CEDR Transnational Road Research Programme
Call 2012: Road owners adapting to climate change

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ROADAPT
Roads for today, adapted for tomorrow

Guidelines

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Executive summary

Infrastructures are the backbone of our society. Citizens, companies and governments have come to rely on and expect uninterrupted availability of the road network. Extreme weather is an important factor for the reliability of the road network. At the same time it is generally understood that the climate is changing and that this will have significant effects on the road infrastructure. Since road infrastructure is vital to society, climate change calls for timely adaptation. Immediately, questions arise how to deal with the large uncertainties involved in both the projections of future climate, how to assess their effects on the road infrastructure and related socio economic developments, and how to integrate adaptation into decision making and development of the road transport system.

The ROADAPT project was granted under the CEDR Call 2012 ‘Road owners adapting to climate change’ and answers to the call objective of prioritizing adaptation measures in order to maximize availability within reasonable costs. It adopts a risk based approach using the RIMAROCC framework (Risk Management for Roads in a Changing Climate) that was developed within ERA NET ROAD in 2010. The approach addresses cause, effect and consequence of weather related events to identify the top risks that require action with mitigating measures. These mitigating measures of road owners are not to be confused with climate change mitigation which aims at the reduction of climate change itself by for example minimizing greenhouse gas emissions. The mitigating measures of road owners and operators have to do with climate change adaptation.

ROADAPT has further developed the RIMAROCC framework into practical and useful methods for road owners and road operators. Output of the ROADAPT project is one ROADAPT-RIMAROCC integrating guideline containing different parts:
A. Guidelines on the use of climate data for the current and future climate
B. Guidelines on the application of a QuickScan on climate change risks for roads
C. Guidelines on how to perform a detailed vulnerability assessment
D. Guidelines on how to perform a socio economic impact assessment
E. Guidelines on how to select an adaptation strategy

1 Introduction

1.1 Purpose of the ROADAPT guidelines

Infrastructures are the backbone of our society. Citizens, companies and governments have come to rely on and expect uninterrupted availability of the road network. Extreme weather is an important factor for the reliability and safety of the road network. At the same time it is generally understood that the climate is changing and that this will have significant effects on the road infrastructure. Since road infrastructure is vital to society, climate change calls for timely adaptation.

Although there are considerable uncertainties involved in both the projections of future climate change and related socio economic developments and in estimations of the consequences of these changes in transportation requirements, there is a constant need for decisions and development of the road transport system. As stated in the CEDR 2012 Climate Change DoRN: *'Road authorities need to evaluate the effect of Climate Change on the road network and take remedial action concerning design, construction and maintenance of the road network.'*

The ROADAPT project is part of this CEDR Call. ROADAPT has an integral approach following the RIMAROCC (Risk Management for Roads in a Changing Climate) framework that was developed for ERA NET ROAD in 2010. ROADAPT aims at providing methodologies and tools enabling tailored and consistent climate data information, a good communication between climate researchers and road authorities, a preliminary and fast quickscan for estimating the climate change related risks for roads, a vulnerability assessment, a socioe conomic impact analysis and an action plan for adaptation with specific input from possible adaptation techniques related to geotechnics and drainage, pavements and traffic management.

Figure 1.1 Flooding of road

1.2 Structure of the ROADAPT guidelines

Output of the ROADAPT project are guidelines that address all these topics. In the main guidelines an overview of all topics is provided. In five following parts the specific topics are addressed in detail. These five parts are:

A. Guidelines on the use of climate data for the current and future climate
B. Guidelines on the application of a QuickScan on climate change risks for roads
C. Guidelines on how to perform a detailed vulnerability assessment
D. Guidelines on how to perform a socio economic impact assessment
E. Guidelines on how to select an adaptation strategy

The underlying guideline is the main guideline in which all parts are integrated into one framework, and linked to RIMAROCC.

1.3 How to use the ROADAPT guidelines

Figure 1.2: Susceptibility to wildfires

All ROADAPT guidelines can be used individually, but should be seen as interdependent and fitting within the broader RIMAROCC framework. The RIMAROCC framework itself namely provides all necessary steps to be taken to adapt to climate change in an explicitly risk based way. It also provides uniformity with clear definitions. Only on specific points the ROADAPT guidelines use different definitions; if this is the case it is clearly written in the specific guidelines.

The guidelines are primarily written for National Road Authorities to gain sight in the steps to take for a climate change risk assessment on roads. However, the guidelines will be beneficial for a broad range of professionals, including road engineers (geotechnics, hydraulics, pavements, traffic management), asset managers, climate change adaptation professionals, innovation managers and project managers. Although the guidelines focus on roads, the topics and methodology are applicable for other infrastructural assets like railways or electricity networks as well.

2 Climate change effects on roads

2.1 Extreme weather effects on roads

The ROADAPT guidelines deal with the way road authorities could adapt to the effects of climate change. It is the extreme weather that affects the road infrastructure and the level of service offered to their users, and climate change may result in changed frequencies of extreme weather. Already from the time that the first roads were constructed, the weather influences the performance of the road infrastructure. Therefore, it is important to have an overview of how the weather can threaten road infrastructure and/or road users. Already in many publications such an overview is presented (for example RIMAROCC table 1 (Bles et al., 2010), and appendix B of the vulnerability assessment framework (FHWA, 2012), but no uniform outline has been found in which 'all possible' threats are explicitly coupled to climate parameters and supplemented with extra information regarding vulnerability and impact. Within the ROADAPT guidelines such an overview has been developed as a starting point for all risk and vulnerability studies to the effects of extreme weather on roads. This overview can be used in studies both for todays and future situations, and is given in Annex I of this guideline.

Figure 2.1 Loss of pavement integrity

Figure 2.4 shows the concept of the overview in Annex I. At first the **threats** are described. They are grouped into 12 main threats and subdivided into 40 sub-threats. The list of threats is intended to provide a complete overview, but the authors realize that probably more threats can be identified. The threats can either originate outside the road asset (for example in the case of a flooding or landslide) but can also originate within the road asset (for example wind damage to lightning fixtures or a decrease in driving ability due to splash and spray). Many of the threats are described in more detail in Part E (selection of an adaptation strategy) of the guideline.

For each sub-threat information can be found regarding the weather that accompanies or initiates the threats. This so called **climate information** is described by the climate variable, the unit that is normally used and the time horizon. More information regarding the climate information can be found in Part A of the guidelines (use of climate data). Here also information can be found regarding how to gain more insight in the climate parameters, both for the current and the future climate.

Figure 2.2 Rock fall

Vulnerability factors are identified for all sub threats. These factors indicate to what extend the road and/or their users are vulnerable to the threats. Contextual site factors provide information about the area surrounding the road. Infrastructure intrinsic factors provide information about the roads/assets themselves. The list of factors in annex I provides the factors that are recommended to be used in the quickscan guidelines (Part B). Part C (detailed vulnerability assessment) continues to build on this list and provides a more extensive and detailed overview of vulnerability factors plus recommendations on how to use the factors and gather the necessary data.

Figure 2.3 Loss of driving ability

The final part of the table provides information on the **impact** of a threat if it occurs. Both estimates of the duration and warning time horizon are provided. This information is worthwhile to use in the quickscan (Part B).

It should be mentioned that all information in the threats table is indicative and should be used accordingly. The information provides a good starting point and should be made specific when used in a risk assessment.

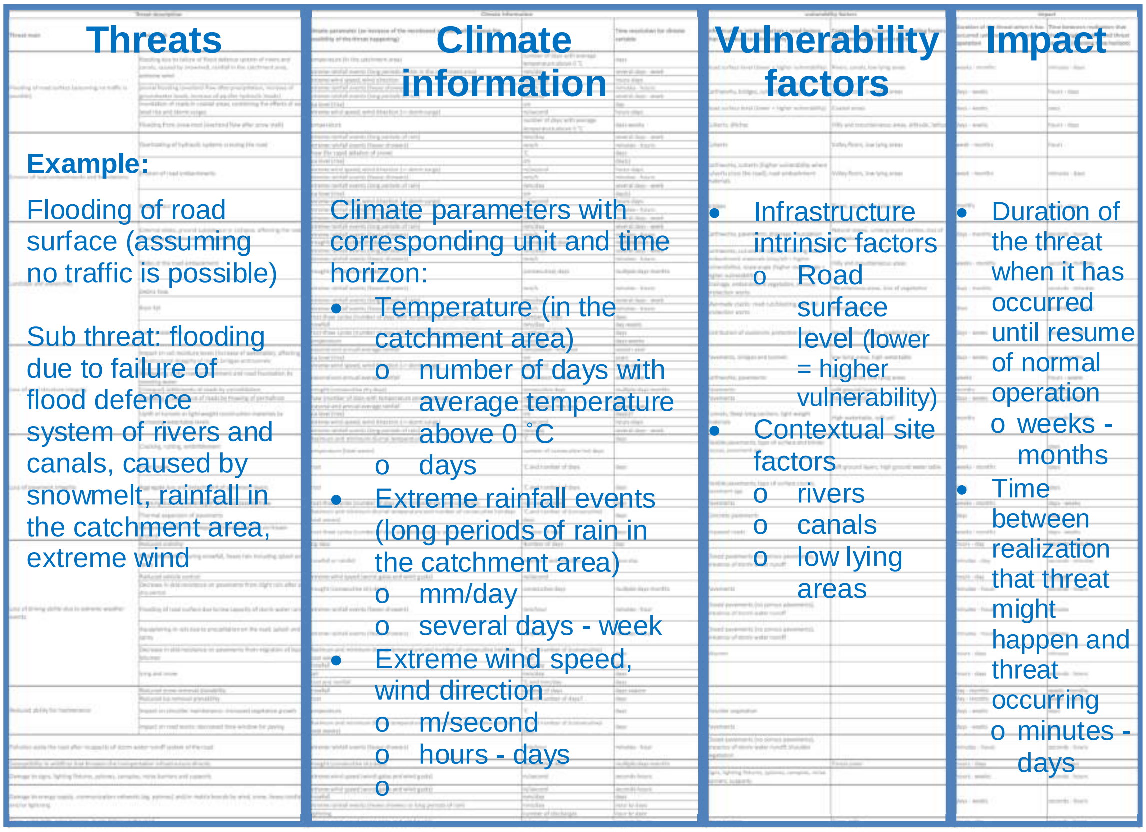

Figure 2.4: Conceptual figure of the table in Annex I. The table shows threats for roads that are related to weather events of which frequency and/or intensity might change due to climate change.

2.2 The world's climate is changing

In chapter 2.1, the effects of weather extremes on road infrastructure and its functioning were introduced. The weather is variable from day to day, year to year and from decade to decade. To deal with extremes, knowledge about the current climate (averages and the return times of extremes) should be achieved. The climate changed already and it will change further in the future, but it is not known exactly how much. To deal with extremes in the future also knowledge about this variation and uncertainty is needed.

It is generally understood that the climate is changing. Average global temperature has increased with 0,85 °C (0,65 to 1,06) over the period 1880–2012 (IPCC, 2013). Figure 2.2 shows the observed (grey) and predicted (red and blue) global average surface temperature and Figure 2.3 shows the observed trends in average temperature over the period 1950-2007 for the four seasons as a factor of the increase in global temperature. For a considerable part of Europe the temperature has increased 1.5 to more than 2.0 times faster than the global average over this period.

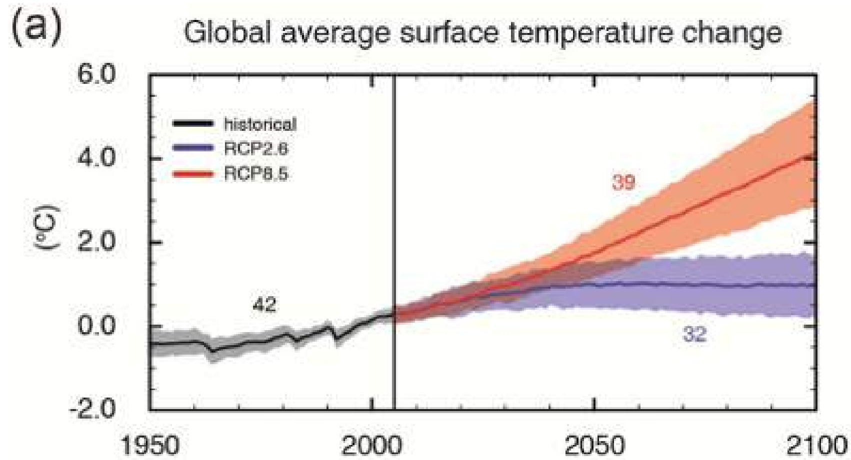

Figure 2.2: Multi-model simulated time series from 1950 to 2100 for change in global annual mean surface temperature relative to 1986–2005. Shading: measure of uncertainty for RCP2.6 (blue; low emission of GHG), RCP8.5 (red; high emission of GHG) and modeled historical evolution (grey). Numbers: number of global climate models used (IPCC, 2013).

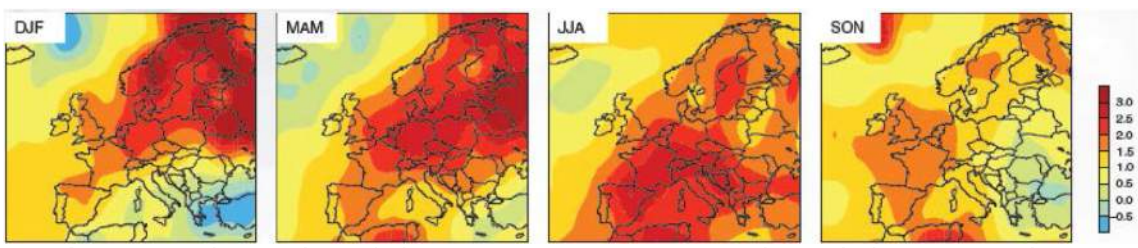

Figure 2.3 Observed trends in average temperature over the period 1950-2007 (local temperature increase per degree global temperature increase) in the meteorological seasons: December-February (DJF), March-May (MAM), June-August (JJA) and September-November (SON). Data: CRU/Hadley Centre. (Van Oldenborgh et al., 2009).

Other climate variables change as well. Both intensity and frequency can change and it is very location specific what the change will be. Part A of the ROADAPT guidelines provides information on how to estimate the possible changes and which data, information and tools exist to help in this respect.

Climate parameter	Projected change for time horizon 2080-2100 compared to reference 1986-2005 (+=increase, -=decrease, 0=no change ?=not clear)			Certainty of projection
Precipitation/drought				
Average amount of rainfall per year(mm/y)	North	+		Likely
	South	-		
Average amount of rainfall per season (mm/season)		Dec.-Febr.	June-August	Likely
	North	+	+/-	
	South	?	-	
Maximum rainfall intensity in heavy showers (mm/h)	+			Very likely over most mid-latitude land
Extreme rainfall events (long periods with rain, mm/d)	+			Very likely over most mid-latitude land
Average snowfall (cm/y or cm/season)	-/?			Likely, due to increase of temperature[A]
Heavy snowfall in 24 h (cm/d or cm/h)	-/?			Likely, due to increase of temperature[A]
Drought (consecutive dry days)	North	+/0		Likely
	South	+		
Sea level				
Sea level rise (cm/y)	+			Very likely: 2050-2100
Temperature				
Average temperature (˚C)	+			Virtually certain
Heat waves (number)	+			Virtually certain
Hot days (number of consecutive days with temperature above 30 ˚C)	+			Virtually certain
Maximum temperature (highest temperature per year; ˚C)	+			Virtually certain
Diurnal temperature range (˚C)	?			Not known
Number of frost days (Min. temperature <0 ˚C)	-			Virtually certain
Frost-thaw cycle (number of days with T=0 crossings)	-[B]			Virtually certain
Wind				
Max. daily wind speed (storm surges; m/s)	?			
Max wind speed (wind gusts; m/s)	+			Often related with heavy rainfall in current climate
Wind direction	?			Not known
Other climate variables				
Days with fog (number of days/y)	-/0			Depends especially on air quality
Lightning (number of days/y)	?			Often related to heavy rainfall in current climate

Table 2.1 (This is table 2.3 of Part A of the ROADAPT guidelines) Summary of present knowledge regarding the future change of critical climate parameters for the transport sector: **projected changes for Europe** (IPCC, 2013)

A. In the northern part of Europe precipitation is likely to increase. This could also result in more heavy snowfall, however at the same time temperatures increase. With higher temperatures more precipitation occurs in the form of rainfall and less as snow;

B. On the long term the number of days with frost-thaw will decrease everywhere, however in some regions it may also increase first. This depends on whether the winter temperature is close to 0 ˚C in the current climate (than decrease in the coming decades) or whether it is far below 0 ˚C (than first an increase may occur).

2.3 Effects of climate change for roads

In order to estimate the effects of climate change for roads it is necessary to compare the list of possible threats (annex I) with the current vulnerability and possible changing future vulnerability. In the table in annex I the climate variables are presented. From climate research it is known how these parameters have changed in the past decades and could change in the future.

Figure 2.7 Slide of road embankment

Part A of the ROADAPT guidelines shows all available information in this respect plus information how to use the information. For local applications usually more detailed climate change information is necessary. Part A also provides many recommendations on how to gain insight in this information (also see chapter 4.1 with a summary of the contents of part A of the guidelines). Table 2.1 (this is a copy of table 2.3 of part A of the ROADAPT guidelines) on the next page shows the projected changes in Europe for the relevant climate parameters.

3 Risk management for roads in a changing climate

3.1 Road owners demands

There is a constant need for decisions and development of the road transport system and it is understood that a change in climatic conditions may? have significant effects. As stated in the CEDR 2012 Climate Change DoRN: *"Road authorities need to evaluate the effect of Climate Change on the road network and take remedial action concerning design, construction and maintenance of the road network. The prioritization of measures in order to maximize availability with reasonable costs is one of the most important tasks of the road owners".*

Basically the main questions of road owners and operators are

- Is climate change really affecting roads?
  This question probably is already answered by most of the road operators and owners in Europe. It is generally accepted that climate change is affecting road infrastructure or the level of service, one way or another.
- How and where will climate change affect roads?
  Underlying question here is about the vulnerability to extreme weather conditions. For road owners and operators it is important to know which unwanted events might happen in the future due to climate change, but also today the weather poses a risk to road transport.
- How likely is it to happen? And if it does happen, what are the consequences?
  When knowing which unwanted events might occur on a road network, it is important to know the likelihood and consequences in order to gain insight in the risk profile. Already in the current climate conditions large uncertainties are present that make it difficult to estimate the probabilities and consequences of unwanted events. When looking into the future the uncertainties will even increase. The uncertainties make a risk based approach a worthwhile approach.
- What should be done to mitigate the risks and when?
  If unwanted events are present with an unacceptable risk profile, mitigation actions need to be taken. Road owners and operators need a methodology that assists in the prioritization of measures.

Given the high uncertainties of climate change, there is no straightforward answer to those questions that is valid in all circumstances. On top of this, uncertainties also exist in changing demands for road infrastructure, originating in socio economic developments and changing technologies. In situations with high uncertainties a risk management approach is generally accepted as a way to keep in control over the situation or, in relation with this guideline, over the road infrastructure.

3.2 The RIMAROCC framework

In the ERA NET ROAD call (2008) “Road owners getting to grips with climate change” the topic of climate change and the way road authorities should deal with it was raised. RIMAROCC (Bles et al., 2010) was one of the results of that call, providing a risk management based framework for decision support for road owners dealing with climate change. Seven general steps help road owners and operators in identifying, analyzing, prioritizing, evaluating and mitigating climate change risks.

The RIMAROCC framework is adopted as being the risk management framework within the ROADAPT guidelines. Reasons are that it is a basic risk management framework that is in line with the ISO 30001 on risk management and the fact that road owners in Europe are already familiar with RIMAROCC. Also, the RIMAROCC framework is a method that exists of different ‘building blocks’ that can efficiently be updated or changed in a specific situation. This allows the ROADAPT guidelines to be plugged into the RIMAROCC framework, providing a ROADAPT-RIMAROCC integrated approach.

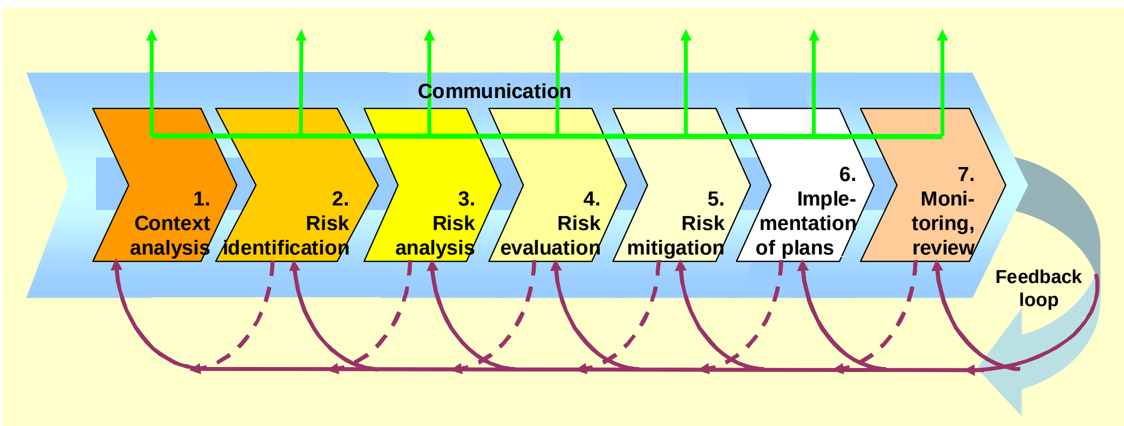

Figure 3.1: The RIMAROCC framework

The RIMAROCC framework consists of seven key steps and 22 sub-steps. In table 3.1 the sub steps are listed. For a detailed description of the different steps a reference is made to the RIMAROCC guidebook (Bles et al., 2010)

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 impact of risk
	3.3	Evaluate occurrences
	3.4	Provide a risk overview
4. risk evaluation	4.1	Risk prioritisation
	4.2	Compare climate risk to other kinds of risk
	4.3	Determining which risks are acceptable
5. risk mitigation	5.1	Identify options
	5.2	Appraise options
	5.3	Negotiating with funding agencies
	5.4	Present action plans
6. implementation of action plans	6.1	Develop and action plan on each level of responsibility
	6.2	Implement adaptation plan
7. monitor, re-plan and capitalise	7.1	Regular monitoring and review
	7.2.	Re-plan in case of new data or delay in implementation
	7.3	Capitalisation on return of experience on both climatic events and progress of implementation

Table 3.1: Steps of the RIMAROCC framework

3.3 The ROADAPT structure

The RIMAROCC framework provides all steps that come along when performing a climate change risk assessment for roads in a changing climate. However, the number of steps can be perceived as being complicated and difficult to execute. Within the ROADAPT guidelines therefore another scheme is introduced that visualizes all basic aspects that need to be considered in a climate change risk assessment. These aspects can be connected to the RIMAROCC steps; note table 3.2 and the matching colors in figures 3.1 and 3.2.

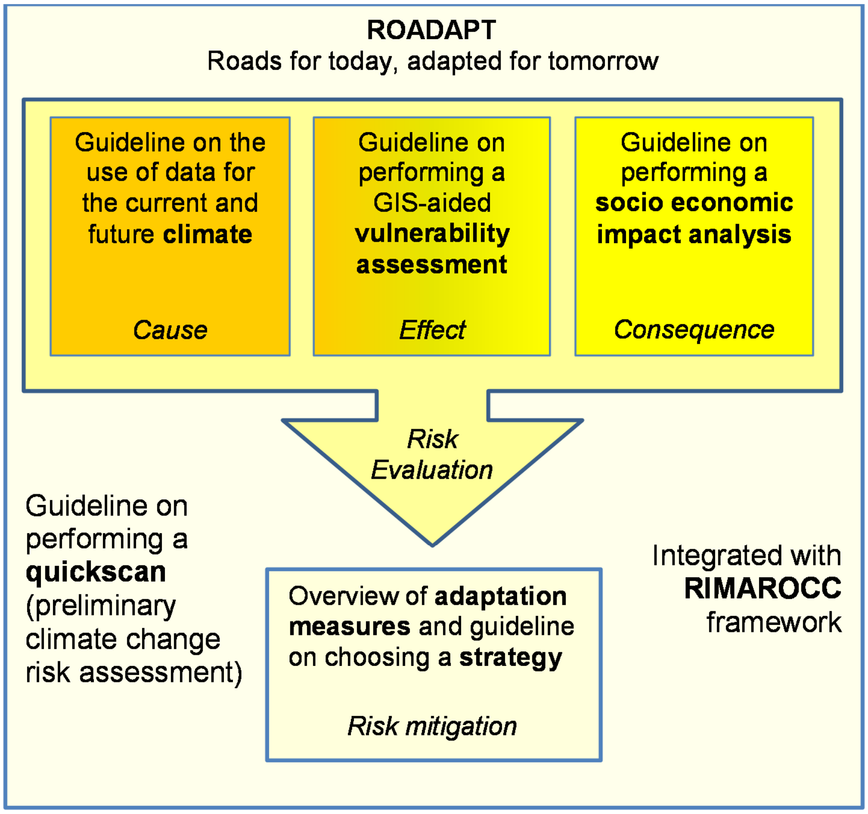

Figure 3.2: Structure of the ROADAPT guidelines

Basically, when performing a risk assessment one needs to know something about the unwanted events, their likelihood and consequences.

- In a climate change context, the **cause** of threats (unwanted events) lies within the changing climate. Climate change may be the cause of new threats or a change in the frequency of occurrence or increased intensity of threats to the roads.
- In order to know the **effects** it is necessary to know the vulnerability of the road or road network. By doing a vulnerability assessment one gains insight in locations on the road or road network that are susceptible to a certain threat and to what extent.
- The cause and effect together determine the **probability** of a threat on a certain location. The exact determination of the probability often is difficult to assess given the high uncertainties both in the climate change scenarios and the vulnerability assessment.
- By performing a socio economic impact analysis one gains insight in the **consequences** of the threat if it happens on a certain vulnerable location.
- All ingredients for a risk profile are assembled when knowing the cause, effect (together providing the probability) and consequences. This makes it possible to do a **risk evaluation**. In the evaluation the level of acceptable risk is important to define.
- Only the threats above a certain unacceptable risk level, need to be **mitigated**. By applying adaptation measures within a certain adaptation strategy, the risk profile of the threats will decrease and should reach the acceptable risk level.

For all the blocks in figure 3.2, guidelines are developed in the ROADAPT project. These specific guidelines are available as five different parts of the underlying ROADAPT guidelines. An additional guideline deals with a **quick scan** approach to perform a climate change risk assessment resulting in an action plan for adaptation. This quick scan method incorporates all blocks that are shown and described above, but in a shorter version.

RIMAROCC		ROADAPT				
		Part A	Part B	Part C	Part D	Part E
Key steps	Sub steps	Guideline on the use of data for the current and future climate	Guideline on performing a quick scan	Guideline on performing a GIS-aided vulnerability assessment	Guideline on performing a socio economic impact assessment	Overview of adaptation measures and guideline on choosing a strategy
1. context analysis	1.1 general context					
	1.2 specific context					
	1.3 risk criteria					
2. risk identification	2.1 identify risk sources					
	2.2 identify vulnerabilities					
	2.3 identify consequences					
3. risk analysis	3.1 risk scenarios					
	3.2 impact of risk					
	3.3 evaluate occurrences					
	3.4 risk overview					
4. risk evaluation	4.1 risk prioritisation					
	4.2 compare with other risk					
	4.3 determine acceptability					
5. risk mitigation	5.1 identify options					
	5.2 appraise options					

Table 3.2: integration of ROADAPT guidelines and RIMAROCC framework
orange: included in the different ROADAPT parts; **yellow**: strong links, but not included

Some remarks on the ROADAPT structure are made:

- Based on the steps 1 to 4 in the RIMAROCC framework (context analysis, risk identification, risk prioritization and risk evaluation) a simplified method is developed in order to gain insight in the vulnerable spots of transnational highway sections. Performing the so called quickscan (Bles et al., 2014) provides a founded first impression on the risks for roads related to climate change.
- The quickscan method results in an action plan for adaptation. The action plan includes global adaptation strategies for high risk threats that have appeared from the risk assessment. Also Part E of the guidelines helps in selecting a proper adaptation strategy. RIMAROCC steps 5.3 to 7.3 can be used to further implement the measures.
- After performing a quickscan, two main actions often develop from the action plan. These are to perform a specific and detailed vulnerability assessment and/or socio economic impact assessment for the high risk threats. The quickscan thus assists in deciding where to invest in more detailed analyses, both from a location perspective and a threat perspective.

- Within the ROADAPT guidelines, vulnerability only includes the effects on the road and not the effects of a degraded road. This means for example that an unimportant road without users still can be vulnerable. Poor maintenance can result in a higher vulnerability. By using this definition there is a clear distinction between the socio economic impacts and the vulnerability assessment, or in other words between the effect and consequences of an unwanted event. This way it becomes easier to perform the assessments, since different disciplines are involved. The ROADAPT-RIMAROCC context ensures integration between the vulnerability assessment and socio economic impact assessment.
- The ROADAPT guidelines generally recommend to use the following criteria for assessing the consequences: availability, safety, surroundings, direct technical costs, reputation and environment. Especially in part B (quickscan), part D (socio economic impact assessment) and part E (adaptation) specific recommendations are made on how to use these criteria.

4 The ROADAPT guidelines

The following chapters provide a summary of the different parts of ROADAPT that are introduced in chapter 3.3.

4.1 Part A – Guidelines on the use of data for the current and future climate for road infrastructure

In order to know and understand the effects of climate change for roads, it is of utmost importance to have proper insight in the current climate and climate change itself. This is the working field of climatologists. They have to provide tailored information to the end users. This implies to make interpretations and suggestions for use in a setting of already large variability of the current climate and even higher uncertainties when considering future climate.
Climatologists all over the world may use different data, methods and tools to provide this information to (end) users. As a consequence neighbouring countries may use different climate (change) information, leading to discrepancies for cross border projects. At risk assessments on roads close to borders or especially in border transcending assessments this will lead to incompatible results. ROADAPT therefore aims to provide methodologies and tools enabling tailored and consistent climate data information. Part A of the ROADAPT guidelines deals with this topic (Bessembinder, 2014a).

In the ROADAPT-RIMAROCC approach in step 2 the risks and threats are identified. The table in Annex I (relevant threats for road infrastructure and related climate parameters) helps in collecting relevant climate data for studies on the possible vulnerability to climate change of road infrastructure. Especially in step 3 of the approach (risk analysis) climate data are used to determine the risks in the current and future climate. Figure 4.1 shows the steps in the use of climate data:

Step 1: Determine threats and related climate variables, the reference period and the relevant time horizon;
Step 2: Collect data on the current and future climate for these climate variables and check the quality and usefulness of the data;
Step 3: Determine which projections/climate scenarios to use with the help of the suggestions in the guidelines on the use of climate data;
Step 4: Perform additional processing, if needed, to get the data with which the risk analysis can be performed.

The steps can be used for both a quick scan and a detailed risk assessment. The guidelines provide recommendations on how to perform the steps in both cases. Generally, NRA's will not take themselves all the steps of figure 4.1. Collection and processing of climate data will mostly be outsourced to researchers or consultancies. The Guidelines on the use of climate data give information on all aspects that need to be taken into account when working with climate data. The guidelines can be used by NRA's to gain understanding of the work of the researchers and consultancies that work for them. This will improve communication between them as well.

The most important questions that are answered in the guidelines are:

- Which datasets on the current climate are available?
- Which period to use as a reference to describe the current climate and natural variability?
- How to check the quality and usefulness of climate data?
- How to get consistent climate data with similar quality for all regions of Europe?
- Which climate model data and climate scenarios are available?

- Which time horizon to use in vulnerability studies?
- How to determine climate change from climate model data?
- Which downscaling methods are available and which one to use?
- Which methods are available to generate time series for the future from climate model information?

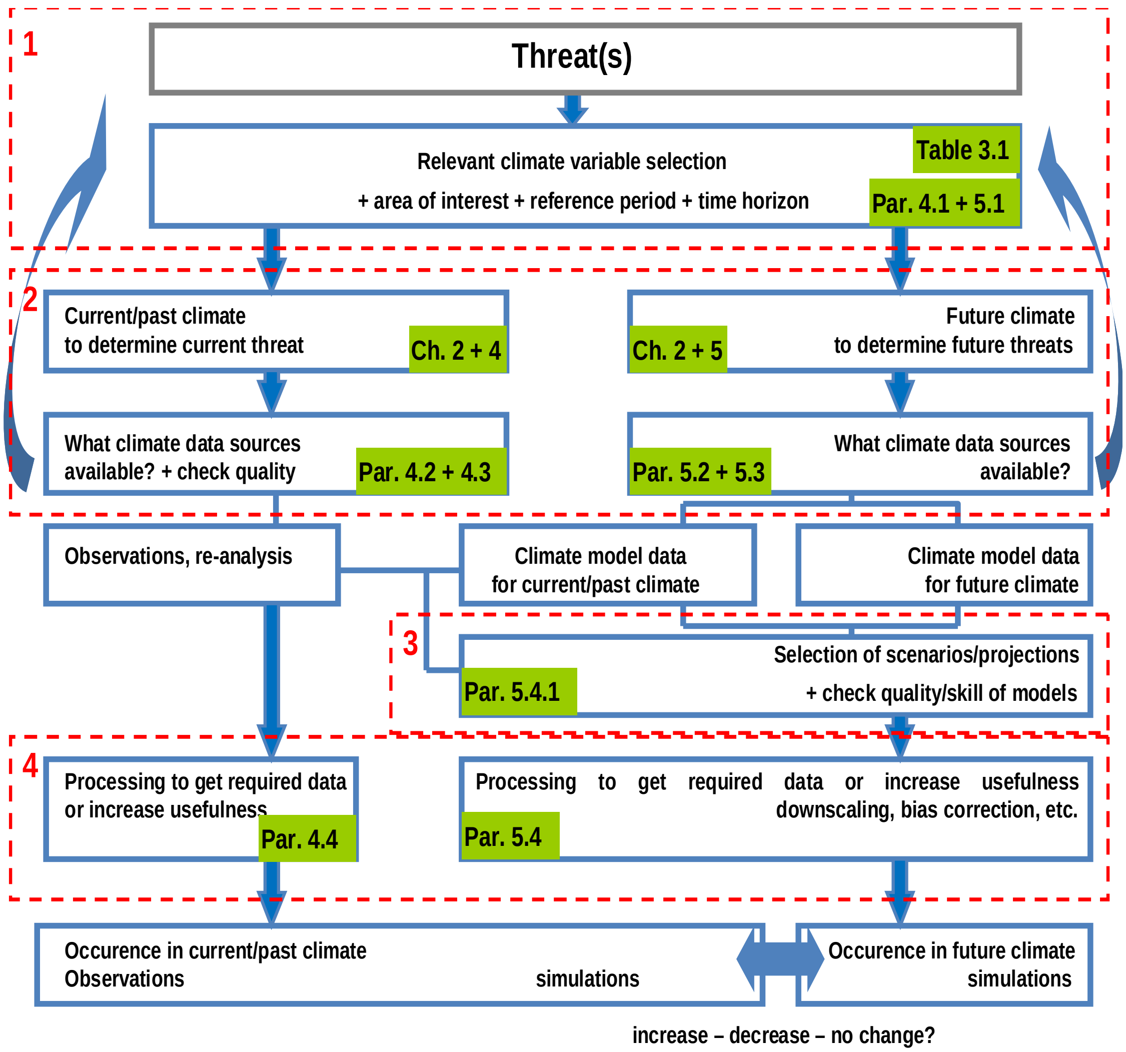

Figure 4.1 Schematised steps in the use of climate data for climate change impact studies (red boxes refer to the steps in the text; paragraph and table numbers refer to the 'Guidelines on the use of climate data'.

4.2 Part B – Performing a quickscan on risk due to climate change

Based on the steps 1 to 4 in the RIMAROCC framework (context analysis, risk identification, risk prioritization and risk evaluation) a simplified method is developed in order to gain insight in the vulnerable spots of transnational highway sections. Performing the so called quickscan (Bles et al., 2014) provides a founded first impression on the risks for roads related to climate change, including an action plan for adaptation.

The quickscan method is applicable in all European countries and therefore probably also all over the world. This posed challenges to the development of the method since the number of possible threats is very high (see chapter 2) and the fact that road design and maintenance procedures are different in all (and within) countries as well as road surroundings and characteristics.

Quickscan phases

- Workshop 1, **determine consequences**
  Participants: understanding of consequences of undesired events on roads
- Workshop 2, **determine probabilities, top risks and locations**
  Participants: technical know-how of threats
- Workshop 3, **determine action plan for adaptation**
  Participants: combination of workshop 1 and 2

Each workshop has a duration of approximately half a day.

The quickscan method uses all existing data, knowledge and experiences for the studied road network in a structured and explicitly risk based approach. Workshops are the core of the quickscan method. The quickscan starts covering all possible threats and continuously narrows the focus with an ongoing process.
The stakeholders are brought together in around-the-table-sessions and are asked to provide input regarding the consequences and probabilities. This is being done in a semi quantitative risk analysis using stakeholder defined criteria, both for the probability and consequence. It is recommended to use the following criteria to score the consequences since these parameters are often used by NRA's in their asset management process: availability, safety, surroundings, direct technical costs, reputation and environment. Locations are only identified for threats that are evaluated as having a high risk profile (high combination of probability and consequence, fig. 4.2).

After the risk evaluation, the threats are identified that have an unacceptable risk level. For those threats an action plan for adaptation can be developed. Since the quickscan mainly uses qualitative information in workshop settings, many actions probably will be in the field of extra research by performing detailed vulnerability analyses or socio economic impact assessments. The RIMAROCC steps are then followed again but more in depth (see figure 4.3. However also direction can be provided to the type of adaptation measures by comparing the maintenance frequency or lifespan of the threatened part of the road with the expected time in which climate change becomes relevant. By doing so, adaptation action can be balanced with regular maintenance.

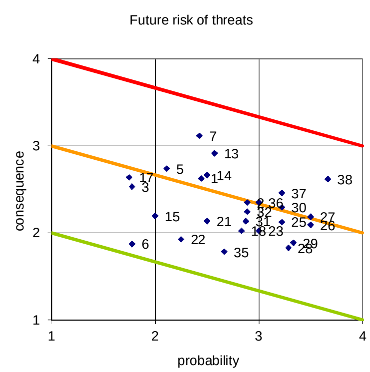

Figure 4.2: risk evaluation using a risk matrix

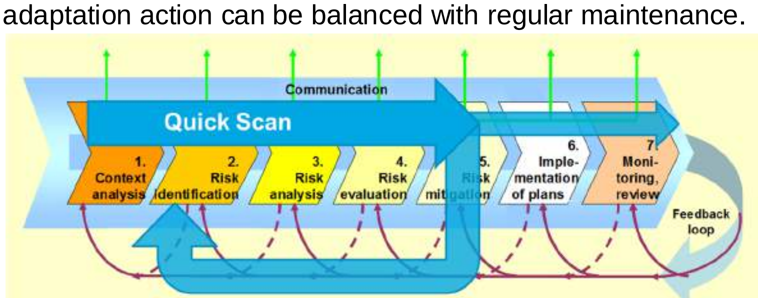

Figure 4.3: The iterative character of risk management, visualized by the feedback loop in the RIMAROCC framework, after performing the quick scan

Figure 4.4: Risk mapping using the quickscan methodology

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4.3 Part C – Performing a GIS-aided vulnerability assessment for roads

The objective of Part C (Falemo et al., 2014) is to describe efficient existing tools for assessing vulnerabilities within TEN-T Network roads. In addition, a new comprehensive vulnerability assessment methodology is suggested, based on and compatible with the RIMAROCC method. The vulnerability maps created in the process can be combined with detailed climate change projections. Using the tools and methods described, users can assess vulnerability to all climate change-related threats within the TEN-T road network.

Using existing GIS-aided vulnerability assessment methods
The approach has been to use existing detailed GIS-aided vulnerability assessment methods as far as possible. Vulnerability to different threats is assessed using different methods and what is provided is really a guide to identify and select the appropriate vulnerability assessment method for the threat that needs to be analysed, and a guide to transnational GIS data sources. Vulnerability will be assessed for each threat in a geographic area using a simple three-step method.

ROADAPT method for Vulnerability Assessment (ROADAPT VA)
The results from the inventory of existing methods show that GIS-aided vulnerability assessment methods are missing for a large number of the climate change-related threats that the TEN-T network is facing. In response, a draft version of a new method, ROADAPT VA, has been outlined in this project. ROADAPT VA calculates a vulnerability index for a selected threat independently of probability and consequence analyses. Therefore this guideline is connected to ROADAPT guidelines part A and part D primarily through RIMAROCC step 3 *Risk Analysis*. ROADAPT VA can be used as an integrated part of RIMAROCC as a replacement for the following RIMAROCC steps:

- Sub-step 1.3 - Establish risk criteria and indicators adapted to each particular scale of analysis (vulnerability indicator identification only)
- Sub-step 2.1 Identify risk sources (contextual site factor identification only)
- Sub-step 2.2 Identify vulnerabilities

ROADAPT VA can also be used stand-alone for vulnerability mapping, however to assess the risk for a certain threat, probabilities and consequences must also be assessed. The output of ROADAPT VA is a list of classified vulnerability factors (contextual site factors and infrastructure-intrinsic factors), vulnerability score maps for each vulnerability factor, and a resulting vulnerability index map. ROADAPT VA is connected to ROADAPT part E through the expected effects of the selected adaptation strategies. There is a range of adaptation measures that are aimed at reducing vulnerability to threats. The expected effects can be visualized by updating the vulnerability index maps accordingly.

Step 1: Defining vulnerability factors
- 1.1 – Identify relevant vulnerability factors

Step 2: Data collection
- 2.1 – GIS data inventory and collection
- 2.2 – Completing missing GIS datasets

Step 3: GIS analysis
- 3.1 – Reclassifying input data into vulnerability factor scores
- 3.2 – Raster calculations
- 3.3 – Documentation

Figure 4.5: steps of ROADAPT VA

4.4 Part D – Performing a socio economic impacts analysis

The part D of the overall ROADAPT guidelines (Chevreuil et al., 2014) is related to the socio economic impact assessment in the RIMAROCC-ROADAPT framework. The impact assessment addresses traffic events caused by adverse weather conditions.

The indicator for socio economic impact

The threats will either affect the infrastructure (eg. deterioration of the pavement or landslides) or directly the traffic conditions (e.g. heavy rain or snow) and therefore both cases reduce the road level of service. For road users, the level of service is generally characterised by three main criteria: safety, efficiency and comfort. It is rather impossible to measure the degradation of safety, as safety is dependent on many factors and the most important being the user's behaviour. Comfort is also more a qualitative criteria. The predominant criterion in socio economic assessment in transport is efficiency which is measured by the costs of travelling from A to B. Cost includes energy consumption, vehicle amortization, taxes and tolls together with the value of time spent per passenger or goods that are transported. In general, other externalities like emissions and noise need to be considered and monetised as well.

There is a high level of uncertainty on the occurrence and real impact of weather events. Therefore, the travel time is considered to be the key indicator for the impact assessment. When translating the travel time in monetary value, the other indicators are anyway of second order.

Selection of threats to be assessed

Selection of the threats is based on the outputs of part B and/or C of the guidelines. It is the choice of the NRA or road network operator to decide what threats deserve to be assessed. Usually, the threats that are evaluated as being of high risk need to be assessed. Based on the vulnerability assessment it can be decided which locations of disruption of the road need to be taken into account. Also, the more frequent ones and/or those generating the most severe impact on traffic preferably are assessed. Combinations of threats can be considered by developing a scenario approach, the results not being an addition of the impact of individual events, but a combination of impacts.

Once this choice is made, it is necessary to characterise the potential consequences on the level of service, namely:

- Reduction of speed
- Held up traffic due to for example lane restrictions
- Access restriction with rerouting or storage of vehicles (eg. Heavy Good Vehicles). In this case the degradation of level of service is not directly due to weather events on the assets but to the measures that are taken to minimize the impact of the event to the asset (lower axle weights preventing damage to the pavement).

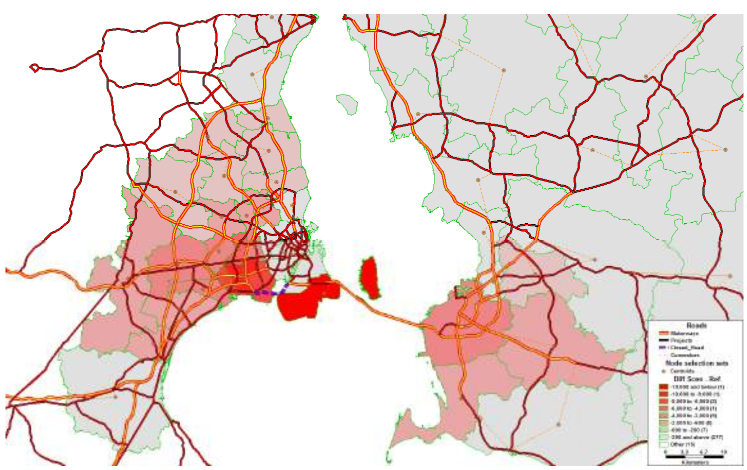

Figure 4.6: example of impact of an event on the economic system

The modeling process
For a simple network and limited event, a rough estimation of the time lost by all network users can be made and translated in monetary value. The HEATCO project (Harmonised European Approaches for Transport Costing and Project Assessment) recommends harmonised values to be used in Europe. But in general, the consequences of a major weather event will impact a large part of the network. It is then required to use a traffic model. A typology of traffic models is presented in the guidelines and recommendations for use are made.

Depending on the shareholder's point of view the socio economic impact will be evaluated at different levels. The guidelines propose three levels of analysis:

- The network level: only the impact on travel time of road users network is estimated
- The territory level (territory which is irrigated by the network): impact on the travel time on the various liaisons that are ensured by the network is estimated
- A wider perimeter which we have named the economic system as a whole and which extends the analysis not only in terms of geography but also in terms of economic activities that can be impacted.

Examples of results illustrate the application of these models in different cases. In order to better visualise the impacts, it is recommended to use a GIS model in combination with the traffic model software.

4.5 Part E – Selection of adaptation measures and strategies for mitigation

Part E of the ROADAPT guidelines (Blied et al., 2014) presents an overview of adaptation measures and helps in selecting an adaptation strategy. This part of the guidelines provides practical support in RIMAROCC step 5: Risk Mitigation. This assumes that the previous RIMAROCC steps have been performed or that the QuickScan approach and the ROADAPT Vulnerability Assessment have been conducted (parts B and C of the guideline), and that relevant climate change threats, asset types under threat and vulnerable locations are known.

Part E of the guideline deals with the following climate change threats: flooding of the road surface (assuming no traffic is possible), erosion of road embankments and foundations, landslips and avalanches, loss of road structure integrity, loss of pavement integrity, loss of driving ability due to extreme weather events, reduced ability for maintenance.

ROADAPT has developed a 10 step approach to answer to the road owner's needs for selecting an adaptation strategy. This approach provides a structure for decision making, gives an overview of decisions that should be taken in the adaptation process and factors influencing the choices, and clarifies which techniques to apply, when and why.

The guideline gives specific information to complete the 10 step approach for all climate change threats. Steps 0 to 3 provide background information on the road owner's needs, impacts and current and future resilience of the assets. Steps 4 to 8 deal with the selection of adaptation measures and strategies. The selection process involves:

- Selecting a combination of measures that constitute an adaptation strategy.
- Ranking measures according to their consequences for operation and sustainability.

Steps 9 and 10 provide an outlook on research that will help climate change adaptation, also estimating the time-to-market to support compilation of research road maps.

The approach uses the following policy matrix (figure 4.7) to identify combinations of measures (policies) that are the building blocks of an adaptation strategy. More information about use of the matrix can be found in Part E.

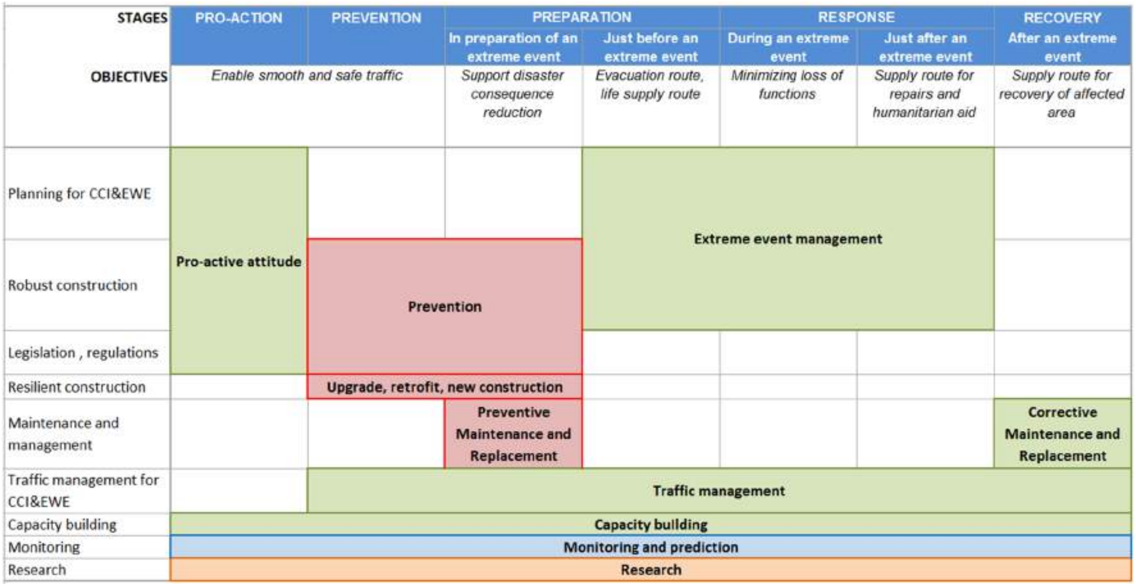

Figure 4.7: Policy matrix for adaptation

A database of more than 500 adaptation measures supports the use of the Part E of the guideline. The database allows easy selection, ranking and presentation of the measures in the policy matrix.

5 Conclusions

It is likely that climate change will cause both an increase in frequency and intensity of many unwanted weather events that can harm road infrastructure and/or transport using the roads. The changing climate therefore forces national road authorities to think about maintaining service levels. Due to high levels of uncertainty a risk based approach is necessary to identify a proper adaptation strategy.

The RIMAROCC framework provides a sound risk management basis for NRA's to deal with the effects of climate change. It provides all steps that come along when performing a climate change risk assessment for roads in a changing climate. However, the number of steps can be perceived as being complicated and difficult to execute. Within the ROADAPT guidelines therefore another scheme is introduced that visualizes all basic aspects that need to be considered in a climate change risk assessment. The RIMAROCC framework is a method that exists of different 'building blocks' that can efficiently be updated or changed in a specific situation. This allows the ROADAPT guidelines to be plugged into the RIMAROCC framework, providing a ROADAPT-RIMAROCC integrated approach.

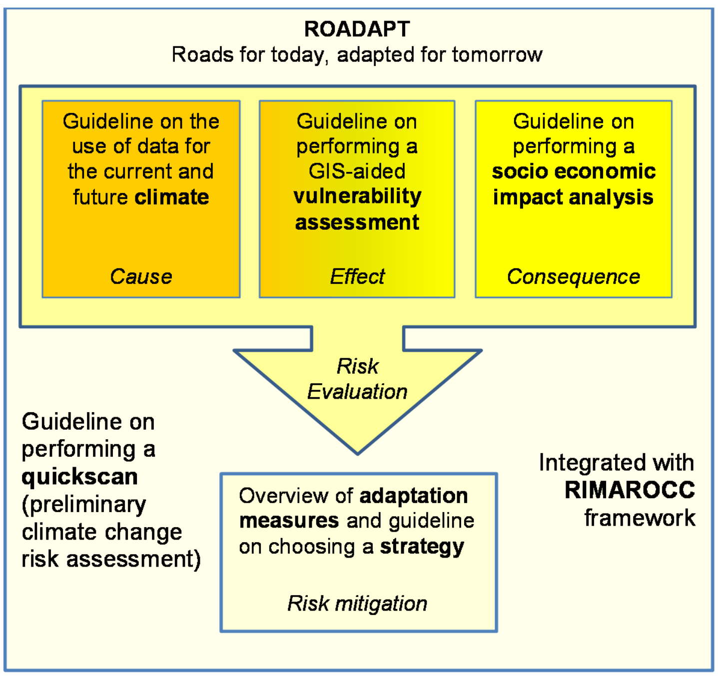

Figure 5.1: Structure of the ROADAPT guidelines
(same picture as figure 3.2)

The ROADAPT guidelines consist of five parts. All parts can be used individually, but also provide input and output to other steps in the RIMAROCC framework. The five parts are:
A. Guidelines on the use of climate data for the current and future climate
B. Guidelines on the application of a QuickScan on climate change risks for roads
C. Guidelines on how to perform a detailed vulnerability assessment
D. Guidelines on how to perform a socio economic impact assessment
E. Guidelines on how to select an adaptation strategy

Beside these guidelines other practical information is assembled. To be mentioned are the table of weather induced threats for roads that might change due to climate change (annex I), a database with adaptation measures and strategies (part E) and an overview of climate data requirements of National Road Authorities for the current and future climate (Bessembinder, 2014b).

The products and guidelines have been used in three case studies, namely the Öresund region (Falemo et al., 2014), the Rotterdam Ruhr corridor (Bles et al., 2014) and the A24 in Portugal (Ennesser, 2014). It is concluded that the guidelines are useful, useable and provide valuable input for NRA's to adapt to climate change.

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- Deltares: Thomas Bles (coordinator and work package leader), Arjan Venmans (work package leader), Mike Woning (case leader) and Niels Eernink
- SGI: Per Danielsson (work package leader), Stefan Falemo (case leader, hired from ÅF), Hjördis Löfroth and Linda Blied
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- KNMI: Janette Bessembinder (work package leader) and Alexander Bakker

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Photos

- Figure 1.1 http://www.dailystar.co.uk/news/latest-news/358584/Forecasters-issue-highest-level-flood-warning-to-stay-off-Britain-s-danger-beaches
- Figure 2.2 http://www.boulevardforum.nl/index.php?topic=294.15
- Figure 2.1 http://www.roadscience.net/services/distress-guide
- Figure 2.2 http://driveeuropenews.files.wordpress.com/2014/02/ronda-3.jpg
- Figure 2.3 http://www.opel-forum.nl/viewtopic.php?f=49&t=138828
- Figure 2.7 http://112inbeeld.nl/page/Nieuwsdetail/19540/veel-overlast-door-hevige-regenval

Annex I: Table of threats

Threat description		Climate information			Vulnerability factors		Impact	
Threat main	Threat sub	Climate parameter (an increase of the mentioned variable will increase the possibility of the threat happening)	Unit	Time resolution for climate variable	Infrastructure intrinsic factors = road factors that contribute to vulnerability	Contextual site factors = surrounding factors that contribute to vulnerability	Duration of the threat when it has occurred until resume of normal operation	Time between realization that threat might happen and threat occuring (warning time horizon)
Flooding of road surface (assuming no traffic is possible)	flooding due to failure of flood defence system of rivers and canals, caused by snowmelt, rainfall in the catchment area, extreme wind	Temperature (in the catchment area)	number of days with average temperature above 0 °C	days	Road surface level (lower = higher vulnerability)	Rivers, canals, low lying areas	weeks - months	minutes - days
		Extreme rainfall events (long periods of rain in the catchment area)	mm/day	several days - week				
		Extreme wind speed, wind direction	m/second	hours-days				
	pluvial flooding (overland flow after precipitation, increase of groundwater levels, increase of aquifer hydraulic heads)	Extreme rainfall events (heavy showers)	mm/h	minutes - hours	Earthworks, bridges, culverts, drainage	Valley floors, low lying areas	days - weeks	hours - days
		Extreme rainfall events (long periods of rain)	mm/day	several days - week				
	Inundation of roads in coastal areas, combining the effects of sea level rise and storm surges	Sea level (rise)	cm	day	Road surface level (lower = higher vulnerability)	Coastal areas	days - weeks	days
		Extreme wind speed, wind direction (-> storm surge)	m/second	hours-days				
	Flooding from snow melt (overland flow after snow melt)	Temperature	number of days with average temperature above 0 °C	days-weeks	Culverts, ditches	Hilly and mountaineous areas, altitude, latitude	days - weeks	hours - days
Erosion of road embankments and foundations	Overloading of hydraulic systems crossing the road	Extreme rainfall events (long periods of rain)	mm/day	several days - week	Culverts	Valley floors, low lying areas	week - months	hours
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Thaw (for rapid ablation of snow)	°C	days				
	Erosion of road embankments	Sea level (rise)	cm	day(s)	Earthworks, culverts (higher vulnerability where culverts cross the road), road embankment materials	Valley floors, low lying areas	week - months	minutes - days
		Extreme wind speed, wind direction (-> storm surge)	m/second	hours-days				
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Extreme rainfall events (long periods of rain)	mm/day	several days - week				
	Bridge scour	Sea level (rise)	cm	day(s)	Bridges	Rivers, canals, low lying areas	months	hours - days
		Extreme wind speed, wind direction (-> storm surge)	m/second	hours-days				
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Extreme rainfall events (long periods of rain)	mm/day	several days - week				

Threat description		Climate information			Vulnerability factors		Impact	
Threat main	Threat sub	Climate parameter (an increase of the mentioned variable will increase the possibility of the threat happening)	Unit	Time resolution for climate variable	Infrastructure intrinsic factors = road factors that contribute to vulnerability	Contextual site factors = surrounding factors that contribute to vulnerability	Duration of the threat when it has occurred until resume of normal operation	Time between realization that threat might happen and threat occuring (warning time horizon)
Landslips and avalanches	External slides, ground subsidence or collapse, affecting the road (including eg. embankments aside the road)	Extreme rainfall events (long periods of rain)	mm/day	several days - week	Earthworks, pavements, drainage, foundation	Natural slopes, underground cavities, loss of vegetation	days - months	seconds - hours
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Drought (consecutive dry days)	(consecutive) days	multiple days-months				
	Slides of the road embankment	Extreme rainfall events (long periods of rain)	mm/days	several days - week	Earthworks, cut and fill slopes, retaining walls, embankment materials (clay/silt = higher vulnerability), slope angle (higher slope angle = higher vulnerability)	Hilly and mountaineous areas	weeks - months	seconds - minutes
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Drought (consecutive dry days)	(consecutive) days	multiple days-months				
	Debris flow	Extreme rainfall events (heavy showers)	mm/h	minutes - hours	Drainage, embankment vegetation, erosion protection works	Mountainous areas, loss of vegetation	days - months	seconds - minutes
	Rock fall	Extreme rainfall events (long periods of rain)	mm/day	several days - week	Manmade cracks: road cut/blasting, rock fall protection works	Mountainous areas	days	seconds - minutes
		Extreme rainfall events (heavy showers)	mm/h	minutes - hours				
		Frost-thaw cycles (number of days with temperature zero-crossings)	number of days	days				
	Snow avalanches	Snowfall	mm/day	day-weeks	Distribution of avalanche protection works	Mountainous areas, avalanche tracks	days - weeks	seconds - days
		Frost-thaw cycles (number of days with temperature zero-crossings)	number of days	days				
		Temperature	mm/day	days-weeks				
Loss of road structure integrity	Impact on soil moisture levels (increase of watertable), affecting the structural integrity of roads, bridges and tunnels	Seasonal and annual average rainfall	mm/season mm/year	season-year	Pavements, bridges and tunnels	low lying areas, high watertable	days - weeks	days - months
		Sea level (rise)	cm	years				
		Extreme wind speed, wind direction (-> storm surge)	m/second	hours-days				
	Weakening of the road embankment and road foundation by standing water	Seasonal and annual average rainfall	mm/season mm/year	season-year	Earthworks, pavements	Rivers, canals, low lying areas	weeks	hours - weeks
	(Unequal) settlements of roads by consolidation	Drought (consecutive dry days)	consecutive days	multiple days-months	Pavements	soft ground layers	months	months
	Instability / subsidence of roads by thawing of permafrost	Thaw (number of days with temperature zero-crossings)	number of days	days	Pavements	frozen ground	days - weeks	days - months
	Uplift of tunnels or light weight construction materials by increasing watertable levels	Seasonal and annual average rainfall	mm/season mm/year	season-year	Tunnels, Deep lying sections, light weight materials	High watertable, soft soil	months	seconds - months
		Sea level (rise)	cm	day(s)?				
		Extreme wind speed, wind direction (-> storm surge)	m/second	hours-days				
		Extreme rainfall events (long periods of rain)	mm/day	several days - week				

Threat description		Climate information			Vulnerability factors		Impact	
Threat main	Threat sub	Climate parameter (an increase of the mentioned variable will increase the possibility of the threat happening)	Unit	Time resolution for climate variable	Infrastructure intrinsic factors = road factors that contribute to vulnerability	Contextual site factors = surrounding factors that contribute to vulnerability	Duration of the threat when it has occurred until resume of normal operation	Time between realization that threat might happen and threat occuring (warning time horizon)
Loss of pavement integrity	Cracking, rutting, embrittlement	Maximum and minimum diurnal temperature	˚C	days	Flexible pavements, type of surface and binder course, pavement age		days	days
		Temperature (heat waves)	number of consecutive hot days					
	Frost heave	Frost	˚C and number of days	days		Soft ground layers, high ground water table	weeks - months	days
	Aggregate loss and detachment of pavement layers	Frost	˚C and number of days	days	Flexible pavements, type of surface course, pavement age		days	days
	Cracking due to weakening of the road base by thaw	Frost-thaw cycles (number of days with temperature zero-crossings)	number of days	days	Pavements		weeks - months	days - weeks
	Thermal expansion of pavements	Maximum and minimum diurnal temperature and number of consecutive hot days (heat waves)	˚C and number of (consecutive) days	days	Concrete pavements		days	days
	Decreased utility of (unimproved) roads that rely on frozen ground	Frost-thaw cycles (number of days with temperature zero-crossings)	number of days	days	Unpaved roads		weeks - months	days - weeks
Loss of driving ability due to extreme weather events	Reduced visibility	Fog days	Number of days	day			hours - day	seconds - minutes
	Reduced visibility during snowfall, heavy rain including splash and spray	Snowfall or rainfall	mm/hour and mm/day	hour-day	Closed pavements (no porous pavements), presence of storm water runoff		minutes - day	seconds - minutes
	Reduced vehicle control	Extreme wind speed (worst gales and wind gusts)	m/second				hours - day	seconds
	Decrease in skid resistance on pavements from slight rain after a dry period	Drought (consecutive dry days)	consecutive days	multiple days-months	Pavements		minutes - hours	seconds - hours
	Flooding of road surface due to low capacity of storm water runoff	Extreme rainfall events (heavy showers)	mm/hour	minutes - hour	Closed pavements (no porous pavements), presence of storm water runoff		minutes - hours	minutes
	Aquaplaning in ruts due to precipitation on the road, splash and spray	Extreme rainfall events (heavy showers)	mm/hour	minutes - hour	Closed pavements (no porous pavements), presence of storm water runoff		minutes - hours	minutes
	Decrease in skid resistance on pavements from migration of liquid bitumen	Maximum and minimum diurnal temperature and number of consecutive hot days (heat waves)	˚C and number of (consecutive) days	days	bitumen		hours - days	minutes
	Icing and snow	Snowfall	mm/day	days			hours - days	seconds - hours
		Hail	mm/day	days				
		Frost and rainfall	˚C and mm/day	days				

Threat description		Climate information			Vulnerability factors		Impact	
Threat main	Threat sub	Climate parameter (an increase of the mentioned variable will increase the possibility of the threat happening)	Unit	Time resolution for climate variable	Infrastructure intrinsic factors = road factors that contribute to vulnerability	Contextual site factors = surrounding factors that contribute to vulnerability	Duration of the threat when it has occurred until resume of normal operation	Time between realization that threat might happen and threat occuring (warning time horizon)
Reduced ability for maintenance	Reduced snow removal planability	Snowfall	number of days	days-season			day - months	weeks - months
	Reduced ice removal planability	Frost	˚C and number of days	days			day - months	weeks - months
	Impact on shoulder maintenance: increased vegetative growth	Temperature	˚C	days	shoulder vegetation		days - weeks	days
	Impact on road works: decreased time window for paving	Maximum and minimum diurnal temperature and number of consecutive hot days (heat waves)	˚C and number of (consecutive) days	days	Pavements		days - weeks	days
Pollution aside the road after incapacity of storm water runoff system of the road		Extreme rainfall events (heavy showers)	mm/hour	minutes - hour	Closed pavements (no porous pavements), presence of storm water runoff, shoulder vegetation		minutes - hours	seconds - hours
Susceptibility to wildfires that threaten the transportation infrastructure directly		Drought (consecutive dry days)	consecutive days	multiple days-months		Forest cover	hours - days	hours - days
Damage to signs, lighting fixtures, pylones, canopies, noise barriers and supports		Extreme wind speed (worst gales and wind gusts)	m/second	seconds-hours	Signs, lighting fixtures, pylones, canopies, noise barriers, supports		hours - weeks	seconds - hours
Damage to energy supply, communication networks (eg. pylones) and/or matrix boards by wind, snow, heavy rainfall and/or lightning		Extreme wind speed (worst gales and wind gusts)	m/second	seconds-hours			days - weeks	seconds - hours
		Snowfall	mm/day	days				
		Extreme rainfall events (heavy showers or long periods of rain)	mm/day	hour to days				
		Lightning	number of discharges	hour to days				
Trees, wind mills, noise barriers, trucks falling on the road		Extreme wind speed (worst gales and wind gusts)	m/second	seconds-hours	Noise barriers	Trees, mills	hours - day	seconds - hours