

In this step the finalised action plan from step 6.1 is executed.

b. Output

The planned actions are implemented.

c. Data collection

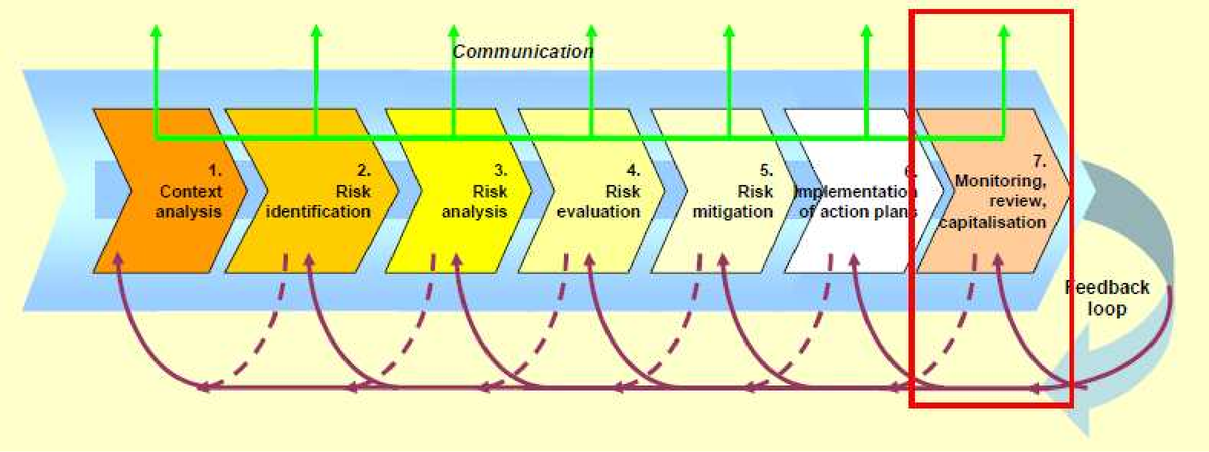
- Action plan
- Economic reports from the implementation team
- Progress reports from the implementation team
  - time
  - funds
  - changed needs
  - etc.
- Stakeholder reactions while implementing the plan

d. Method

Implementation of an action plan for climate change adaptation is similar to other development project implementation. It is beneficial for the road administrator to use the same routines as in other development projects.

Implementation of an action plan is an operational step: the approved action plan is implemented by roads managers on each appropriate level.
A checklist could be used to follow the process, including questions such as: Is the funding in place? Are all stakeholders participating?

Step 7 - MONITORING, REVIEW & CAPITALISATION



Since risk management is a learning process this step aims to monitor and review the implemented actions and to capitalise the knowledge gained within climatic events and implementation of action plans. If conditions change, re-planning starts within this step.

2. Proposed sub-steps

7.1 Regular monitoring and review

7.2 Re-plan in case of new data or a delay in implementation

7.3 Capitalisation of return of experience on both climatic events and progress of implementation

Sub-step 7.1 - Regular monitoring and review

a. Objective	This is an ongoing process involving regular checking or surveillance of both the risk management process and of the implemented adaptation measures. The main purposes are to ensure that the risk management process is correct, that the implemented action has the intended effect and that changes in risk are being identified and addressed.
b. Output	Monitoring and review of reports will act as feedback to earlier steps in the method. Information on emerging or changing risks will act work as input in step 7.2.
c. Data collection	Monitoring indicators are identified in the action plan (steps 5.4 and 6.1); these are monitored continuously or periodically.
d. Method	Both monitoring and review should be regular activities in the risk management process. These can be periodic, involving regular checking or surveillance, or ad hoc, responding to a certain situation.

Responsibilities for monitoring and review should be clearly defined.
All aspects of the road administrator's risk management process should be monitored and reviewed. The possibilities for monitoring and review are, according to ISO 31000:

- ensuring that controls are effective and efficient in both design and operation;
- obtaining further information to improve risk assessment;
- analysing and learning lessons from events (including near-misses), changes, trends, successes and failures;
- detecting changes in the external and internal context, including changes in risk criteria and the risk itself, which can require revision of risk treatment and priorities; and
- identifying emerging risks.

Monitoring indicators identified in the adaption action plan, steps 5.4 and 6.1, are examined and reviewed. The residual risk from implemented adaptation actions documented in step 6.1 is subject to monitoring and review. If further mitigation is needed, re-planning will start in step 7.2.

Some ways to follow the risk management process are:

- Site manager (responsible for implementation) produces progress reports
- Person responsible for project finance produces financial reports
- Risk manager reviews progress and economic reports:
  - time
  - funds
  - resources
  - changed needs
- Physical controls:
  - Equipment, inventories and other assets are secured physically and counted periodically.
- Legal control:
  - Are laws, regulations, Road Authority's Code of Statutes being followed? If the scale of analysis is large, a legal department could handle this.

Monitoring at the structure level can be raised to a national level encompassing all structures of the same kind.

Sub-step 7.2 - Re-plan in case of new data or delay in implementation

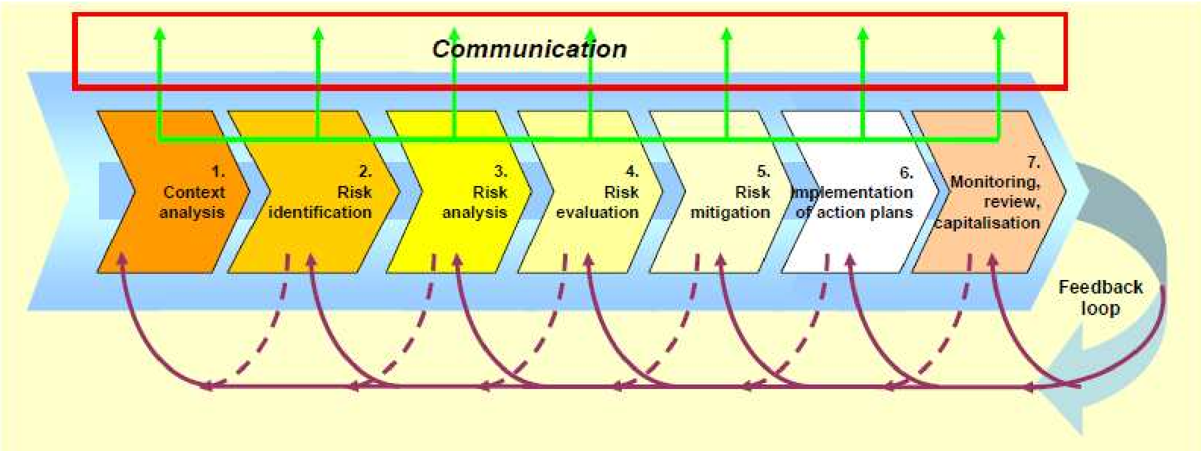
a. Objective	To have the flexibility to change, alter or make new plans as new data become available.
b. Output	A new risk management process related to new data.
c. Data collection	Continuously reviewing present and new data.
d. Method	The action taken in this step depends largely on what kind of problem has occurred. If an emerging or changed risk is discovered it may be necessary to

analyse this from step 2 onwards. If there is a problem with implementation the action plan from step 6.1 should be reviewed. If the problem persists the adaptation measures in step 5 can be analysed again. Another of the identified options may be easier to implement.

Sub-step 7.3 - Capitalisation on return of experience on both climatic events and progress of implementation

a. Objective	Results from monitoring should be used to update, correct and reorient the actions on various scales of analysis.
b. Output	A database of events and results of applied action plans; positive and negative experience.
c. Data collection	Monitoring activity, step 7.1.
d. Method	Define an appropriate database, Use the same organisation for capitalisation as for developing and implementing the action plan. Communicate or disseminate: seminars or other knowledge transfer actions Evaluation of the project

CONTINUOUS COMMUNICATION



Continuous communication throughout all the steps is required to ensure an effective risk management process. Information is needed at all levels on both internal and external subjects. Effective risk management requires that all persons involved have the right information at the right time. The communication, illustrated by the feedback loop and the communication arrows, covers the whole risk management process – from early initiation to the capitalisation on experience gained during the work.

Continuous communication

a. Objectives	The objectives of the communication activities are to ensure that the working procedures are understood and followed in the organisation and that correct information about the work is spread to all relevant external stakeholders in a way that enables them to understand the scope of the work and participate in a relevant way in the process.
b. Output	The communication process may be formal, in the form of a communication system, or informal as part of a risk management culture. In both cases the output should be a documented process. The output should also be a common risk language implemented in the organisation.
c. Data collection	The communication process should be followed and documented, either as part of a communication plan or as part of the normal communication procedure. Experience from the communication process should be used to evaluate if anything in the work or results could have been better with more or different communication, if the statements from the managers were appropriate or if there was “information overload”.

PART 3 – Case studies

Four case studies have been run. Each one is a specific case, highly dependent on the country features, climatic conditions under consideration, and contextual site factors. These case studies are not standard models but illustrations of possible use of the RIMAROCC method.

The case studies were developed to illustrate four different scales: structure (e.g. bridge or very short road section), section (e.g. a motorway section between two interchanges), network (e.g. > 1,000 km of interconnected roads), and territory (e.g. a road network and its associated territory). However, for practical reasons (including difficulties obtaining data), the territory level was represented by a relatively small area. It has been necessary to adapt the case studies to the actual situation encountered by each of the RIMAROCC partners.

The case studies are available as separate reports and include:

- The territory case study was conducted in The Netherlands by Deltares. The territory is relatively small but interesting because of specific contextual site factors. The territorial aspect of this case study mainly relies on the analysis of the consequences of land management decisions regarding the road network operation. Lessons from this case study are relevant on all study scales.

- The network case study concerns the French northern motorway network (more than 1,000 km long) and was conducted by EGIS. This network is connected to other road networks of lower importance. This example could be usable for roads owners who operate large but not dense networks in order to evaluate risks and define a response strategy.

- The section case study, conducted by NGI, deals with a mountainous section in Norway. Although the section length is relatively short (approx. 18 km), the study allowed several sub-sections to be identified according to climate risk level. The particularity of this section is the lack of an alternative solution for transport. This example is particularly relevant to a similar context.

- The structure case study produced by SGI relates to a single point in a road section under direct climate threat. It may be considered as an example of a “black spot”, already identified by the road authority, for which a thorough analysis of climate change impact is required.